PLANNING AND DECISION-MAKING FOR ENERGY RECOVERY FROM WASTE AT THE SUB-REGIONAL LEVEL

DAVID MARK LONGDEN

A THESIS SUBMITTED FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

ASTON UNIVERSITY

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THESIS SUMMARY

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Energy-from-waste policies can provide an essential part of landfill diversion and climate change strategies. Many UK waste disposal authorities are currently deciding which energy-from-waste policies are most suitable for their local areas. Such decisions are challenging since the environmental, economic and social implications of any energy-from-waste policy must be fully considered now that planning guidelines require a full Sustainability Assessment. More specifically, waste disposal authorities must identify the optimal scale and number of facilities together with suitable site locations.

This research project has developed a novel decision support system using Geographical Information Systems and Multi Criteria Decision Analysis and used it to develop and evaluate energy-from-waste policy options. The system was validated by applying it to the UK administrative areas of Cornwall and Warwickshire. Different strategies have been defined by the size and number of the facilities, as well as the technology chosen.

Using sensitivity analysis on the results from the decision support system, it was found that key decision criteria included those affected by cost, energy efficiency, transport impacts and air/dioxin emissions. The conclusions of this work are that distributed small-scale energy-from-waste facilities score most highly overall and that scale is more important than technology design in determining overall policy impact.

This project makes its primary contribution to energy-from-waste planning by its development of a Decision Support System that can be used to assist waste disposal authorities to identify preferred energy-from-waste options that have been tailored specifically to the socio-geographic characteristics of their jurisdictional areas. The project also highlights the potential of energy-from-waste policies that are seldom given enough attention to in the UK, namely those of a smaller-scale and distributed nature that often have technology designed specifically to cater for this market.

Keywords: Energy-from-waste; Geographical Information Systems; Multi-criteria decision analysis; Decision support systems.

DEDICATION

This thesis is dedicated to the memory of Sally Macgill - Professor of Environmental Risk Management at the University of Leeds. I will always be grateful for the encouragement she gave me to pursue a career assisting us to live and work in a more sustainable manner with our environment.

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To Joanna, Jamie, Eloise and my friends who have been there for me through all the challenges of the PhD process and offered advice and support at every stage. To my father Michael, Nicholas Cooper and Tony Marmont whose interest and enthusiasm have been a great source of encouragement and energy.

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List of Publications and Reports

The following journal and conference papers have arisen from work in this thesis. Journal papers are presented in Appendix G.

1. Longden D.M., Brammer J.G., Bastin L. and Cooper N. (2007) ***Distributed or centralised energy from waste policy?*** Implications of technology and scale at municipal level. Energy Policy, 35 (4), p2622-2634.

2. Bastin L. and Longden D.M. (2009) ***Comparing transport impacts for energy recovery from domestic waste: Large and small-scale options for two UK counties.*** Computers, Environment & Urban Systems, 33 (6), p492-503.

3. Bastin L. and Longden D.M. (2006) ***Comparing transport impacts for energy recovery from domestic waste: Large and small-scale options for two UK counties.*** GISRUK, Nottingham, UK.

4. Longden D.M. and Brammer J.G. (2006) ***County planning of energy from waste facilities: A new approach to strategic assessment of technology and scale applied to Warwickshire, UK.*** Annual CIWM Conference incorporating the 5th International Symposium on Waste Treatment Technologies, Paignton, UK.

5. Longden D.M. Brammer J.G. and Cooper N. (2005) ***GIS-based evaluation of energy provision from waste and biomass plant at local community level.*** 6th International Conference in Science and Thermal-Chemical Biomass Conversion, Vancouver, Canada.

Project Website: To ensure availability of results to non-academic parties for comment and critique, the results of this thesis have been published at http://www.beyondyourbin.org.

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LIST OF ABBREVIATIONS

AHP	Analytical Hierarchy Process
ATT	Advanced Thermal Treatment
BMW	Biodegradable Municipal Waste
BPEO	Best Practical Environmental Option
BSP	Bulk Supply Point
C&I	Commercial/ Industrial wastes
CAS	Central Area of Search
CBA	Cost Benefit Analysis
CCC	Cornwall County Council
CCL	Climate Change Levy
CEA	Cost Effectiveness Assessment
CHP	Combined Heat and Power
CO_2	Carbon dioxide
COA	Census Output Area
CPL	Compact Power Limited
CPU	Central Processing Unit
CV	Calorific Value
CWM	Collectable Waste Resource Model
DEFRA	Department for Environment, Food and Rural Affairs
DEM	Digital Elevation Model
DfT	Department of Transport
DG	Distributed Generation
DLUA	Developed Land Use Area
DSS	Decision Support System
DTI	Department for Trade and Industry
EfW	Energy-from-Waste
ELECTRE	Elimination and choice translating reality
ETS	Emissions Trading Scheme
EU	European Union
FBC	Fluidised Bed Combustion
FSI	Final Site Identification
GB	Gigabyte
GHz	Giga-hertz
GIS	Geographical Information System
Ha	Hectare
HCC	Hampshire County Council
HDD	Hard Disk Drive
HGV	Heavy Goods Vehicle
IPPC	Integrated Pollution Prevention and Control
km	Kilometre
ktpa	Kilotonnes per annum
LATS	Landfill Allowances Trading Scheme
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
M	Million

MB	Megabyte
MBT	Mechanical and Biological Treatment
MCDA	Multi-Criteria Decision Analysis
MFA	Material Flow Analysis
MRF	Materials Recycling Facility
MSW	Municipal Solid Waste
NGO	Non-Governmental Organization
NNR	National Nature Reserve
NPV	Net Present Value
NTDP	New Technologies Demonstration Programme
PFI	Private Finance Initiative
PIU	Performance and Innovation Unit – now the Government's Strategy Unit
PPC	Pollution Prevention and Control
PPS 10	Planning and Policy Statement 10
RAM	Random-Access Memory
RCEP	Royal Commission of Environmental Pollution
RCV	Refuse Collection Vehicle
RO	Renewables Obligation
ROCs	Renewables Obligation Certificates
SAC	Special Area of Conservation
SD	Sustainable Development
SEA	Strategic Environmental Assessment
SSSI	Site of Special Scientific Interest
WCC	Warwickshire County Council
WCED	World Commission for Environment and Development
WDAs	Waste Disposal Authorities
WID	Waste Incineration Directive
WIP	Waste Implementation Programme
WISARD	Waste-Integrated Systems for Assessment of Recovery and Disposal
WLP	Waste Local Plan
WRATE	Waste and Resources Assessment Tool for the Environment
WSM	Weighted-sum method
WTS	Waste Transfer Station

1. INTRODUCTION

1.1. AIMS OF CHAPTER

This introductory chapter presents the project's inception, aims, parties involved, central issues and project justification. Section 1.3 outlines the importance of municipal solid waste (MSW) as an alternative 'low-carbon' fuel for energy recovery and the move towards the use of more distributed energy production facilities in UK energy policy. The role of combined heat and power (CHP) is presented as a means of further maximising reductions in Carbon Dioxide (CO_2) emissions. The two main types of thermal treatment currently available in the UK for processing MSW are presented. Section 1.3 discusses some of the difficulties encountered in large-scale EfW development in the UK at present, the need to address the principles of sustainable development and the central role of waste disposal authorities in EfW decision making. The challenges of EfW development are clearly summarised in the case study of 'Project Integra'. Decision support systems (DSS) as a means to assist WDAs in EfW planning are defined in Section 1.4 and a synopsis of key points to take into consideration for the development of an EfW DSS at the sub-regional level is made in Section 1.6 with a statement of project aims presented in Section 1.5. An outline of the thesis is made in Section 1.7 with a summary of the chapter.

1.2. PROJECT INCEPTION

This project has been supported by an EPSRC Industrial CASE award in collaboration with Compact Power Ltd, a developer of advanced EfW systems located in the UK. Compact Power's interest in supporting this work centred in observing how a distributed approach to Energy-from-Waste policy incorporating the use of their technology compares with the traditional UK approach of using combustion technology in a more centralised approach. To assist this work, the company has provided techno-economic and environmental performance data.

Significant effort is often required to gather a substantial amount of data to be used in GIS modelling. To this end, voluntary collaborations were made with Cornwall and Warwickshire County Councils in order to gain access to the Councils extensive archive of geographic digital data. The collaborations also established officer working groups that were formed for the purposes of providing modelling inputs and feedback.

1.3. BACKGROUND

1.3.1. UK ENERGY PRODUCTION AND CLIMATE CHANGE

The Royal Commission on Environmental Pollution (RCEP) started a fundamental review of Energy Policy with its 22nd report - Energy: The Changing Climate - published in 2000 (RCEP, 2000). Its focus was on the implications of considerable reductions in the use of fossil fuels as sources of energy by 2050. The report concluded that current UK energy policies did not meet the combined aims of protecting the interests of generations to come, and the achievement of higher qualities of life, social justice and industrial competitiveness (RCEP, 2000). The RCEP also clearly made the link between the use of non-renewable fossil fuel and climate change, with action immediately required to limit the damage already caused by global emissions of greenhouse gases.

Following the RCEP report, a report in 2002 from the Government's Policy and Innovation Unit (PIU) emphasised the need for security of supply and the need for energy policy frameworks to address all three objectives of sustainable development – economic, environmental and social – as well as security of supply (PIU, 2002). Where energy policy decisions involve trade-offs between environmental and other objectives, then the environment should tend to take preference. The report also stated that barriers to renewable and CHP investments must be addressed urgently. One such barrier includes planning permission and the delays or refusals encountered by EfW proposals. This project aims to assist the implementation of EfW policy by developing area-tailored options in an approach that is capable of taking account of the range of stakeholder values encountered in the planning process.

1.3.2. THE MOVE TOWARDS DISTRIBUTED GENERATION

The Government's response to the PIU report was detailed in the Energy White Paper (DTI, 2003). In its scenario for a 2020 energy system, the paper stated that: "*There will be much more local generation, in part from medium/small community power plant, fuelled by locally grown biomass and locally generated waste. Plant will also increasingly generate heat for local use.*" This vision presents great challenges for the UK planning system and is related to the Proximity Principle detailed UK Waste Strategy (Appendix A.3.1.3). For it to be implemented there must be the following:

a. Identification of power generation sites that can economically *exploit local resources –either in situ or collected from resource catchment areas.*
b. Deployment of facility, *sized suitably for community integration and the economic exploitation* of resources.
c. *Co-operation of the local community* in which the plant is to be situated.
d. *Effective communication* between all stakeholder groups and partners.

In order for the vision above to be achieved, there is clearly a need to support decision makers involved in developing EfW schemes, since waste is a locally generated resource. The UK Department of Trade and Industry (DTI) Energy Review of 2006 also emphasises the potential that 'distributed' and smaller-scale systems have to provide flexibility and to reduce the energy lost in transmission and distribution networks (definitions of scale and locality are discussed Section 5.3.3). The community basis of smaller plants can also lead to greater awareness of energy issues, driving a change in social attitudes and in turn, enabling more efficient use of our energy resources (DTI, 2006b). This project considers smaller-scales of EfW provision from the outset in respect of the RCEP and PIU recommendations outlined in Section 1.3.1 and above.

1.3.3. THE USE OF WASTE AS AN ALTERNATIVE TO FOSSIL FUELS

The combustion of municipal solid waste (MSW) as well as other wastes can play a limited but worthwhile role as an alternative fuel and to displace fossil-fuel derived CO_2 emissions from electricity production (Oakdene Collins, 2005). These resources form part of the group of fuels under the 'biomass' designation (Boyle, 2004a), which currently make only a minor contribution to the UK's long-term climate change strategy (Gill et al., 2006). The combustion of biomass is defined 'carbon-neutral' and renewable provided the biomass is replaced in the short term, as the CO_2 released on combustion is equal to that captured during growth. EfW is regarded as partly renewable, since approximately 70% of MSW is defined as of recent biogenic origin (AEAT, 2005). There are indirect emissions of CO_2 associated with the use of biomass fuels, originating from road transport for example, but it is reported that overall emissions in electricity production are considerably lower than from fossil fuels (RCEP, 2000).

The appreciation of waste within the biomass family of fuels is growing (Gill et al., 2006). Its negative cost as an input fuel (in that plant operators are paid to dispose of the 'fuel' rather than have to pay a price for its production, as is the case with purpose grown crops) can assist pioneer projects that have a large part to play in the development of the infant biomass-to-energy UK industry. In its recent report, the Biomass Task Force emphasised its support for the use of waste, but commented that the Waste Hierarchy guidance tool (see Appendix A.3.1.1) does not attach enough importance to EfW (Gill et al., 2006). The report recommended that the Government takes a clear position that waste is an asset and that efficient (via use of CHP) and safe recovery of energy (post re-use and recycling) should be actively encouraged. The RCEP (2000) report also emphasises the use of EfW CHP plants in two of its four energy scenarios for 2050 and highlights the associated environmental issues as being very similar to those of other biomass sources. RCEP acknowledges the increase in related traffic impacts and suggests building small plants supplied with waste fuel from their immediate vicinities to minimise them. This is explored in Chapter 7.

1.3.4. THE USE OF CHP TO REDUCE CO_2 EMISSIONS

UK energy policies have, for far too long, favoured the generation of electricity in ways that waste vast quantities of heat, and the Royal Commission for Environmental Pollution suggest that this could be used to heat buildings (RCEP, 2000). CHP must be encouraged by planning policy to ensure that plants are built in urban locations where heat can be used and this is explored in Section 6.4.3.5. Local communities should be encouraged to establish heating networks where possible (RCEP, 2000) but Clift (2007) reports on the "general resistance of local authorities and the construction sector to contemplate anything other than single-dwelling space and water heating". During the completion of this project, it was observed that while the WDAs collaborated with did not understand the implications of CHP at the start, they certainly understood the political importance of ensuring CHP was taken account of in EfW planning at the end. The PIU report acknowledges the slow growth of CHP is a problem and has an invaluable role in carbon emission abatement.

Electricity generation continues to be a primary concern of EfW developers, as the high value of electricity has a favourable effect on the economic balance sheets of capital-intensive schemes. However, low electricity generation efficiencies of typically 25% (Oakdene Collins, 2005) result in a great amount of potentially useful energy being lost in the form of waste heat. In order to make maximum savings in CO_2 emissions, it is clearly sensible to deploy EfW plant in a CHP mode, where efficiencies can reach up to 80% (Beggs, 2002). Of 19 plants in the UK only 4 are producing heat *and* electricity. Of the remaining 15, one plant generates heat only, with the remainder producing electricity only. The implications of CHP in EfW options are discussed in Section 9.3.1.3.

Despite the low uptake of EfW CHP in the UK, it has been noted that 63% of operating plants are built on the site of former incinerators and are located in urban areas with significant potential heat demand (ILEX Energy, 2005). Since, such sites are rapidly becoming occupied for a variety of land uses including waste management, EfW plants, are increasingly being built on industrial sites in more sensitive rural/suburban environments, often more remote from potential heat consumers. This trend may further inhibit the potential for large EfW plants being able to operate in CHP mode and exploit the energy efficiency gains. More common smaller-scale heat demands such as schools, hospitals, leisure-centres, shopping centres and municipal buildings provide numerous opportunities, but are only suitable for matching with smaller-scale heat producing plants, unless linked by expensive heating networks that will require significant extra investment (AEAT, 2005). There is clearly a need for a more sophisticated approach to identifying sites and this project presents methods and results in Chapters 6 and 7.

Where district heating networks do not exist, as is often the case in the UK, smaller-scale facilities are more likely to be successfully deployed in a CHP role. This is illustrated in a recent survey (DTI, 2006a) where 72% of all 1 MWe and above UK CHP plants were between 1 and 10 MWe outputs (28% were greater than 10 MWe). The rate of increase in numbers of 1–10 MWe plants commissioned between 1996 and 2004 was also higher than their larger counterparts. This trend has been appreciated within a sensitivity analysis of EfW options in Section 9.3.1.3. The overall CHP capacity achieved by a number of smaller systems, however, may not always be greater than a large one where sufficient heat demand may exist, and the influences that determine this depend very much on the local conditions of the site.

1.3.5. THERMAL TREATMENT TECHNOLOGIES FOR WASTE

This project takes into account some of the most important implications of using two types of thermal treatment, namely conventional grate combustion or the emerging advanced thermal treatment (ATT) technologies. ATT is an acronym that includes many different designs that can include pyrolysis, gasification and oxidation thermal conversion processes. Such combined technologies are in effect incinerators, but each step's reactor temperature and pressure conditions may be controlled (Williams, 2005). This has the advantage in that conditions can be optimised to produce desired end products or to minimise un-desired emissions.

Pyrolysis and/or gasification can not only be used to recover energy but can also produce gas or oil products that have use in the petrochemical industry. These technologies fall within the "umbrella" phrase of ATT and also come under the Waste Incineration Directive (WID) regulations, since incineration is defined as *any* thermal process dedicated to the thermal treatment of waste, with or without energy recovery. The use of ATT instead of conventional combustion has been cited as a means to potentially mitigate public opposition in the planning process due to higher environmental performance (Malkow, 2004). This project aims to investigate the implications of using ATT or combustion technology, not solely on the basis of environmental criteria, but also economic and social.

Regardless of the thermal process and technology used, incineration is the oxidation of the combustible material in the waste, and produces heat, water vapour and carbon dioxide. Other emissions include nitrogen oxides, sulphur dioxide, carbon monoxide, dioxins, furans and heavy metals. Expensive and complex gas clean-up systems are required to remove these emissions from the flue gases in order to meet the EC WID requirements (Appendix A.2.4). The public, however, remains quite opposed to the incineration of waste (Williams, 2005) and local authorities clearly need to demonstrate they have investigated the alternatives in a transparent approach. Table 1 presents a summary of the advantages and disadvantages of conventional incineration over landfill practices.

Table 1: Advantages and disadvantages of incineration over landfill (adapted from Williams, 2005).

Advantages	Disadvantages
Can usually be carried out near to the point of waste collection.	High cost and long pay-back periods, due to high capital investment required.
Waste is reduced to an ash product that is 10% of its pre-burnt volume and 33% of its pre-burnt weight.	High capital cost must be tied to long-term waste disposal contracts causing a lack of flexibility in long-term choices of waste disposal options.
Produces no methane - a powerful "greenhouse gas" and significant contributor to global warming.	Incinerators are designed for a certain calorific value of waste. Recycling requirements may remove plastic or paper in the waste and may reduce the calorific value leading to low incinerator performance.
Can be used as a low cost source of energy to produce steam for electricity, industrial process heating or hot water for district heating. This displaces the need to use fossil-fuel resources.	Public concern of emissions and adverse effects on health.
	Incineration processes still produce a waste residue that requires management.

Table 1 provides examples of the types of 'trade-off' issues that are faced by decision makers requiring EfW solutions to replace existing landfill disposal practices and demonstrates the need for support in deciding which EfW policy to implement. This project aims to develop and demonstrate an approach to assist local authorities and the communities they serve.

1.3.5.1. *Conventional Grate Combustion*

Most conventional incinerators are based on grate combustion technology but other designs include fluidised bed, rotary kiln, cement kiln and starved-air incinerators. Due to data availability, this project has used grate combustion technology to represent conventional incineration options. A schematic of the process is shown in Figure 1. This can be divided into the five main areas of waste delivery, bunker and feeding system; furnace; heat recovery; emissions control and energy recovery.

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Figure 1: Schematic of a conventional grate combustion incineration process (Williams, 2005).

Refuse collection vehicles (RCVs) deliver waste fuel into a bunker that is large enough to allow storage to enable balance to be made between intermittent delivery of waste and continuous operation of the plant. Crane grabs feed waste to hoppers that use hydraulic rams to transfer feedstock to the furnace. In order to ensure odours are not emitted, air used for combustion in the furnace is drawn from the delivery hall which keeps it under a slight negative pressure.

The hot combustion gases heat the waste as it enters the furnace and moisture is driven off. Volatile components of the organic material are produced in the form of hydrogen, carbon monoxide, methane, ethane and other hydrocarbons. Combustion of these gases occurs above the surface of the waste on the grate in the chamber above. Complete combustion requires sufficient temperature and residence time. The minimum conditions of two seconds at 850 degrees are set by the WID described in Appendix A.2.4. Secondary air is added to avoid areas within the furnace of zero oxygen levels that could lead to hazardous and excessive emissions. The grate is central to the system and serves to move the waste from in the inlet hopper to the discharge end in its final form as bottom ash, while providing agitation to loosen combusting materials. The grate is a key process control mechanism that can adjust residence time of waste in the combustion zone in response to changes in composition and calorific value.

While the hot flue gases from waste combustion are transferred to a boiler using ducting in ATT equipment, conventional grate technology have their boiler systems located above the combustion chamber which is the reason why building heights are higher than for ATT facilities. Heat recovery is enabled in EfW systems because flue gases must be cooled before they can discharge through flue gas cleaning systems. Flue gases are passed over banks of boiler tubes to produce steam that can be used for electrical power generation or heat production for industrial process or district heating.

Once temperatures have reduced to less than 300 degrees, the flue gases must be cleaned up to WID conditions described in Appendix A.2.4. Particulate material is first removed by electrostatic precipitators, followed by acid gas removal by lime scrubbing which may be of wet or dry type (Williams, 2005). Following scrubbing, activated carbon is added to adsorb mercury, dioxins and furans. A fabric (or bag) filter is then used to remove the fine particulate and activated carbon with the adsorbed pollutants. The latter is flyash and requires disposal to hazardous landfill. Finally, oxides of Nitrogen are removed by the addition of ammonia ro form inert nitrogen and the flue gases are discharged to atmosphere via the stack. The height of the stack is a function of WID limit emission concentrations and the volume of flue gases as well as the topography of the surrounding area.

1.3.5.2. ATT, Pyrolysis and Gasification

The main differences between ATT and conventional grate combustion incineration exist in the furnace and thermal conversion design with most components of process technology, such as boilers and feeding systems remaining reasonably standard in the industry. The main difference between combustion, gasification and pyrolysis is the amount of oxygen supplied to the thermal reactor/s. Table 2 shows further differences in the temperatures of the processes and the products. Incineration based solely on combustion involves the complete oxidation of waste in an excess supply of air, while gasification takes place in limited air and pyrolysis in a complete absence of air.

Table 2: Differences in combustion, gasification and pyrolysis processes

Process	**Oxygen supplied**	**Temperature (°C)**	**Products**
Combustion	Excess air	850-1200	Flue gas & ash
Gasification	Limited air/steam/pure oxygen	800-1400	Gas & ash & tar
Pyrolysis	No air	400-800	Gas & oil & char

While conventional combustion is typically performed in one furnace chamber shown by Figure 1, ATT can be identified by the staging of the overall thermal conversion process by using multiple and separate furnace chambers in which pyrolysis and/or gasification and oxidation of the resultant synthetic gases is performed. The Compact Power process exemplifies this and is shown in Figure 2. ATT systems may be argued to provide greater flexibility in that their gas products may also be used as a chemical feedstock (Williams, 2005) instead of oxidising them to raise steam for energy production.

Figure 2: Schematic of the Compact Power process (Fichtner, 2004).

While technology used in emissions control will be similar, the extent of air pollution control equipment can also differ between ATT and conventional grate combustion. Perhaps most importantly, pyrolysis/gasification systems can produce significantly reduced gas volumes for clean-up compared to conventional grate combustion. This results in scale-down of the gas cleaning system and a resulting reduction in cost. It can also be observed that while combustion processes require electrostatic precipitators, scrubbers, fabric filters and NOx reduction, the two ATT technologies on the UK market of Energos and Compact Power require only fabric filters with minimal NOx reduction and ammonia injection. Such cost reductions in the gas-clean up requirements have been argued to make smaller-scales of pyrolysis/gasification/combustion systems more economically attractive over similar scales of combustion systems (Dawber, 2006).

It is likely that small-scale ATT will be more economically attractive at small-scale due to the savings accrued from reductions in gas-clean up capital, but both technologies may be economic if all the energy can be recovered in a CHP or steam/heat only configuration, since this saves the need for the expensive equipment required in electricity generation (Gershman et al., 1986; Dawber, 2006). It is clear that from the outset, comparisons of performance of alternative EfW technologies as well as different scales of deployment are required in local authority policy development and appraisal in order to evaluate such arguments.

1.3.6. THE CENTRAL ROLE OF WASTE DISPOSAL AUTHORITIES

Local authority appraisal studies for residual waste have been conducted due to increasing public disquiet at the dominance of large-scale incineration EfW policies in the UK (Wheeler and Jainter, 2006). Studies are also often done with local government in mind, since the siting of industrial waste treatment facilities has become one of their most pressing problems (Maniezzo et al; 2008). Commissioned by national organisations such as the Environmental Services Association and DEFRA, Mc Lanaghan (2002), Livingston (2002), Fichtner (2004) and Enviros (2004) have also produced studies to inform local authorities in the selection of EfW technology. With the exception of Fichtner (2004) these authors provided data that the WDAs could compare themselves with no views or support on which technology is best for their particular circumstances and for which they could meet their landfill diversion targets under the Landfill Directive (Appendix A.2.1). In contrast, Fichtner (2004) concluded that combustion technology was preferable over the new and novel advanced thermal treatment technologies in terms of commercial risk, efficiency and operational reliability.

These studies emphasise the central role of WDAs, in that they have often been conducted with the aim of providing outputs to support WDA EfW decision making processes. There is clearly a need to develop the support available. Since WDAs have a statutory duty to manage waste, it is sensible that they should be identified as the main end-user of any decision support approach and that methods should be reproducible within WDA resources for EfW planning.

1.3.7. WDA EFW DECISION MAKING TOOLS

WDAs have previously used Best Practical Environmental Option (Appendix A.3.1.4). as the basis on which to select waste management options and policies (Williams, 2005). BPEO has now been replaced by the Planning and Policy Statement 10 (Appendix A.3.4) requirement to use more inclusive Sustainability Assessment in evaluating waste policy options (ODPM, 2005). Life Cycle Assessment (LCA) has often been used to assist in identifying the BPEO (White et al., 1995), in the form of software tools such as WISARD. In WISARD, waste management scenarios are devised to test the implications of varying extents of recycling/composting, landfill and energy recovery, the latter being based on traditional incineration technology (Ecobilan, 2006). Examples of these include those conducted by Jainter and Poll (2005) and Higham (1999) WISARD does not consider the emerging ATT technologies based on pyrolysis/ gasification or even conventional EfW plant below the 250 ktpa capacity (Purser, 2003).

WISARD was replaced by the WRATE software in late 2007 to ensure that new and emerging technologies are included within the Sustainability Assessment of EfW options (ERM, 2005). ATT and Combustion technologies along with their advantages and disadvantages are discussed in Section 1.3.5. Despite the debut of WRATE, there is still need for a decision support system (DSS), which can take into account the local physical, institutional and population characteristics of any particular WDA area for EfW planning. DSS are further described and defined in Section 1.4.

1.3.8. EfW POLICY AND MANAGING CONFLICT USING DSS

The counties selected for analysis in this project, Cornwall and Warwickshire, are moving towards the option of one facility in a central location for EfW provision. This choice has attracted criticism because it is seen by some to have evolved from decision-support processes that have not fully considered the merits of using new technology, CHP or local community-sized facilities. Opposition groups are concerned that the often preferred WDAs' centralised approach does not properly address the obligations of climate change and sustainable development (Larke & BBC, 2008). The most widely used definition of sustainable development was given in the Brundtland report (WCED, 1987).

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

In essence, this definition requires that decisions made that strike a balance between the three, often conflicting, objectives of economic activity and avoidance of damaging impacts on the environment and/or society. Regarding EfW policy, it has been argued that small-scale distributed ATT EfW options that incorporate CHP and have reduced transport requirements are more consistent with Sustainable Development, than the typically followed large-scale centralised approach using combustion technology (Conway, 2006). A DSS and its results are required to substantiate such claims and this is perhaps, one of the most significant reasons for the need for an EfW DSS at the local level.

On the other hand, there are the arguments that large-scale facilities enjoy economies of scale and have a lower impact on the environment overall than a network of smaller facilities (Wheeler and Jainter, 2006). There is also concern that multiple local facilities will not all gain public support and face a greater aggregated delay in the planning process than a single application for a large-scale facility (Paynter, 2006). Planners also understand the need to achieve competitive cost in their proposals in order to gain Private Finance Initiative (PFI) credits and have even been advised by DEFRA to consider joining sub-regional area requirements to focus on building very large-scale schemes of over 500 ktpa (Haggard, 2006). Such an approach fulfils the Regional self-sufficiency principle (Appendix A.3.1.2), but arguably frustrates the Proximity principle of EU Waste Legislation (Appendix A.3.1.3)

Due to such pressures, the benefits of distributed EfW policy may be overlooked. Government policy and strategy documents, as well as stakeholder concern suggest this is not advisable. The DSS developed by this project will include the capacity to include smaller-scale distributed EfW facility options in addition to the typical large-scale centralised one (RCEP, 2000; PIU, 2002; DTI, 2003). The results of this analysis are shown and discussed in Chapter 9.

Transport is considered an important part of waste management planning in general, and a sensitive issue for the acceptance of any EfW proposal (Gershman et al., 1986). The WDAs considered in this thesis' case studies have used consultants' in-house spreadsheet models to estimate the associated transport impacts of any waste management strategy and its constituent EfW policy. Unfortunately, it is often unclear how these models work and what their underlying assumptions are. This point is generally true of much research and analysis that has been undertaken by the WDAs in the production of their chosen strategy. In addition these studies may not be publicly available and many decisions based on them are similarly made with minimum public involvement. Any DSS should be transparent in that its methods and outputs are not too complex to the end that stakeholders can understand how preferred options have been arrived at.

General secrecy and lack of consultation can very easily lead to distrust and conflict between actors and stakeholders involved in waste management policy, and particularly EfW policy (Upreti & van der Horst, 2004). Such distrust and conflict can escalate to the point that interested parties will actively oppose projects at the planning stage, leading to possible delays or cancellations to vital EfW infrastructure (Upreti & van der Horst, 2004). The public can form effective opposition groups, but it has been noted that the groups observed in the course of this project have not been as concerned about the concept of EfW, but rather about the scale-related issues such as transport and daily lorry deliveries.

The potential for conflict is exacerbated because EfW planning is a complex policy area affected by the convergence of many existing policies in the fields of energy, waste, planning, climate change and other related environmental, economic and social areas. In addition to this 'policy junction', there are many different actors, each with their own interests or roles in influencing EfW decision-making and the formulation of policy. The most important of these in a local context are the WDAs whose officers and publicly elected councillors have a statutory duty to manage waste (Lisney, 2001). Central government organisations also take an interest in observing how national policies are influencing local activity. Expert academics and consultants advise each of these public bodies (Upreti & van der Horst, 2004). In the commercial arena there are large waste management and technology companies which are interested in winning lucrative contracts - the UK EfW market has been reported to be worth £7 billion (Pfeifer, 2006). Non-governmental organisations (NGOs) play an important part in motivating the public and raising awareness, often from environmental impact perspectives (Upreti & van der Horst, 2004). Any DSS must be able to take account of the values of different actors in the EfW planning arena.

1.3.9. Project Integra: Case study

The key UK case study of Hampshire County Council (HCC) serves to illustrate the issues outlined in the previous Section. The WDA found that it was necessary to move from a centralised EfW policy to a more distributed one, in order to find a politically acceptable solution to stakeholders that could be realised in delivery. Waste management planning in Hampshire was 20 years in the making after plans were made to close down an original network of 5 outdated incinerators, and EfW considerations were inherent from the start of the overall decision making process. Initially, concerns surrounded the deliverability of the supply company and not the technology itself. Out of county landfill was also considered as an alternative to EfW located within the administrative boundary but rejected in the procurement process and on grounds of political moral concerns of elected members.

In 1989, HCC awarded a contract for a large-centralised EfW plant of 400 ktpa. HCC had selected a suitable site in Portsmouth and attempted to emphasise EfW as a local solution that aids self sufficiency. From the outset, however, there were concerns regarding the environmental impact associated with a large-scale plant, the electricity prices on which their viability depends and satellite transfer station requirements. These are typical of today and identical to concerns expressed by WDAs and other stakeholders today, some 15 years later.

The drivers for the large-scale scheme were the green premium for electricity generation (worth £24m) and plant economies of scale (Lisney, 2001). It was hoped that Portsmouth City Council would be 'euphoric' in its support to have the Hampshire centralised scheme within its community, but the proposal was leaked by elected member politicians (Lisney, 2001). Marches were led by elected HCC members themselves, public meetings were attended by several hundred people and a very effective opposition campaign was led by the local newspaper (Lisney, 2001).

The key concerns of the public included increased traffic generation over existing roads, the effect of EfW on recycling and the overall size of the plant and the height of its stack. Lisney (2001) notes "The key to the political decision process was held by the councillors whose political support, originally strong for the centralised scheme, wavered and succumbed to the pressure of the public". This supports the view of the need to select

DSS methods that are capable of taking account the opinions of the public and cannot simply rely on the input of experts. It also indicates that the public should be consulted in the formulation of EfW options from the start of the decision making process. In the final planning decision meeting held in 1992, councillors refused on the grounds of unacceptable visual impact and recommended an investigation into a series of smaller incinerators combined with the maximum use of recycling. In effect, local politicians had given a strong policy lead to implement smaller, multiple plants to cater for the same capacity as the centralised facility.

The final EfW policy adopted and successfully executed, consisted of three plants (one 90 ktpa and two 165 ktpa) located in proximity to serve the densely populated urban areas of Portsmouth, Southampton and Basingstoke. It is disappointing that despite the lessons of Project Integra, clearly communicated in Lisney (2001), many WDAs remain indifferent to the experience gained and do not consider the potential of smaller-scale EfW policies from the outset of strategic planning. This case study shows that pursuing any one route to EfW within a municipal area without thorough investigation of the merits of alternative routes can lead to effective criticism. There is need for a DSS methodology that measures the merits and impacts of different scales and technologies of EfW options developed for each WDA context.

1.4. DECISION MAKING AND SUPPORT SYSTEMS

It is clear from Section 1.3 that EfW planning is complex and there is need for support to all interested parties and particularly the WDAs who have a statutory duty to manage waste. "Decision Making is a process of choosing among alternative courses of action for the purpose of attaining a goal or goals." (Turban and Aronson, 2001). Modelling that may inform this process is called Decision Analysis. Alternatives are listed with their forecasted contributions to the goal. Multiple goals can be modelled using techniques such as Multi-criteria decision analysis (MCDA). In the context of this project, the alternatives are area-tailored EfW options of varying scale and technology. The goal is to identify the option that performs best on environmental, economic and social criteria as required by the principles of Sustainable Development (WCED, 1987). A more important goal however, is to provide insight and intelligence into the EfW decision making process to all parties involved at the local level, where policies are to be implemented.

Earlier sections mention the need for a Decision Support System or DSS. "Decision support systems couple the intellectual resources of individuals with the capabilities of the computer to improve the quality of decisions. It is a computer-based support system for management decision makers who deal with semi-structured problems" (Keen and Morton, 1978). A structured problem is one that is typically repetitive for which standard solution methods exist. An unstructured problem is complex and has no 'cut and dried' solution methods. A semi-structured problem lies between these extremes. Previous sections indicate that EfW planning is a semi-structured problem in that although some data can be used, a simply quantitative and formal approach fails to take account of stakeholder values and there is no standard solution. DSS are used for long-range and strategic planning and integrated problems areas. In solving semi-structured problems, DSS are often a 'blend' of judgment and modelling.

Wey (2005) states that the two main aims of applying DSS is to improve the quality of the decisions taken, and to supply technical documentation in support of decisions for both authorities and the public. Nilsson et al. (2005) present five questions on which to evaluate DSS methods:

1. What functions do the various methods provide and to what extent are they fulfilling them?
2. Are the methods able to cover sustainability concerns and how can they be combined to broaden the scope across more dimensions of the problem?
3. Are the methods transparent and formalised enough to enable peer review with reproduction of results by an external team?
4. Are the methods likely to be considered valid, legitimate and trustworthy by multiple actor constituencies, given their underlying frames of values?
5. Can the methods facilitate a broader process of involvement of different types of expertise and stakeholders.

Freppaz et al. (2004) caution there is a risk that results from a 'black box' analysis may not be understood by non-experts or laymen. In short, the use of more complicated approaches depends on the level of knowledge and understanding of the audience to whom the results are directed. If this project is to make a useful contribution, it must consider the expertise and understanding of the end-user it is aimed at – principally the WDAs. Previous sections support the use of these criteria to select and test methods for final inclusion in the DSS to be developed by this project.

1.5. AIMS OF PROJECT

This project aims to develop and test a decision support system (DSS) to assist sub-regional WDA decision-makers in the formulation and appraisal of EfW implementation options that incorporate choices about the size, number and locations of facilities as well as the technology used. In addition, this project also aims to identify if smaller, multiple or large-scale centralised systems of either Combustion or Advanced Thermal Treatment technology are preferred options and identify the key factors that may affect this outcome.

1.6. SYNOPSIS OF KEY POINTS FOR DSS DEVELOPMENT

Taking account of the material in this Chapter and the Energy and Waste Management EU policies in Appendix A, the proposed DSS in this thesis should:

- Identify EfW sites on industrial locations that are in close proximity to waste production and heat demand.
- Any definition of EfW option capacity must meet local WDA landfill allowance (LATS) targets.
- Formulate options on the basis that waste minimisation, re-use and recycling targets are met, thus satisfying the Waste Hierarchy framework.
- Use techniques that can take into account cross sub-regional boundary phenomenon if required.

- Consider tools that can quantify and/or appraise the environmental impacts of several waste management options on a consistent basis, including those associated with transport.
- The Environment Agency's WISARD LCA tool does not consider the emerging ATT technologies based on pyrolysis/ gasification or even conventional EfW plant below the 250 ktpa capacity. This DSS should consider the need to include the emerging thermal technology and smaller-scale distributed EfW facility options, in addition to the typical large-scale centralised option.
- Be capable of accommodating additional technology options as new technologies are proven.
- Include an appraisal element that can incorporate environmental, social and economic criteria to assist preferred option outputs to pass through Strategic Environmental Assessment successfully and ensure contributions to the objectives of Sustainable Development are maximised.
- Be transparent in that its methods and outputs are not too complex for stakeholders to understand how the preferred options have been arrived at.
- Have methods which can potentially take account of the opinions and values of a range of stakeholder groups, including the public.
- Consider WDAs as the main end-user, and hence ensure techniques are reproducible within WDA resources for EfW planning.

For the DSS to be effective, it must be able to prove its capacity to define what EfW policy is most suitable and be transparent. To do this the methodology for any one defined area has:

1. Identified sites for smaller-scale distributed EfW plants. To do this the following was required:
    a. Identification of where concentrations of local MSW fuel arise, in order to minimise transport impact.
    b. Identification of sites that are within planning regulations and are suitable in technical terms.

2. Allocated waste resources to their local plant.
3. Compared derived small-scale EfW options with large-scale, together with implications of technology.
4. Produced a ranking of options to identify which is preferred.

The development and use of a DSS that meets the requirements above could lead to more widely supported sub-regional EfW policies and could reduce the problems described in Section 1.3.8. Such a tool would make a useful contribution to the UK EfW planning arena.

1.7. CHAPTER SUMMARY AND THESIS OUTLINE

This chapter has provided the background and justification for the development of a decision support system to help formulate and appraise EfW policy in the UK (Sections 1.3.1 to 1.3.5). Thermal treatments for waste including conventional combustion and the newer alternatives of pyrolysis and gasification (ATT) were introduced and the importance of CHP discussed. Section 1.3.6 identified that WDA officers and politicians are in a central EfW decision making position and that any DSS proposed by this project should be made suitable for use by them and be capable of taking into account the values of other interested parties. Sections 1.3.7 and 1.3.8 discussed how the expanse of policy and legislation in Appendix A can influence EfW decision making at the local level, also how the range of actors' values can lead to conflict, delays and public sensitivity to the size and technology of schemes. As an example of the problems, Section 1.3.9 provided an important UK case study that described how and why Hampshire County Council moved from a centralised to a more distributed EfW policy in the 1990s. Section 1.4 introduced the concept of decision support systems, while Section 1.5 stated the aims of this project was to develop a DSS capable of formulating EfW policy options for a specific area and appraise them, ensuring that new and varying scales of technology are considered, while taking account of the key points summarised in Section 1.6.

Chapter 2 is the first of three literature review chapters and explains why this project has chosen to use Geographical Information Systems (GIS) and Multi-criteria decision analysis (MCDA) with elements of life-cycle assessment (LCA) in an overall decision support system to assist WDAs formulate and appraise EfW policies.

Chapter 3 reviews GIS methods, criteria and data used in previous Energy DSS studies that may be adapted to assist EfW policy development and used to solve some of the problems identified in Section 1.6.

Chapter 4 reviews the criteria typically used, defined, selected and weighted in previous studies to appraise energy and waste policy as well as the data used to derive performance scores.

Chapter 5 presents an outline of the EfW DSS proposed by this project, a result of the review of analyses tools and testing of techniques, criteria and data. This chapter also provides the parameters in which the DSS is applied to the WDA contexts of Cornwall and Warwickshire and definitions of scale and technology that are combined to define the EfW options appraised in this project.

Chapter 6 is the first of two chapters that present the methods and results of the application of the GIS-based element of the overall DSS. Residual MSW production and site identification map modelling results are presented for both medium and local EfW options for both UK WDAs of Cornwall and Warwickshire and discussed. Factors such as the effects of increased waste production or diversion of waste to alternative disposal routes are also discussed.

Chapter 7 presents the methods and results of two alternative GIS-based approaches for estimating the transport impacts associated with each of the EfW options in terms of the haulage of waste from their allocated catchments and the ash produced for final disposal. The results of each method are compared and guidance provided as to which method is preferred.

Chapter 8 presents how the overall MCDA appraisal element of the DSS was developed in terms of criteria definition, selection and weighting. Also described is how performance scores for each of the EfW options was derived and data sources. The procedure for combining weights and scores is also presented.

Chapter 9 provides the results and discussion of the application of the MCDA appraisal to the Cornwall and Warwickshire WDA contexts. All EfW options have been ranked in terms of overall score and a discussion has been made regarding the possible influences that may change criteria score derivation and ultimately the overall ranking of options. The chapter concludes by comparing the results of this project with the 'real' UK EfW decision making context and explains possible reasons for the difference.

Chapter 10 presents the conclusions of this project in terms of the effectiveness of the DSS methodology and the results of its application. The chapter concludes with a discussion of the wider implications for UK EfW policy.

Chapter 11 presents aspects of further work that could be undertaken in order to improve the DSS methodology as well as topics of further study in their own right.

2. DECISION SUPPORT METHODS FOR FORMULATING AND APPRAISING ENERGY AND WASTE POLICY

2.1. AIMS OF CHAPTER AND REVIEW STRUCTURE

The need to incorporate local considerations has led to an increasing use of Geographical Information Systems in formulating energy and waste policy options. The need to add environmental and sustainability elements to decision making has led to the increased use of Multi-Criteria Decision Analysis (MCDA) and Life Cycle Analysis (LCA) over methods such as Cost-Benefit Analysis (CBA), Life Cycle Costing (LCC), Material Flow Analysis (MFA) These solely economic methods have not been the focus of this review, since they do not address the need to take into account environmental and social impacts as required by PPS 10 and the requirements of Sustainable Development. EfW is an area of planning in which environmental issues must be addressed in addition to economic ones. Environmental Impact Assessment (EIA) studies have also not been the focus of this review since they are designed for specific site assessment rather than overall policy implementation and strategy appraisal, while Strategic Environmental Assessment (SEA) could in principle use several of the analysis tools above (Finnveden & Moberg, 2005) – including the DSS developed in this project.

For these reasons, the review of literature in this and the following two chapters has concentrated on GIS, MCDA and LCA energy and waste analysis studies. Sections 2.2 to 2.4 provide background to these approaches, while Section 2.5 explains how it is possible to combine them in order to exploit their relative advantages. Section 2.6 presents the rationale for the selecting GIS and MCDA as the core tools used in the overall DSS approach for achieving Points 1 to 4 in Section 1.6. Section 2.7 introduces and reviews various MCDA methods. Section 2.8 describes software typically used by authors and reasons why ArcView GIS and HIVIEW has been selected for use by this project. A summary of the main review points from this chapter is presented in Section 2.9

2.2. GEOGRAPHIC INFORMATION SYSTEMS

The need to account for local conditions in formulating waste management options has led to an increasing use of spatial decision tools based on Geographical Information Systems (GIS) to model baseline waste conditions, identify potential facility locations and to estimate transport impacts (Cheng et al., 2003; Maniezzo et al., 1998; Matejicek et al., 2006; Nilsson et al., 2005; Shmelev and Powell, 2006). A GIS is a computer-based system for capturing, storing, integrating, manipulating and displaying data using digitised maps (Turban and Aronson, 2001). A distinguishing feature of a GIS, is that it assigns a geographical location for every object (or feature). GIS users can generate information for problem solving and decision making by integrating maps of different geographically located objects and their non-geographic attributes (Turban and Aronson, 2001). GIS has a unique capacity to integrate and analyse multi-source and subject spatial datasets (Malczewski, 1999). A common data format output of GIS is mapping, but other types of output include: text – lists or numbers in response to queries. Queries often result in numerical results, such as totals, distances, areas and counts (Malczewski, 1999).

GIS analysis is resolution-dependent and it is necessary to consider the appropriate spatial scale for addressing problems (Graham et al., 2000). A detailed site identification study, will for example, require much finer-scale data than broader county-wide resource studies. For many variables of interest, a spatial distribution must be created using at least one variable (such as population) with geographically explicit (census output areas) dataset, (Graham et al., 2000). An example of this includes the project example of using the geographic distribution of human population to estimate MSW in Tyson et al. (1996)

GIS data can be classified as either raster (cell-based) or vector data. Vector data can be in the form of a 'point', 'line' or 'polygon' and are called objects. A point represents geographic features that are too small to be depicted as lines or areas. Lines represent features too narrow to be depicted as areas and polygons represent larger continuous features. A point can be a small building, lines can be roads or rivers and polygons can be larger area phenomenon such as a building complex or wood. Raster-based cell modelling is typically used for modelling continuous geographic features, but vector based modelling can be useful for network analysis or distance queries. Examples of vector and raster data are shown in Figure 3.

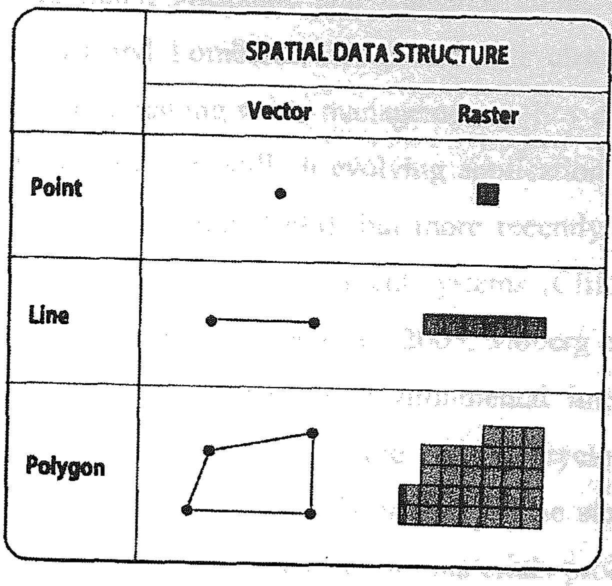

Figure 3: Vector and raster data representation from Malczewski (1999).

Centroids are point data representing the 'centre' of a polygon area. Usually they are calculated by the geographic latitude and longitude coordinates of the polygon. Regarding the inputs to the resource models in Section 6.2.1, however, Census Output Area (COA) population-weighted centroids were used with their attribute numbers of households. The population-weighted centroid is calculated by subdividing the COA into its population census constituent sub-units (collector's districts) and calculating the geographic centroids of these. The population-weighted centroid is found by weighting the average of the latitude and longitude coordinates of the sub-unit centroids by the populations of those sub-units. This increases the accuracy of where the point is located as regards the majority of the population resident within the COA polygon area. Hence, population-weighted centroids have been used to estimate transport impacts for example.

2.3. LIFE CYCLE ASSESSMENT

In terms of deriving environmental impact of waste management options, much of the literature makes use of life-cycle assessment (LCA) (Finnveden et al, 2005; Moberg et al, 2005; Wenisch et al, 2004; Azapagic and Camana, 2005; Consonni et al. 2005b; Bergsdal et al. 2005; Corti and Lombardi, 2004) and it is clear that the technique has emerged as a powerful tool in making waste management policy decisions (Rebitzer et al., 2004; Ekvall et al., 2007). LCA is still an evolving application, with its roots based in energy analyses of the 1960s (Curran, 1996), but more recently publications have been made on how to apply LCA to waste management systems (Clift et al., 2000) and more specifically to energy from waste (Finnveden et al., 2005; Moberg et al., 2005).

An LCA practitioner investigates the environmental impacts by tabulating the emissions and resources involved throughout the full life-cycle (cradle-to-grave) of a product or system (Rebitzer et al., 2004; Weisser, 2007) The stages in a life cycle can include raw material extractions, energy acquisition, materials production, manufacturing, use, recycling and ultimate disposal (Rebitzer et al., 2004). An application of LCA consists of four different phases that include: Goal definition and scoping. Life cycle inventory (LCI); Life cycle impact assessment (LCIA) and interpretation of the results (Curran, 1996). Specifically within the impact assessment, impact categories indicators and models are selected and the processes of classification, characterisation and weighting are carried out (Moberg et al., 2005). Contributions to the impact categories are quantified in the characterisation.

Characterisation is the assessment of the magnitude of potential impacts for the chosen impact categories and can be performed using equivalency. The latter is when models use derived factors to aggregate inventory data with the assumption that aggregated equivalency factors measure potential impacts. Aggregation of criteria scores is an area of LCA that can be used within MCDA, for example, the aggregation of sub-criteria to give an overall score of 'equivalent' impact. Such a technique will be used for environmental criteria such as emissions to air as outlined in Section 8.4.3. Further information regarding LCA in waste management applications is presented in Appendix B.

2.4. Multi-criteria decision analysis

MCDA is a decision making tool that can evaluate a problem by giving an order to preferences for multiple alternatives on the basis of several criteria that may have different units (Hermann et al., 2007). The effective application of MCDA to assist decision makers with multi-criteria problems in both the public and private sectors was spearheaded by the classic works of Keeney and Raiffa (1976). Their MCDA approach was also applied to site selection and identification when geographic database DSS were in their infancy (Keeney, 1980). The aim of an MCDA is to compare and rank alternative options and to evaluate their (environmental, but also social and techno-economic if necessary) consequences according to the established criteria (Zopoundis and Doumpos, 2002).

When choosing criteria, it is important that their underlying option performance score are consistent with the importance of the issue being considered and must be mutually exclusive. The data for scoring the criteria must be collectable within the limitations of the project resources. Scores can be summarised in a performance matrix, in which each column describes an option and each row describes the performance of an option against each criterion (the matrix generated by this project is shown in Table 42). Scores can simply reflect the directly measurable aspects of an option or may be calculated with respect to other variables. All are converted into preference values, which express the extent to which the options achieve the objectives represented by the criterion. For example, a value of 100 can be given to the top score option, representing the highest preference, while a value of 0 can be assigned to the bottom score option, indicating lowest preference.

Value functions are the process by which this conversion is made, which can be custom defined, but are most often of a linear nature. This can also be seen as normalising all the criteria scores to a common scale for later comparison. Weights are numerical values that are assigned to define the relative importance of a shift between the top and bottom of the chosen value function scale. Mathematical routines are then used to combine scores and weightings to give an overall assessment for each option. These routines can be written into computer programs, most of which are commercially available (Dodgson et al., 1999). Formal MCDA methods (such as those described in Section 2.7) can be used to identify the most preferred option, to rank options or to identify several options worth further detailed appraisal.

Figure 4 shows the key stages in any application of MCDA. The order is not a strict agenda and options for example, can be identified after the criteria are proposed. MCDA, by reference to an explicit set of measurable criteria can identify preference between alternatives that can solve a decision problem. MCDA often centres on the judgement of the decision makers in that they provide choices of objectives, criteria, weights and assessments of the overall achievement of objectives (Dodgson et al., 1999).

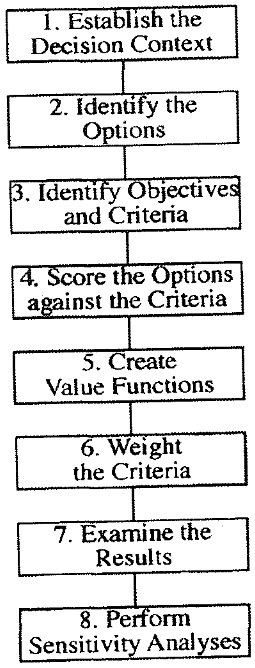

Figure 4: The MCDA process.

2.5. COMBINING ELEMENTS OF GIS, MCDA AND LCA TOOLS

GIS, MCDA and LCA approaches are being increasingly combined within overall waste management decision support systems to exploit their relative strengths (Elghali et al., 2007). For example, GIS and MCDA have been used together to identify and prioritise sites for EfW facilities. Maniezzo et al (1998) and Cheng et al (2003) use GIS to derive potential sites and MCDA for evaluating the different derived options.

A key area where MCDA and LCA are combined is in the development of weighting factors. These can be created by using MCDA and then applied to Life Cycle

Impact Assessment (LCIA) as discussed by Soares et al, 2006. Another key area of integration is the aggregation stage of LCIA, where MCDA is applied to LCA output data to calculate a single overall index (Benoit and Rousseaux, 2003). Hermann et al (2007) state that the reasons for combining LCIA and MCDA tools lie in their 'complementary characteristics'. These include the objectivity and method standardisation of LCA, as well as the ability for MCDA to take into account subjective elements, such as the opinions of stakeholders and decision-makers. Hermann et al, 2007 note, however, that for all the effort required in collecting and analysing a large amount of data for LCA, this will not be realised but diminished in the MCDA aggregation phase and uncertainty created. Therefore a key weakness however of combining LCA and MCDA is that the comprehensiveness of LCA is diminished since a full assessment has not been fully carried forward and the use of MCDA implies value-laden choices have been made, possibly influencing the results.

Integration of tools for use by the public with other decision support tools such as those derived from LCA will be challenging due to the risk of their complexity not being understood by users. DSS designed for the public sector include Wheeler and Jainter (2006), Jainter and Poll (2005) and Higham (1999) who used the LCA tool WISARD (Appendix B.7) for the assessment of environmental impacts associated with waste management options, but assess socio-economic objectives using in house models and 'professional judgement' analyses. The problem with these studies is that they do not adequately describe their methods or what 'professional judgement' is and how it is justified. The scores from these 'analyses' were combined in an MCDA weighted-sum method (Section 2.7.5) with weights provided by WDA councillors and officers to produce final rankings of options in closed meetings. The outputs of these tools were often used to justify the choices for intended technology procurement but are vulnerable to criticism due to their lack of transparency and exclusion of the values of other stakeholders. They can also be criticised for not considering emerging EfW technologies.

Despite the potential problems described above, different tools for environmental systems analysis can focus on modelling different aspects of reality, and a combination of can provide a more holistic (Ekvall et al., 2007), promising (Hermann et al., 2007) and comprehensive (Finnveden and Moberg, 2005) picture. The relative advantages of different methods are discussed further in Shmelev and Powell (2006) who conclude that despite the large amount of research done in this area, the application of single methods employed does not provide a holistic picture of the impacts of municipal solid waste management systems. A holistic model needs to take into account transportation, technology and siting issues simultaneously. Nilsson et al. (2005) also conclude that they complement each other rather than substitute for each other. In responding to these issues and to enjoy the advantages and strengths of more than one method, this project will use both GIS and MCDA to take into account transportation, technology and siting issues simultaneously in an overall DSS approach. The next Section explains why GIS and MCDA have been used but not LCA.

2.6. A DSS METHODOLOGY USING BOTH GIS AND MCDA

GIS can be used to model the production of waste across a georeferenced area and the locations of present and planned waste incinerators as well as spatial criteria that can assist the identification of new site locations such as proximity to suitable road and electricity networks. In contrast, it is problematic for LCA to include site-and area related aspects of EfW planning (Finnveden and Moberg, 2005; Weisser, 2007). GIS methods can be used to formulate EfW implementation options tailored to the unique geographical characteristics of the study areas. GIS, using local data has been successfully used together with MCDA to combine the advantages to ensure that area specific concerns are included in the waste management appraisal of options (Matejicek et al, 2006; Cheng et al., 2003; Maniezzo et al, 1998; Nilsson et al, 2005; Shmelev and Powell, 2006). Munda (2004) notes that scale implications of the development of infrastructure and the geographical context are very important for multi-criteria evaluation. This further justifies the linking of GIS and MCDA techniques in an overall DSS that is intended to consider scale-related implications of EfW options from the start. Due to the strong relationship that EfW policy has with geographic influences for the in Section 1.6, this project has chosen to use GIS as the key tool in its overall DSS method to formulate EfW policies that reflect the geographic conditions of the specific WDA area.

Waste management policy appraisal that includes EfW solutions, has made extensive use of LCA (Azapagic and Camana, 2005; Bergsdal et al., 2005; Consonni et al., 2005b; Corti and Lombardi, 2004; Nilsson et al., 2005; Wenisch et al., 2004). But different actors within the EfW planning arena have different rationales and Nilsson et al. (2005) note that LCA which is based on a "rationalistic paradigm" has been argued to be ill suited to a multi-actor environment. The challenge for the analyst in a multi-actor arena is that different actors will have different perceptions on what is relevant. To this end, Multi-Criteria Decision Analyses are superior over Life Cycle Assessments in that subjective political values can be included and scrutinised. This is one of the most important reasons supporting the decision of this project to use MCDA over LCA. By using MCDA, the proposed DSS can potentially accommodate the views of a range of stakeholder groups. The value in MCDA is inherent in that it allows this processing of values from the different stakeholder groups. Rozakis et al. (2001) have indicated that more criteria should be used if there is a desire to represent each stakeholder's viewpoint and LCA which uses standardised impact categories is unlikely to be able to accomodate this.

LCA is time consuming, as well as data intensive and may not be possible within WDAs scope of assessment. For example, Shmelev and Powell (2006) argue that LCA may not able to cover the breadth required in sustainability considerations. There is a need to create an overall appraisal that requires less detailed data, time and expert knowledge, but that still provides a comprehensive analysis (Hermann et al., 2007). EfW planning and policy has technical, economic, environmental, social and political elements and MCDA can cover the breadth of criteria required within project resources than LCA. MCDA has also been extensively used to compare different waste management technology options on technical, economic and environmental criteria. Methods for this vary and the most popular ones include PROMETHEE (Khelifi et al. 2006), AHP (Dai et al, 2001), ELECTRE (Norese, 2003) and weighted sum (Dujim and Markert, 2002; Cheng et al, 2003).

Several authors emphasise that value can be derived from MCDA approaches is not just in the results themselves, but more importantly from the process itself (Keeney and Raiffa, 1976; Keeney, 1980; Keeney et al., 1987). Section 1.3.8 described the conflict that can arise in EfW planning and the need for an approach that can mitigate these conflicting values and interests and build consensus in the decision making process. Elghali et al (2007) suggest that MCDA is the best tool to achieve this. Norese (2003) expressed that participatory MCDA requires active input from all parties, and this led to a more co-operative attitude towards decision making. The author also reports that MCDA methodology is also understood by the majority of participants and became a 'local language' which was shared and accepted. To the benefit of this project and the parties involved, such benefits of MCDA could assist the collection of weights from participating WDA officers as well as empower then to master the EfW decision making context.

Another advantage of MCDA is that criteria with their own indicator dimensions can be used and the tool is quite unique in that it includes subjective elements and results in a single number output, unlike LCA. One of MCDAs potentially greatest weaknesses however, that must be considered, is the subjectivity of the weighting step that is needed to value the different criteria (Hermann et al., 2007). Unlike CBA, MCDA cannot show that an action increases welfare more than it detracts. In principle, a best option from an MCDA may be inconsistent with improving welfare and therefore, a 'do nothing' option might be preferable (Dodgson et al., 1999). This is not possible within this study however, when WDAs must divert waste from landfill under European Legislation or face large fines (Appendix A.2.1).

2.7. MCDA METHODS

Due to the need to include the qualitative views and opinions of conflicting actors and experts, MCDA methods have remained a useful appraisal tool and this was the primary reason for using MCDA as the EfW option appraisal element of the DSS and not LCA. This Section reviews MCDA methods used in energy and waste planning.

2.7.1. DIRECT PERFORMANCE MATRIX ANALYSIS

These analyses output performance tables of techno-economic and environmental emissions data and can be regarded as a non-compensatory MCDA technique (Dodgson et al., 1999). These tables have no further analysis worked upon them, but are intended to be used for decision-making processes in general, particularly regarding choices in EfW technologies. Several studies of this type, such as by Mc Lanaghan (2002), Livingston (2002) and Fichtner (2004) have been rapidly commissioned to assist local authorities make informed choices on the emerging EfW technologies. The results of these studies are often summarised in relative advantage tables and normalised to allow comparison. While straightforward to compare, they do not allow any scope for expressing value judgements on the relative importance of selection criteria and hence are not suitable for use in this project where the method must capture the values of stakeholders.

2.7.2. MULTI-ATTRIBUTE UTILITY THEORY

The classic work of Keeney & Raiffa (1976) is the key reference for multiattribute utility applications (MAUT). The terms attribute and criteria are synonymous. The authors established a set of fundamental axioms of rational choice, for example, more of a desirable good is preferred to less of it. Following this with the use of mathematical reasoning, the authors showed that the only way an individual can act consistently and rationally within the set of axioms was by choosing the options that provided maximum expected utility. They acknowledged that because of uncertainty, different options will have potentially different values (or utilities). A useful summary of MAUT can be found in Dodgson et al. (1999) and detailed reading can be found in Keeney (1992). This model of rational choice is one of the most widely accepted, but is not however extensively used in energy planning and this may be due to the requirements of the participatory environment in which MAUT is implemented (Pokehar and Ramachandran, 2004). Its application however in the public sector (WDA) arena can be costly due to the need for specialist consultants and its methods are reported as being of greater complexity (Dodgson et al., 1999) than those described in the following sections.

2.7.3. ANALYTICAL HIERARCHY PROCESS

The Analytical Hierarchy Process (AHP) was developed by Saaty (Saaty, 1980) and is a popular MCDA technique for energy and sustainability studies that include Wey (2005) and Dai et al, (2001). AHP essentially uses pair-wise comparisons to determine the relative weights of any single criterion or indicators. A problem is divided into a hierarchy with the goal objective at the top. Criterion and sub-criterion form the levels of the hierarchy with alternative decision options at the bottom. Elements at any level are compared in pairs to assess their relative preference with respect to each of the elements at the next higher level. Saaty's ratio scale and verbal comparison are used for the weighting of quantifiable and non-quantifiable elements. Eigenvectors of the elements are aggregated and computed by the method until the composite final vector of weight co-efficients is obtained. Final weight co-efficients reflect the value of each alternative with respect to the goal at the top of the hierarchy.

After the weight vector has been obtained, it is multiplied by the weight co-efficient of the element at a higher level and repeated until the top of the hierarchy is reached. The overall weight co-efficient with respect to the goal for each decision alternative is obtained. The highest of these indicates which alternative is best. AHP has the advantage of being able to compute an inconsistency index to assure the decision makers that judgements are consistent, it is unlikely however, that such a method could be easily communicated to WDAs and stakeholders that may question how 'best' alternatives have been computed.

2.7.4. OUTRANKING METHODS

After AHP, outranking techniques are the most popular technique for academic energy and waste policy studies (Pokehar and Ramachandran, 2004). These include PROMETHEE (Preference Ranking Organization METHod for Enrichment Evaluations) and ELECTRE (Elimination and Choice of Translating Reality) techniques and contextual studies include Haramlambopoulos & Polatidis, 2003 Barda et al., 1990, Goumas & Lygerou 2000, Norese 2003 & Georgopoulou et al, 1997). Reasons for use range from preventing decision makers asking too many intricate questions (Norese 2003), to ease of use and decreased complexity (Haramlambopoulos & Polatidis, 2003). There is a risk that the former of these reasons may be regarded as undermining transparency.

Outranking techniques produce a core of leading alternatives by eliminating less favourable ones. It is therefore, convenient for decision making problems with a large number of alternatives with fewer criteria. In the context of EfW planning, it is likely that the reverse is more useful, where there are fewer alternatives of EfW options to be assessed. Outranking techniques can only express alternative A is preferred to alternative B, but cannot indicate how much. They do not produce a complete ranking of options, which may be problematic, where decision makers prefer to understand how options perform in relation to each other. Other methods such as WSM in the next section do not have this disadvantage (Georgopoulou et al, 1997).

2.7.5. Weighted sum method

In the review of mathematical methods for MCDA it is noted that WSM is not one of the most complex MCDA methods in academia, but that generally it is the most widely used (Pokehar and Ramachandran, 2004). This method is recommended for public sector decision making by the UK Government (Dodgson et al., 1999) and this supports the use of this method in a DSS designed to assist WDA officers. Generally, if there are M options and N criteria, then the best option is the one that satisfies the expression in Equation 1.

$$A_{WSM} = Max \sum_{i}^{j} a_{ij} w_j \qquad \text{for } i = 1,2,3,...N \qquad (1)$$

Where A_{wsm} is the WSM score of the best alternative option, N is the number of decision criteria; a_{ij} is the actual value of the i^{th} alternative in terms of the j^{th} criterion and w_j is the weight on the j^{th} criterion. The total value of each option is equal to the sum of the products.

From the review of studies that have used MCDA to appraise energy or waste managment options, it is clear that authors decide which technique they will use to combine criterion decision maker weights and performance scores based on perceptions of what the end decision maker audience will understand and be comfortable with. There is therefore, no 'typical' technique used. While Norese (2003) used ELECTRE because it is "easily elaborated and understood", Haramlambopoulos & Polatidis, 2003 used PROMETHEE instead of ELECTRE due to its ease of use and considered ELECTRE to be complicated and not easily understood by decision makers. Meanwhile, considerable support exists for using WSM due to ease of use for handling data and understanding by decision makers and its application in many fields (Cheng et al, 2003)

Authors report that decision makers involved when implementing their chosen technique find the process difficult to understand (Georgopoulou et al, 1997). It is clear that the method used by this project must be understood by WDA officers and the public if it is to be fit for purpose in supporting WDAs move towards establishing an EfW implementation plan that is generally supported. This was discussed with WDA officers involved in this project, and it was clear that there was a far better knowledge and understanding of the WSM method (Lea, 2006b). For this reason, it was decided to use the WSM MCDA technique within the development of the proposed DSS in this project.

2.8. SOFTWARE: GIS AND MCDA

When authors have included a spatial element in their energy and waste decision studies, ESRI's ArcInfo or ArcView has been the GIS software of choice (Noon and Daly, 1996; Varela et al, 2001; Dai et al, 2001; Shmelev and Powell, 2006; Matejicek et al. 2006), since the platform supports both raster (cell based) and vector (line and point based) modelling. Other software includes the IDRISI (Schneider et al, 2001), which is noted to be very powerful for cell based modelling and MAPINFO Professional (Voivontas et al. 2001). Others have adapted commercially available emissions dispersal GIS software such as the 'add in': EcoSense 2.0. (Nilsson et al 2005).

Freppaz et al. (2004), Graham et al. (2000) and Matejicek et al (2006) have specifically programmed GIS modules to carry out customised calculations and optimisation. The authors use a variety of codes including Visual Basic 6.0 and C++ assisted by ESRI MapObject 2.1 and Microsoft Mappoint 2002 software. Consonni et al. (2005a) developed their own code for estimating the performances of EfW plants for energy and mass balance purposes to derive further data for inclusion into LCA procedures. Other authors such as Wey (2005) and Khelifi et al. (2006) program their own decision support systems using a variety of languages such as Java, Visual Basic, C++ and Delphi.

Since, ESRI GIS software already contains many of the data processing and query tools necessary to use in spatial decision making and has an inbuilt capacity for authors to create customised code for tasks that the platform does not support on the usual user interface, it was decided to use the ArcView GIS software. Choice of software is important since many authors use tools and methods already included in the software to carry out both non-spatial and spatial calculations. ESRI GIS software is also typically used by the majority of UK WDAs, including Cornwall and Warwickshire.

There are several software packages on the market to aid multi-criteria decision making including Expert Choice that uses the AHP technique (Section 2.7.3), Decision Pro, Hipre and Web-Hipre. A well-known and recommended MCDA software tool using the WSM technique is HIVIEW, developed by the London School of Economics. In HIVIEW, option scores are normalised to a scale of 0-100 for each criteria, with 100 corresponding to the most desirable score. The normalised scores are then multiplied by the cumulative weights. The results for each criterion are finally added to produce an overall result for each option alternative. HIVIEW uses the weighted sum method (WSM) presented in Section 2.7.5. The overall value of option i is shown by Equation 2.

$$V_i = \sum_j w_j v_{ij} \qquad (2)$$

Where v_{ij} is the value associated with the value of option i on criterion j and w_j represents the weight assigned to criterion j. This tool was used in a highly publicised nuclear waste treatment site problem (CORWM, 2006). HIVIEW is recommended for use by the public sector by the UK Government (Dodgson et al., 1999) and WDA officers involved in this project were also aware of the software, with some also having experience of using it themselves (Lea, 2006b). A key objective of this project is that techniques used can be replicated by WDAs – the intended end-user, hence it ws decided to use this software.

2.9. REVIEW SUMMARY

- There is a risk that method elements may not be understood by WDA personnel and the proposed DSS should therefore consider the expertise and understanding of the WDA end-users when selecting methods for use within the overall DSS.

- The application of single methods does not always provide a holistic picture of the impacts of system options. A holistic model using a combination of methods should take into account transportation, technology and siting issues simultaneously.
- The need to account for local conditions in formulating waste management options has led to an increasing use of spatial decision tools based on GIS.
- In order to enjoy the advantages of more than one method and to extend the scope of the DSS as much as possible, it was decided to use GIS for formulating EfW options and MCDA to appraise them in an overall DSS method.
- LCA has been argued to be ill suited to a multi-actor environment, is also time consuming, data intensive and may not be possible within the scope of assessment or policy decision studies. It has been argued that LCA may not able to cover the breadth required in sustainability considerations and will not be used as a DSS component.
- The disadvantages of LCA and the need to include the qualitative views and opinions of conflicting actors and experts due to the level of conflict currently encountered in EfW planning are the reasons for using MCDA instead of LCA in the proposed DSS. Equivalency and weighting factors commonly used in LCA will, however, be used to aggregate sub-criteria scores.
- The WSM MCDA method will be used within the development of the proposed DSS, since it is the most widely used and is recommended for public-sector decision making.
- ESRI's Arc Info or Arc View has been the GIS software of many authors' choice. Its inbuilt data processing tools and capacity to create customised code are also reasons for using the software to develop and test the DSS described in this thesis as well as its familiarity with the WDAs.
- The HIVIEW, MCDA software tool will be used in the development of the DSS because of its included tools to aid the group-orientated task of acquiring weights. This software has also been recommended for use by the

UK public sector and is already known and understood by WDA personnel engaged in this project.

3. FORMULATING EFW OPTIONS USING GIS: METHODS, CRITERIA AND DATA

3.1. AIMS OF CHAPTER

In the context of meeting the requirements in Section 1.6, this chapter has concentrated on reviewing GIS-based studies that have used methods, criteria and data to identify suitable sites in Section 3.2. Section 3.3 reviews what methods that can be used to estimate the associated transport impacts of hauling waste to the facilities in each EfW options. Upon consultation with WDA GIS officers (Holmes 2005a), the following criteria have been used to assess whether various approaches to waste resource, site identification and estimation of policy transport impact are suitable for the intended WDA end-user. These include: reasonable computer processing times; suitable for application by non-expert users of GIS software; calculations adaptable to residual MSW; output results at a suitable resolution for UK WDA EfW decision making; technically executable using tools already available in ArcView GIS; minimal additional programming requirements and data availability in the UK context. A summary of the review and selection of methods identified from the literature for modification and inclusion in this project is made in Section 3.4.

3.2. SITE IDENTIFICATION

3.2.1. WASTE FEEDSTOCK PRODUCTION MODELS AND PARAMETERS

If EfW sites are to be identified across a study area that can minimise transport impact and requirement, it is first necessary to develop a baseline map model that shows where densities of waste production occur across a study area. This project has selected methods from Tyson (1996), Bergsdal et al (2005) and Shmelev & Powell (2006) on the basis of meeting the criteria in Section 3.1. They are designed specifically to model waste production geographically and use census data sources since these are readily available. Waste production can be derived directly as a function of census derived variables such as per capita or per household. In contrast, methods from other GIS-based energy planning DSS (Dagnall et al, 2000; Graham et al, 2000; Freppaz et al, 2004; Varela et al, 2001) are not suitable since they are specific to other forms of biofuels such as forestry residues, energy crops and agricultural residues. They use different underlying data and cannot be adapted to the MSW context.

Some Bio-energy DSS are very detailed in their GIS-derived calculations of resource. This project has avoided methods that have a high level of complexity such as Graham et al (2000). Much detail occurs in the calculation of the costs of resource production. This is not applicable to waste, since it is a resource where developers are paid to 'dispose' of it rather than have to pay a price for its production, as is the case with energy crops for example. Highly complex resource models can take several hours to run, require an expert GIS software developer and use multiple software packages and data formats. Such levels of detail and requirement are not suitable for the intended WDA end-user and are not necessary in the process of identifying suitable sites for EfW facilities, processing thousands of tonnes per annum.

None of the authors above have formalised their spatial waste availability calculations, but the following equation from Voivontas et al. (2001) summarises the general mathematical technique used. The total annual production of agricultural wastes in a region was characterised below,

$$B = \sum A_n Y_n \qquad (3)$$

where B (t of residue/yr) is the sum of cultivated area A_n for crop n, multiplied by Y_n the residue yield for crop n (t/ha/yr). In the case of waste, Equation 3 can be modified by replacing A_n by the number of households and Y_n by the waste production per annum per household minus target recycling rate. Tyson et al (1996), Bergsdal et al. (2005), Maniezzo et al. (1998), Wenisch et al. (2004) and Shmelev and Powell (2006) estimate waste production in this way by using population statistics on size and growth of households or per capita and extrapolate to a future year value.

The methods chosen also produce results at a suitable resolution (level of detail) for siting facilities in WDA areas. Shmelev & Powell (2006) for example, executed their study at the sub-regional level of Gloucestershire. Despite being applied at the US national and state level, the method from Tyson et al (1996) is still applicable as long as local parameters are used. Studies such as Noon & Daly (1996) that have assumed all resources are aggregated at the US 'county' are not suitable for this DSS, where it has been decided to locate opportunities for multiple small-scale EfW facilities within a study area. The methods chosen above can output data at a resolution of 1 km^2. This contrasts with unsuitable methods for national studies reviewed that range between 10 km^2 (Price et al, 2004) and 50 km^2 (Freppaz et al, 2004).

Key parameters in the spatial resource modelling of MSW availability for energy generation include assumptions on composting, diversion from landfill and recycling rates and timescales. These assumptions are often based on WDA landfill diversion targets enforced by the Landfill Directive. To be fit for purpose, this DSS must assist WDAs meet their targets. In addition, Consonni et al (2005b) and Bergsdal et al. (2005) agree that energy recovery is only suitable for residual waste after recyclable components have been extracted. Gill et al (2006) challenge this and state that EfW should be given greater priority against recycling in the Waste Hierarchy, since low carbon energy production (Appendix A.3.1.1) is more important than materials recycling. Some LCA studies however, do not support this since, energy consumption is saved in the processing of virgin materials (Boer et al, 2007). From a political point of view, it is in the interests of decision makers to maximise recycling efforts and size EfW facilities accordingly (Kristiansen, 2006) since this form of recovery is popular with the public who have concerns that EfW may undermine recycling efforts (Kondakor, 2007). In order to minimise the potential for conflict, it is arguably worth sizing facilities to residual MSW after recycling to gain public support for facility planning permissions. The definition of residual MSW waste assumed for energy recovery after recyclates have been extracted in this project can be found in Section 5.3.2.

Tyson et al (1996) also takes into account the need to allocate waste production to existing EfW facilties and that this should be considered when modelling potential feedstock availability for new plants. To account for this, Tyson et al (1996) located existing facilities locations and demands for feedstock tonnages have been subtracted from the resource maps on a proximity basis. In the interests of preventing a situation where facilities may compete for feedstock to the point that operational efficiency is compromised, this project will also use this procedure.

Table 3 shows examples of variables from the literature and illustrates that assumed parameters for waste production are significantly different. Such variance will have a very strong influence on final results and variables should be made subject to sensitivity analysis. This has been explored in Section 6.4.3.2 with respect to recycling rates within the contexts of the test WDA areas.Regarding per capita growth in waste generation, while most studies reviewed in Table 3 quote increases in waste growth such assumptions can depend on seasonal and socio-economic factors and can be very different depending on the affluence of the country in that developed nations create more waste than developing ones.

Table 3: Waste production variables from the literature.

Authors	Country context	Waste growth rate (% p/a)	Recycling & Composting rate (%)	Per capita waste generation (kg/pa)
Murphy & McKeogh, (2004).	Ireland	2		326
Tyson et al, (1996)	US		17% 25% (scenario) 50% (scenario)	
Kirkby and Azapagic (2004)	EU	3		250
Consonni et al, (2005a).	Italy		35%	500
Porteous, (2005).	UK	3 & 4	40%	
Wenisch et al, (2004).	France		0, 35 and 60%	365

Tyson et al (1996) stress that it is important in any application of EfW DSS to take into account the waste production characteristics of the geographic area in which the approach is applied, since identifying locations for particular scales of facility at the local level can depend on it. As a result, the authors recommended the use of locally derived waste production parameters for modelling to ensure local conditions are taken into account. In support of this, Bergsdal et al (2005) used different growth rates for different municipalities.

In contrast of respecting local conditions, some studies assume that resources are uniformly arising over the study area (Krukamont & Prasertsan, 2004). In the case of

MSW particularly, this is simply not true, since urban areas generate more waste than rural areas as MSW generation is a function of population. This project will apply waste production and recycling parameters derived from local studies already undertaken by the individual WDA administrations. These take account of local population growth expectations due to different housing development forecasts. Recycling rates used in this project will be set by the WDA targets for 2011.

3.2.2. MODELLING CONCENTRATIONS OF FEEDSTOCK WASTE RESOURCE

Section 1.6 identified that modelling concentrations of resource is an important process in identifying suitable sites. Dagnall et al, (2000) and Bergsdal et al, (2005) note that sites for facilities are only appropriate in geographic locations where suitable concentrations of fuel occur. Bergsdal et al. (2005) also emphasise that locating incineration plants where waste is produced reduces the need for transportation. These references are supported by the recommendations of the PIU (2002) and RCEP (2004) reports. In contrast, Varela et al. (2001) included in their criteria that facilities should be sited greater than 20 km away from population centres. In the UK context however, where population density is relatively high and congestion on roads common, the references made by Dagnall et al, (2000) and Bergsdal et al, (2005) are more relevant than that by Varela et al. (2001). This DSS will identify sites for plants that are in fuel concentrated areas.

Sites for new processing facilities have been selected from locations of existing facilities for energy generation (Noon and Daly, 1996) or more commonly, from pre-study identified lists of potential locations from regional or local development plans (Wey ,2005 and Jainter, 2005) that already outline suitable areas for the construction of EfW facilities. These methods have their weaknesses in that they may only have been identified with a particular scale and type of technology in mind from the outset. The need to satisfy both heat and power production may have been overlooked as well as sites that only have sufficient area to accommodate smaller-scale facilities.

Some methods of site identification are based only on resource production aspects and use query-based calculations to identify if suitable economic and technical conditions exist for supplying a potential facility with fuel from the surrounding procurement area

(Graham et al, 2000; Freppaz et al, 2004). These methods are not flexible and cannot take into account different scales of plant, often focussing on large-scale facilities of up to 630 ktpa (Graham et al, 2000). In addition they may be developed for specific biomass fuels and difficult to adapt to MSW. For example, Graham et al. (2000) identify sites by assuming the best locations are within 1 km cells that exhibit the lowest marginal cost in being supplied with feedstock from all the other cells in the study area but note that their method is not suitable for non-expert GIS users, and hence, may not be suitable for WDA users.

Resource-only based site identification models include Tyson et al (1996) and Nuberg and Bugg (2002). These studies use a 'scanning program' that allows a user-defined radius and MSW capacity of plant. If a particular region has insufficient MSW, the program moves on to query the MSW in the next region until the required capacity is met. Both conclude that derived site outputs may not actually be 'suitable' but imply that their approach may be of some use in the strategic site identification role. Unfortunately, no details on the precise methods or algorithms are given in the literature. In the context, that WDA decision makers must justify their choices of site for any EfW facility and that they must meet Planning Policy Statement 10 requirements, use of such models addressing resource only aspects of facility site identification are not robust enough for this project and any method must incorporate other criteria. These are reviewed in Section 3.2.3.

Resource-concentration models when combined with other criteria in a GIS overlay approach are much more promising. These are used to identify potentially suitable sites (Dagnall et al, 2000; Voivontas et al, 2001; Noon & Daly, 1996). As in the case of Nuberg and Bugg (2002) they often define a radius in which enough feedstock must arise in order to judge whether a particular location is desirable. An example of this type of method using an overlay analysis and maximum radii for identifying concentrations of collectable feedstock resource is shown in Figure 5.

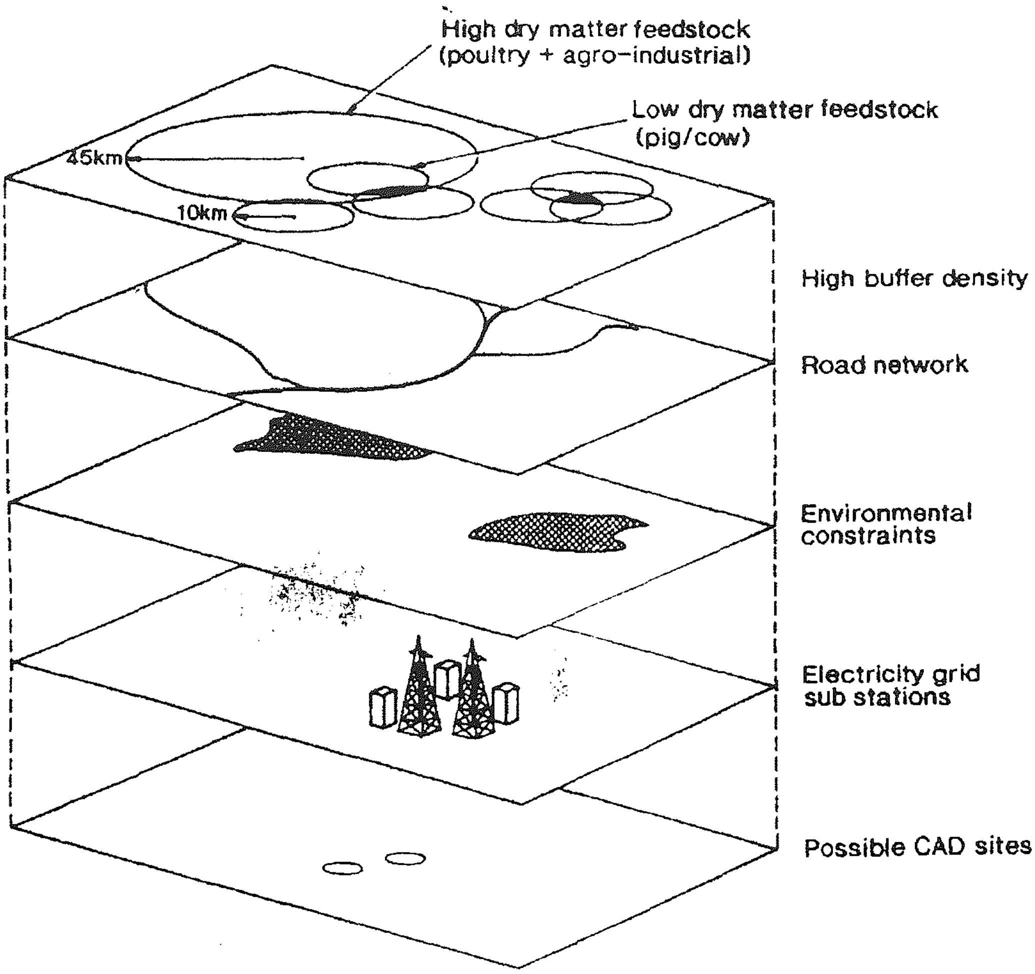

Figure 5: Example of overlay analysis from Dagnall et al (2000).

Dagnall et al. (2000), Voivontas et al. (2001) and Cole et al (1996) estimate the size of the potential scheme at any particular site by calculating the collectable resource for that point within an economic transport radius that depends on the characteristics of the feedstock. If the required feedstock of the plant for any set capacity is greater than that in the surrounding transport radius, the potential plant is rejected. The definition of this radius is often limited on grounds of cost and is a key factor in identifying sites. Dagnall et al. (2000), for example, assume that the transport distance in which the feedstock can be economically moved depends on its energy density and uses results from Tafdrup (1994) which state that a maximum radius of 40 km is economic for high dry matter (70%) feedstock while low dry matter feedstock or slurries (<10%) can be transported economically within a maximum 10 km radius. Within these radii, costs of £1.50/m^3 for slurries in $20m^3$ tankers and £7/t for high dry matter feedstock within the 40 km radius in 20t covered trucks were used. Noon and Daly (1996) present a maximum radius of a 120 km radius for mill residues.

Generally, the greater the capacity of the plant, the larger the supply area it will require. In the case of waste, the overall size of the supply catchment area will also depend on the density of waste fuel availability within it (Bergsdal et al., 2005). In order to identify the supply area of any plant, the most commonly used approach is to use a distance query tool (within the GIS software) in an iterative manner to define a radius that identifies the area necessary to satisfy the feedstock capacity of the facility. This has the advantage of identifying radii which are unique to the study area and avoids the inflexibility of applying a fixed parameter such as those discussed above. Using the algorithm shown in Figure 6 from Voivontas et al (2001) and adapting it to allow the minimum (not maximum as is the case with other less available biomass resources) transport distance radii to be identified for each EfW facility ensures they are located in areas where waste concentration is high and therefore, transport costs can be minimised.

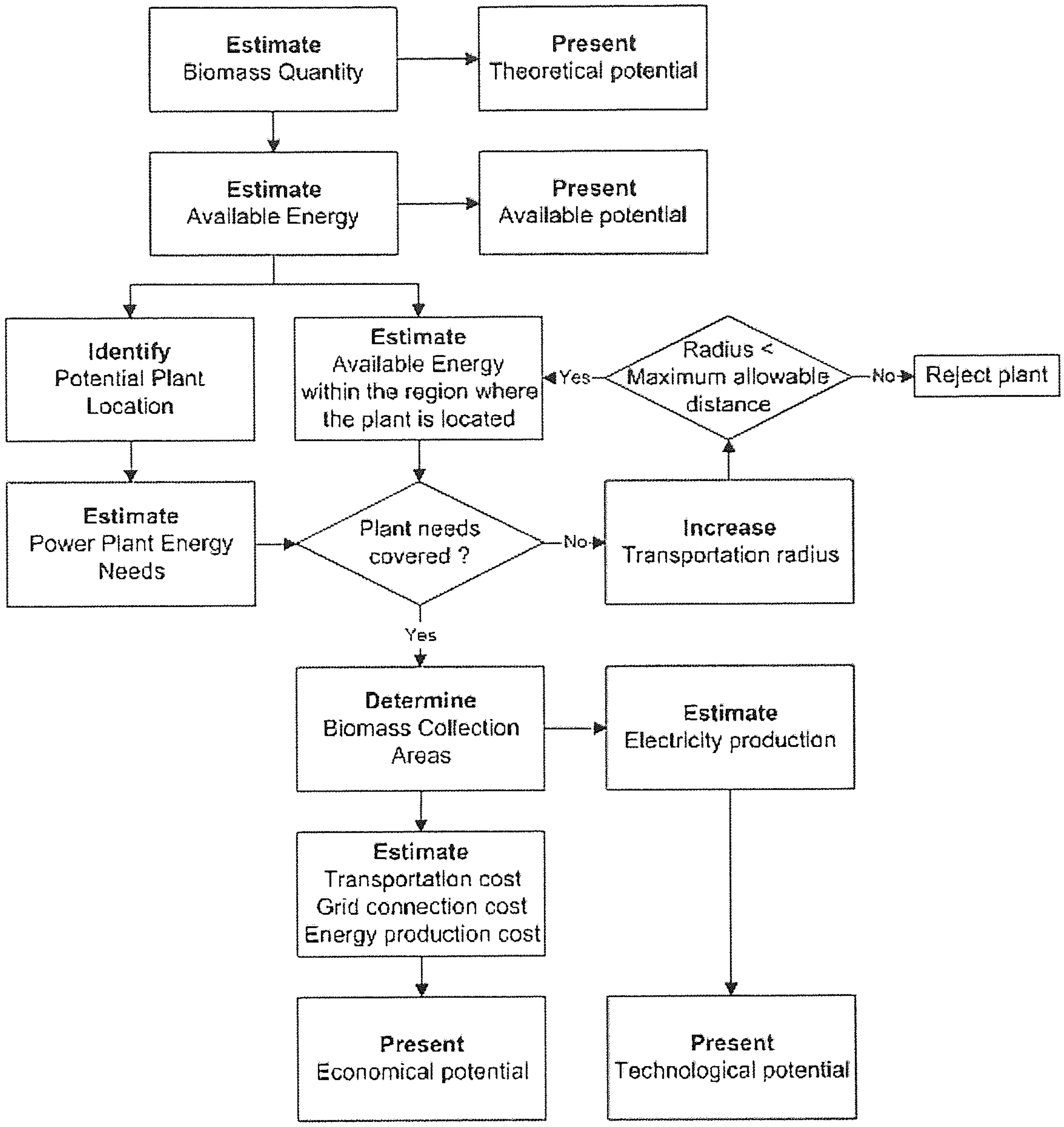

Figure 6: Overview of the algorithm for site identification from Voivontas et al (2001).

Once minimum transport radii have been derived, 'scanning programs' (Tyson et al, 1996) also described as 'Collectable Waste Modelling' (Dagnall et al, 2000) can be used to identify 'hotspot zones' in which further criteria can be applied with which to identify suitable sites. These are versatile models whose methods are easily explained to WDA officers and the public who may have a specific interest in understanding how sites have been identified. Data layers and criteria can be added without the need to re-write programs.

Testing identified that the Voivontas et al, 2001 algorithm can be successfully used within the Dagnall et al (2000) approach that overlays concentrations of waste feedstock modelling layers with other site identification criteria layers such as proximity to: Suitable transport routes; Heat demand; Electricity grid connection; Environmental and institutional constraints and Industrial sites (decision rules and definitions of these criteria are reviewed in Section 3.2.3) within a GIS system. These methods are fit for WDA user purpose, since they can be applied using query and modelling tools within commercial GIS software packages and no additional programming is required. These are executable by non-expert WDA GIS users.

3.2.3. NON-RESOURCE RELATED CRITERIA AND DATA

Section 1.6 identified that technical and planning criteria are important in identifying sites. This section reviews the use of spatial criteria in previous GIS-based bio-energy DSS.

3.2.3.1. Proximity to suitable transport routes

In most studies, road is the principal mode of transport for bioenergy and waste feedstocks but in the UK context a waste-by-rail feasibility study for Cornwall has been conducted by Capita Symonds (2004). This concluded that within the WDA context, rail was feasible but at significant cost and risk existed in potential delays in connecting new infrastructure to the existing national rail network. In an urban context, barges use the River Thames to transport waste from the city of London to landfill sites in Essex. This effectively bypasses the problem of city congestion. Within the majority of UK WDA situations, however, it is by road that most wastes are transported and this DSS reflects that but uses methods that could be adapted to river and rail transport.

Regardless of mode, studies reviewed take into account the need to locate close to a good transport route. There is however, some ambiguity with regard to what a 'good' transport route is. Dagnall et al. (2000) use the term 'major roads' which is further refined as motorways and 'A' roads. Voivontas et al. (2001) and Nuberg and Bugg (2002) present the opportunities to fulfil this criterion based on 'primary' and 'secondary' roads. Graham et al. (2000) simply classify their road network as consisting of either 'slow' or 'fast' roads.

Varela et al. (2001) have stated that any type of road should be within 1 km of a facility. Dagnall et al. (2000) and Cole et al. (1996) also use this distance, except that it must be from a 'major' road. It is clear that authors do not always agree on which level of the road network is most suitable for proximity to a potential site location. The essence of what is important is to ensure that the facility is served by a road that has good links to the rest of the network, and is suitable for heavy goods vehicles. This DSS will include the 'proximity to transport route' criterion and use motorway junction, A and B road data. These can be reasonably assumed to provide adequate access to any proposed EfW plant within the UK context. In addition, proximity to good road networks can coincide with industrial sites and heat demand, since the latter often co-locate in order to assist the supply and manufacture of goods and services.

3.2.3.2. Proximity to heat demand

Most of the authors reviewed do not take into account proximity to heat demand. The reasons for this are not clear, but it is possible that researchers do not fully appreciate the need to utilise the waste heat from energy generation facilities as described in Section 1.3.4. For example, Dagnall et al. (2000) have assumed that it is not possible to sell the surplus heat from small-scale schemes, but others acknowledge the importance of heat demand in improving project economics and that heat producers must locate closely with customers in order to manage distribution costs where existing district heating networks do not exist (Wenisch et al, 2004).

Bergsdal et al. (2005), however, does include the heat issue and actually makes heat a key decision criterion in identifying suitable sites by matching waste availability with equivalent heat demand. Heat demand is estimated by using municipal data on building type and average floor area. While it would be desirable to include such a technique within the proposed DSS, no such heat demand data at this geographic resolution exists in the UK at present (Wiltshire, 2003). A discussion of how heat demand can be included in the overall DSS approach is presented in Section 6.4.3.5.

3.2.3.3. Proximity to electricity grid connection

Proximity to electricity grid connection is frequently included in studies. Dagnall et al. (2000) and Cole et al (1996) considered that sites within 5 km of a grid substation are acceptable as potential power-station locations. Nuberg and Bugg (2002) consider the use of biomass resources within 25 km of the 110kV electricity transmission network, while Varela et al. (2001) consider proximity of within 15 km to 66kV grid substations. These rules are only suitable for scales of facility far larger than those anticipated for recovery of energy from a UK WDAs residual waste tonnage. In the UK context, Dagnall et al. (2000) assume that if electricity is to be exported in large quantities, then facilities must be connected to the grid through a 33kV substation. This study assumes that 0.5 to 1 MWe scale plants are 'suitable' for 33kV connection. This is a generalisation, since it is possible for plants of this size to be connected at the 11kV without grid reinforcement. Authors often do not acknowledge that different capacity plants require different grid voltages and costs of connection. Graham et al. (2000) and Freppaz et al (2004) for example, do not explain if they have accounted for these differences in their GIS cost calculation modules. After consultation with Central Networks, the local distribution company for the Warwickshire WDA test area, it was decided that potential plant should be located within 3 km of a bulk supply point (BSP) or 33kV substation. This was desirable from a cost of connection and cabling perspective (Brown, 2003).

3.2.3.4. Proximity to environmental and institutional constraints

In meeting the requirements of PPS 10 it is important to respect environmental and institutional constraints when identifying sites. Dagnall et al. (2000), Wey (2005) and Shmelev and Powell (2006) obtained data of sites of special scientific interest (SSSIs), national nature reserves (NNRs), special areas of conservation (SACs), special protected areas (SPAs), and RAMSAR sites within their study areas. In the UK context, Shmelev and Powell (2006) applied a 5 km exclusion radius around the sites to guard against emissions related damage from the EfW facilities, while Dagnall et al. (2000) did not apply any 'buffer' zone, simply ensuring no site co-located with a protected one. This DSS has assumed a 2 km buffer zone, since this represents the limit of the formal consultation zone (FoE, 1995). Such an assumption enables the DSS to minimise potential conflict which may occur if facilities are located too close to designated sensitive and protected areas.

3.2.3.5. *Industrial land use*

Wey (2005) emphasises that EfW plants need to be sited with respect to local development plans. This also corresponds to Planning Policy Statement 10 (PPS 10) guidance (ODPM, 2005), which states EfW facilities should be sited on appropriate industrial or derelict/brownfield land where possible. Dagnall et al (2000) also propose siting plants in proximity to industrial areas but use urban area boundary data as proxy. This criterion will be taken account of and use GIS data representing the locations of industrial land areas and estates. Ensuring that sites are situated on such a land use within the proposed DSS may also lead to co-location with potential heat demand.

3.2.3.6. *Other criteria*

Nuberg and Bugg (2002) have in addition to the 'standard' criteria described in earlier sections stated that being not more than 20 km from a population centre is also important. Cole et al (1996) introduce an energy crop resource back-up criterion in the selection of plant locations and use a proximity rule of 60 km to a source of forest residues. In the context of waste however, this can be rejected since it is likely that operators will provide preference for processing a fuel they receive revenue for using. The approach from Varela et al. (2001) used the rules that the distance from plant to a small population (<20,000) should be less than 20 km and distance from a plant to large populations (>20,000) should be more than 20 km but with little justification. This DSS will not consider a minimum distance from an urban area, since proximity is desirable from transport (Gershman et al., 1986) and potential heat demand perspectives (ILEX Energy, 2005).

3.3. TRANSPORT COST ESTIMATION

Two groups of GIS-based methods for formally estimating transport impact: Planar Distance and Windage Factor or Geometric Networks were identified in the literature. The first assumes that the distance between any supply sources is a straight line (planar) distance to the proposed facility and uses this to define the maximum feedstock supply area. A 'windage factor' (WF) is applied to account for the deviation actual road distances have from planar distances (Perlack & Turhollow, 2002). Discussion of quantifying transport impact is further discussed in Section 7.2. Typical windage factors from the literature have been reviewed by Bastin (2006) and are presented in Table 4.

Table 4: Example winding factors (Bastin, 2006).

Winding factor	Source	Application
1.3	*Perlack & Turhollow, 2002*	Biofuels: Transport of corn stover for ethanol conversion
1.2	*Warwickshire County Council (pers. comm.)*	Default as used in the ACCESSION software
2	Ramirez et al., 2000	Sewage sludge transport – uses ORWARE program
1.32 – 2.08	Drobne & Paliska, 1998	Study of the effect of local relief and road density on route circuity in Slovenia
2	Kumar et al., 2005	Biofuels: Wood transport to power plant in Canada
1.3 – 1.4	*OPET, VTT,* 2001	Biofuels: Forest chip harvesting for incineration, Finland. Estimates fall as distance increases.
1.45	Prestemon et al., 1999	Forestry: timber haulage to sawmills. Value calculated specifically for their study by linear regression of network /Euclidean distances for 25 example paired locations.
1.338	Berens & Körling, 1985	Mathematical investigation: Estimation of inter-city road distances in Germany
1.13	Love & Morris, 1988	Mathematical investigation: Estimation of inter-city road distances in Germany
1.16	Love & Morris, 1972	Mathematical investigation: Estimation of inter-city road distances in US
1.19 – 1.83	Chalasani et al. 2004	'Detour factors' for Euclidean distances from 0 to 100km, from an analysis of geocoded travel diaries. Values fall as Euclidean distance rises.
1.22	Qureshi, Hwang et al., 2002	Supply chain routing: Transport distance estimation for commodity flow between zipcodes in the US
1.12 – 2.1	Ballou et al., 2002	Average circuity factors for inter-city distances within a variety of countries (1.4 for England)
1.3 /1.14	Levi et al., 2003	Supply chain routing: Recommended values (1.3 within metropolitan areas, 1.4 across US)
1.2 / 1.7	Hess, 1997	Pedestrian modelling: Measured values of 'Pedestrian Route Directness' in two contrasting areas of Seattle.
1.4 – 1.88	Randall & Baetz, 2001	Pedestrian modelling: Measured values of 'Pedestrian Route Directness' in US cities.
1.21 – 1.34	O'Sullivan & Morrall, 1996	Pedestrian modelling: Average circuity factors calculated for commuter walks to rail stations (40 m – 3.7 km)

Freppaz et al. (2004), Maniezzo et al (1998), and Noon and Daly (1996) use the more complex geometric network method to enable costs to be calculated using GIS data representative of the actual road system. It was desirable to test geometric network approaches using travel times, and data describing existing traffic conditions of the roads in the WDA areas. Unfortunately, although such data exists, it could not be obtained for this project, since it was considered to be too commercially and politically sensitive. Since transport is important in EfW planning (Gershman et al, 1986), this project has used both Planar Distance and Geometric Network approaches to estimating transport costs to compare the results and consider their strengths and weaknesses (Section 7.3). The network approach however was tested using typical UK average road speeds due to existing road traffic data not being available as noted above.

Transport costs have been calculated by Graham et al, (2000) using a raster-based cell approach (Section 2.2) and have calculated costs from one cell to others using Equation 4), where TC is the cost of transporting feedstock (\$/tonne), KF is the fixed cost of unloading and loading feedstock, KD and KT are the distance and time-dependent costs (\$/tonne). DIST and TIME is the road distance and travel time between pixel X and pixel Y (km one way).

$$TC_T\{X,Y\} = KF + KD \times DIST\{X,Y\} + KT \times TIME\{X,Y\} \quad (4)$$

Freppaz et al (2004) used Equation 5, where C_{TR} is the unit cost for transport (\$/kg/km), MV_i is the biomass density and D_{ik} is the distance (km) from source location i to location K computed by the GIS. Φik is the biomass quantity, in m^3/Y that is yearly sent to the kth plant from the ith source location;

$$C_T = \sum_{I=1}^{N} \sum_{K=1}^{K} C_{TR} \varphi_{IK} MV_I D_{IK} \quad (5)$$

Such approaches as the two above, while transferable to waste are complex. They are reported to have long run times and are not suitable for more casual GIS users. For these reasons they have been rejected. Alternatively, Bergsdal et al. 2005 used Equation 6 to derive transport 'need' (TR) for any one EfW option from calculations of waste flows (WFL) and distances (DST) from 'sources' (waste production points) to 'sinks' (plants).

$$TR = \sum WFL \times DST \quad (6)$$

This calculation is suitable for application to catchments of source waste points to derive the cumulative distance per annum with less programming requirements. A range of parameters, such as costs or emissions may be derived from this calculation. Unfortunately it is not clear if a geometric network has been used or straight-line analysis, but the paper notes that "paths are traced" with no further explanation. This is an example of how GIS methods for energy planning within the literature can be difficult to interpret. Despite this, the calculation can be directly applied to the UK context by using the data methods from Shmelev and Powell (2006), where centroid points of population wards were used to define the waste generation sources. It is unclear why Shmelev & Powell (2006) suggest that they use a GIS for estimating transport but do not provide truck capacities, or detail as to method. Since this work was conducted in the UK context, this is unfortunate, since an interesting outcome would have been to compare methods.

Dujim and Markert (2002) note that in their transport impact assessment, vehicles are required to return and hence total demand on transport is twice the distances noted between waste source and point of disposal. The authors also note the average payload of trucks is not the maximum capacity of the vehicle. Average payload as well as two journey parameters should be used in order to not under or over estimate transport impacts. Parameters of studies not undertaken in the UK context, such as the US work of Noon & Daly (1996) should be treated with caution since truck designs and capacities can be very different. In order to ensure such parameters are reasonable in the UK context, data from Biffa (2002) – a major waste management company (presented in Section 7.2) will be used in this project. This DSS will assume that all waste is transported by road and will use the same data sources used by Shmelev and Powell, (2006), while using the calculation from Bergsdal et al, (2005).

3.4. REVIEW SUMMARY

Formulation of options

- Many authors do not provide detailed equations, algorithms or description to support their decision support techniques.
- Residual MSW resource map modelling can be achieved by the techniques used by Tyson (1996) and Bergsdal et al (2005) using UK data sources shown by Shmelev & Powell (2006).
- Assumed variable values for waste production should be made subject to sensitivity analysis due to the range of cited parameters.
- In the identification of sites, access to the road network, proximity to heat demand, co-location on industrial land area and proximity to institutional constraints are key criteria as discussed in Section 3.2.3.
- Modelling methods from Dagnall et al, (2000) and Voivontas et al (2001) will be combined to produce an overall site identification procedure for identifying EfW sites of location and scale.
- All waste will be transported by road and impact analysis will be done by combining elements from the methods from Shmelev & Powell (2006) and Bergsdal et al, (2005). This project will use both Planar and Network alternative approaches to estimating transport costs.

4. APPRAISING EfW OPTIONS: CRITERIA AND DATA

4.1. AIMS OF CHAPTER

Section 4.2 reviews the criteria typically used in previous studies appraising EfW options and how they are defined. Sections 4.3 and 4.4 review how they can be selected and weighted. Section 4.5 reviews sources of data that can be used to derive EfW option performance scores while 4.6 provides a summary of key points learnt from the review together with a description of how the project's contributes to the field of EfW planning.

4.2. CRITERIA USED IN ENERGY AND WASTE POLICY APPRAISAL

4.2.1. ECONOMIC

4.2.1.1. Monetary costs

Studies differ significantly in their choices of monetary cost indicator. Murphy and McKeogh (2004) considered capital costs and waste disposal revenues but did not take into account financing over time or apply a discount rate. Nilsson et al. (2005) note that several authors of the literature "suggest that an economic valuation approach of net present value (NPV) is needed to evaluate the relative merits of various decision alternatives". Cheng et al, 2003 derived a total cost criterion, using the indicators of transportation cost, capital cost minus potential revenue. In addition, Maniezzo et al. (1998) used operating costs and summed all costs for each location to yield the total costs for each scenario of potential sites and plants. Consonni et al. (2005a) provided the most complete study of cost considerations and revenues from the sale of material products and heat. These were summarised in an overall gate fee figure (£/t processed). This is a useful criterion understood by WDA officers and this indicator can use NPV, and hence, is an important criterion within the DSS to represent the cost of option concern. It can also take into account temporal implications of financing, which is essential when project lifetimes of EfW facilities can reach up to 25 years.

4.2.1.2. Transport

Regardless of the choice of assessment method, transport is an ambiguous criterion which is as equally emphasised in some studies (Bergsdal et al, 2005) as it is neglected in others (Wenisch et al, 2004; Consonni et al, 2005b). When modelling with respect to dense and scarcely populated areas, Nilsson et al. (2005) attached shorter and longer transport distances accordingly. Whilst the authors acknowledge this is an overly simplified model of waste flow, it "serves the purpose of demonstrating the effect of transport". A deviation from standard transport impact assessment is described by Wey (2005) and Maniezzo et al. (1998), in that some authors compute transport costs only on the length of the routes used from municipalities to waste incineration plants independently of the amount of waste that has been sent along the routes. This seems too simplistic, since cost can be a function of both distance and the tonnage of waste transported.

Wheeler and Jainter (2006) do not mention use of a GIS but calculated distance by using Web-based route planners. The transportation of residues such as bottom ash is not included in their transportation scenarios. Consonni et al (2005b) have, however, considered this. This study assumed that all plants regardless of size are located exactly 50 km from the final landfill site for bottom ash residue. This approach does not take into account the local geographical conditions. Truck capacity was assumed to be 16t. Since, this study aims to compare the impacts of both large-small-scale facilities of the same technology type within a defined area, it is likely that differences in overall transport impact due to the transportation of ash residues from both options would be negligible. However, since different technologies are used to characterise options in this project, the transportation of ash should be taken into account. The DSS will assess the impact of both the transport of waste to supply the facilities and resulting bottom and fly ash from the facilities to landfill.

Costs of transport can be environmental as well as economic and can include other externalities such as traffic congestion and deaths caused by accidents. Corti and Lombardi (2004) note that if a high weight has been applied to the transport criteria, the effects of air emissions such as NO_x can have a great influence on the final score. Dujim and Markert

(2002) conclude that traffic emissions are a significant source of air pollutant emissions, even when compared to the cleanest technologies. They also argue that risks relating to transport (accidents etc) are not insignificant and cannot simply be ignored. This DSS will include two transport criteria – one representing the 'external' environmental impacts and the second representing an estimation of financial cost will be calculated for all routes. GIS based methods of calculating transport costs were discussed in Section 3.3.

4.2.2. ENVIRONMENTAL

4.2.2.1. Displacement of Carbon Dioxide emissions

The displacement of Carbon Dioxide (CO_2) emissions from conventional fossil fuel sources in the production of energy is often a key criterion in energy planning studies. Consonni et al. (2005b) have compared CO_2 emission savings from using CHP EfW plant and assume thermal losses of the heating network. This was done for large-scale systems with no regard to heat output for the small-plant scenarios. There is no explanation for this and it is reasonably challenged by Kristiansen (2006) who states that heat revenues are a key factor in ensuring attractive project economics for smaller-scales of plant. It can therefore be assumed that it is important to use the heat produced wherever possible. The subject of efficiency in heat and power generation for emerging technologies, such as pyrolysis and gasification is discussed by Malkow (2004) who suggests that designers aim to improve fuel utilisation and energy efficiency, while minimising emissions and hazardous process residues. He also states that the latter often is at an expense of the former. This indicates that assessing pyrolysis and gasification technologies against conventional incineration on the criterion of displaced CO_2 is an important aspect within the proposed DSS.

Corti and Lombardi (2004) state that in the calculation of displaced CO_2 emissions reference to the national electricity generation mix should be made. EfW can offset more CO_2 from coal-derived electricity generation than from gas-derived, for example, the latter releases 62% less CO_2 to atmosphere than the former (Porteous, 2005). Finnveden et al (2005) and Moberg et al (2005) argue that coal fired power plants are the base-load marginal electricity sources whose power generation is most likely to be displaced, but using this assumption for the UK as made by the WISARD tool has been justifiably criticised (Purser, 2003), since electricity generation from other renewable sources such as wind is expected to increase, thus meaning the environmental benefits of EfW are exaggerated. In contrast again, Consonni et al. (2005b) used the assumption that conventional natural gas and oil steam plant derived electricity generation were to be displaced by the EfW plants. The importance of assumptions cast on the marginal electricity source is made by Weisser (2007) where he concludes that renewables and nuclear power plants generate far less CO_2 than their fossil fuelled counterparts. To avoid conflict and disagreement, this DSS has assumed an average of all displaced primary fuels to ensure the CO_2 savings from EfW are not exaggerated.

4.2.2.2. Air emissions

In addition to CO_2 the effects of other air pollutants are also important. In their emissions inventory, Consonni et al. (2005b) comprehensively considered emissions from the: Stack of the EfW plants; Transport of solid residues to landfill; Building of the plant and finally from the production of recyclable metals recovered from the bottom ash. Porteous (2005) argues that while flue gas volumes are up to 40% less for gasification compared to incineration, there are extra CO_2 emissions from the transport (separation) and pre-treatment (shredding) of waste. While it is important to understand the potential implications of these technical differences, the CO_2 emissions from the transport and shredding of feedstock is insignificant compared to the flue gas volumes from facilities (RCEP, 2004) and these latter factors will not be taken into account within the proposed DSS. What is important are the flue air emissions and previous studies typically include CO, NO_2, PM, SO_2, HCL, HF and heavy metals. These are important, and regulated by the standards in the Waste Incineration Directive (Appendix A.2.4), despite this air emissions are considered in this project, since they continue to be of concern to WDA officers and the public (Lea 2006b).

4.2.2.3. Emissions to land

Bottom ash is inert material that is extracted from the grate after thermal processing. Fly ash arises from from particulate removal using air pollution control equipment and includes heavy metals and reagents such as lime that is used to remove pollutants from the flue gas streams. The hazardous nature of fly ash derives from the use of the lime which is alkaline and significantly higher fees are charged for its disposal (Williams, 2005). In contrast, bottom ash is sometimes used as aggregate for road building (Porteous, 2005). Some controversy surrounds the use of bottom ash production as a criterion. For example, Porteous (2005) emphasises that this is a useful material for road building and aggregate and that the UK should recognise this as recycling, as is done in mainland Europe. Williams (2005) states however, that bottom ash is a low-value recyclate which is difficult to market in the UK and can require costly landfill disposal (Wenisch et al. 2004, Azapagic and Camana, 2005, Bergsdal et al., 2005 and Dujim and Markert ,2002) if a market cannot be found. The DSS will include indicators of both bottom and fly ash, but in a conservative approach respecting the difficulties and potential costs if a market for the bottom ash cannot be found, this project will assume that bottom ash production is a negative factor, where supporting references for its management within the WDA context cannot be found.

4.2.2.4. Dioxin production

The risks (and perceptions of risk) posed to human health from incinerators are of key political importance in EfW decision making. Consonni et al (2005b) include dioxin production from different technologies as a criterion. Porteous (2005), however, argues that in the present day of extensive monitoring and legislation by the WID, this is no longer an issue that needs to be considered. In contrast, public perception dictates that it should be (Barda et al, 1990). Porteous (2005) concludes that EfW is an "extremely low risk, environmentally benign method of post recycling/composting residual MSW disposal" and criticises the UK industry for failing to be more proactive in its uptake. It can be argued however, that it is not the fault of industry, but indeed public perception and WDA fear that is responsible for the lack of EfW uptake in the UK. The importance of health effects continues to be a focus of debate, with a specially commissioned government report by Enviros et al (2004) concluding that there is very little risk to human health from dioxins from EfW facilities. The methods and risk assessments used in this report however, were publicly criticised by Thompson and Anthony (2006) in that they were incomplete and not based on medical science. The disagreements of such reports have little effect in reassuring the public. Since, such debate exists, credit should be provided for technology options within the DSS that minimise dioxin production, and hence, can be regarded as most effectively managing any potential risk in the absence of scientific consensus (Loosemore et al., 2006).

4.2.2.5. Site footprint

Dujim and Markert (2002) used the area occupation of site (or site footprint) as a measure for the "level of distortion and the impact on the cultural and natural heritage". They argue that the smaller the area needed, the lesser will be the distortion. The true importance of this however is questionable, and ease of procurement and cost may be more of an issue to WDAs. Maniezzo et al. (1998), Shmelev and Powell (2006) and Jainter and Poll (2005) have also taken into account the impact of land use for waste management in local studies. Since, this criterion is certainly most relevant at the local level in terms of WDA procurement (Lea, 2006b); the proposed DSS should take land requirements into account when comparing options.

4.2.3. TECHNOLOGY

4.2.3.1. Technical maturity and commercial acceptability

This is an important factor to include in the appraisal of EfW options, since WDAs must deliver solutions in time to meet their landfill diversion targets, or face serious fines. Consonni et al (2005a) assumed that technologies that were not in 'commercial implementation' such as the emerging ATT technologies did not justify an option, and stated that those chosen for study were derived from those considered by local authorities, which seemed to be combustion only. This study does not define exactly what 'commercial implementation' means and contrasts with the experience of a UK developer (Compact Power) of pyrolysis systems that has commercially run a 7.5ktpa facility on clinical waste for over five years. Despite the proven track record being too small scale, to be of practical interest in solving UK WDA waste processing needs, there is still considerable interest in the technology by WDA decision makers (Hopkins, 2008).

The issue of 'commercial acceptability' (passage through due-diligence and release of funds from the banking sector in order to finance a project), does not necessarily lead to unproven technologies being excluded in option definitions of previous work. Murphy and McKeogh (2004), Livingston (2002), Mc Lanaghan (2002), Fichtner (2004), Khelifi et al

(2006), Harbottle et al (2006), Dujim and Markert (2002) and Porteous (2005) assessed the benefits of 'new', 'novel' or 'emerging' technologies against those that are already established and considered commercial, but there is still no consensus on what technologies are superior overall. Murphy and McKeogh (2004), for example, compared the performance of anaerobic digestion and gasification with conventional combustion technology. The study concluded that gasification and anaerobic digestion was superior to incineration in terms of cost and efficiency despite not being commercially proven for processing MSW. Malkow (2004) agrees that while pyrolysis and gasification are commercially proven in energy generation, they are not proven for processing MSW. While Higham (1999) includes gasification but only within a centralised, large-scale context and stresses that the technology is not established in the UK, the presence of the Energos 40 to 80 ktpa gasification technology, originating from Norway and their success in developing smaller-scale distributed facilities in the UK (Dawber, 2006) contradicts this. The debate regarding commercial acceptability and maturity of new technologies on the market must be addressed in the design and testing of the DSS developed by this project. Options to be formulated and appraised will include options of both mature and emerging technology in order to ensure the DSS is capable of providing reassurance to the public that their relative merits have been considered.

At the time of writing, two alternative thermal technologies using pyrolysis and/or gasification developed and commissioned in the UK, is the small-scale 7.5ktpa Compact Power facility in Avonmouth and Energos gasification plant on the Isle of Wight. It is the role of the DEFRA New Technologies Demonstration Programme (Appendix A.3.3) to bring these technologies and others to proven market status at scales that can meet WDA residual disposal/recovery needs. In contrast, 8 of the 19 UK EfW facilities use combustion technology and have capacities equal to or greater than 180 ktpa The remaining 9 plants ranging between 90 and 165 ktpa are also using combustion (ILEX Energy, 2005). These points show that combustion technology is mature at multiple scales and represent a greater likelihood of successful project development, commissioning and operation. WDAs are risk adverse and are likely to show a strong preference towards technology with proven market status. It would however, be wrong to ignore the support that new technologies have and appreciate that they are 'coming to market'. This project will also include a 'Technical maturity' criterion based on the number of plants operating in the UK in the appraisal element of the DSS to acknowledge relative commercial acceptability.

4.2.3.2. Efficiency

Efficiency has been a much discussed subject within the field (Consonni et al. 2005b; Murphy and McKeogh, 2004; Malkow, 2004; Fichtner, 2004; Porteous 2005). There is significant risk of double counting regarding this criterion, since it is included in the derivation of other criteria scores such as economic costs and revenues and environmental performance in the form of displaced Carbon Dioxide emissions (Section 4.2.2.1). This project has therefore, not included it as a separate criterion.

4.2.3.3. Other

Other criteria in addition to those discussed above include job creation, potential for public involvement and education. Other qualitative criteria include noise, litter/vermin, landscape and visual impact, likelihood of implementation within required timescale and planning/public perception (Jainter and Poll, 2005). The latter are often very subjective, but seen as necessary criteria to support quantitative analysis of environmental impacts. Generally other criteria attempt to capture the factors that affect planning permission for potentially controversial, waste management projects. It can be argued that planning permission and public perception is a function of many potential criteria, and there is a risk of double counting (Coulson, 2006). For this reason, the DSS will not have a 'planning permission' criterion, but will allow WDA officers to select from among job creation, visual impact and technology maturity, since these have been identified as key areas of concern within EfW decision making (Juniper, 2003; Enviros, 2004; Jainter and Poll, 2005).

4.3. SELECTING CRITERIA

The number of criteria and sub-criteria in any study typically range from between 4 to 7, and 10 to 16 respectively (Azapagic and Camana, 2005; Cheng et al, 2003; Wey, 2005;

Bergsdal et al, 2005; Norese, 2003; Harbottle, 2006; Corti and Lombardi, 2004). The number however can reach as high as 39 (Dai et al. 2001) and 45 (Shmelev and Powell, 2006). The DSS developed in this project is aimed primarily for WDA officer use, and the numbers of criteria used in the Dai et al. (2001) and Shmelev and Powell (2006) studies are excessive, in that it is important that decision makers understand the significance and definition of all criteria, in order to select and weight them.

A significant proportion of the criteria used in most studies reviewed are environmental. Khelifi et al. (2006) note however, that investors are more interested in the capital cost than the environmental acceptability of a technology, while often people residing in close proximity to the proposed plant site and the environmentalists have exactly the opposite viewpoint. Harbottle et al. (2006) cite that there is increasing support for the inclusion of sustainable development principles when selecting a (remediation) technology for use on a particular site". Wey (2005) is one of the few authors that acknowledge the need for criteria to represent the impacts to social "strata" and effects on the quality of life of neighbouring residents. Such criteria include effects on local scenic resources and adjoining land use. This DSS will include a "visual impact" criterion and include others that encompass the three principle areas of sustainable development: environment, society and economy, since this is also a requirement of Strategic Environmental Assessment and PPS 10.

Regarding the choice of criteria, many authors do not describe how they arrived at their selection but Norese (2003) reported that the final choice of criteria was the result of stakeholder meetings. This project will organise WDA officer working groups to advise the final selection of criteria within their perspective MCDA models, since Section 1.6 identified WDA officers as the key target end-user of the EfW DSS.

4.4. WEIGHTING CRITERIA

Weights can be based on different methods as discussed in Soares et al (2006) and include monetary evaluation and public/expert opinion. The latter is the preferred LCA community approach and involves a 'panel' which establishes a hierarchy of impacts followed by a value allocation (Soares et al, 2006). Nilsson et al. (2005), Wey (2005) and

Cheng et al. (2003) also used expert groups to qualitatively weight different criteria within waste management systems. Monetary evaluation weighting can be made on the basis of costs related to environmental consequences. Monetarisation can include 'willingness to pay' (WTP) surveys or taxes to value the significance of criteria and has been noted as a convenient method for aggregating health impacts (Spadaro and Rabi, 2001). Such an approach to weighting is not as useful to represent the values of specific WDA officers, but may be more suited to capturing the more generalised values of the public.

In previous UK waste management MCDA studies, Higham (1999) and Jainter and Poll (2005) have used 'officer experts' from both the county and district levels of government. Using the MCDA weighted-sum method (Section 2.7.5), Dujim and Markert (2002) used expert weights, gathered from questionnaires to reflect actual priorities in decision making. However, in order to ensure maximum participation, a more direct method of interaction with WDA officers is required, such as that advocated by Norese (2003) discussed later in this Section. A limitation of using expert groups in a local decision making context is that people may not be willing to say what they really believe, since they are afraid of the consequences in daily life. To manage this, Munda (2004) suggests the use of anonymous questionnaires is an essential part of the participatory process.

Norese (2003) expressed that participatory MCDA, where weightings are provided is extremely difficult in the first meetings, but that the MCDA work routine which requires active input from all parties, actually led to a more co-operative attitude. The author also reports that MCDA methodology is also understood by the majority of participants and became a 'local language' which was shared and accepted. It is for these reasons that this DSS will use participatory MCDA to capture the weights and values of WDA officer 'experts' within workshops.

4.5. PERFORMANCE DATA SOURCES

Many authors such as Bergsdal et al. (2005), Consonni et al. (2005b), Corti and Lombardi (2004) and Azapagic and Camana (2005) used data from LCA databases and fill gaps from the literature or with proprietary sources and patents (Fichtner, 2004).

Legislation limits, from WID, for example can also be used to assume data values for criteria. While this is acceptable, care must be taken in order to ensure consistency in the way data is sourced, derived or calculated.

In the UK context, the Environment Agency (2006b) is attempting to disseminate EfW performance data from technology supply companies. The quality of this data may be questionable, since it is from commercial sources. It also may be estimated and not gathered from actual facility operating data. Consonni et al. (2005b) attempt to uphold the quality of data estimates by basing their measurements of impact from actually operating (combustion) plants rather than current legislation. Wenisch et al. (2004) obtained data direct from EfW plant operators and cross-referenced this for consistency with national data. This approach is sensible, but difficult when data representing the performance facilities of similar technology and scale is not available. McLanaghan (2002) and Porteous (2005) emphasise that data on environmental releases from proven technologies is more readily available, but limited for the emerging technologies.

In order to overcome the difficulties in obtaining data for pyrolysis/gasification options, this project will use data from Compact Power, (the sponsor of this project). While such a relationship is useful in order to collect data, it should be noted that the values are estimates from in-house modelling tools that extrapolate to sizes of pyrolysis/gasification facilities that have not yet been commissioned and operated. Data cannot be independently validated until Compact Power build and operate examples of their technology at the 60 and 30 ktpa capacity. The company currently operates a 7.5 ktpa facility based on a single line of their modular system and in most cases, data has been linearly scaled up to required capacities. It is on the performance of this small plant that all third party appraisals of data are based. This project will use a combination of all the data collection techniques outlined in this Section to represent combustion technology. Pyrolysis and gasification will be represented by data from the proprietary Compact Power source. This will be cross-referenced and compared wherever possible with other sources.

4.6. REVIEW SUMMARY AND CONTRIBUTION

Appraisal of options

- There is little consensus on what EfW implementation option is superior regarding scale and technology.
- This DSS should include criteria that represent the three principle areas of sustainable development: environment, society and economy, since this is also a requirement of Strategic Environmental Assessment.
- Regarding the choice of criteria, many authors do not describe how they arrived at their selection. This project will organise WDA working groups that will be given an opportunity for input on the final choice of criteria.
- The number of criteria and sub-criteria in any study can typically range from between 4 to 7, and 10 to 16 respectively. This indicates there is little standardisation in how studies appraise options. There is also a need not to introduce criteria that is not necessary and hence, the number should not exceed these stated.
- Commonly used appraisal criteria include those discussed in Section 4.2 and predominately fall into the 3 categories of technology, environmental and economic performance.
- The proposed DSS will not have a 'planning permission' criterion, since it can be argued that this is a function of many criteria and its use could lead to the risk of double-counting.
- The proposed DSS will use a combination of all the data collection techniques outlined Section 4.5, to represent combustion and use the proprietary Compact Power source to represent an emerging pyrolysis/gasification technology.
- The proposed DSS will use WDA officer 'experts' within a participatory workshop to provide weightings.

To date, no research has been done on comparing the impacts of small-scale and distributed pyrolysis and gasification with conventional incineration EfW facilities at the local (sub-regional) level. With the exception of the regional study by Bergsdal et al. (2005), the literature does not include appraisal of technology that has been designed to be economically feasible at small-scale. Regarding context, studies formulating and appraising EfW policies in more rural or suburban areas are also missing from the literature, hence this project will test its methods in the WDA areas of Cornwall and Warwickshire. Many studies such as (Consonni et al, 2005 & 2005b; Azapagic & Camana, 2005) do not take into account the geographic nature of their areas in the generation of EfW scenarios – either in choice of site locations, scale or technology.

Section 5.2 presents an overview of the EfW DSS approach developed by this project. It has multiple tools that can formulate and appraise area-tailored distributed and centralised EfW options for sub-regional WDAs in the UK. These will incorporate the emerging, small-scale pyrolysis and gasification systems as well as conventional incineration technology. The contribution that this project can make has been noted by the UK Sustainable Development Commission (Porritt, 2006, Appendix D).

5. DSS OVERVIEW AND PARAMETERS

5.1. AIMS OF CHAPTER

This Chapter familiarises the reader with the overall structure of the proposed EfW DSS in Section 5.2. Section 5.3 describes the system parameters in which the decision support techniques are applied and includes definitions of waste feedstock and technology size as well as the spatial extent and boundary conditions.

5.2. DSS OVERVIEW

The Decision Support System that has been developed for this project has two main components consisting of Geographical Information System (GIS) and Multi Criteria Decision Analysis (MCDA) based modelling that is carried out sequentially. These decision analysis tools have been chosen and combined to exploit their relative strengths identified in Chapter 2. These are preceded by data acquisition and definition of specifications and followed by implementation of the results on which recommendations can be made. An outline of the complete methodology is shown in Figure 7, which consists of 5 stages:

Step 1: Identification of WDA area boundaries, waste growth trends, composition and recycling and landfill management tonnages as well as the tonnage of residual waste destined for EfW either existing or planned. In the case of Cornwall and Warwickshire, these input parameters for the DSS are discussed later in Sections 5.3.1 and 5.3.2.

Step 2: Assumptions on the tonnage of residual waste destined for EfW are made and parameters set regarding size of facility and technology are used to define each EfW option. All options process the same annual tonnage of residual MSW in 2011, since this is the necessary timescale in which to meet landfill diversion targets. In the case of Cornwall and Warwickshire, technology input parameters are discussed later in Section 5.3.3.

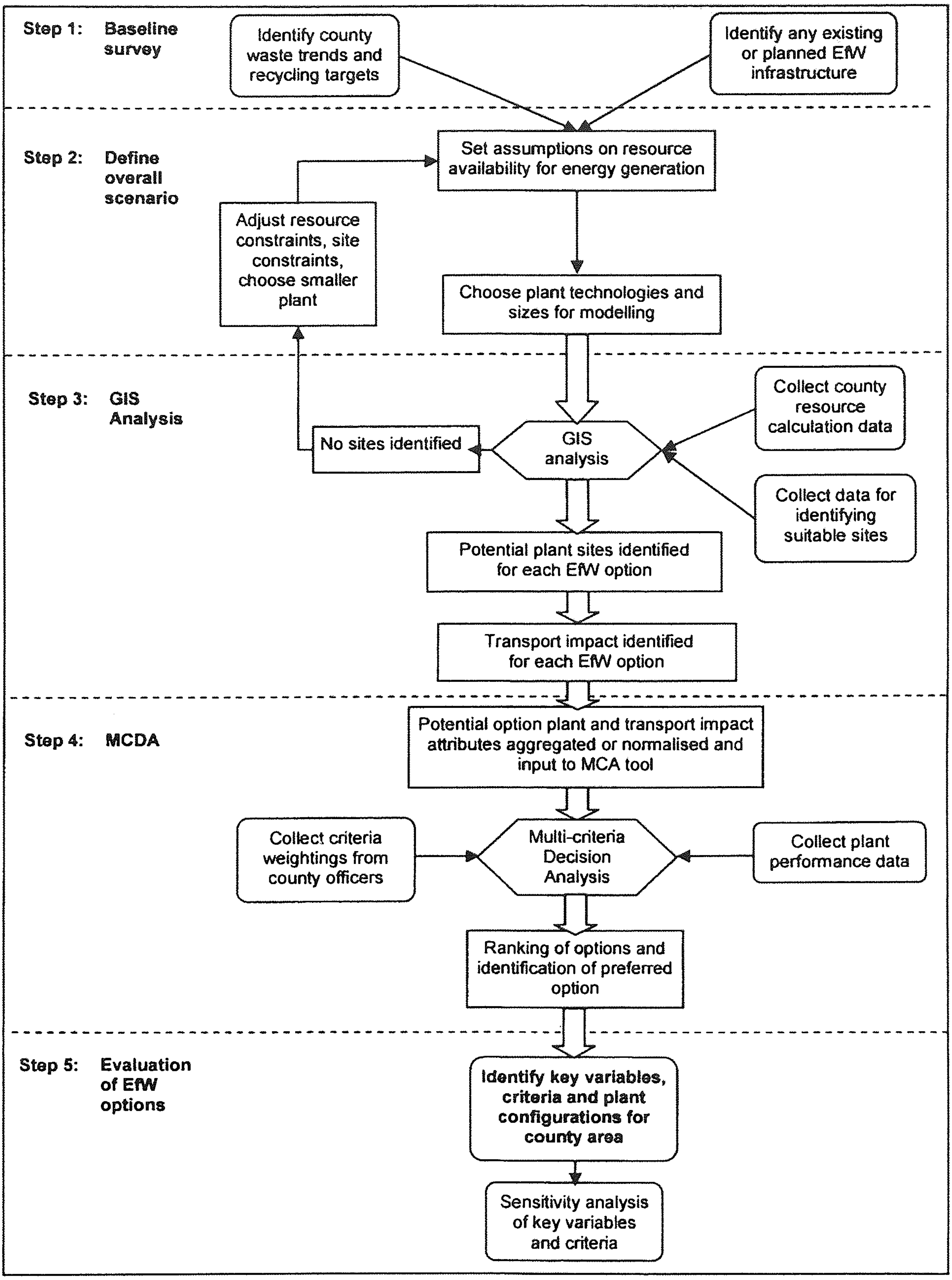

Figure 7: Diagram showing the overall DSS methodology.

Step 3: Involves using the baseline data, waste and technology assumptions from the previous steps to formulate EfW option locations. Step 1's collection of baseline data on a WDA area's present waste production, recycling and waste growth rate is used to produce a geographic residual waste resource model following the same principles as Tyson (1996), Bergsdal et al (2005) and UK data sources from Shmelev & Powell (2006). The review of GIS methods, criteria and data to identify sites for EfW facilities in Chapter 3 selected elements from Dagnall et al (2000) and Voivontas et al, (2001) on the basis that they were were best suited to the WDA end user environment using the criteria in Section 3.1. Methods include production of Collectable Waste Map models that identifies 'hotspot' concentrations of collectable residual waste resource within each WDA study area (Section 6.2). Other non-resource related data maps of criteria necessary in suitable site selection (such as proximity to road and electrical grid) are combined to produce a *Potential* Site Identification map across the study area (Section 6.3). The selection of criteria is similar to other studies (Dagnall et al, 2000; Voivontas et al, 2001; Varela et al, 2000) but have been finally decided in respect of Planning and Policy Statement 10 (PPS 10) (ODPM, 2005) in order to make the procedure fit for purpose in the UK context.

This project contributes to the EfW planning area by extending the methods above by using sequences of overlaying Potential Site Identification maps and hotspot zones of the Collectable Waste Model Maps to generate *Final* Site Identification locations for each EfW facility in a large, medium or local-scale option (Chapter 6). Catchments of waste resource source points are then allocated to each plant, again using methods proposed by this study and tools available in most commercial GIS software packages. These extra elements ensure that EfW options are formulated in the context of the specific population and other geographic characteristics of the WDA area, thus ensuring that options are 'tailor made'.

Once site locations are finalised, the overall transport impact of hauling waste and ash to and from each facility in every EfW option is estimated while taking account of the effect of Waste Transfer Stations (Chapter 8) using two purpose written programs executed in ArcObjects. Transport impacts and plant performance data for all facilities processing the same amount of residual MSW are derived and aggregated for each EfW option.

Step 4: The purpose of the MCDA tool is to compare and appraise the GIS-derived EfW options. All studies reviewed in Chapter 4, included those mentioned here execute their policy appraisals with no respect to the geographic and population characteristics of the areas in which their EfW options are to be implemented. They also do not incorporate the values of decision makers within any specific WDA context – a factor of great significance as discussed in Section 1.3.8. It is primarily for these reasons the decision was taken to use GIS and MCDA in a combined decision support approach.

The criteria for assessment and the underlying data indicators used to represent them were selected from a review of the literature (Section 4.2) and presented to the working groups of council officers within each case study WDA in order to give representatives of the intended DSS end-user an opportunity for input from the start of the project (Section 8.2). This was to ensure that the choices of criteria were fit for purpose in the context of the individual WDAs. Some of these criteria are represented by underlying indicator scores derived as a function of geography and location, such as transport for example, while others, such as costs and emissions are derived as a function of technology performance (Section 8.4). The literature review identified WDAs as key target end-users of such a DSS, and they provided the weightings to the MCDA model (Section 8.6).

Step 5: Evaluates the EfW options that have been formulated and appraised by identifying key variables, criteria and preferred facility options specific to the WDA study area (Section 9.3). While the results in Section 9.2 only apply to Cornwall and Warwickshire, the DSS and its methods is intended for use in any WDA context. A key contribution to the development of this DSS was to successfully create partnerships with the relevant local administrations (WDAs) and Voivontas et al, (2001) acknowledges that it is often difficult to engage participants. However, this was achieved in order to incorporate views and feedback of officer experts currently working in fields related to EfW strategy in their areas.

Acquiring planning permission is particularly difficult for EfW plants at the local level in the UK (Ares and Bolton, 2002). This is particularly true for large and medium-scale (>5MWe) biomass plants (PIU, 2002). It is intended that the GIS methods within the proposed DSS could mitigate the difficulties encountered in the planning process by identifying sites of minimum sensitivity and of a geographic position in which to minimise transport impacts. The attitude of local communities to proposals for new energy developments has been a key factor in determining the success of these projects in gaining permission (FoE, 2002). The PIU report highlights that community residents must continue to have their say in the planning process (PIU, 2002). The DSS presented in this thesis appreciates the need to address local concerns by the inclusion of key decision criteria and uses an MCDA method that could potentially incorporate public consultation inputs in the form of weightings (Chapter 4).

5.3. SYSTEM PARAMETERS

5.3.1. SPATIAL EXTENT AND BOUNDARIES

The WDA authorities have a statutory duty to manage waste within their administrative boundaries. This project uses the same geography in which to formulate EfW option locations. The assumption means that modelling does not account for any geographical or population-related factors immediately across the borders, but boundaries can be extended to include other areas to examine cross-regional influences if required. Recently, WDAs have been encouraged by DEFRA to merge their decision making boundaries beyond their own geography (Haggard, 2006). It is therefore likely that cross boundary consideration will become more important. The techniques in this Chapter can be applied to cross boundary opportunities, using additional data as required covering the extended area. In respect of temporal boundaries, all EfW options are considered to be operational by the year 2011. This year has been chosen since this is the timescale in which strategic EfW development decisions must be made by the WDAs in order for them to avoid paying landfill fines (CCC, 2003; Jainter and Poll, 2005).

Other studies have used a different approach, transferring thermal conversion procurement to outside of the WDA area in which waste is produced, hence avoiding the challenges of developing EfW infrastructure. Wheeler and Jainter (2006) and Jainter and Poll (2005) assume residual MSW will be sent to a third party for thermal conversion and recovery in a power station for example. Such 'export of waste' approaches do not adhere as well to the proximity and self-sufficiency principles of the National Waste Strategy, but have been adopted by some WDAs. In contrast, Hampshire believed they had a moral responsibility to manage their own generated waste. This project will formulate and appraise policy options that manage WDA waste within their jurisdictional boundaries unless cross-boundary working is planned. Such different views on waste management only support the argument that EfW policies should be WDA and area-tailored at the sub-regional level.

5.3.2. DEFINITION OF WASTE FEEDSTOCK

Residual MSW is the feedstock assumed for all options since its management is a priority for WDAs in meeting their landfill diversion targets. Residual MSW is municipal waste that has already had suitable components for recycling and composting separated from the total MSW arising. EfW policies are often proposed for Residual MSW. This project has followed the recommendation from Tyson et al (1996) that waste production and recycling rates should be sourced from local area work. This is particularly justified since, planned routes for recovery and disposal of MSW are determined by the individual WDA requirements for Government defined 'best-value indicator' landfill diversion (ODPM, 2006); to meet their landfill allowances targets for 2011. In the specific WDA case study examples, such local work was conducted in the Warwickshire BPEO study (Jainter and Poll, 2005) and the Waste Local Plan (CCC, 2003).

To derive the tonnage for residual MSW to be directed to energy-from-waste in Table 5, deductions from total MSW production tonnage were made to account for the tonnage diverted for recycling and landfill. 30 and 40% recycling rates were used for Cornwall (CCC, 2003) and Warwickshire (Jainter and Poll, 2005) respectively. In the case of Cornwall, 49 ktpa are intended for landfill, while in Warwickshire 30 ktpa are intended for an existing large-scale EfW plant in Coventry. The remaining 180 ktpa is to be processed by each alternative technology and scale option defined in the next Section. This project selected Cornwall and Warwickshire as the WDAs in which to test its methods, since the same tonnage of 180 ktpa destined for energy from waste policies allow comparison of site identification and transport impact estimates in different geographic areas.

Table 5: Waste management routes for Cornwall and Warwickshire

Tonnages per annum for 2011	Cornwall	Warwickshire
Total MSW production	327,000	351,000
Recycling	98,000	140,000
Residual for Landfill	229,000	210,000
Residual for EfW	180,000	180,000

Figure 8 shows the waste projections for Cornwall (CCC, 2003) and Warwickshire (Jainter and Poll, 2005) and the values for 2011 can be cross-referenced to Table 5. It is interesting to note that the predicted waste growth projections are different in trend and this can be explained by the population and household growth conditions of the respective areas. Warwickshire's projection is based on an assumption that the number of households will rise at a constant rate between 2003 and 2011, while Cornwall's projection assumes that growth will be relatively higher between 2003 and 2005, but will then decline towards 2011. This is an example of how WDA areas are specific in nature when formulating and appraising EfW policies based on their individual tonnages of production and other factors. This again supports EfW planning and the application of the DSS at sub-regional level.

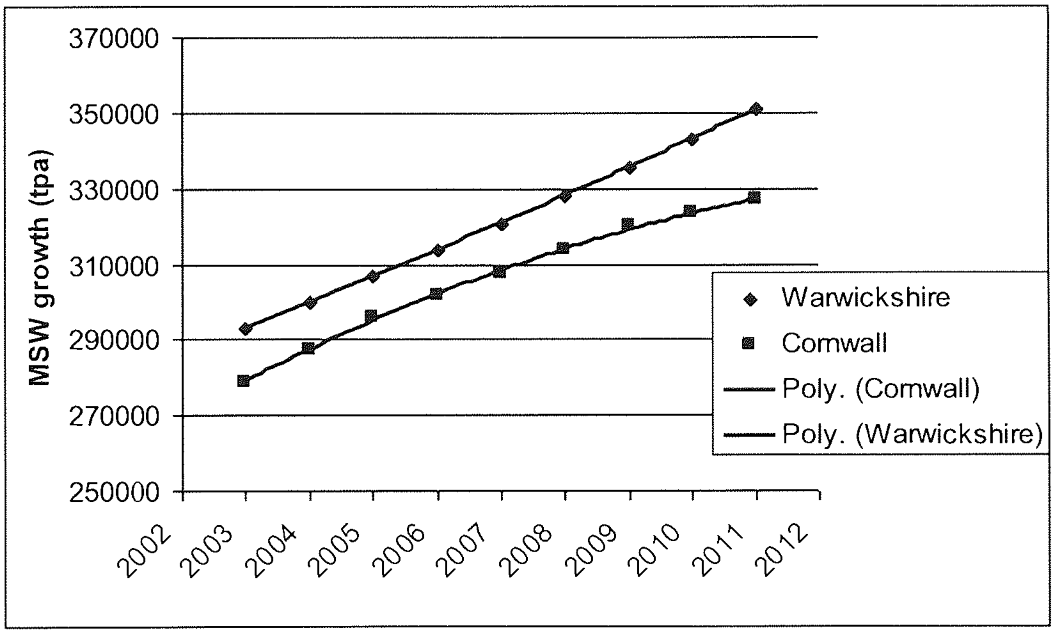

Figure 8: Growth patterns of MSW in Cornwall and Warwickshire (CCC, 2003 & Jainter & Poll, 2005).

Many studies have typically assumed MSW compositions with no assumptions of recycled components already removed before thermal treatment (Finnveden et al, 2005). In using WDA provided waste flows for management, this project has used the waste composition assumed by Consonni et al, (2005a). This composition assumes that 35% of the weight of MSW is reduced by recycling. This value is within 5% of the WDA objectives of 30 and 40% materials recovery and the difference is not significant in the process of deriving overall EfW option scores in an MCDA appraisal method. Consonni et al, (2005a) have defined their residual MSW composition based on collection of data provided by waste management authorities. The composition and heating value assumed is shown in Table 6.

Table 6: Composition and heating value assumed for residual MSW (Consonni et al, 2005a).

Constituent	Content in residual MSW	Moisture	Ash	Volatile fraction	LHV (MJ/kg)	Volatile fraction % of weight of total	
Paper and cardboard	24.5	14.0	5.0	81.0	13.22	C	27.6
Wood	6.0	22.0	1.5	76.5	13.87	Cl	0.64
Plastic	19.0	6.0	9.0	85.0	26.18	H	3.49
Glass and inert material	3.5	5	95.0	2.5	-0.061	O	19.7
Metals	3.5	5.0	92.5	2.5	-0.122	N	0.15
Organic fraction	31.5	70.0	9.0	21.0	1.719	S	0.06
Fines	12.0	30.0	35.0	35.0	4.395		
Residual MSW	**100**	**31.8**	**16.6**	**51.6**	**10.11**	**Total**	**51.6**

5.3.3. PROJECT OPTION DEFINITIONS OF SCALE AND TECHNOLOGY

This project principally uses five options representing two different EfW technologies at three scales of capacity shown in Table 7. Options 1, 2 and 3 utilise conventional combustion technology with unit capacities of 180, 60 and 60 or 30 ktpa respectively, corresponding to *large*, *medium* and *local*. Options 4 and 5 use the ATT design from Compact Power (Section 1.3.5.2) which has unit capacities of 60 and 30 ktpa (*medium* and *local*).

Table 7: EfW options modelled for Cornwall and Warwickshire.

	Options				
	1	2	3	4	5
Description	Large	Medium	Local	Medium	Local
Technology	Combustion	Combustion	Combustion	Pyrolysis/ gasification	Pyrolysis/ gasification
Notation	L SC	M SC	Loc SC	M S ATT	Loc S ATT
Tonnage input wet MSW (ktpa)	180	60	60/ 30	60	60/ 30
Use of WTS	Yes	Yes	No	Yes	No
No of plants	1	3	3 to 5	3	3 to 5

There is ambiguity in definitions of what is 'local'. The Energy White Paper (2003) makes a clear distinction that there will be more local and community plants, but does not define what this means. The term 'local' can be defined as: "Relating or restricted to a *particular area* or one's *neighbourhood*". 'Neighbourhood' is defined as a "*district or community* within a town or city". The term 'local' is also given to several layers of administration. These include the county, district and parish levels. In the case of the *local* EfW options, the term 'local' is defined in this project to be equivalent to the UK district level of local government. The locations of the *large* options in both counties are pre-determined from the local WDA waste management strategies (CCC, 2003; Jainter and Poll, 2005). These are located on large areas of derelict post-industrial land and been the subject of much detailed unpublished local planning work.

Performance data on pyrolysis/gasification ATT systems and indeed, all commercial EfW technologies is difficult to source, but due to the collaboration with Compact Power Ltd, data was available at the 30 and 60 ktpa capacity. Hence, *Local* facilities have capacities of either 60 ktpa or 30 ktpa (determined by the size of the locally collectable waste resource using the GIS techniques) and are aggregated to meet the overall recovery demand of 180 ktpa of residual waste as set by the WDA planning documents. Many combustion plants are already built across Europe at a multitude of scales and performance data is much easier to obtain from various sources and the literature. It was possible to extrapolate scores for combustion technology at 180, 60 and 30 ktpa. A large-scale ATT scenario was not included as no suppliers are offering this option in the UK (Cooper, 2003; Dawber, 2006) and WDA officers were insistent that only technology proved deliverable in the UK context warranted inclusion in EfW decision making. Detailed design has only been made for smaller-scale (30 to 80 ktpa) ATT facilities, therefore performance data is not available for a facility of 180 ktpa.

5.4. CHAPTER SUMMARY

This Chapter has provided an overall outline of the proposed EfW DSS and provided the parameters in which it is applied. WDA areas have been defined in which to apply this DSS since WDAs have a statutory duty to manage waste produced within their political boundaries. The techniques within this DSS could be used to accommodate cross-boundary collaboration of WDA if necessary. Residual MSW feedstock and how the relative tonnages routed to EfW for each WDA areas were specified. Section 5.3.3 defined the EfW options in terms of scale and technology that are formulated and appraised by this project.

6. Formulating EfW options using GIS: Residual MSW production and Site Identification modelling

6.1. Aims of chapter

The aim of this Chapter and Chapter 7 is to present the methods and results of the GIS-based formulation of EfW options for Cornwall and Warwickshire in terms of residual MSW production, site identification and transport impact modelling. Collectively, these Chapters present the findings of Step 3 in the overall DSS approach presented in Section 5.2 and also discuss data collection and analysis issues and how these were overcome. Sections 6.2 and 6.3 present the methods and results of the residual MSW and Potential Site Identification modelling and discuss them for both WDA areas. These models form the basis for deriving the Final Site Identification output for large, medium and local EfW options (Section 6.4.1). Section 6.4.2 reports the derived locations for medium and local-scale options. A discussion of the results is made in Section 6.4.3.

6.2. Residual MSW production modelling

6.2.1. Methodology

The method for modelling the geographic residual MSW production is shown in Figure 9. It is a result of a review of the literature (Section 3.2.2) and selection of method elements from Tyson (1996), Bergsdal et al (2005) and Shmelev & Powell (2006). In order to map MSW production in the UK WDA context, the data sources from Shmelev & Powell (2006) were used with the exception that census lower output area (COA) population statistics were used in place of census ward. This was done in order to make processing times faster and because the extra geographic resolution available at ward level does not add any additional benefit to siting facilities processing a minimum of 30,000 tpa of waste.

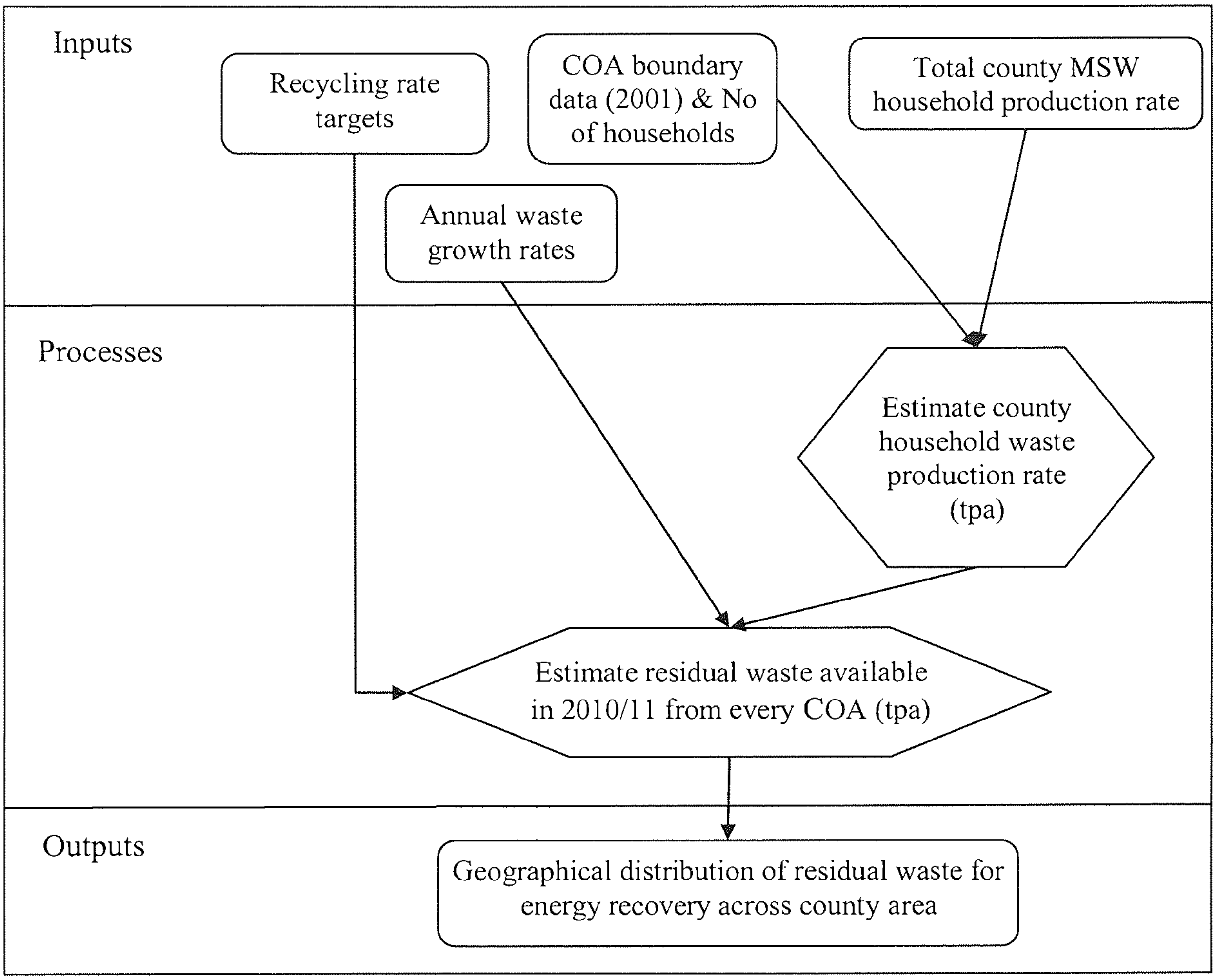

Figure 9: Overview of residual MSW mapping method.

GIS population data based on 2001 Census Output Areas were used together with waste growth and recycling rate assumptions from Jainter & Poll (2005) and CCC (2003) to derive the residual MSW production maps for Cornwall and Warwickshire. Census Area population-weighted centroids with their attribute numbers of households were sourced for the study areas from UK Borders (Edina, 2006b) and Casweb (UK Census, 2006). Further explanation of population-weighted centroids and different GIS data types is presented in Section 2.2. Waste production as a function of population in a GIS can be referred to as a 'source' with the end destination or facility for energy recovery as the 'sink'.

The average amount of household waste produced per annum in each WDA was calculated by dividing the total WDA household waste production (2001) by the total number of WDA households (2001). Since such data is dependent on household building rates, these values are unique to each WDA area. MSW can include other wastes such as street sweeping and some trade wastes and where this data was available, it was taken account The annual rate of waste generation was 1.34 and 1.12 tpa for Warwickshire and Cornwall per household respectively. The Cornwall value did not take into account trade and street sweeping, since this data was not available. The total residual waste production for energy recovery in 2011 per COA 'source' location was calculated by multiplying the population (by household) derived waste production by the annual waste growth and recycling rates in Section 5.3.2. The main output of the waste resource model is a geographical distribution map of residual waste for energy recovery that has been generated for each WDA and presented in the next Section. GIS metadata is presented in Appendix C.

6.2.2. RESULTS

Figure 10 and Figure 11 show the residual MSW production model map results for Cornwall and Warwickshire. The 'polygon' shading symbolises the amount of waste production per annum from the corresponding Census Output Areas (COAs). These figures represent the geographic density of waste production, since they are normalised by area. This is not necessary within the overall facility site identification process, since facilities are of a scale far greater than individual COAs, (For example, 30,000 tpa plus compared to an average COA annual waste production 120-130 tpa).

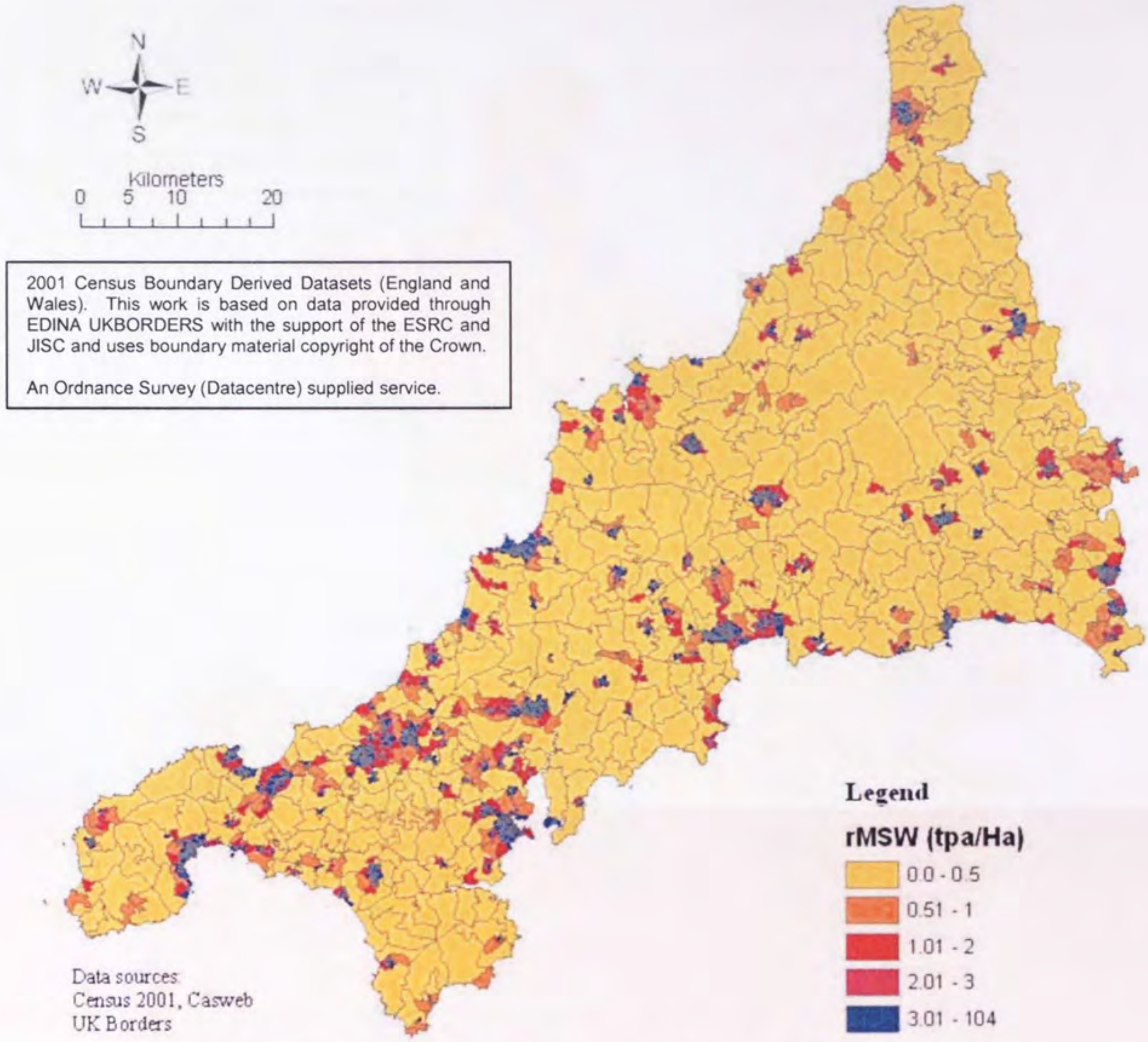

Figure 10: Residual MSW resource map of Cornwall.

The polygon shading symbolises the amount of waste production per annum per Ha from the corresponding COA areas. More urban zones can be identified from higher densities of waste production. These areas are generally more distributed and less apparent than the clusters of urban areas which can be identified in Warwickshire's waste magnitude map (Figure 11).

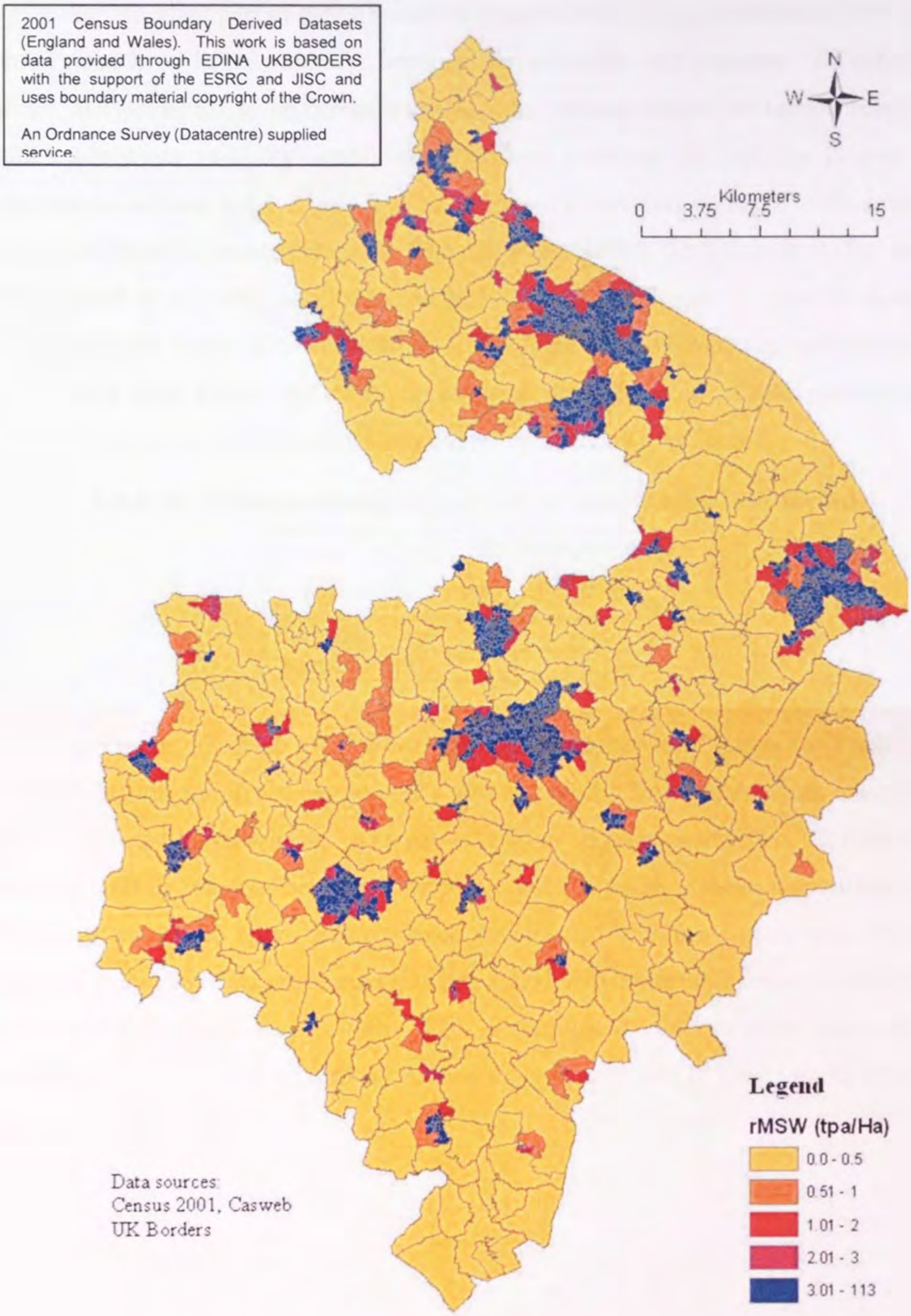

Figure 11: Residual MSW resource map of Warwickshire.

An important part of the GIS modelling is to derive where distributed EfW facilities can be sited in order to minimise transport requirements and impacts. To achieve this, further analysis needs to be carried out upon the residual MSW production results using 'collectable waste mapping' iterations. This was achieved by applying Process 'C' as described in Section 6.4.1.1, and is used to identify 'hotspot' zones of collectable waste with a pre-defined distance parameter (Dagnall et al., 2000). To demonstrate the technique from Dagnall et al (2000), applied to MSW, Figure 12 and Figure 13 show 'hotspot' zones in Cornwall and Warwickshire which are areas where 30 and 60 ktpa of residual waste can be collected from within the minimum required distance radii. These parameters were iteratively derived for both county study areas and are shown in Table 8 .

Table 8: Minimum transport radii for 60 and 30 ktpa EfW facilities.

	Min transport radii (km)	
	60	**30**
Cornwall	12	8
Warwickshire	12	4

In Figure 12, Map 'A' shows that the area between Camborne/Poole/Redruth (CPR), Falmouth and Truro can service a 60 ktpa facility from a catchment of only 12 km radius – denoted by dark blue. Alternatively, Map 'B' shows that two, 30 ktpa facilities could be built in the area between Camborne and Falmouth. These maps illustrate how EfW facilities can be approximately sized and located within a county according to the proximity principle of its production (DETR, 2000). No collectable density is shown in the area between Liskeard and Saltash. This is because the waste after composting and recycling in this area of Cornwall is assumed to have been sent to Lean Quarry (the nearest waste disposal facility).

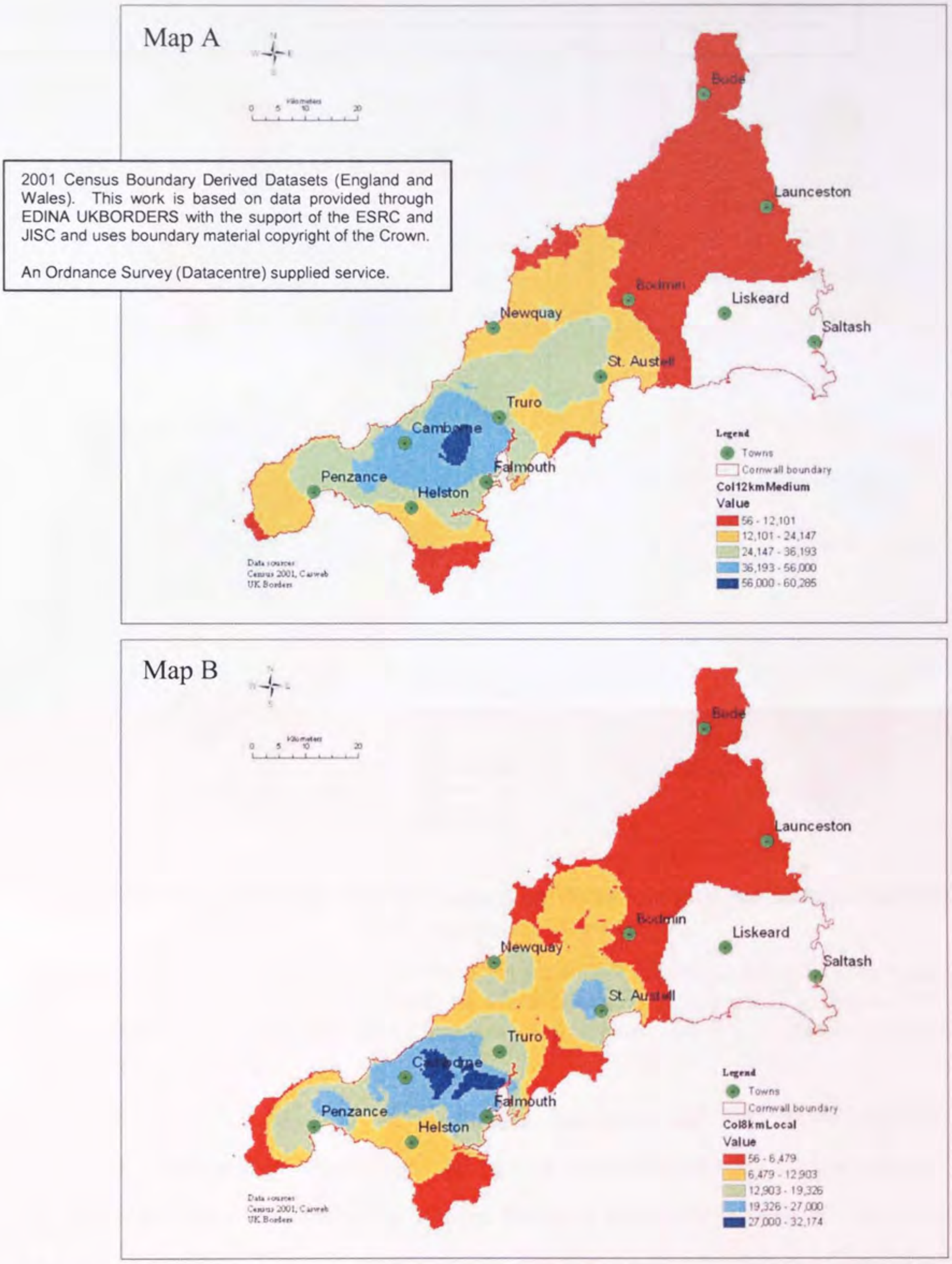

Figure 12: Maps showing 'hotspot' areas of Cornwall for 60 ktpa facilities (top) and 30 ktpa facilities (bottom).

For every 1 ha cell within the study boundary, a query has been made to sum the total amount of residual waste that can be collected (to that cell) within a preset distance. The legend illustrates the residual waste (tpa) that can be collected to every cell within 12km (for 60 ktpa in Map A) and 8 km (for 30 ktpa in Map B).

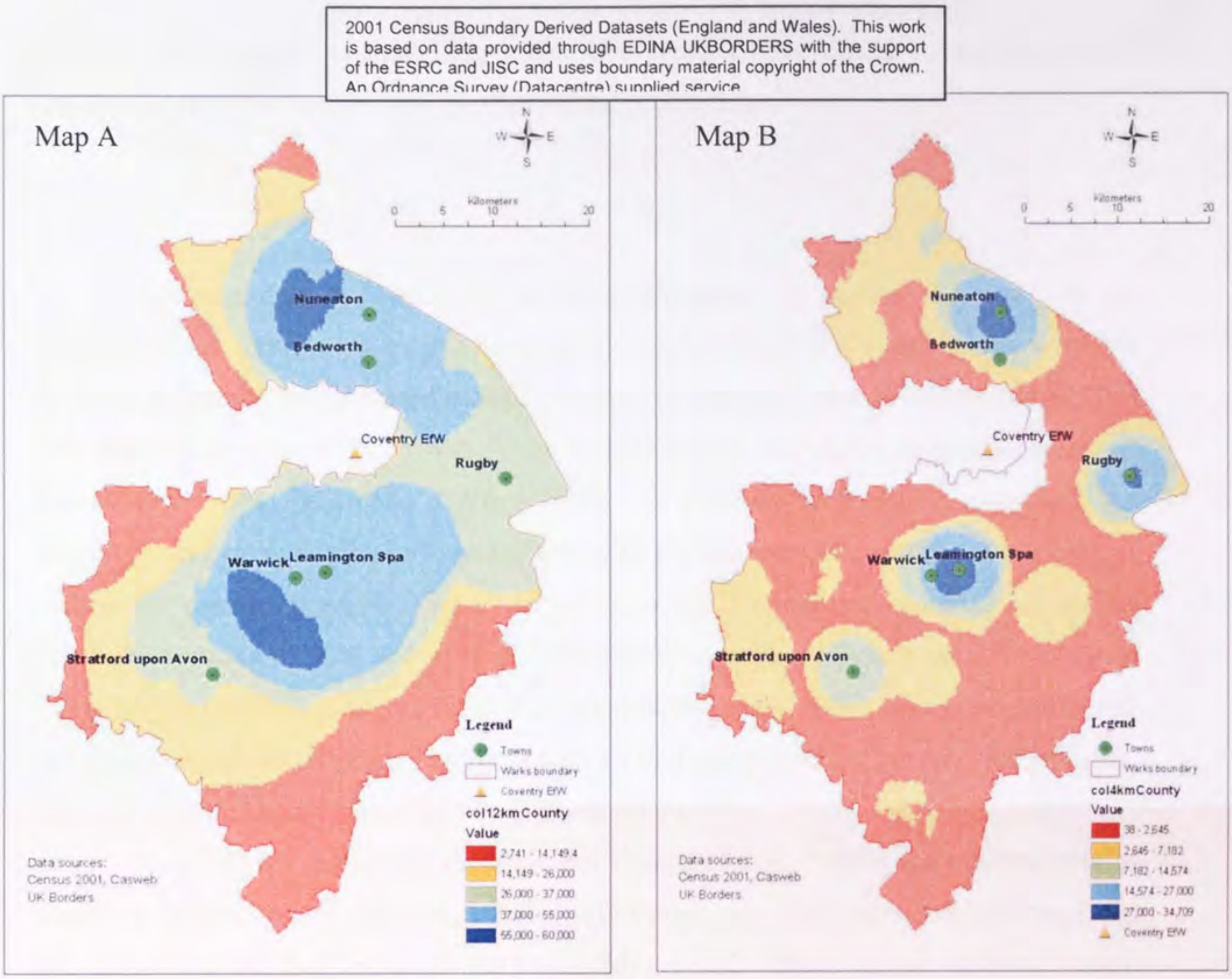

Figure 13: Maps showing 'hotspot' areas of Warwickshire for 60 ktpa facilities (left) and 30 ktpa facilities (right).

The maps show where waste collection densities are at their highest at 12 and 4 km respectively and this is also where the population centres of Warwickshire are situated. The legend illustrates the residual waste (tpa) that can be collected to every cell within 12km (for 60 ktpa in Map A) and 4 km (for 30 ktpa in Map B).

In Figure 13, Map 'A' shows that W. Nuneaton and SW. Warwick have areas in which a 60 ktpa facility can be serviced from a catchment of only 12 km radius – denoted by dark blue. Map 'B' shows that 30 ktpa facilities should be built in W. Nuneaton, Rugby and SW. Warwick. These locations can be serviced from catchments of only 4 km radius. Although, not necessary within the DSS developed in this thesis, for the interest of the reader, The models show that generally, both Cornwall and Warwickshire are study areas with low densities in waste production due to their predominantly rural nature. If the same methods were applied to modelling urban city areas, COAs would be expected to be smaller, more numerous and have greater annual production.

6.2.3. Discussion

Data regarding the variability of waste generation throughout the year was not available since tonnages were provided on an annual basis and waste teams were not prepared to release unaggregated monthly data for unspecified reasons of sensitivity. This was more of an issue for Cornwall, since some areas of the county experience seasonal variability in waste generation due to tourism. In planning EfW policy, it is clear that capacity needs to be flexible enough to cope with the extremes of demand for disposal, as well as the changes brought about by recycling or waste minimisation initiatives. Using fixed assumptions of 40% and 30% of MSW production for recycling rates for the year 2011, may not be fully achieved for several reasons, including: difficulties in procuring and developing materials recycling facilities (MRFs); finding markets for the recycled products; and public participation rates (Poll and Oglivie, 2005).

Waste growth projection methods can be ambiguous. While the national rate of growth is 3% per annum (DEFRA, 2006b), WDA rates have been quoted as between 1 and 3% in any given year between 2003 and 2011 (CCC, 2003; Jainter & Poll, 2005). Predicting waste production is difficult, since the success of recycling and waste minimisation strategies, as well as the consequential changes in waste composition, may affect the volume and calorific value of waste available for energy recovery (Subramanian, 2000). The effects of an overall change in residual waste availability on the final site location outputs are investigated in Section 6.4.3.2. A major difference in the residual waste modelling of both WDA areas was the different waste growth rates applied (shown in Figure 8). These rates are difficult to justify for long time periods and are often controversial in that some authors argue rates are and will continue to decrease (Kondakor, 2007).

Local waste planning documents often do not make clear how many years worth of MSW arising data have been used on which to base their extrapolated forecasts or how they are considering future growth. The Cornwall Waste Local Plan, for example, shows data collected on MSW production from 1996 (CCC, 2003), and if this is the only data used on which to extrapolate for a 10 year period as required by PPS 10 (ODPM, 2005), this may not be sufficient to make a reasonable forecast. A limit of extrapolation has been cited as 25% before or after of the time period for which you have data (Arrowsmith et al., 2003). In using waste generation statistics from local-level planning documents, produced by different authors, it cannot be guaranteed that the methods used to derive input values (such as baseline waste tonnages) are the same when applying waste resource modelling to different WDA areas. Such dependence on local studies with regards to these issues as recommended by Tyson et al (1996) clearly has its disadvantages if WDAs decide to undertake cross-boundary working as encouraged by DEFRA (Haggard, 2006).

In applying the residual MSW production methods to the two different WDA areas, it was apparent that Cornwall has a proportion of its waste production from islands including, most notably, the Isles of Scilly. This factor will not significantly affect the identification of sites for large, medium or local-scale plant, because production from the islands constitutes only 1.2% of the total amount of waste represented in the model. Warwickshire is landlocked; hence, this issue does not arise.

The data in Table 9 shows that the residual MSW production model statistics in both counties are similar; with the mean residual waste (tpa) production per OA was 129 and 121 in Cornwall and Warwickshire respectively, with standard deviation 23.2 and 19.8. The deviation indicates that waste production in Cornwall varies more with geography than in Warwickshire. The spatial distribution of the collectable waste models shown in Figure 12 and Figure 13, are also very different. Warwickshire has four distinctive urban areas of Nuneaton, Warwick & Leamington Spa, Rugby and Stratford which may be seen as 'clusters' of waste production. In Cornwall, however, there are no such obvious clusters - waste and population is more distributed over Cornwall than in Warwickshire, where waste production is more concentrated in towns. In essence, Warwickshire provides clearer indications of where multiple plants may be situated than Cornwall. On the basis of the baseline residual MSW production models, further GIS analysis is required to identify sites and estimate transport impact within the WDA specific geographies. Many waste policy studies do not take such factors into account (CCC, 2003; Jainter & Poll, 2005; Wheeler & Jainter, 2006).

Table 9: Overall resource model statistics predicted for 2011 (tpa of residual MSW).

	Cornwall	**Warwickshire**
Number of COAs	1776	1740
Min	42	37
Max	331	289
Sum	229,657	210,428
Mean	129	121
Standard deviation	23.2	19.8
RW to alternative disposal p.a.	48,657	29,993
RW for new EfW capacity p.a.	181,000	180,435

Figure 14 has been produced to show an example of the density of COA polygons in urban areas that are not possible to observe at the resolution of the county level maps in Section 6.2.2. Like Figure 10 and Figure 11, the grayscale shows waste production normalised by area, with results in tpa/ha. The urban areas are clearly shown, against the light grey of the surrounding rural area. Smaller built up settlements such as villages are also visible. The figure implies that transport times and costs may be much lower when collecting waste from a dense (more urban) waste production area than less dense (rural) area. Such detail cannot be seen at the higher county resolution. This is discussed further in Section 7.3.4.

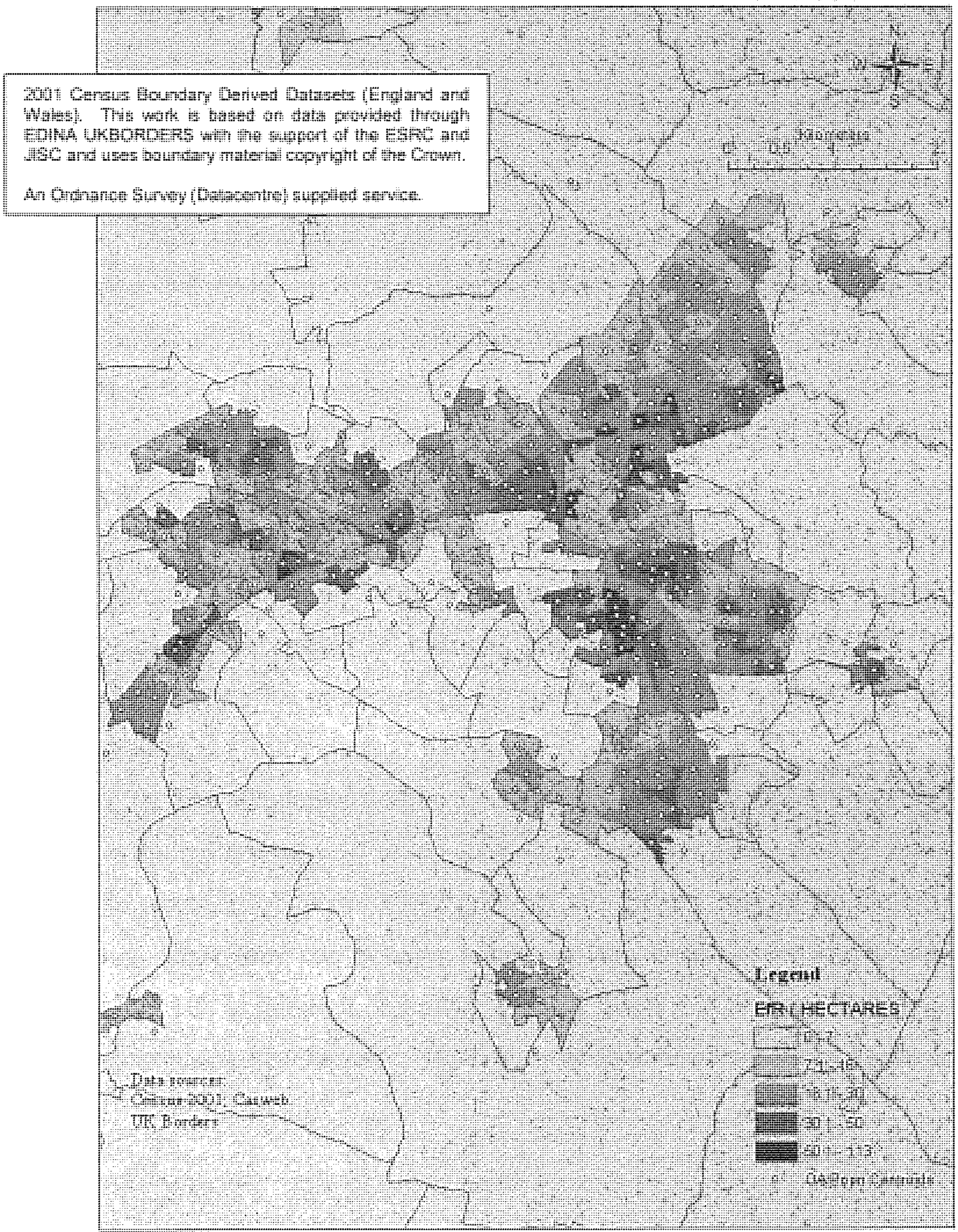

Figure 14: Normalised residual MSW resource map of built-up areas.

6.3. POTENTIAL SITE IDENTIFICATION MODELLING

6.3.1. METHODOLOGY

The residual MSW production identifies areas of high waste production within the WDA area. Other criteria need to be taken into account when identifying potential sites such as those reviewed in Section 3.2.3. These include proximity to suitable grid connection and roads, as well as ensuring that facilities are located in zones of suitable land use (ODPM, 2005). Other considerations include the need to respect institutional barriers such as conservation areas. Review of the literature in Section 3.2 identified that adaptations of the techniques used by Dagnall et al (2000) were best suited to the WDA end user environment using the criteria in Section 2.2. The selection of criteria above is similar to other studies (Dagnall et al, 2000; Voivontas et al, 2001; Varela et al, 2000) but have been finally decided in respect of Planning and Policy Statement 10 (PPS 10) (ODPM, 2005) in order to make the procedure fit for purpose in the UK context. The process used by the Dagnall et al (2000) study is shown as an example of a GIS 'overlay' in Figure 5 (Section 3.2.2). The adapted technique used in this project is shown in Figure 15. The key difference is the replacement of 'urban area' with 'industrial sites' map criteria data. This was because rejection of urban zones presents too great a loss of opportunity for EfW facility siting, since they can contain industrial land areas which are recommended as suitable by PPS 10. In addition, industrial users of steam and heat are attractive, since they can be less seasonal in heat demand. Input GIS metadata is presented in Appendix C.

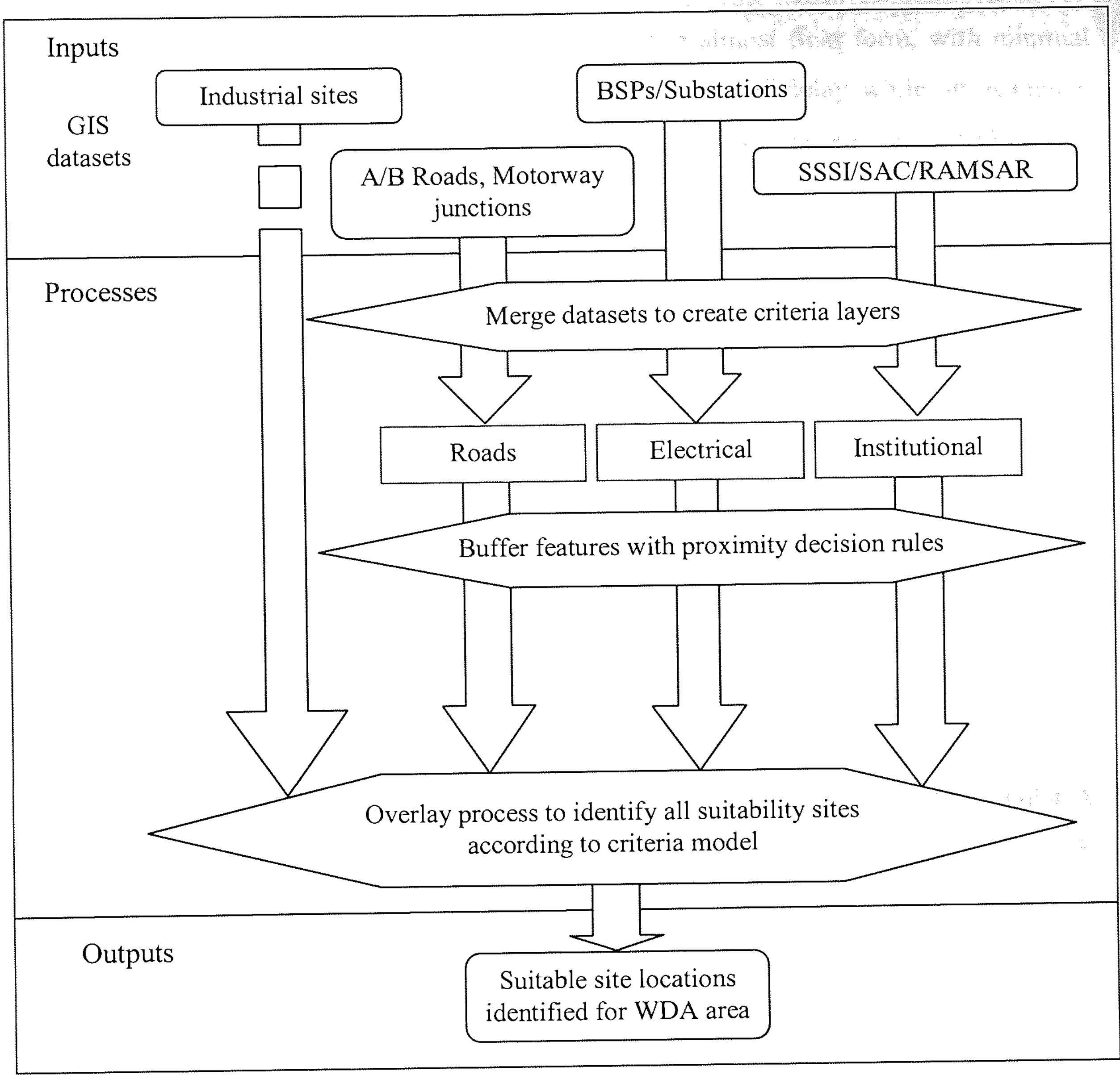

Figure 15: Overview of Potential Site Identification modelling method.

All the inputs of this procedure are digital GIS datasets containing the locations of the features in polygon, line or point format (Section 2.2). In the case of polygon data, such as industrial sites, data depicts a set of boundaries, in which the area can be calculated. These data have been collected from several sources, and some required pre-processing before inputting into the model, the extent of which depended on the area of study. For example, due to the unusable format of data from Western Power Distribution representing the electrical distribution grid in Cornwall, it was necessary to manually digitise paper maps. In the case of Warwickshire, lengthy negotiations of over a year with the electricity distribution company enabled the data to be supplied in almost final form, with minimal needs for pre-processing. There were also several months of delay while an academic agreement was made in order to successfully access the extensive amounts of Ordnance Survey data required, which would otherwise have not been possible to acquire due to cost.

GIS analysis using data may not fully reflect the real situation if it is not regularly updated. This can particularly be a problem for data drawn from non-Ordnance Survey sources, such as the WDAs, and includes the industrial site data in the Warwickshire model and the electrical grid data from the distribution companies. Data from the Ordnance Survey is updated regularly and is more reliable (Edina, 2006a). These problems can be mitigated by cross-referencing different sources of GIS data and the 1:25,000 mapping was useful in fulfilling this role.

The first processing task within the GIS is to merge individual datasets into feature layers. This process assumes that all datasets in any one feature layer are given equal importance, ie they are not weighted. For example, the *roads* feature layer contains the A/B roads and motorway junctions geographic datasets and traffic capacity data which may be available at the county level is required to justify a greater preference to a particular A road for example, than a B road. This has been applied, since actual road capacity network data was not available, despite efforts to secure this from the WDAs due to commercial sensitivity.

Bulk supply points (BSPs) and primary (11/33kV) substations are merged, as are institutional constraints such as SSSI (Sites of special scientific interest, SACs (Special areas of conservation) and RAMSAR sites. Other constraints such as national nature reserves (NNRs) have been added to the institutional layer as necessary. For example, there are many more types of conservation areas in Cornwall than in Warwickshire.

Table 10: Criteria and decision rules for identifying suitable sites.

Criteria	Data type	Source	Sub-criteria	Reference
Industrial Sites	Polygon	Warwickshire CC (Holmes, 2005a)	Within boundary	ODPM, 2005
BSPs/Substations	Point	Central Networks (Cooper, 2006) Western Power Distribution.	Within 3 km	Brown, (2003)
Roads	Line	Ordnance Survey (Edina, 2006a)	Within 1 km	Varela et al. (2001) Dagnall et al. (2000) Cole et al. (1996)
Institutional constraints	Polygon	Magic (English Nature, 2006)	Over 2 km	FoE, (1995)

In order to prepare the layers for an overlay analysis to produce WDA site identification maps, suitability zones based on proximity decision rules in Table 10 were created. ESRI's ArcView provides the necessary geoprocessing tools within its standard User Interface. A key criterion is that all potential site areas must be within industrial areas; therefore, in this case, identifying areas in proximity to these input data is not required.

Two important connectivity concepts used within the elements of buffering and proximity in order to produce the input layers for the final overlay process are those of distance and proximity. In 'buffering' processes, proximity to a geographic feature is measured in terms of a straight-line distance. A buffer is a region or zone of specified width around a point, line or polygon GIS data feature. These widths can be user-defined (as in Table 10) with output layers depicting circular, corridor or polygon shaped objects. These represent input points, lines or polygons respectively. For example, Point data buffering is shown in Figure 16. In general, proximity operations generate boundaries around objects with equal distance in all directions (Malczewski, 1999). The buffered output layers are then overlaid to identify sites within the WDA area that meet the criteria in Table 10.

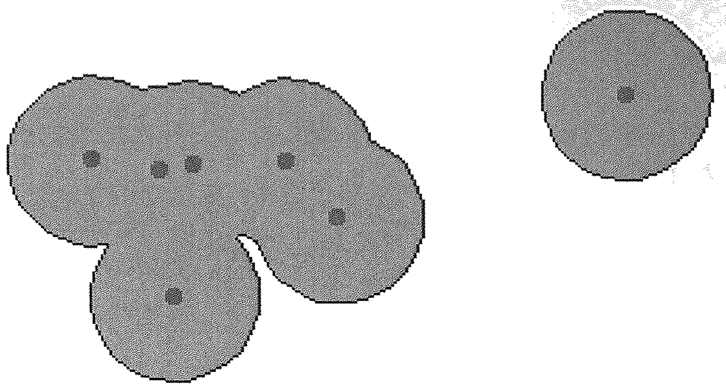

Figure 16: Example of buffering

Initially, the Potential Site Identification models were produced at a resolution of 2 ha, but it was found that the model often failed to take account of the smaller SSSI site areas. The solution was to regenerate the models at a 1 ha resolution. A further problem identified at the 1 ha resolution was that a small number of industrial sites were missed. This was not considered to be an important issue, since small-scale EfW of 30 ktpa capacity require an area of at least 1.5 ha for development (Enviros, 2004). This may be a conservative parameter, however, for smaller-scale sites that may require an area as small as 1 ha (Beswick, 2006). For large-scale facilities, it was necessary to screen the sites from the Potential Site Identification model to ensure that they were all over 4 ha, since this is the minimum land area for required for development (Enviros, 2004).

6.3.2. RESULTS

Figure 17 and Figure 18 show locations in Cornwall and Warwickshire, which correspond to the application of the criteria outlined in Table 10. Result map models are computed in raster (cell-based) format and comprise of 1 ha cells. 33 and 31 potential site locations for Cornwall and Warwickshire were identified respectively. This result can challenge the commonly put forward argument by some waste planning officers that there are not enough sites for multiple EfW plant options (Wood, 2005).

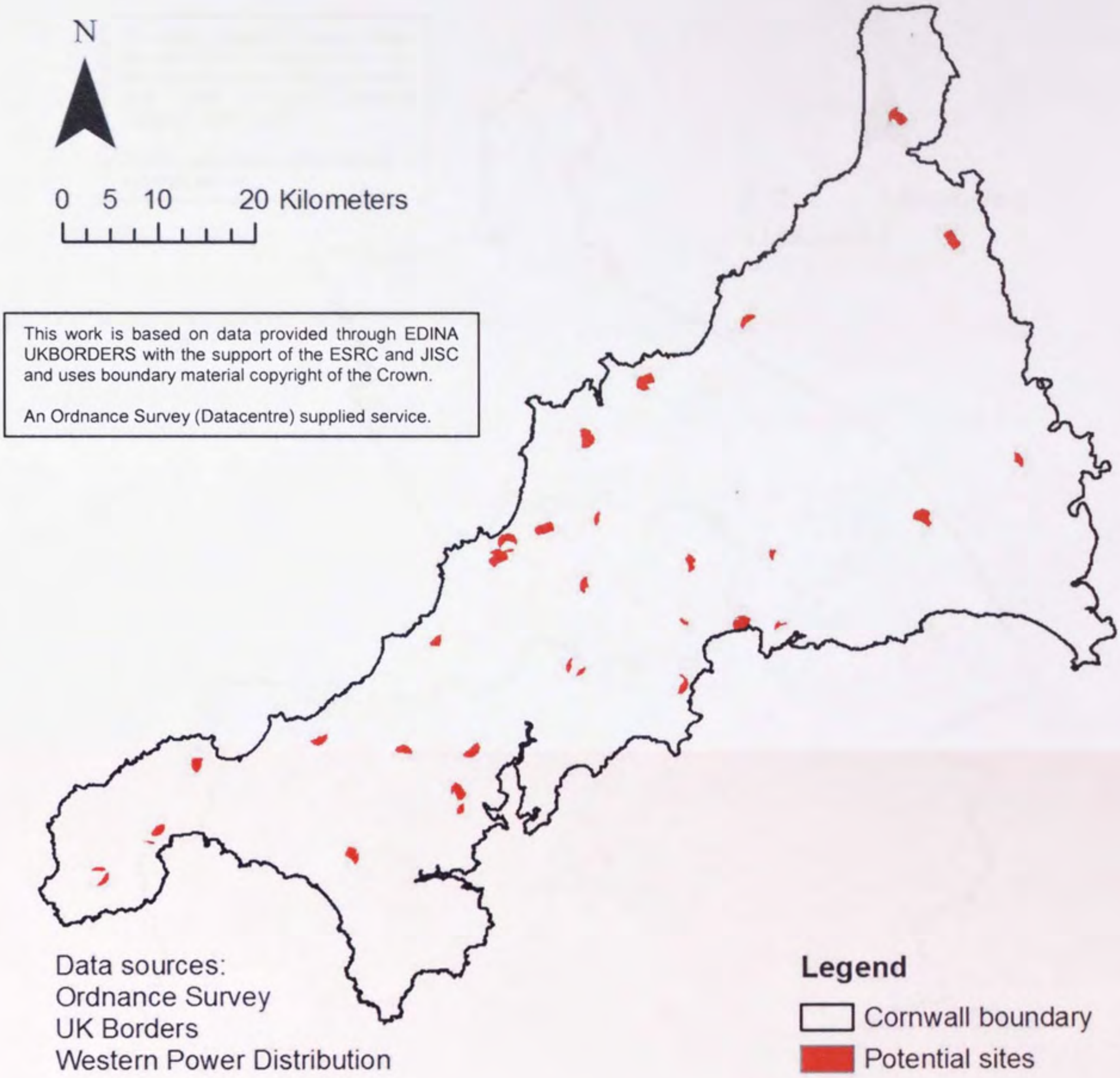

Figure 17: Map showing potentially suitable site areas for EfW in Cornwall.

Figure 18: Map showing potentially suitable site areas for EfW in Warwickshire.

6.3.3. DISCUSSION

The first difference to be noted between the results presented in the previous Section is that the Warwickshire map is of higher resolution and detail. This can be explained by the fact the industrial-site GIS data in the Warwickshire criteria overlay model yields a more detailed resolution output map. On this basis, it would be possible to conduct a site visit to judge further suitability for development. In contrast, the Cornwall model results show fairly expansive areas of grey and black which could be more accurately described as 'areas of search'. This is illustrated in Figure 19 which shows the 'search area' of over 100 ha for a potential EfW site in Delabole, Cornwall. In contrast, Figure 20 shows a potential site in Nuneaton, Warwickshire that is just approximately 5 ha. Site suitability may be judged further at the desktop from background Ordnance Survey 1:25000 Land Ranger mapping as shown in the figures.

Figure 19: Map showing EfW site at Delabole using Cornwall's potential map for final identification.

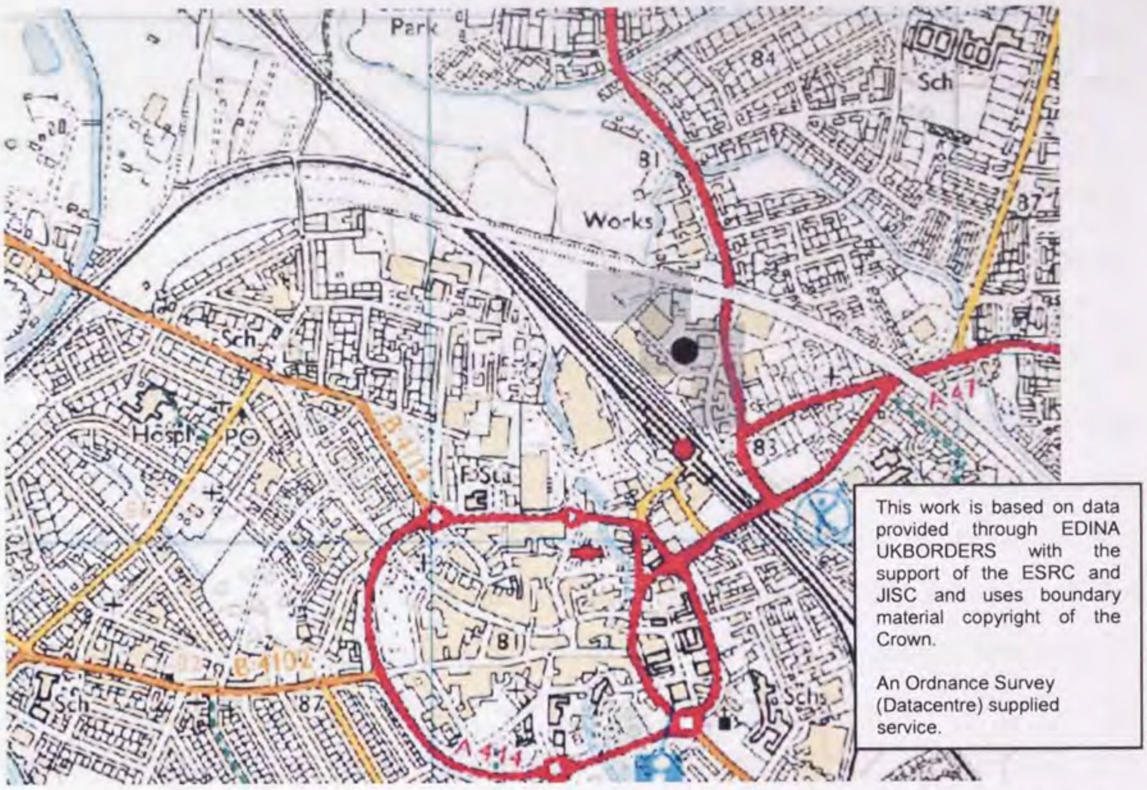

Figure 20: Map showing EfW site at Nuneaton using Warwickshire's potential map for final identification.

The aim of the Potential Site Identification modelling was to take into account non-feedstock related issues in the identification of suitable sites or areas for developing EfW facilities. Overall, the Cornwall model results can be regarded as less useful than the Warwickshire results because of the lower resolution due to the omission of industrial site data. Only two of the six Cornwall districts had this data available and the criterion was omitted since it would heavily influence the Final Site Identification procedures in favour of areas where data was available. This problem was overcome by user judgement based on 1:25000 Land Ranger Ordnance Survey mapping.

Whatever method is chosen or possible, it is important that industrial land is taken into account when identifying sites for potential EfW development of any scale. This is a requirement of Planning & Policy Statement 10 (ODPM, 2005) and also increases the chances of co-locating with an industrial process demand for heat to allow opportunities for the co-generation of heat and power (ILEX Energy, 2005). There is, however, the argument that finding only one potential demand for the heat, results in a significant risk in that if the demand's industrial activity ceases for any reason, the heat revenue is also lost, unless it can be replaced with other demands from the immediate area. An interesting UK example of this was the closure of the Peugeot manufacturing plant which was supplied with heat from the Coventry EfW facility situated nearby (Turner, 2005).

The fact that only geographic locations of criteria objects (such as industrial sites) are taken into account with little attribute data (ownership of land and availability, for example) is also relevant to other input datasets. This is also an issue regarding use of the 'electrical' dataset. This data shows the locations of primary substations and areas in proximity to them. Its use in the overlay procedure is based on the assumption that significant grid capacity exists to accommodate inputs of electricity output from plant situated in close proximity to the primary substations. It is generally assumed that the further a location is away from a primary substation, the lower the capacity of the distribution network to accept injections of power (Brown, 2003). In reality, however, all distributed generation proposals are independently assessed for connection suitability by the distribution network companies. Feasibility analysis includes the need to take into account the affects of power injection on fault and voltage levels at any particular 33 or 11 kV network node. These are a function of the total power output, and hence, scale of the proposed plant (Brown, 2003).

Regarding the GIS dataset representing 'roads', some attributes are covered such as the type of road (A, B or motorway), but others are not. For example, the baseline traffic load before plant development would have been useful, as it needs to be considered in an Environmental Impact Assessment required for actual EfW development. The WDA administrations may also specify preferred routes on which to build infrastructure to ensure that traffic impacts and congestion are minimised (CCC, 2003). This is particularly important for large-scale 180 ktpa facilities where deliveries could entail over 90 lorry movements per day.

The constraining effects of applying the criteria are also worth discussion and these are summarised in Table 11. After industrial sites, the most constraining influence on the model derives from the inclusion of electrical grid data. The effect is similar for both county areas constraining approximately 95% of the total area. This is interesting, since statements are sometimes made referring to the weakness of Cornwall's distribution grid. This may be in terms of large-scale injections of power, but may not be as serious for multiple smaller injections as would be the case if medium or local-scale EfW implementation options were undertaken (Brown, 2003).

Table 11: Effects of site criteria rules results and summary of potential site identification results.

		Cornwall	Warwickshire
% of study area available after rule application	Roads	30.2	37.6
	BSPs/ Substations	5.5	5.2
	Institutional constraints	39.1	62.9
	Industrial sites	No data	1.0
% of study area	Total	1.1	0.34

There is much greater contrast between the two counties in the constraining effects of 'Roads' and 'Institutional constraints'. The road network in Warwickshire is stronger since only 62% of the total study area is constrained compared with 70% in Cornwall. This observation however, does not take into account baseline traffic flows or routing, but reflects the higher number of A and B roads across the county area. The greatest difference between the two areas is the institutional constraints. Cornwall has over twice the number of SSSIs than Warwickshire which results in a 61% constraining of area compared to 37%. The greater number of 'sensitive' planning areas could certainly increase the challenge of finding suitable sites for any scale of plant. Overall, the Potential Site Identification method produced results that suggest that 1.1% and 0.34% of total land area may be suitable for EfW development in Cornwall and Warwickshire respectively. These observations may indicate that Warwickshire is more suitable for identifying potential sites than Cornwall, but such a conclusion would be premature, since it would be useful to have more input data layers with detailed attributes. More datasets can increase detail in the Potential Site Identification modelling and include: Suitability of land for purchase; locations of derelict or brownfield land; areas of pre-defined suitability by the local distribution grid company. They were not included due to data availability – either in terms of cost, actual existence or commercial and political sensitivity.

It was noted in the literature review that most previous studies do not take into account the need to use heat, which requires facility co-location within a reasonable distance to heat demand. In the UK, there is no digital GIS data which shows the location of heat demand or its magnitude, although a method has been used to estimate 'heat potential' (Wiltshire, 2003). This study used gas supply data at an aggregated postcode sector level that makes it difficult to transpose to a site suitability level. In contrast, heat demand GIS data and mapping has been more greatly developed and used in Denmark (Moller, 2000) and Norway (Bergsdal et al., 2005), where data is available at the postcode and individual building levels. Identifying heat demand at the site level resolution can only be done by site visits and local knowledge in the UK at present. The decision to use industrial sites mitigates this issue, in that it is reasonable to expect that there are significant demands for heat within such a land-use. Planning Policy Statement 10 (ODPM, 2005) also requires that waste management activities are conducted within a land-use zone that is in keeping with the nature of waste management facilities. An approach to include heat demand in the DSS has been tested and discussed in Section 6.4.3.5.

In general, regardless of whether it is possible to include higher resolution data into the overlay analysis, the results of both models should be regarded as indications of potential sites which require further investigation to confirm their true suitability. They do not replace the need for detailed electrical grid or heat load connection feasibility studies. The analyses used in this project's DSS, however, would be of significant use at the beginning of an EfW planning project in identifying areas where investigative efforts could be concentrated.

6.4. Final Site Identification Modelling

6.4.1. Methodology

The third GIS model in Step 3 of the DSS (Section 5.2) uses the residual MSW production and Potential Site Identification map model results to identify the final site locations for each EfW option. These final locations are used as inputs for the transport impact model calculations.

6.4.1.1. Large-scale facilities

An outline of the model applied to identify final sites for large-scale plants is shown in Figure 21. Several of the processes in Figure 21 are used in iterative techniques to identify sites and catchments for medium and local-scale facilities. They have therefore, been provided in Figure 21 and Figure 22 (on Page 126) with notation for ease of future referencing. Process 'A' involves making extractions from the residual MSW models to account for feedstock that is intended for processing in existing waste disposal infrastructure unique to each WDA area. This may be existing EfW or landfill sites. Waste source points are allocated to them, on a proximity basis, until the tonnage required is met to satisfy facility capacity. These tonnages have been referenced from the local planning documents. Process 'A' is justified since it may not be sensible to create a market in which shortages of waste feedstock may make new facilities less financially attractive to develop (Tyson et al, 1996).

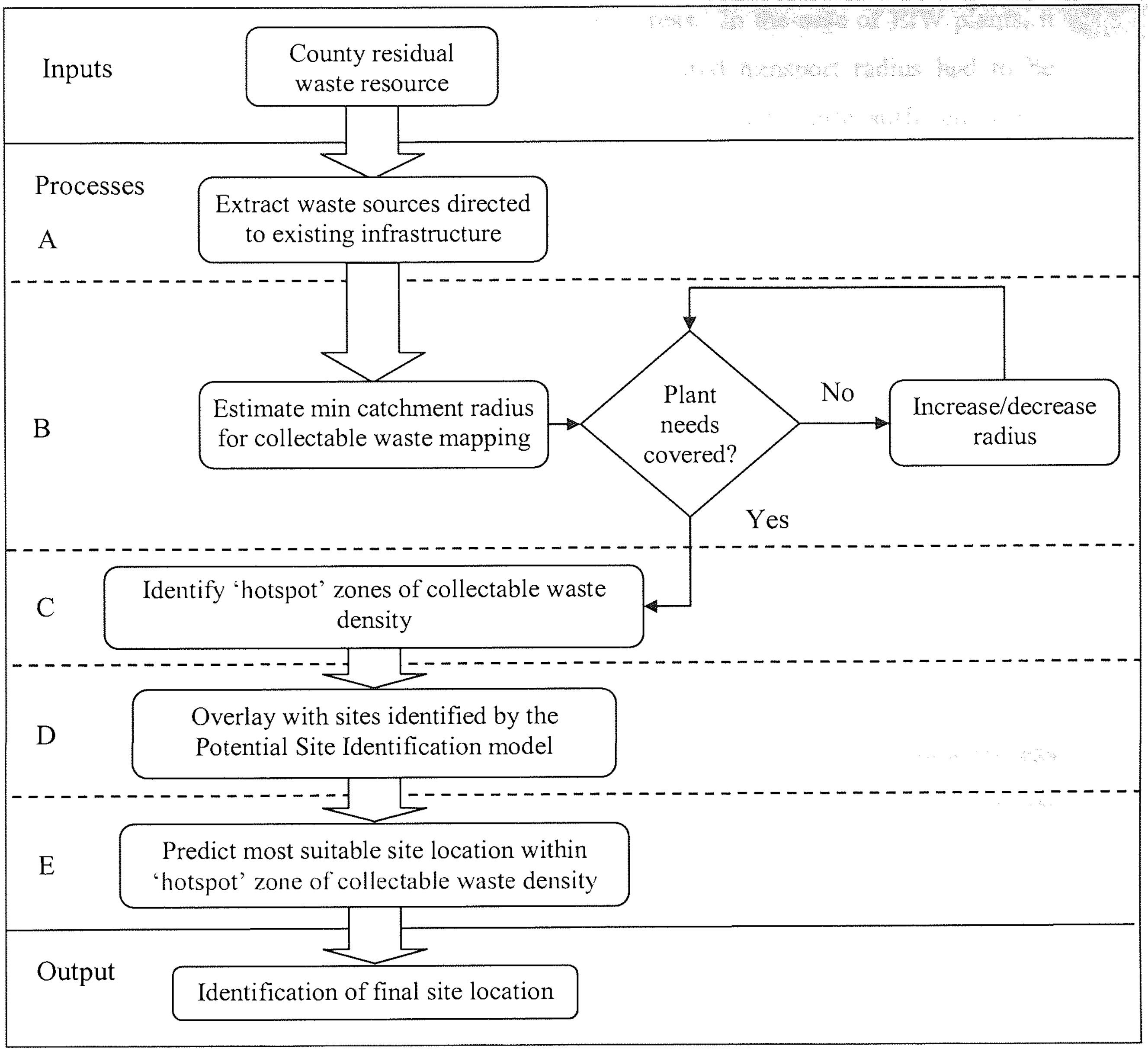

Figure 21: Overview of final site identification model for identifying large-scale facilities.

Process 'B' is an adaptation of the plant selection/rejection algorithms from Voivontas et al, (2001) and Tyson et al (1996). They identify the minimum transport radius required to 'gather' sufficient residual waste from within the WDA area to satisfy the scale capacity of the plant/s in each EfW option. This is iteratively identified using Neighbourhood Statistics tools within ESRI's Spatial Analyst extension to ArcView 8.3. In most parts of the UK, MSW is a more common arising in comparison with the agricultural waste used in the Dagnall et al (2000) study and large quantities are potentially available within short transport distances, particularly in urban areas. In the case of EfW plants, it was the case that a minimum and not a maximum desired transport radius had to be identified, and this is the purpose of Process 'B'. This was because sufficient waste feedstock was available well within the maximum economic transport radius (with other biofuels this is often not the case). A minimum transport radius is desirable in order to minimise the associated cost of haulage.

Process 'C' is adapted from Dagnall et al (2000) and can be referred to as 'collectable waste modelling'. These models are derived from the residual MSW maps and are used to identify zones or 'hotspots' where concentrations of collectable residual waste. The map models are generated by laying a grid of square cells across the study area. The minimum transport radius variable required to supply a facility with waste feedstock (identified by Process 'B') is used to execute a query to sum of the tonnage that could be potentially 'collectable' for an EfW scheme within this distance for every 1 ha cell location within the WDA study area. Such GIS processes are collectively called neighbourhood operations – where the result for one location is determined by a calculation involving the attributes of the surrounding locations within a pre-defined proximity. This process was also executed using Neighbourhood Statistics tools within ESRI's Spatial Analyst extension to ArcView 8.3. The output map identifies which cells have the required plant capacity feedstock that is collectable within the minimum transport distance.

Process 'D' involves overlaying the 'hotspot' zones, (identified from Process 'C') with the potential sites generated as described in Section 6.3.1. In the situation that there is more than one potential site area within the hotspot zone, Process E introduces extra criteria shown in Table 12 and selects them using an MCDA and the same technique described in Section 2.7.5. These include: Area of vacant or derelict land on which development could take place in accordance with PPS 10 (ODPM, 2005) and the number of potential heat users (Section 6.4.3.5). These factors and associated data were identified using the 1:25000 Land Ranger mapping. Engineers from Compact Power provided group-agreed weights to indicate the importance of these. The MCDA technique was applied outside the GIS environment using the HIVIEW software and was applied only when multiple Potential Site Identification sites were identified by a hotspot within a Collectable Waste Mapping iteration.

Table 12: Weights of criteria in Process E.

	Area of Derelict/vacant land area	Distance to centre of hotspot zone	No of potential heat users
Weight (Total % of model)	25	20	55

The weighting applied to the number of potential heat users is twice that of minimising distance to the high density of waste arising, since the latter has already been taken into account in Process 'D'. Weighting on the area of vacant or derelict land was only believed to be half as important as the number of potential heat customers, in that the latter can provide heat revenue and improve project economics. MCDA modelling was not used in order to identify Potential Identification Sites, since the decision was taken to limit subjectivity in this phase of the project.

6.4.1.2. Medium and local-scale facilities

To identify medium or local-scale sites, there are two process sequences outlined in Figure 22. The processes which make up the sequences are the same as those for large-scale, but include the need to introduce new decision rules. The first sequence provided 'preliminary' sites for further verification to 'final' status in the second sequence after waste source points had been allocated. The major difference in the first sequence compared to the second, is in Process 'B' where the minimum catchment radius is always based on supplying a 30 ktpa facility. This is to ensure that multiple areas with the highest collectable waste density are identified within the WDA study area. The Process 'B' iteration is used together with a spatial query, which is used to identify all the waste source points within this radius of proximity. Points within this queried catchment of proximity to the proposed plant are then extracted from the overall WDA residual MSW map.

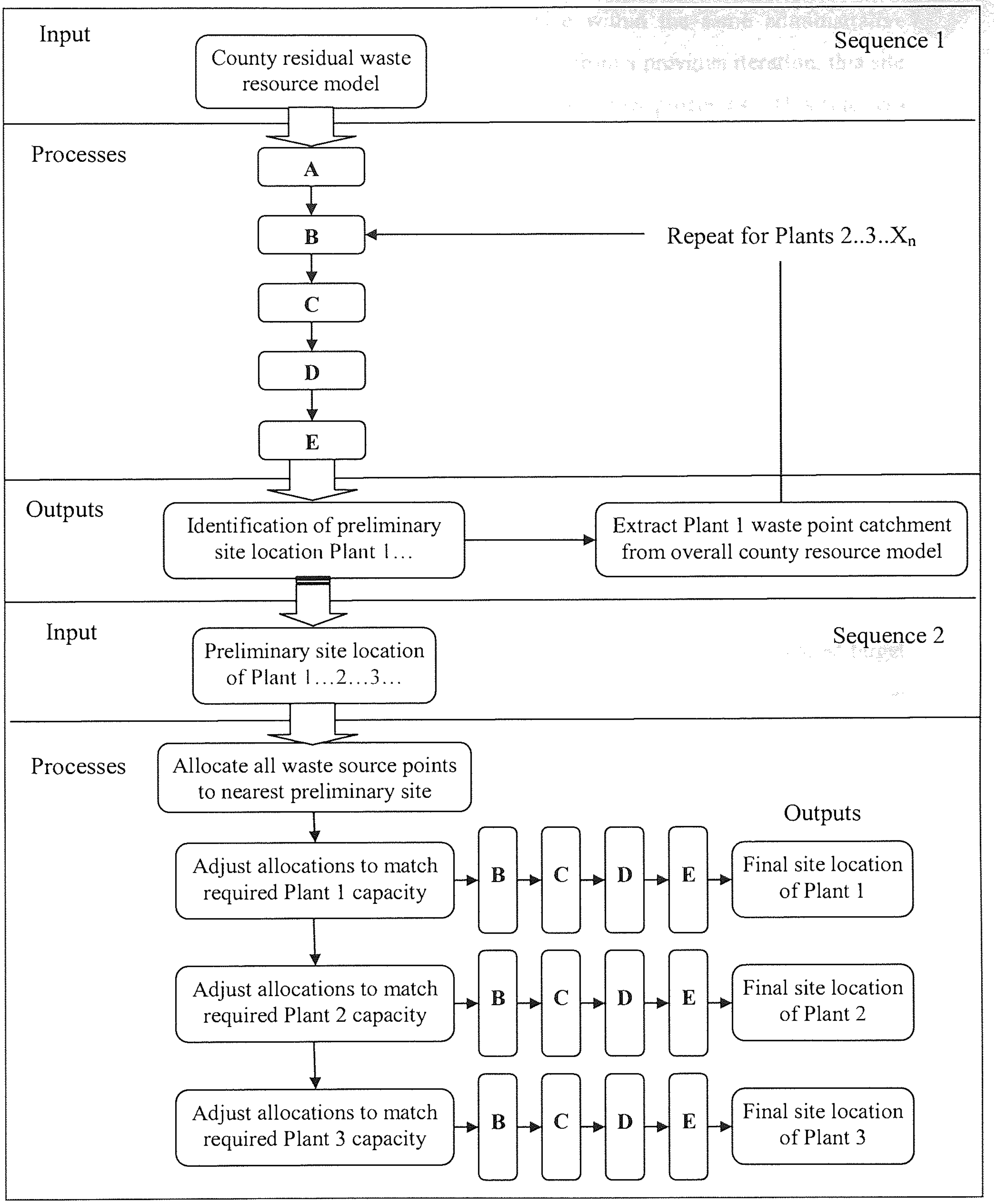

Figure 22: Overview of final site identification and resource allocation models for medium and local-scale facilities.

In Process 'C', if a hotspot zone occurs twice within the same administrative government district, which already has a preliminary site from a previous iteration, this site is upgraded from 30 to 60 ktpa and treated as such in all further processes. This rule was applied since larger facilities typically benefit from economies of scale in their construction and can have higher energy generation efficiencies (Consonni et al, 2006a). Iterations of Process 'C' ensure that facilities are sized to the waste recovery requirements of the surrounding area and community. The processes in Sequence 1 were repeated until enough preliminary sites had been identified at either 30 or 60 ktpa to sum to the total processing requirement for the EfW option.

Once preliminary site location had been identified, the first Sequence 2 process uses ESRI's Spatial Analyst extension to ArcView 8.3 to execute a Thiessen polygon 'proximity operation' to allocate all the waste 'source' COA point locations in the WDA area to derived EfW sites. Proximity operations generate concentric equidistant zones around a specified location or set of locations (Berry, 1993). Instead of measuring the distance between two points, the distance is dealt with as 'proximity zones'. The Thiessen polygon procedure is a specific proximity operation that allocates each location to its nearest target point, in this case an EfW or other disposal facility. The distance between each location and target point is measured in terms of the 'planar' (straight line) distance. The polygons are defined geometrically by drawing straight lines between each target point and all of its adjacent points, and bisecting these with new lines at right angles. An example of this procedure is shown in Figure 23.

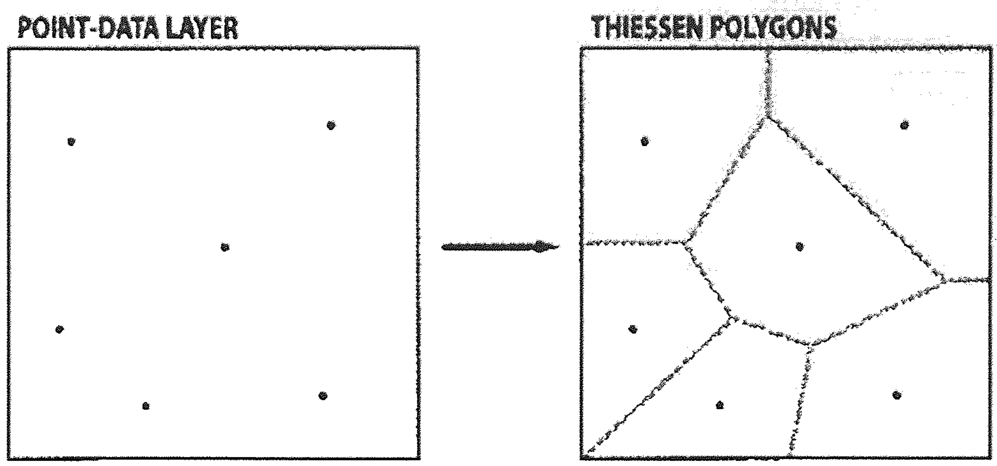

Figure 23: Example of Thiessen polygon procedure from Malczewski (1999).

Final adjustment of allocated COA waste collection points to meet required facility capacity thresholds was made using the Geoprocessing 'clip' and 'merge' tools using waste tonnage proximity parameters calculated using the 'selection' and 'spatial statistics' database query tools available in the ArcView 8.3 interface. An overview of the method is shown in Figure 24. Another upgrade rule is applied if a catchment of allocated source points contains a waste tonnage greater than 70% of 60 ktpa, a 30 ktpa facility would be upgraded to 60 ktpa. The 70 % threshold was chosen since EfW facilities can run at 70% of their maximum capacity before experiencing considerable operational penalties (Sweeting, 2006). Processes 'B' to 'E' were executed again for each EfW facility in order to verify if the final site location (based on the adjusted allocation of waste source points and Process D identified potential site location) was the same as the preliminary one. If not, then the output from the second sequence Process 'E' defined the final site location for that particular facility in the option.

In order to allocate catchments of waste production resource points to and decide whether any particular Waste Transfer Stations (WTS) was necessary within an EfW option, a 5 km boundary radius from all WTS site governed the upper capacity limit as well as deciding whether they should be utilised. This value is reasonable in the UK since Biffa (a major UK waste management company) has suggested that MSW should not travel directly from source to management more than 5 km (Biffa, 2002). This is supported by

Wilson (1981) who more specifically recommended 5.4 km before bulking stations were necessary in terms of cost.

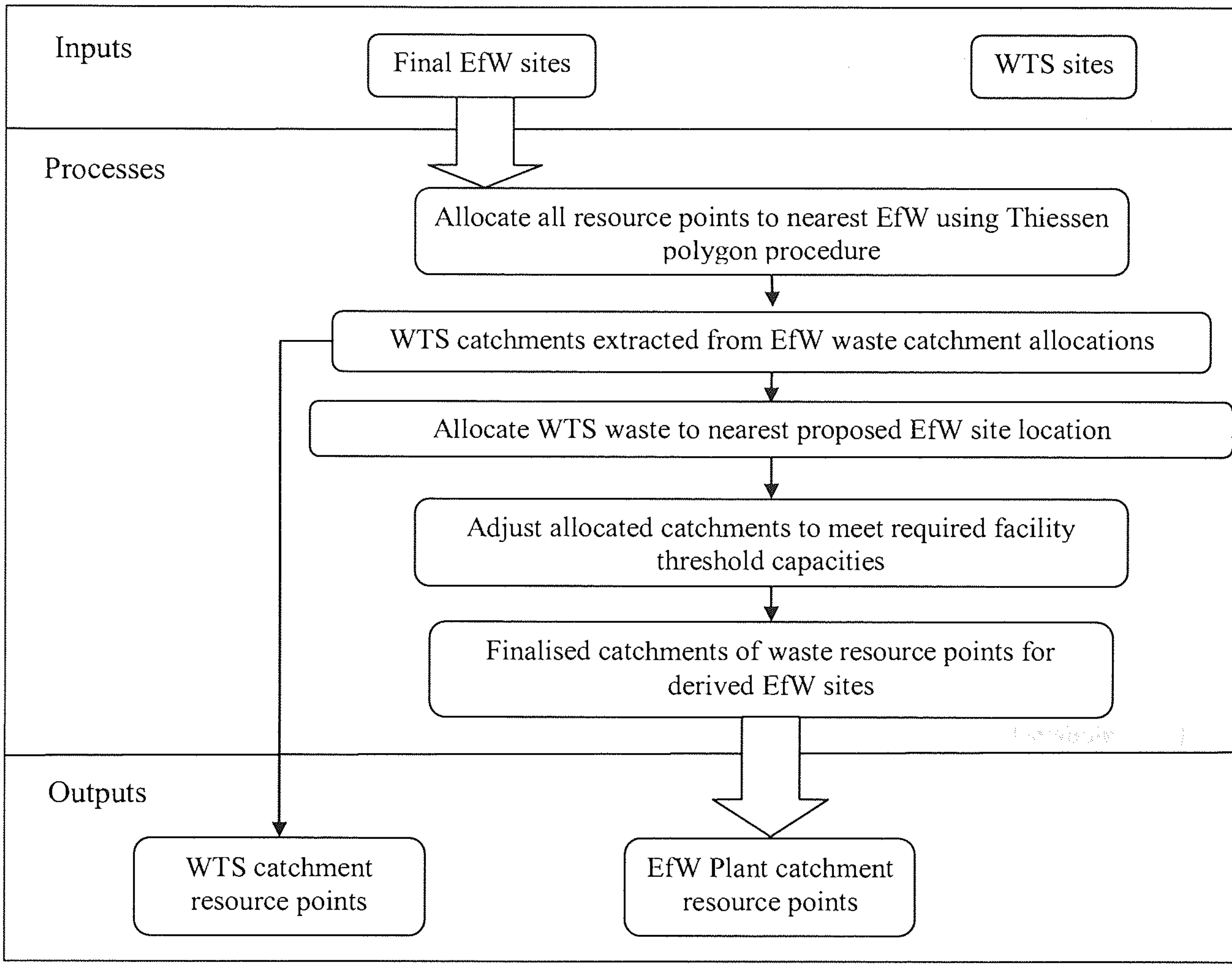

Figure 24: Overview of spatial resource allocation model.

6.4.2. RESULTS

This section presents the Final Site Identification modelling results for medium and local-scale EfW options. Section 6.4.3.1 presents the large-scale option results that have been derived from applying the same procedures but to formulate large-scale (single) plant options. This was done to compare the results of the techniques in this DSS with those specified by the local waste management planning studies that have been commissioned by the WDA administrations. Also shown in the output maps are the Waste Transfer Stations (WTS) that have been identified as being necessary in mitigating the transport impacts. The results are summarised in Table 13 and Table 14.

Table 13: Derived final locations of large, medium and local EfW options in Cornwall.

Plant No	**Large**		**Medium**		**Local**	
	ktpa	Location	ktpa	Location	ktpa	Location
1	180	St Columb Major	60	Truro	60	Truro
2			60	Camborne	60	Camborne
3			60	Delabole	30	Bugle
4					30	Delabole

Table 14: Derived final locations of large, medium and local EfW options in Warwickshire.

Plant No	**Large**		**Medium**		**Local**	
	ktpa	Location	ktpa	Location	ktpa	Location
1	180	Leam Spa	60	W. Nuneaton	60	Leam Spa
2			60	S. Leam Spa	30	Nuneaton
3			60	W. Rugby	30	Rugby
4					30	Atherstone
5					30	Stratford

Regarding large-scale options, if the project-identified site locations that did not spatially approximate the ones specified in the local planning documents, these have also constituted an additional option for appraisal in the MCDA model and this has been the case for the Warwickshire WDA context.

6.4.2.1. *Medium-scale final sites*

Figure 25 shows the medium-scale EfW option site distribution for Cornwall. The medium option makes use of the existing WTS at St Austell, Launceston and Newquay. 60 ktpa facilities are located at Camborne, Carnon Downs (between Falmouth and Truro) and Delabole.

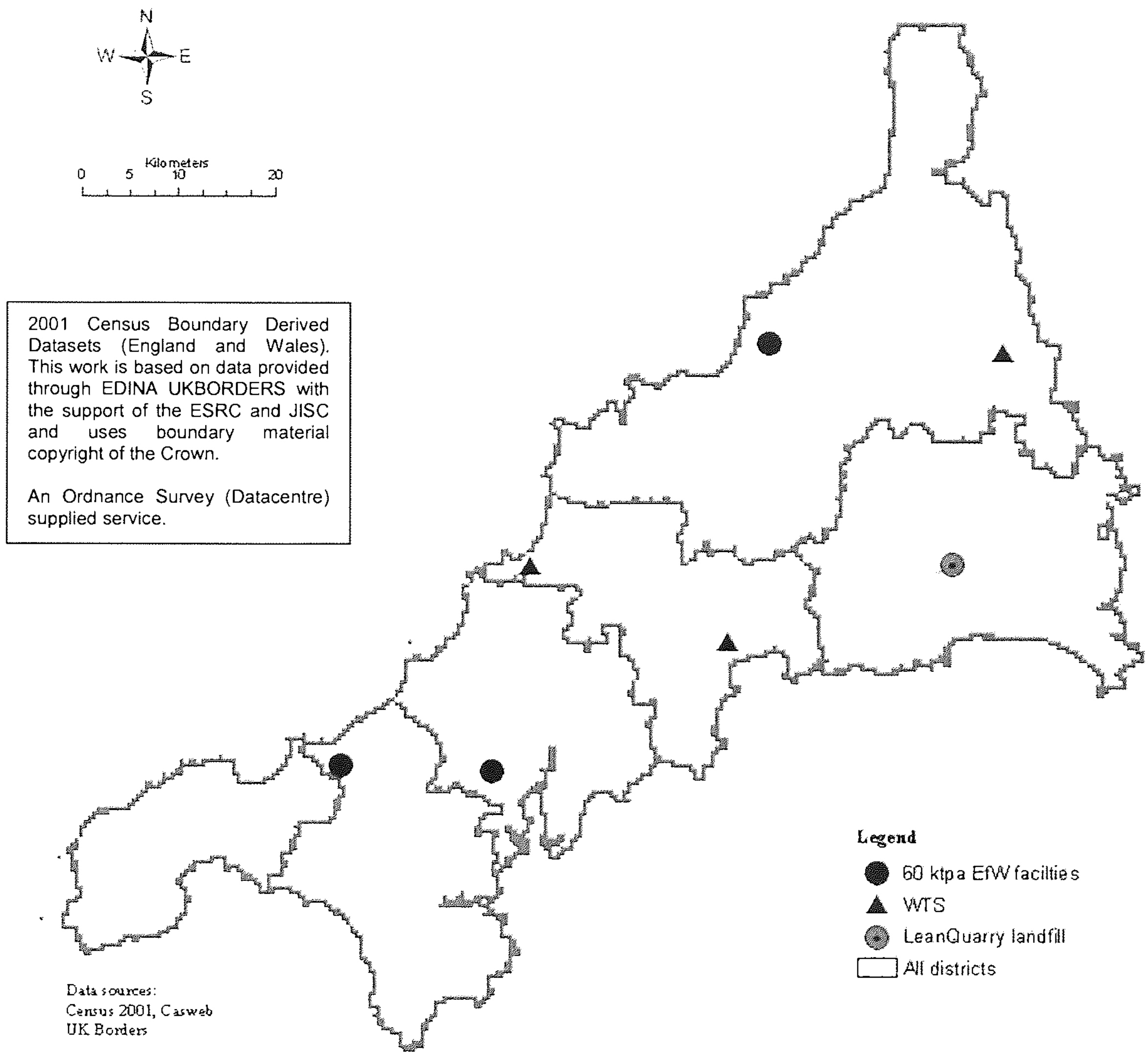

Figure 25: Map showing final sites for medium-scale EfW in Cornwall.

Figure 26 shows the medium-scale option results for Warwickshire with sites at Atherstone, Rugby and Stratford-upon-Avon. The grey circle in these maps represents the location of an existing 230 ktpa incinerator at Coventry, which is a large urban area, whose borders are partially surrounded by Warwickshire in the centre. These locations take into account the effect of diverting 30 ktpa to the Coventry incinerator. Note that this option makes use of the existing WTS at Warwick. The mitigatory effects of WTS, as well as the costs of operating them are taken into consideration in Chapters 7 and 9.

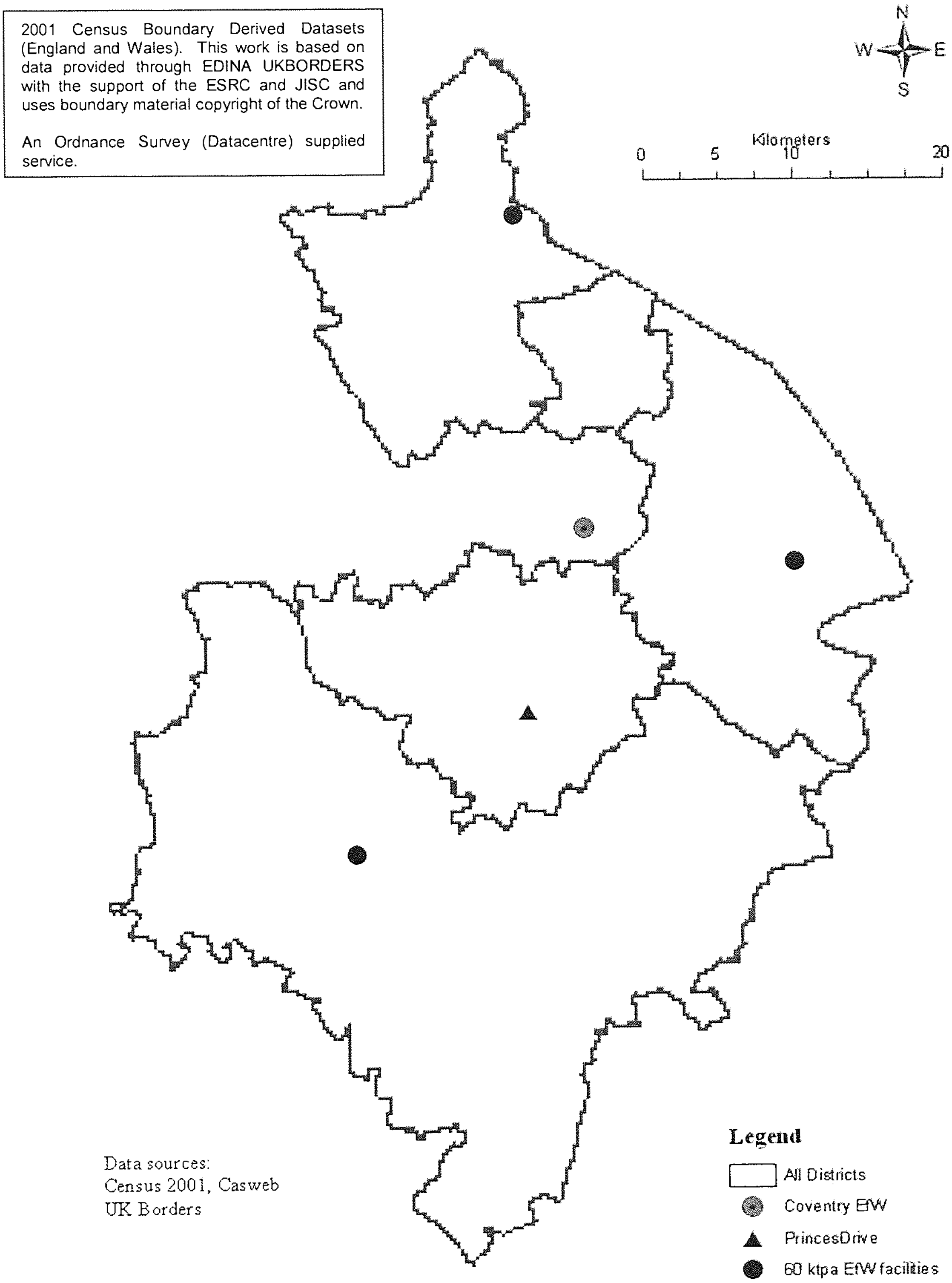

Figure 26: Map showing final sites for medium-scale EfW in Warwickshire.

6.4.2.2. *Local-scale final sites*

Figure 27 illustrates the local-scale EfW option site distribution for Cornwall. The black circles represent 60 ktpa facilities at Camborne and Carnon Downs. The black pentagon symbols represent 30 ktpa facilities at Bugle and Delabole. The locations of the medium and local scenarios were significantly influenced by the location of the Lean Quarry landfill site (shown as a grey circle) and the 49 ktpa of residual waste directed to this disposal route. Use of existing WTS included Launceston, Newquay and St Austell.

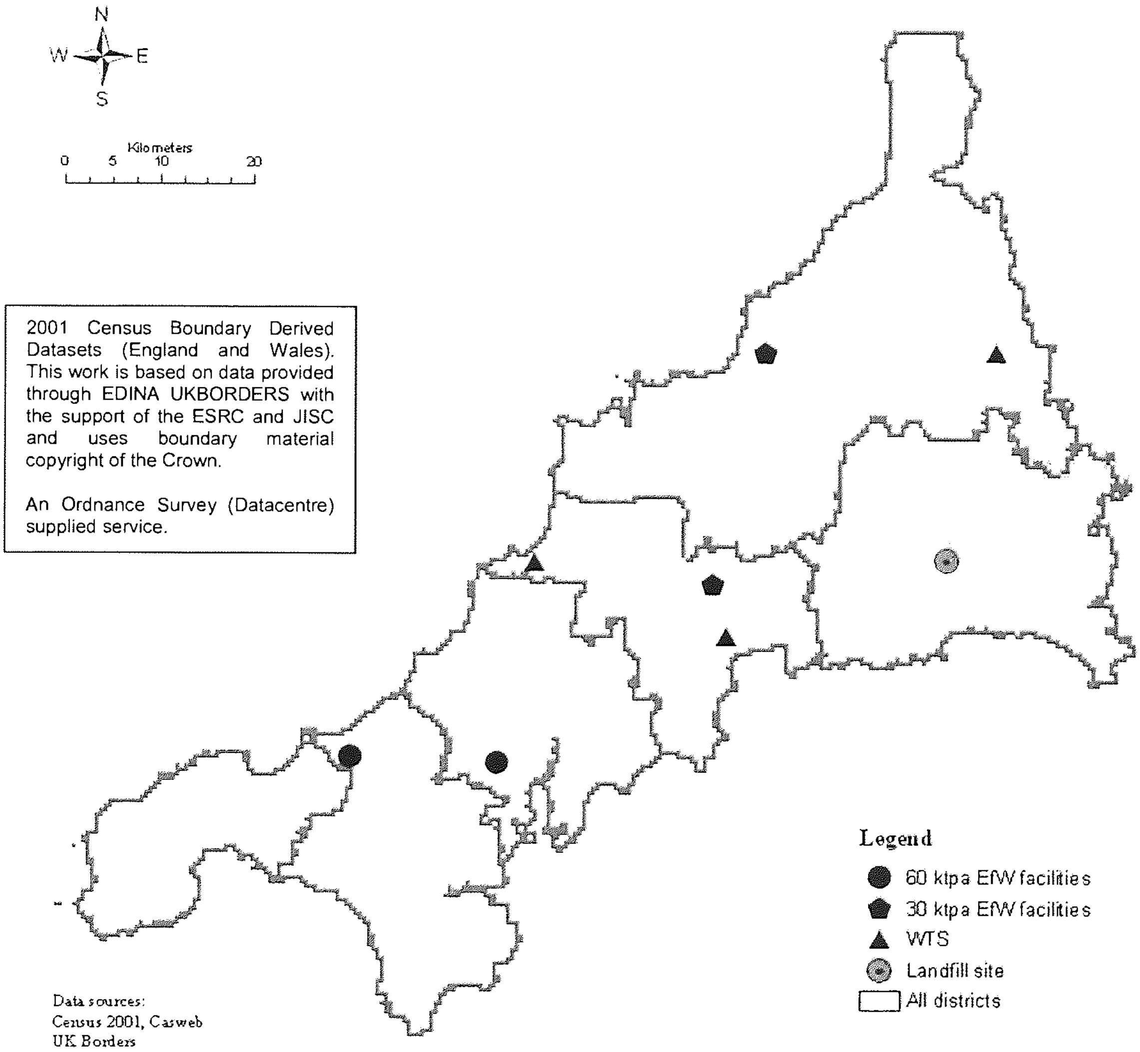

Figure 27: Map showing final sites for local-scale EfW in Cornwall.

Figure 28 shows the local-scale EfW site distribution for Warwickshire. The black circle represents a 60 ktpa facility at Leamington Spa, while the black pentagons represent 30 ktpa facilities at Atherstone, Nuneaton, Rugby, and Stratford-upon-Avon. There is no use of WTS in this option because the distributions of sites practically co-locate with existing facilities and, hence, make them redundant in their waste transport role.

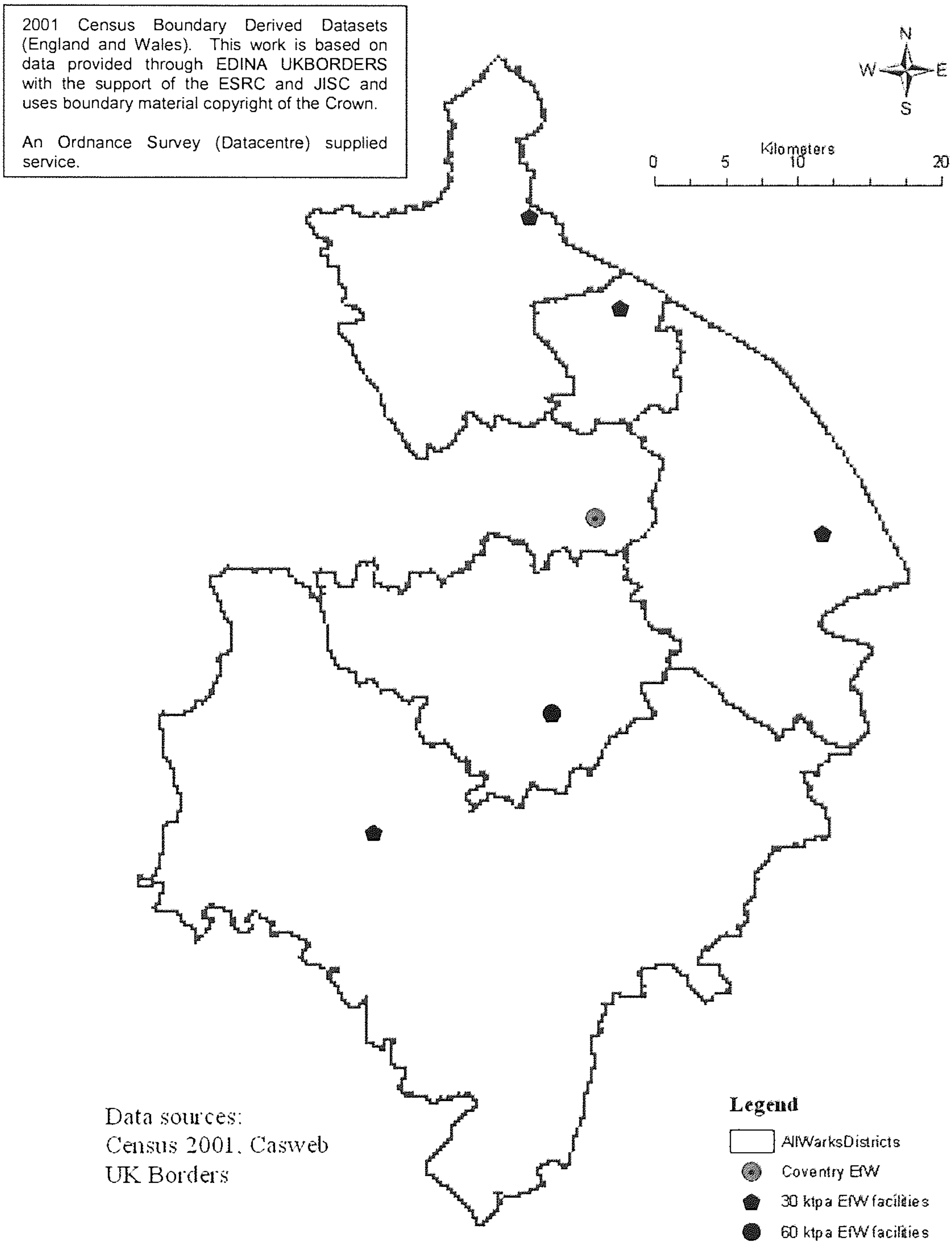

Figure 28: Map showing final sites for local-scale EfW in Warwickshire.

6.4.3. Discussion

6.4.3.1. Large-scale final sites and locations identified by previous studies

In order to discuss the results, it is interesting to compare the outputs of the Final Site Identification models with those of other waste planning studies in the two WDA areas. In the case of large-scale options, the planned sites for centralised EfW indicated in the local waste planning documents are the ones actually used in the MCDA appraisal model in order to compare the 'real' policy context with the different medium and local-scale EfW implementation options developed in this study. The GIS techniques of this project however, were applied to see if they produce a different final site location for a large-scale centralised facility. A Collectable Waste Model map for 180 ktpa of residual waste is shown in Figure 29. A minimum 63 km radius of catchment is required in order to collect residual waste to within the dark grey zone. It should be noted that the proposed Large-scale Indian Queens site (shown by a black circle) is well inside the minimum theoretical 63 km collection radius of this zone. The radius is large because Cornwall is a peninsula and bound by coastline. The elongated shape means that distance-based queries must be relatively larger to collect the same amount of residual waste than in a more circular study area like Warwickshire. This observation also suggests that Cornwall may be an area in which multiple smaller EfW options may be more desirable to reduce transport requirements.

The closer the potential site location is to the centre of a dark grey area, the lower its theoretical collection-area radius. Hence, Figure 29 shows that the Indian Queens site outlined in the Cornwall Waste Local Plan (WLP) document (CCC, 2003) is near to optimal for a large-scale facility in terms of minimising transport distance for a plant of large-scale capacity. This observation, however, is made on an analysis using straight line distances between waste points and the potential plant that did not take into account the county's real road network and other topographical influences. The Potential Site Identification model however, identified an alternative site just 3 km from the one proposed in the WLP. Both sites are within the defined central area of search (CAS) outlined in the WLP. Figure 29 shows that both locations are within the 'hotspot' and this is useful planning information, in that it shows that the need to minimise transport requirement is being upheld for a large-scale facility in Cornwall. This has legal implications in defining planning decisions made by the county administration, in that the suitability of a site can be effectively challenged if not centrally located to receive waste. Both sites are located within the CAS (CCC, 2003).

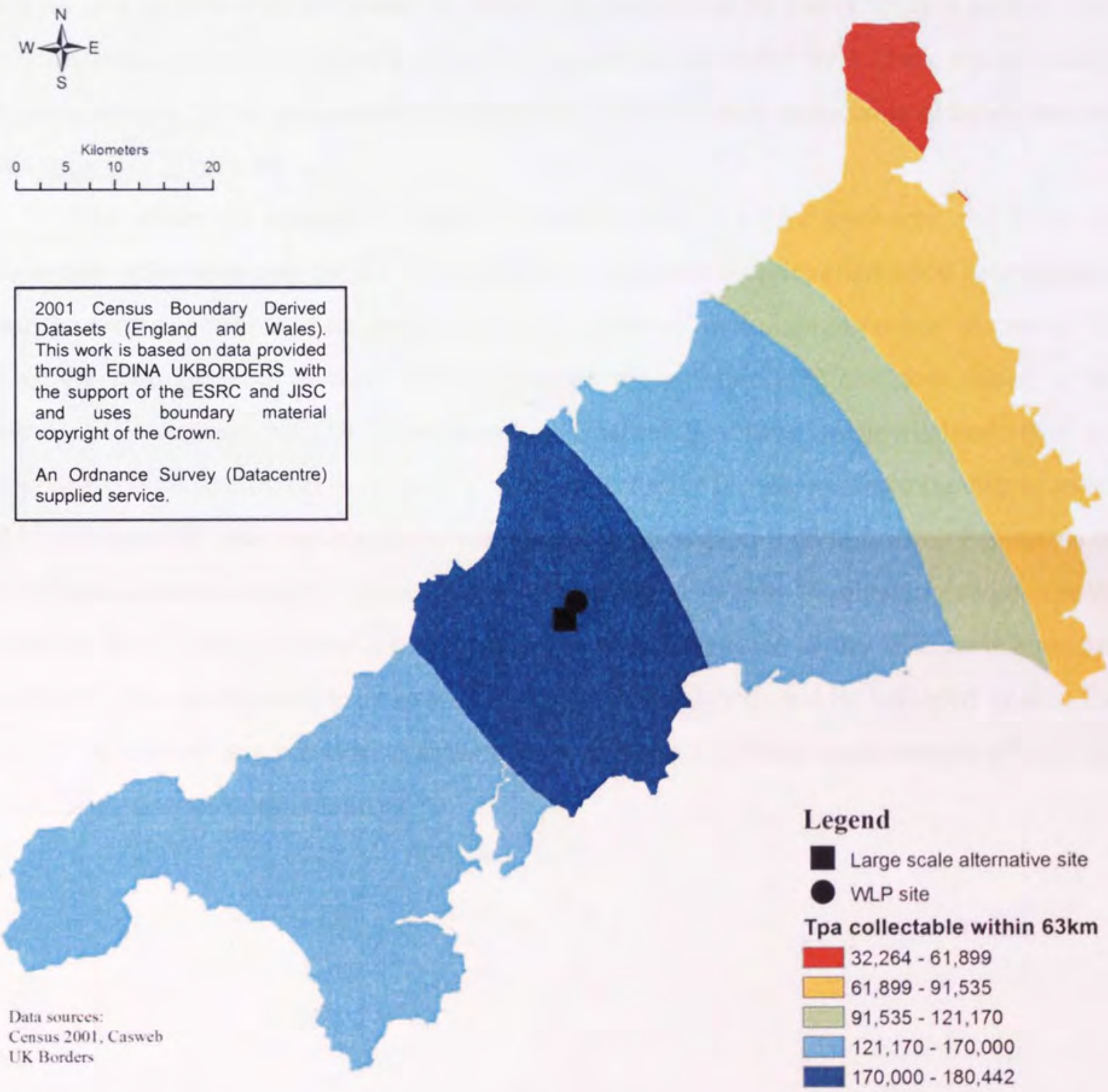

Figure 29: Map showing WLP large-scale EfW site and project alternative in Cornwall.

Figure 30 shows the results of large-scale Collectable Waste Model mapping for Warwickshire. A Process 'B' iteration described in Section 6.4.1.1. identified that the minimum collection radius for a large-scale 180 ktpa facility at the actually proposed Warwickshire large-scale centralised EfW site was 43 km. The black circle representing the originally proposed site in Jainter & Poll, (2005) for a large-scale 180 ktpa plant (as defined in a local study) is outside the minimum theoretical 38 km collection radius. The location identified by the techniques in this project is illustrated by a black square within the hotspot zone. The proposed site is not within the minimum collectable distance hotspot area shown in Figure 30

The closer the potential location is to the centre of a dark grey area, the lower its theoretical collection area radius. Hence, Figure 30 shows that the alternative potential site near the centre of the map is an improvement in terms of minimising transport distance. To judge the consequences of this, a second large-scale scenario (1b) has been added to the overall EfW options MCDA assessment in Chapter 9. It is acknowledged, that the proposed site (Scenario 1a) may offer a good opportunity for a large-scale facility in terms of its site-specific benefits, such as the availability of derelict land and history in terms of waste management activity. These factors are outlined in PPS 10 planning requirements (ODPM, 2005) and such data could be added in future versions of the DSS as it becomes available. This is an example of how site-specific suitability should be balanced against the need to be located in a position to minimise the transport haulage requirements of residual waste from sources to the facility.

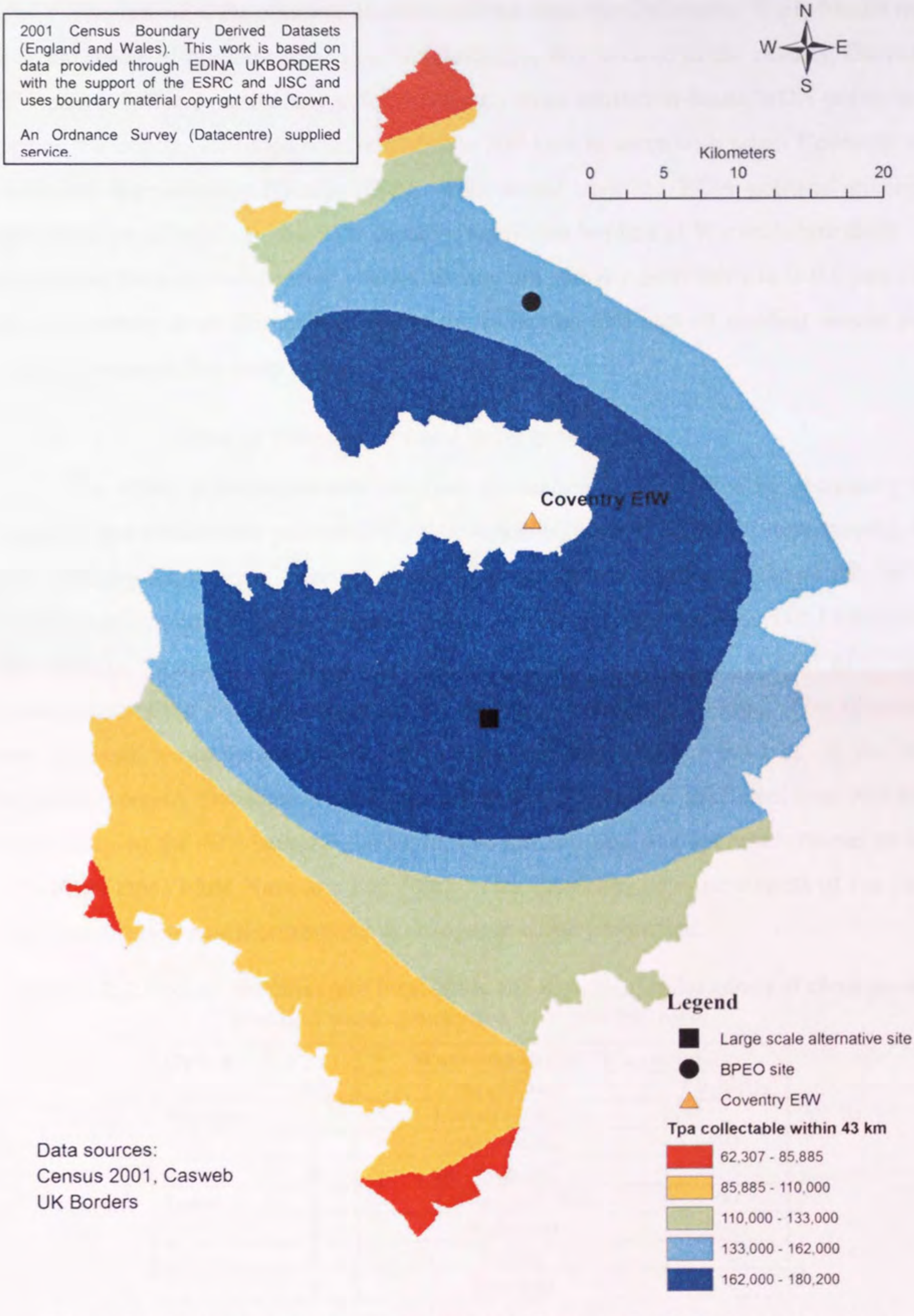

Figure 30: Map showing currently proposed large-scale EfW site and project alternative in Warwickshire.

Theoretically, the optimum location derived from the Collectable Waste Model map is at the centre of the dark grey area. Interestingly, this is close to the existing Coventry EfW plant. Officers particularly noted this result, since another in-house WDA policy is to replace the existing 230 ktpa with one of over 500 ktpa to serve both urban Coventry and semi-rural Warwickshire (Geary, 2006). This would save the WDA potential planning complications of building new EfW capacity within the borders of Warwickshire itself. In conclusion, the project-identified alternative site and actually proposed site is 9.5 and 19.6 km respectively from the optimum point for collecting 180 ktpa of residual wastes to a central location in this study area.

6.4.3.2. Effect of increased residual waste generation

The effect of increased residual waste generation was modelled by decreasing the recycling rate assumption parameter for Warwickshire from 40 to 30%, while keeping the EfW capacity requirement constant at 180 ktpa per annum. Table 15 shows that in the medium-scale option, the Atherstone and Rugby locations stay constant, but Leamington Spa replaces Stratford. In the local-scale option there are 4 plants instead of 5, as a consequence of the Nuneaton facility being upgraded from 30 to 60 ktpa. This illustrates how increased waste generation can activate upgrade rules (Section 6.4.1.2). In the 30% recycling scenario, Nuneaton was upgraded because its allocated catchment area was 84% of 60 ktpa. In the 40% scenario, however, Leamington Spa was upgraded instead (it had 83% of 60 ktpa, while Nuneaton had 66%). This illustrates how the outputs of the Final Site Identification model correspond to changes in waste production.

Table 15: Effect on medium and local-scale site distribution locations of changes in residual waste generation in Warwickshire.

Option	Plant No	Warwickshire at 30% recycling	
		Area/town	Capacity
Medium	1	Leamington Spa	60
	2	Atherstone	
	3	Rugby	
Local	1	Leamington Spa	60
	2	Nuneaton	60
	3	Rugby	30
	4	Stratford	30

During modelling it was observed that lower residual waste generation per Census Output Area (COA) results in the need to increase the Collectable Waste Model search radius leading to coverage of a greater proportion of rural area in any resulting catchment zone. This 'pulls' the 'hotspot' zone further into rural areas. Conversely, when greater amounts of residual waste are produced per COA source point, the urban areas have a greater influence on the Collectable Waste Model results in that the 'hotspot' area results are drawn towards the more concentrated (urban) areas of residual waste production. This explains the loss of the (predominantly rural) Atherstone 30 ktpa plant in the medium EfW option and its capacity replacement by an upgrade from 30 to 60 ktpa at the urban town plant situated at Nuneaton. It also explains the shift from the rural to urban situation of the Stratford plant to Leamington Spa in the medium option.

6.4.3.3. Effect of other disposal routes on Final Site Identification

Table 16 shows the effects on Final Site Identification distributions before extracting 49 ktpa from the overall Cornwall residual MSW production model for allocation to the Lean Quarry landfill site as detailed by the Waste Local Plan (CCC, 2003). The latter was done in terms of proximity and required a 25.1 km radius for the extraction of sufficient COA waste production points to meet the required 49 ktpa. The effect of this on the Final Site Identification results was investigated by repeating the Final Site Identification modelling using a residual MSW production model which had not had the Lean Quarry allocation production points extracted. In contrast to the results in Table 13, Table 16 shows that the distributions are quite different, indicating ensuring correct information on which to base assumptions of alternative disposal routes is important.

Table 16: Effect on medium and local-scale site distribution locations from diversion of residual waste to an alternative disposal route in Cornwall.

Option	**Plant No**	**30% Recycling**	
		Area/town	**Capacity**
Medium	1	Camborne	60
	2	Truro	
	3	Bugle	
Local	1	Camborne	60
	2	Truro	30
	3	Bugle	60
	4	Callington	30

In the medium option, the third identified site shifts from Delabole to Bugle. There was however, no change in the derived locations of the first and second plants. In the local option, the fourth plant location changes from Delabole to Callington. In addition, the capacities of the second plant at Truro and the third plant at Bugle change capacities from 30 to 60 ktpa and vice versa respectively.

An observation during modelling was that the effects of other disposal routes are more pronounced in Cornwall, since the extraction and related area were much larger. Conversely, in Warwickshire only 30 ktpa is diverted for alternative disposal at the existing Coventry EfW plant and this is mostly extracted from a rural area with low waste production density. This extraction, however, also takes some of Nuneaton's waste resources which resulted in the derivation of the two separate 30 ktpa plants for Atherstone and Nuneaton. It is interesting to note that at 30% recycling, the effect is not as sensitive, and hence, only one larger 60 ktpa plant was identified for Nuneaton.

6.4.3.4. *Suitability of derived site locations*

In order to show the characteristics of the derived Final Site Identification location results in more detail and to judge their suitability for EfW further from at the desktop level, two sites are shown in Figure 31 and Figure 32. Figure 31 shows potentially vacant land within an industrial works. Adjoining the area is an additional industrial estate and trading estate. There are also significant opportunities for combined heat and power generation, since as well as potential industrial demand there are two schools and a hotel in the vicinity. There is also an extensive residential area nearby, but opposition may be mitigated by the use of a medium or local-scale of facility, and a technology of lower visual impact such as ATT. The urban area of Warwick and Leamington Spa comfortably satisfies the majority waste feedstock requirement of a 60 ktpa facility, hence, this capacity and catchment area can be quite adequately described as local. This site has been identified for either Large (180 ktpa) and Medium (60 ktpa) scale facilities by the GIS techniques used in this project.

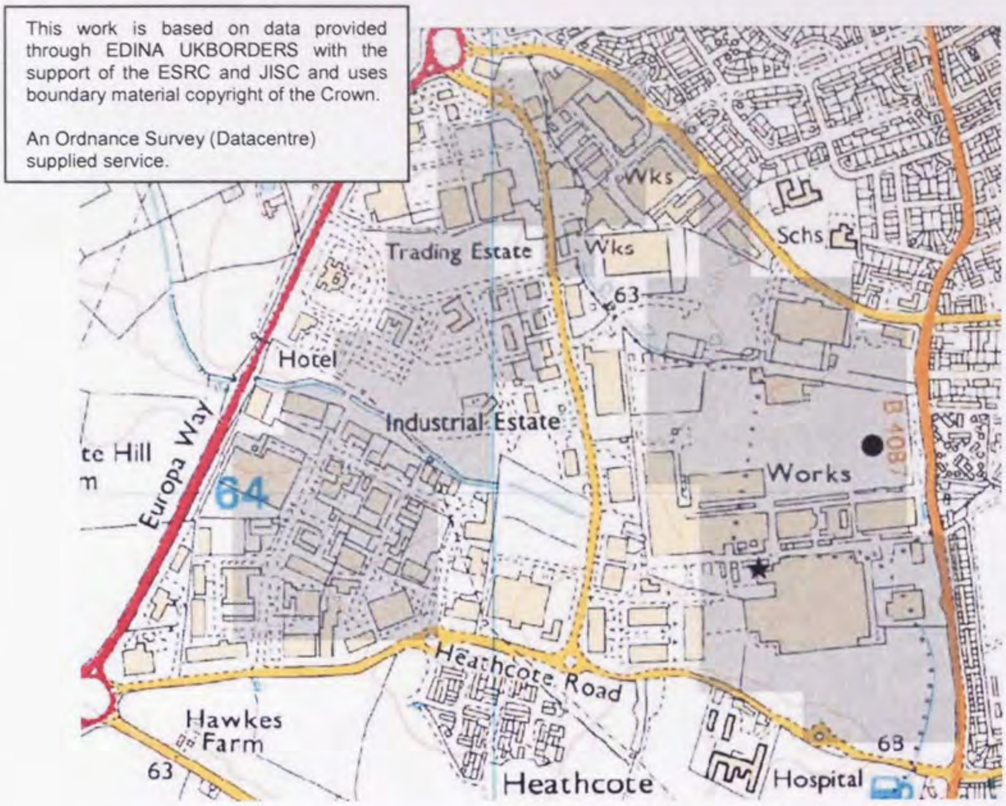

Figure 31: Map showing EfW site at Leamington Spa, Warwickshire.

The site at Bugle in Cornwall, shown in Figure 32 is in an extensive area of industrial land which is potentially vacant. The large works may provide all year round heat demand. Bugle was not identified as a site in the medium-scale option and this is due to the waste production parameters and the location of the Lean Quarry landfill site and its demand of 49 ktpa of residual waste. Should these assumptions change (as explored in Section 6.4.3.3), the DSS identified that Bugle would be a potentially suitable site for 60 and 30 ktpa EfW facilities.

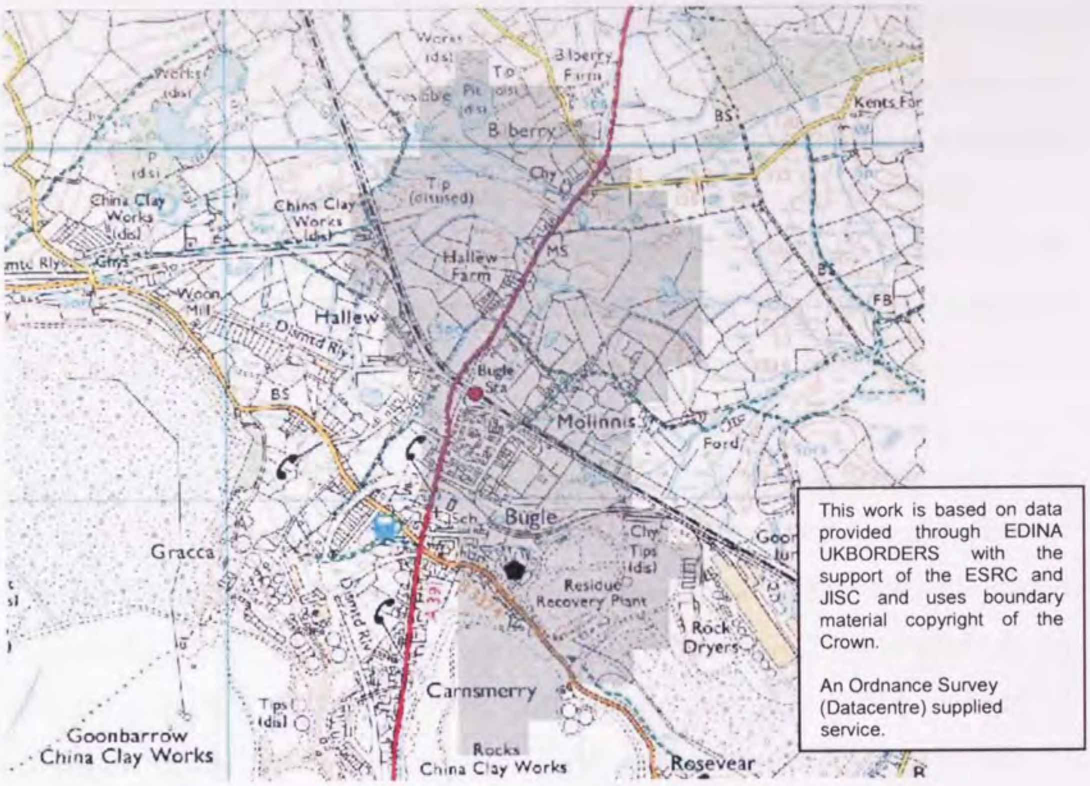

Figure 32: Map showing EfW site at Bugle, Cornwall.

The Bugle and Goonbarrow Junction site has been appraised in previous planning documents for its suitability in terms of being a terminus for the transport of waste by rail and for development as a final EfW disposal route (Capita Symonds, 2004). Proximity to railway is an extra criterion whose data could be included in the derivation of the Potential Site Identification model. Use of such data, however, would not include the required re-opening of railway lines as specified by this study and its use may be misleading. This is further the case in that the use of rail for waste is not as straightforward as the use of roads, where additional lorry traffic has immediate access to the road network. In the case of rail, new rail and waste transfer infrastructure can only be developed at significant cost and timescale (Capita Symonds, 2004).

6.4.3.5. Mapping potential heat users

This Section discusses how heat requirements may further be taken into account, particularly when GIS data on industrial sites with corresponding heat demand is not available. The intention of heat mapping is to co-locate heat loads from potential users with a facility's capacity to generate heat that would otherwise be lost to atmosphere in electricity-only generation. Most CHP capacity in the UK at present is in use for industrial applications (Boyle et al., 2003). A scheme with a significant industrial load is preferable for CHP since domestic loads are much more seasonal and intermittent (Poslethwaite, 1980). For this reason, the GIS approach for identifying potential distributed sites for EfW facilities developed in this thesis has used 1:25000 Land Ranger Mapping and industrial land data with the assumption that industrial users of space or process heating are likely to be present.

During the time of the production of this thesis, two heat mapping exercises were carried out in the UK. The first, by Wiltshire (2003), used gas consumption data of commercial, industrial and residential users and aggregated these at the postcode sector level. The second by AEAT (2007) whose method is noted in DTI (2006a) used carbon emissions data from the EU ETS to estimate heat consumption after taking account of typical boiler efficiencies and primary fuel type. These estimates were then aggregated to produce a UK wide map of 10 km^2 grid cells. Such techniques, however, are of limited use in guiding the identification of suitable EfW facility locations, since they are of too low a geographic resolution. This view is supported by AEAT (2005) who note that it is desirable for direct users of heat to be within 2 km of the generating plant. Not all CHP schemes have industrial users. Others include government offices, retail parks, universities, prisons, swimming pools, hospitals, schools and large hotels (Boyle, 2004b; DTI, 2006a). Beggs (2002) acknowledges the suitability of the above but claims that offices and schools are generally thought to be unsuitable due to their annual load profiles.

Related to the DSS's capacity to map collectable waste resource density, Poslethwaite (1980) highlights that "this low cost fuel is produced in direct proportion to the number of population and is located where it can be converted into useful energy as heat or heat and electricity". In order to explore an alternative approach to mapping heat users to those studies discussed above, leisure centres, hospitals, prisons, universities and large hotels in Cornwall and Warwickshire were located by postcode and mapped as shown in Figure 33 and Figure 34. Overlaid on the locations of potential heat users, is the collectable waste modelling of Section 6.2.1. 51 and 74% of all identified users in Cornwall and Warwickshire respectively are within areas of highly collectable waste resource and Warwickshire particularly supports the observation made by Poslethwaite (1980). It is likely that many other heat users, such as high density housing could be found in such areas within urban zones. District heating networks could be formed on the basis of these 'clusters' of users and extended as new users are identified.

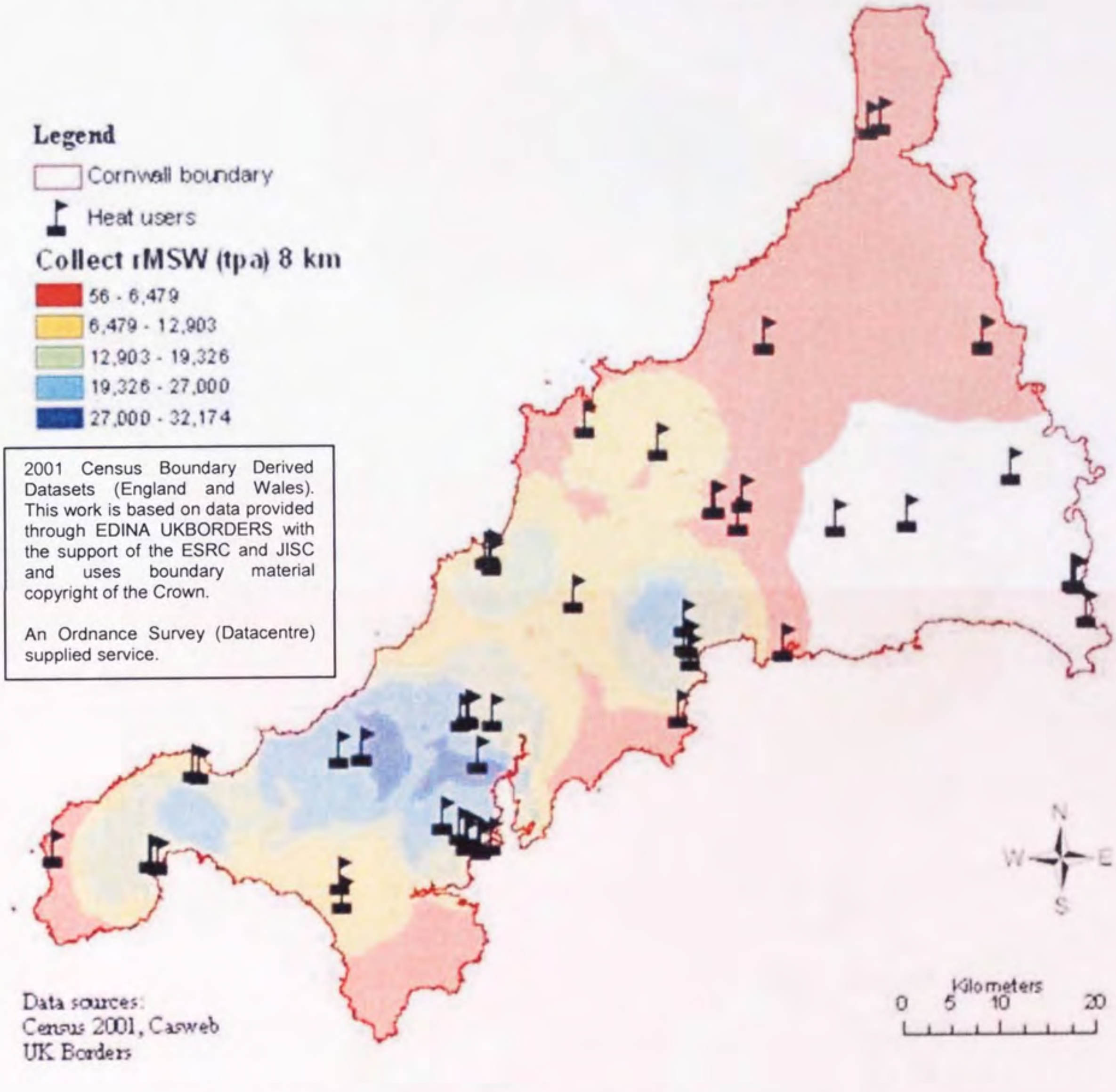

Figure 33: Map of potentially suitable heat users in Cornwall.

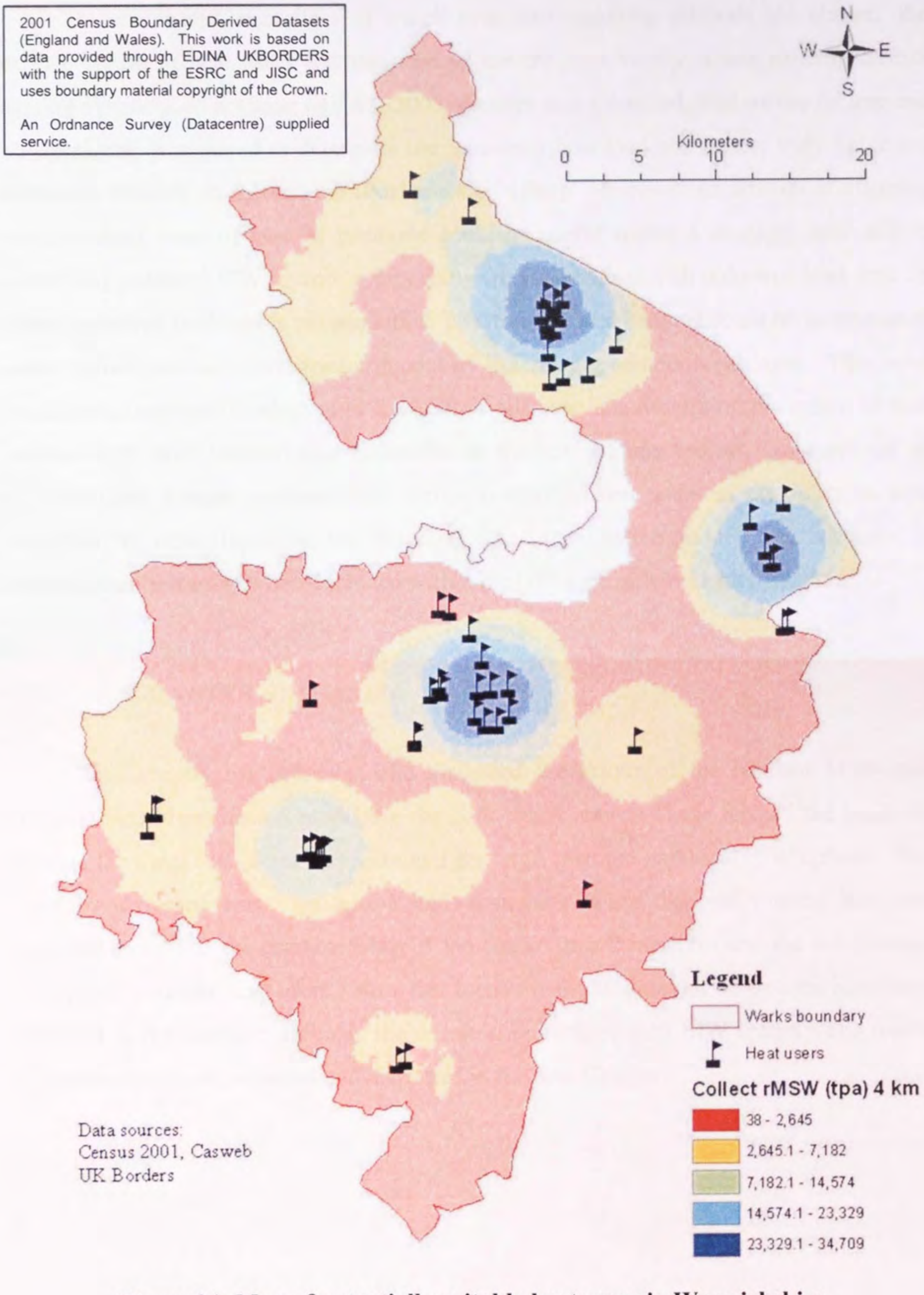

Figure 34: Map of potentially suitable heat users in Warwickshire.

In conclusion, regardless of which heat user mapping methods are chosen, the diverse nature of heat users and the need to use the heat locally where existing district heating networks do not exist (AEAT, 2005) dictates that a detailed field survey (at any one potential site) is required to determine the minimum heat load and hence, truly judge the economic viability of the scheme (Poslethwaite, 1980). However, an attempt at mapping non-industrial users of heat by postcode could be useful within a strategic approach to identifying potential EfW locations, especially when combined with industrial land data, or where industrial land data is not available. Locations of heat demand could be incorporated into the Potential Site Identification model by introducing an additional layer. This layer would be a more useful addition to the DSS, if attribute data describing the extent of heat demand with each location was included. In the case of this project, however, use of 1:25000 Land Ranger mapping with which to identify heat users in proximity to sites identified by other layers in the Potential Site Identification model was adequate in ensuring that heat users where included within the GIS approach to identifying sites.

6.5. CHAPTER SUMMARY

This chapter has presented and discussed the results of the residual MSW and Potential Site Identification modelling for both WDA areas. These formed the basis for deriving the Final Site Identification output for large, medium and local EfW options. The effect of increased waste generation and alternative waste disposal routing has been discussed as well as the characteristics of the output sites themselves and the implications of mapping potential heat users. Now that locations for facilities of all options have been identified, it is possible to estimate the transport impacts of each EfW option. The results of these analyses are presented and discussed in the next Chapter.

7. FORMULATING EFW OPTIONS USING GIS: ESTIMATING TRANSPORT IMPACTS

7.1. AIMS OF CHAPTER

The aim of this chapter is to present and discuss the transport impact estimates for large, medium and local EfW options identified for Cornwall and Warwickshire. This was done using the methods discussed in Section 7.2 Section 7.3 presents and discusses the results from the haulage of waste (7.3.1), haulage of ash residues (7.3.2) and compares the results of using the straight-line and windage factor vs. geometric network approach to estimating transport distance (7.3.3). Finally Section 7.3.4 discusses the implications of collection and haulage routes visiting multiple COAs.

7.2. METHODOLOGY

The review of GIS-based energy planning studies in Section 3.3 indicated that the method from Bergsdal et al (2005) was most suited to assessing the transport impact associated with different EfW options, since it could be adapted to the UK by using similar GIS data to that by Shmelev & Powell (2006) and parameters published by Biffa (2002). The assumption has been made that all waste is transported by road, since there is no rail or water transport infrastructure currently developed or planned within the WDA areas. These methods could however, be easily adapted to assess the implications of river or rail transport albeit with different underlying assumptions.

Considering waste transfer stations (WTS) is important when assessing transport impact by road, particularly in the case of *large* scale facility options, since their role in allowing the bulking of waste from lower capacity collection trucks to higher capacity Heavy Goods Vehicles can significantly reduce impact (Tchobanoglous et al, 1993). Planned and actual WTS locations were provided by the two case study WDAs. The cost of owning and operating a WTS was assumed to be £5.75/metric ton of capacity, inflated from Biffa, (2002) and £6.77/metric ton of capacity from Wheeler & Jainter, (2006). Since, although the Biffa research was independently funded by landfill tax credits and not commercial interests, it is interesting that the Wheeler & Jainter (2006) study uses a parameter that is 15% more. Since the difference is significant, in the absence of further supporting evidence, an average has been taken of the two.

All waste points not allocated to a Waste Transfer Station based on proximity are assumed to have their production delivered directly to their allocated EfW or other disposal site facility. All journeys, either waste or ash laden are assumed to be 'two-way' (Dujim & Markert, 2002), hence, for any fixed payload of waste, the truck is empty on the journey to the waste resource point, but laden to average payload on the return trip to the final disposal point.

The overall transport distance in any one EfW option is derived from aggregating:

- The collection distances of hauling waste directly from production points to the Waste Transfer Station.
- The collection distances of hauling waste directly from production points to final disposal sites (EfW or landfill, existing, planned or derived).
- The bulk transfer distances of hauling waste from the Waste Transfer Station to the nearest final disposal site.

An overview of a run of the transport impact estimation model for any particular catchment (WTS of EfW facility within an option) is shown in Figure 35.

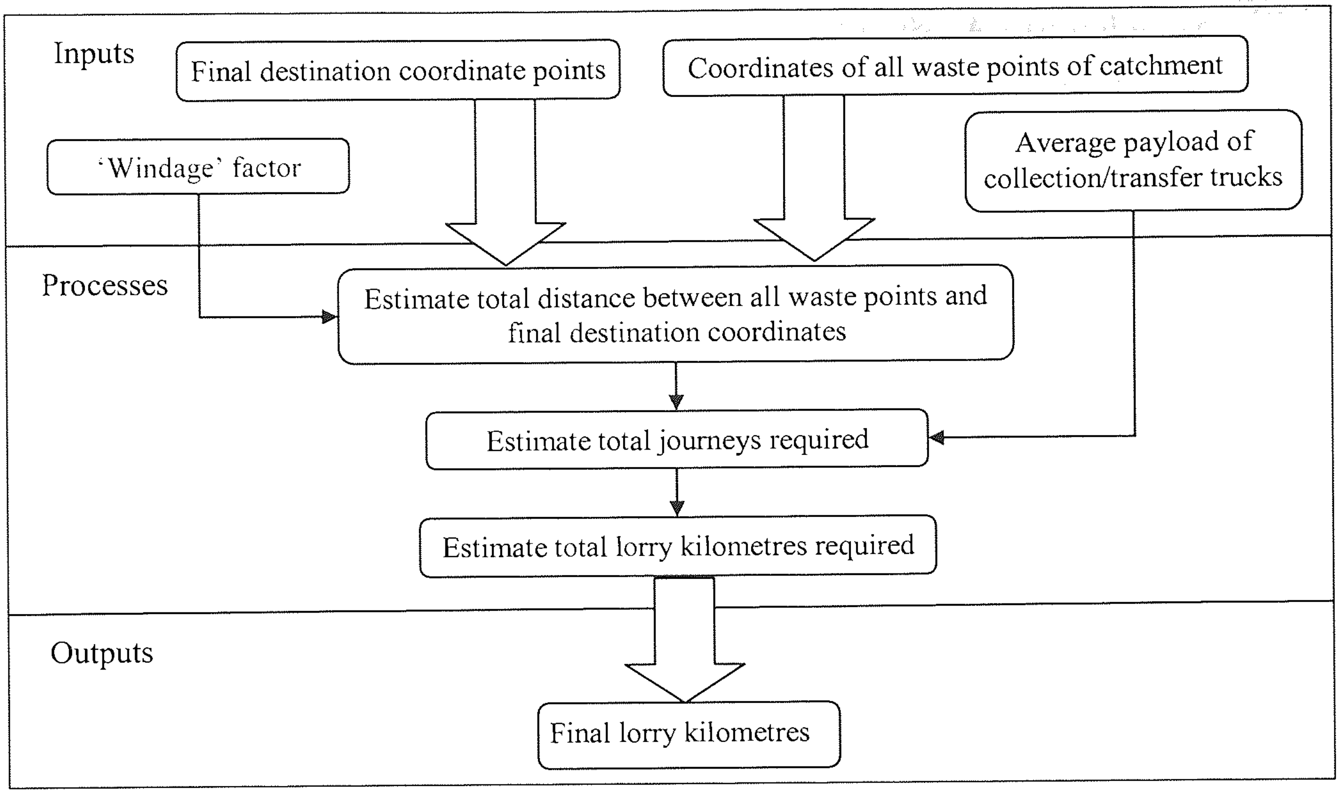

Figure 35: Overview of transport impact estimation model

As described in Section 6.2, GIS points (based on the location of the population centroid) include attribute data representing the annual waste production from any particular census output area. These models do not take into account the impact of the collection round at street level, but assume that the waste arising for haulage is located at the population weighted centroid of the census area (Section 2.2). The annual waste production waste source point was in high enough ratio (ie. much greater than 1) with a typical average payload of a lorry, that the sum of the annual journey distance for one point is a reasonable estimate for the actual routes (perhaps collecting from 2 to 3 waste source points), undertaken on a weekly basis over the year. The sensitivity on the final analysis caused by this assumption is explored in Section 7.3.4.

To investigate if the final ranking of EfW options were sensitive to use of alternative transport impact estimation method, two different methods were used for calculating cumulative distance travelled to transport waste to each facility in each EfW option. The first method uses planar distances (Section 7.2.1) to estimate the cumulative travel between waste sources and targets, based on Cartesian coordinates and 'windage' factors, the latter of which account for the spatial structure of roads. A second distance calculation model using geometric networks is presented in Section 7.2.2. These models differ in the calculation of distance. The transport impact results from using the geometric network method were used to provide estimates of where the increased traffic impact occurs (over ambient levels) in a further piece of work and are presented in Bastin and Longden (2007).

For each EfW option, estimations of journey frequency and lorry distances required to transport the residual waste from every source point to allocated final disposal point (via Transfer Station or direct) was made. These models are implemented by extending the ESRI ArcMap GIS software interface by writing customised VBA tools in Arc Objects. The planar-distance method model was written by the author, while Dr. Bastin wrote the geometric network routing model, which is discussed further in Bastin and Longden, (2007).

A series of input boxes hold the parameters used to estimate the economic and external costs of transport (see Sections 8.4.9 and 8.4.11). Important input parameters include the average payload of collection and transfer trucks and the 'windage' factor to account for the tortuosity of the road network. Total journeys required were derived by dividing the total waste production (tpa) by the average payload of the vehicle. Variables used for the latter were 21 metric tonnes if a bulked transport (HGV) vehicle or 7 metric tonnes if it is a collection vehicle (RCV) (Biffa, 2002; US-EPA, 2002). These parameters can be reasonably cross-referenced with Wheeler & Jainter, (2006) who assume 20 and 10 metric tonnes for HGV and RCV respectively. Lorry kilometres are then the product of the total number of journeys and the total distance travelled. Lorry kilometres were multiplied by £0.35 (Strategic Rail Authority, 2003) to derive the monetarised external costs of transport (£/a), and £1.07 (Biffa, 2002; US-EPA, 2002) to derive the economic costs (£/a). The multiplier from the SRA was used since this includes other externalites such as road infrastructure wear, accidents and noise as well as the costs of air pollution.

Section 3.3 identified that previous studies typically did not assess the impacts resulting from the transport of bottom and fly ash to inert and hazardous landfill sites respectively and did not justify why. Since tonnages of ash produced are related to the choice of technology used, this project has taken the transport of bottom and fly ash into account within its methodology. The average capacity of a suitable truck for such material was assumed to be 16 metric tonnes (Consonni et al, 2005a). This was chosen over the 18 metric tonnes assumed capacity used by Wheeler and Jainter (2006), since the source of the data used was not clear. In Cornwall, where there is a shortage of both inert and no hazardous landfill sites, the only existing site with voidspace (Lean Quarry) was assumed to be the destination for bottom ash, while Bishops Cleeve in Gloucestershire was assumed to the destination for fly ash as indicated by the Waste Local Plan (CCC, 2003). No assumptions regarding route destinations could be referenced for Warwickshire. Therefore, this project has assumed that routes from EfW facilities to the nearest landfill site would be defined on a nearest proximity basis since Warwickshire has several landfill sites licenced to take both inert and hazardous wastes within and just beyond the county boundary. Bottom ash may be reprocessed to produce building aggregate (Porteous, 2005) but at the time of writing no details regarding the locations for these facilities were available; hence, this project has assumed the actual locations of existing landfill sites.

7.2.1. PLANAR DISTANCE METHOD

In the case of the first transport impact model, the distance (d) between waste resource point and final destination are calculated on a planar basis using Equation 7.

$$d = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \qquad (7)$$

Where X_1 and X_2 are the coordinates of the waste resource point, Y_1 and Y_2 are the coordinates of the final disposal site (WTS, EfW or other facility). The model does not use the road network, but applies a 'windage factor' (WF) to estimate the actual distance travelled between resource point and destination. A selection of WFs sourced from the literature is shown in Table 4 of Section 3.3. The Windage Factors used for Warwickshire and Cornwall are 1.2 and 1.3 respectively. The Warwickshire factor was chosen, based on local expert advice (Holmes, 2005b), and had been obtained by the Authority from experimental work for calculating Key Performance Indicators for street works. The 1.2 value is close to that used in several other similar geographic contexts, and is also used as the default 'straight-line walk distance factor' in the UK Department for Transport's

'Accession' software package (DfT, 2007). A value of 1.3 however, was used for Cornwall, since the background geography of the study by Purlack and Turhallow (2002) is a closer fit with the rural nature of Cornwall.

7.2.2. GEOMETRIC NETWORK METHOD

The Geometric network method of estimating transport impact is based on 'Network Routing'. A network consists of connected linear features. In this project, networks were created from the 'roads' geometry data from the Meridian Ordnance Survey dataset for both WDA areas. Connectivity attribute data at nodes is important for the network to simulate the real-world. In this study, particular attention was made to ensure that motorways could only be accessed at their junctions, for example.

A 'shortest-path' method derives routes between industrial source points and final destinations. A shortest-path analysis essentially finds the path with the minimum cumulative impedance between nodes on a network (Chang, 2002). The analysis begins with an impedance matrix between all nodes on the network and is followed by an iterative process of finding the shortest distance from node 1 to all other nodes (Dijikstra, 1959). This was done for all Census Output Area (COA) 'source' points to their allocated EfW facility 'sinks' and distances of all routes were totalled for each option.

Geometric network results for cumulative travel distances were based on both 'shortest path' and 'least-cost' routing basis. The shortest paths through the network were identified for all COA waste source points to their final EfW facility destinations using the Dijikstra algorithm (Dijikstra, 1959) using routines embedded in ESRI's ArcMap 9.1 GIS software. 'Least-cost' routes were identified by the same algorithm but in this analysis every road link was cost-weighted by type according to the values in Table 17. These are based on observed average speeds (DfT, 2005) and are inversely proportional to the applied weight. A multiplication of road link length and the type weight is performed to calculate the 'impedance' value.

Table 17: Static weights applied to the Geometric Network least-cost routing analysis (Bastin and Longden, 2007).

These are estimated from UK DfT statistics (2005) and are assumed to represent ease of travel. They are based on average speeds of rigid and articulated HGVs.

Type of road	Average speed: km per hour	Impedance factor
Motorway	54	1.00
A-road	48	1.125
B-road	35	1.543
Minor road	29	1.862

7.3. RESULTS AND DISCUSSION

7.3.1. HAULAGE OF MSW

Table 18 shows road transport cost estimates for each EfW option in Cornwall and Warwickshire. In Cornwall, monetary and external costs for the large-scale option (1) are 27% higher than the medium-scale options (2 and 4). Overall, the local-scale options (3 and 5) have the lowest transport impact, 34% lower than the Indian Queens large-scale option and 11% lower than the medium-scale option. In Warwickshire, impacts for the alternative large-scale option (1b) are 3% lower than its proposed Judkins location (Jainter & Poll (2005) counterpart (1a). Overall, the local-scale option has a significantly reduced impact, 60% lower than the Judkins large-scale option.

Table 18: Total estimated costs of waste transport.

These have been estimated using the cost parameter of £1.07 lorry km (including return journey) (US-EPA, 2002). External costs of transport have been estimated using the figure of £0.35 per km travelled from the (Strategic Rail Authority, 2003). The latter includes costs of pollution, road traffic accidents, congestion, road wear and noise.

Area	Option	Description	Total distances (km)	Total number of journeys (p/a)	Total lorry km (p/a)	Monetary costs of waste transport (£/per a)	External costs of waste transport (£/per a)
Corn -wall	1	Large	52,280	77,430	1,454,720	1,556,550	509,152
	2 & 4	Medium	52,009	68,012	1,067,931	1,142,686	373,776
	3 & 5	Local	46,522	68,014	953,365	1,020,101	333,678
Warwic k-shire	1a	Large	34,909	60,564	897,220	960,025	314,027
	1b	Alt Large	40,384	57,504	870,905	931,868	304,817
	2 & 4	Medium	26,228	54,842	512,903	548,806	179,516
	3 & 5	Local	20,795	51,510	350,731	375,282	122,756

Table 19 shows how the costs of owning and operating waste transfer stations (WTS) combined with waste transport compares between the options. On a county basis, Cornwall has significantly higher costs and impacts than Warwickshire.

Table 19: Total estimates of the combined costs of waste transport and operation of Waste Transfer Stations.

The costs of WTS is on an own and operate basis and is calculated on capacity at £6.26 metric ton (US-EPA, 2002) - 2006 prices.

Area	Option	Description	Number of WTS	Capacity of WTS (tpa)	Cost of WTS (£/pa)	Costs of waste transport (£/pa)	Total costs (£/pa, K's)
Corn-wall	1	Large Indian Queens	5	129,000	807,540	1,556,550	2,364
	2 & 4	Medium	3	35,000	219,100	1,142,686	1,362
	3 & 5	Local	3	35,000	219,100	1,020,101	1,239
Warwick -shire	1a	Large Judkins	3	89,000	557,140	960,025	1,517
	1b	Alt Large L. Spa	2	59,000	369,340	931,868	1,301
	2 & 4	Medium	1	35,000	219,100	548,806	768
	3 & 5	Local	0	0	0	375,282	375

An interesting result for Cornwall is that waste transfer stations still play a role in transport for the medium and local-scale EfW approaches, albeit of small capacity. Since Cornwall already has an extensive network of WTS, it has been assumed that existing stations will be available for use by all approaches in strategic urban centres if required. St

Austell and Newquay are examples of this, as shown in the maps of Section 6.4.2. In Cornwall, the combined costs of road transport impacts and operation of WTS in monetary terms for the large-scale option (1) are 41% higher than the medium-scale options (2 and 4) and 47% higher than the local-scale option (3 and 5)

Regarding Warwickshire, the alternative large-scale option (1b) located at Leamington Spa, saves the need for the Warwick WTS, and hence only two WTS are required in this option, in comparison with three for the actually proposed Judkins location. The total cost of waste transfer station and road transport for the project derived Leamington Spa location are 13% lower than for the Judkins location. This shows that the techniques used in this project could potentially lead to substancial savings in the formulation of centralised, single facility EfW options as well as more decentralised options.

The local EfW options do not use WTS and hence make significant monetary savings. When considered with the savings in road transport, the local options are 75% lower in monetary costs than the large-scale Judkins 1a option. To compare the results in the context of each county area and between the scale options, Table 20 shows ratios of the large-scale centralised impact to lower-scale options.

Table 20: Large to lower scale option CT ratios of transport impact.

Area	Option ratio	Costs of transport	Total costs inc WTS	No of WTS
Cornwall	Large	-	-	5
	Large to medium	1.36	1.74	3
	Large to local	1.53	1.91	3
Warwick-shire	Large	-	-	3
	Large to Alterative Large	0.97	1.17	2
	Large to Medium	1.34	1.98	1
	Large to local	2.48	4.05	0

Regarding the cost of transport (CT) ratios, the most interesting observation is that Cornwall has a significantly lower large-to-local ratio than Warwickshire. This would indicate that Warwickshire may acquire greater marginal benefit in following a local-scale option rather than a large-scale one. Cornwall however, has four plants in its local option, while Warwickshire has five and this may explain the lower CT ratio of 1.53 compared to 2.48. To determine if Warwickshire's marginal benefit is confirmed at the local-scale option of five plants, cost functions derived from a regression of costs of transport (excluding any WTS costs) vs the number of plants (shown in Figure 36) can be used. The large-to-local ratio when Cornwall has 5 plants is 1.61 and this helps to confirm Warwickshire's marginal superiority between scale options.

When considering the total cost (TC) ratios (that include the costs of owning and operating WTS), the difference between the county ratios is even more significant. This is due to the fact that three WTS have been retained for the Cornish local option by the decision rules used in this project, namely if *existing* WTS are greater than 5 km away from a derived EfW site, they would be used in this study. The latter enables the achievement of low collection cost targets (Biffa, 2002). Planned but un-built WTS are not assumed, except in the large-scale options and their locations have been defined in waste planning documents.

Local options make lower use of WTS and will accrue significant savings over the large-scale option. This is apparent in the Cornwall options, but more so in the Warwickshire ones in the large-scale alternative site (which reduces the need for a WTS of a significant 35 ktpa capacity) and local five plant options. As well as the savings, closure of WTS presents the opportunity to use the sites for alternative waste management purposes, such as recycling, composting or small EfW facility.

The magnitude of the cost savings presented in Table 19, make it quite clear that the potential savings in following a local EfW option in Cornwall are greater than in Warwickshire. This is shown clearly in Table 18, where at the medium-scale; savings are estimated at £414k per annum but rise to £536k for the local-scale option. The latter difference though may again be explained by Cornwall's four plants to Warwickshire's five. On this basis, it may be said that in general, it is less expensive to dispose of waste in local plants within Warwickshire rather than Cornwall. Cornwall's isolated position in the UK, however, means it is more worthwhile to dispose of waste locally in any EfW option (large, medium or local), rather than transport waste for treatment outside its boundary, even though its geography leads to higher overall in-county costs than local thermal treatment in Warwickshire.

The curves in Figure 36 illustrate that the relationship between the costs of transport (excluding WTS) and number of plants is not linear, with the marginal benefit decreasing with an increasing number of distributed plants. The Warwickshire curve illustrates this better than the Cornwall one, the latter of which could be interpreted as being more linear. In short, making any sound judgment on the nature of the relationship is not possible when it has been derived using only three or four data points. More work is required to derive more EfW options (consisting of different distributions of site location, scales and numbers of plant) on which more data points can be obtained for the county contexts. It would also be interesting to apply the same analysis on different case study WDA geographies to investigate how their jurisdictional boundary shapes influence the cost functions.

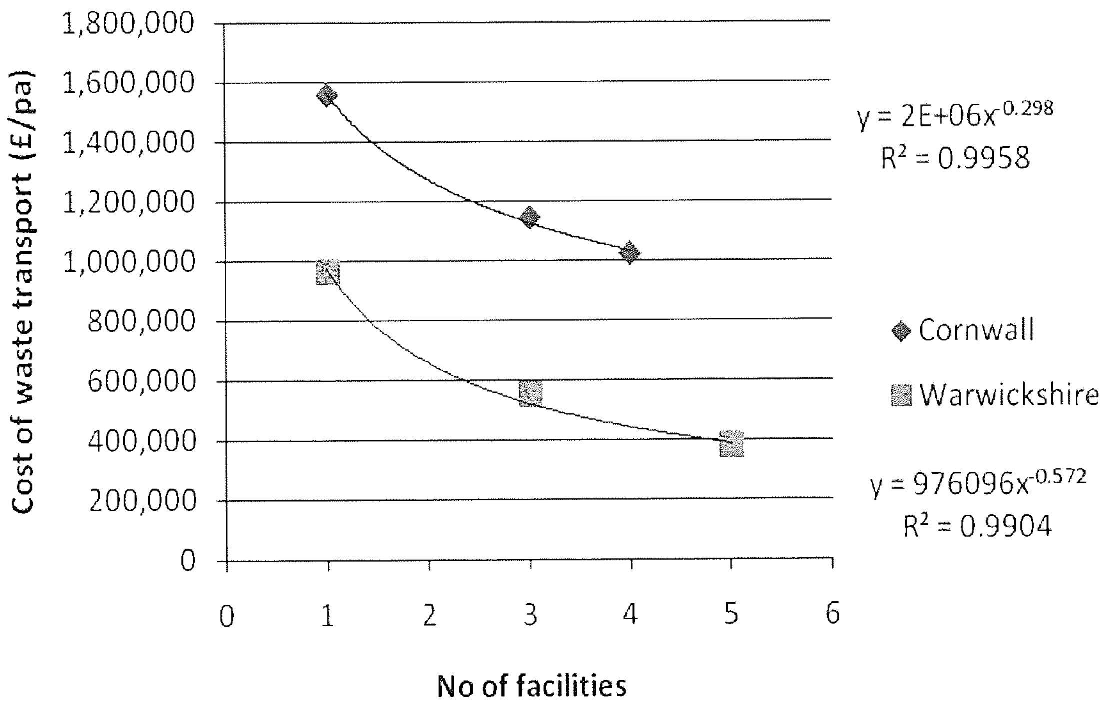

Figure 36: Cost functions of the relationship between transport costs (£/pa) and the number of plants.

Wheeler & Jainter (2006) observed that in Cornwall there is only a 7% reduction in transport distance travelled if 5 sites are used and 4% if two sites are used. The result is very different to the 41 and 47% reductions identified for the 3 medium and 4 local plant sites estimated by this project. This is because their methods have taken into account the fact that the recyclate products, although lower in tonnage, often have to be transported for greater distances to their final markets. Essentially, these combined distances required to manage different fractions of municipal waste (shown in Table 21) conceal the potential benefit of locally treating *all* waste and identifying local markets for recycling products.

Table 21: Average distances for Cornwall's recyclates to markets.

Material	Destination	Distance (km)
Paper	Aylesford, Kent	457
Plastic	Liverpool	531
Textiles	Local	15
Glass	Local	15
Iron metal	Llanelli, Wales	380
Non-iron metals	Llanelli, Wales	380

The data in Table 21 may have been correct at the time of publication, but the destinations are likely to change. For example, there is the possibility that alternative market destinations could be found, since Kent is situated at the opposite side of the UK to Cornwall. The controversy regarding sending recyclate material to China (Videl, 2005) shows the range of market distance possibilities. These examples indicate that such arrangements are probably more a matter of pricing and contracts than the requirement to manage transport cost or impact. Hence, it can be argued that including the aspect of recyclate market delivery is not helpful to the objective estimation of transport impact within the local study area and only detracts attention from the view that as much waste as possible, recyclate or residual should be managed as near as possible to source to minimise transport related costs and impacts. At this point, it is worth introducing the concept of Resource Recovery Centres (RRCs). These are essentially Material Recycling Facilities (MRFs) and can be co-located with EfW facilities or landfills (Coggins, 2006). This is supported by Harbottle et al (2006) who concluded that a major effect in their LCA originated from the transport of materials, contributing to emissions and consumption of crude oil and disturbance. They determined that co-location of waste management facilities to treat waste locally is preferable.

Cornwall WDA have proposed the use of RRCs for industrial and commercial waste, but not for MSW (Lea, 2006b). The reason for this may be that the urgency in diverting MSW from landfill and achieving LATS targets is encouraging development of facilities such as MRFs, composting or EfW on a more opportunistic site by site basis. Currently the Landfill Directive only applies to MSW, but this may change shortly (Lea, 2006a). RRCs have the advantage of being able to separate parts of the waste stream, while recovering energy from the non-recyclable (residual) fractions on site, hence omitting the need for further transport. These transport gains include savings gained from:

- Local management of up to 70% of the waste stream with the remainder going to landfill;
- Reducing the need to bulk waste at WTS;
- Unnecessary distances to MRFs outside of the study area.

Wheeler & Jainter (2006) concluded that while there is a saving in transport infrastructure and costs resulting from the use of multiple facilities, these are outweighed by the much higher costs incurred of building and operating them. This judgment has been made in respect of minimum gate fees required to make facilities economic to build. Gate fees are used as a comparative figure derived from the cost of capital, operation and revenue streams and comparisons of those used in the Wheeler & Jainter (2006) study and of this project are shown in Figure 37. Further background to gate fees which are essentially profit margin plus Net Cost per Tonne values (NCT) is provided in Section 8.4.10.

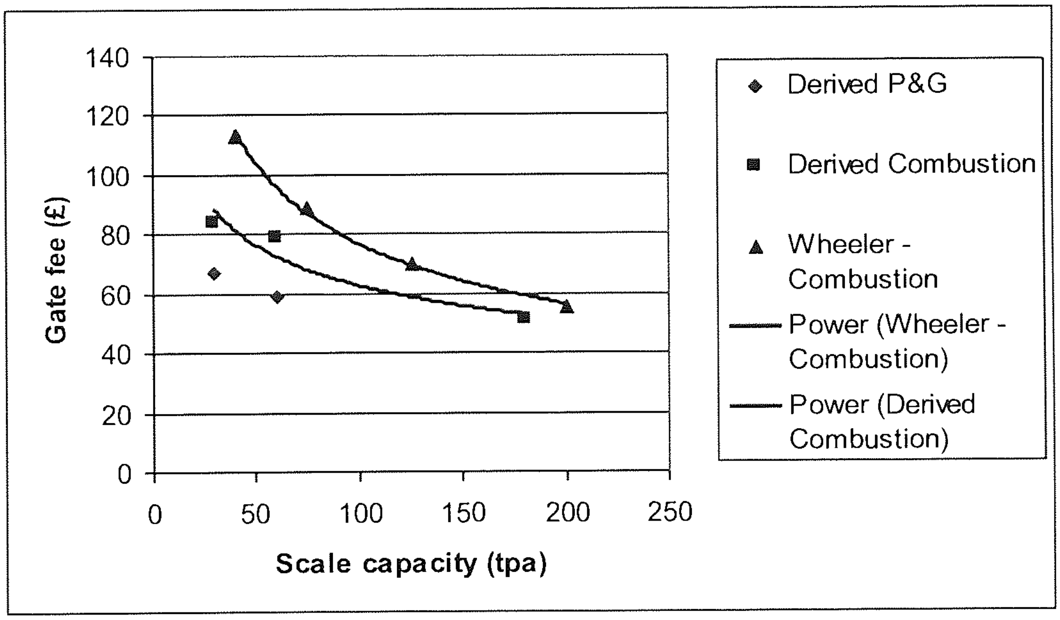

Figure 37: Comparison of gate fee costs of combustion with Wheeler & Jainter (2006).

The graph shows that combustion gate fees are greater at lower scale than they are for pyrolysis and gasification. It also shows that the Wheeler & Jainter (2006) combustion cost curve shows significantly higher gate fees for smaller scales of combustion plant than the derived curve produced by this project using data from a variety of literature sources (see Section 8.4.10). Therefore, it is not surprising that the Wheeler & Jainter (2006) study concluded that transport savings were marginal from a multiple plant strategy and that they are outweighed by the savings from developing a centralised, single plant option. It is clear that care must be taken when sourcing data.

7.3.2. HAULAGE OF FACILITY ASH RESIDUES

Assumptions regarding truck capacity and routing of fly ash have been presented in Section 7.2. Table 22 shows the total estimated costs of fly ash transport for all EfW options of the two WDA test areas. Since, fly ash residue production is related to choice and design of technology, the option performance data is presented in both scale and technology description.

Table 22: Costs of bottom and fly ash residue transport.

Area	Option	Description	Total distance (km)	Total number of journeys (p/a)	Total lorry km (p/a)	Monetary costs of ash transport (£/per a)	External costs of ash transport (£/per a)
Cornwall	1	Large Combustion	633	404	255,351	273,226	89,373
	2	Medium Combustion	658	459	301,851	322,981	105,648
	4	Medium Pyrolysis/Gasification	658	113	74,353	79,558	26,024
	3	Local Combustion	622	487	321,984	344,523	112,694
	5	Local Pyrolysis/Gasification	622	113	75,335	80,608	26,367
Warwickshire	1a	Large Combustion (Judkins)	4	404	1,646	1,761	576
	1b	Alt Large Combustion (Leam. Spa)	21	404	8,328	8,911	2,915
	2	Medium Combustion	33	459	15,276	16,345	5,347
	4	Medium Pyrolysis/Gasification	33	113	3,763	4,026	1,317
	3	Local Combustion	26	452	11,582	12,393	4,054
	5	Local Pyrolysis/Gasification	26	94	2,419	2,588	847

Most studies reviewed with the exception of Consonni et al, (2005a) did not take into account the impacts from the transport of ash residues. This is more important for fly ash than for bottom ash since modern incineration methods for waste regardless of whether they are combustion, gasification or pyrolysis must ensure sufficient burn out of the carbon content to be within 3% Total Organic Carbon (TOC) as dictated by the Waste Incineration Directive (Appendix A.2.4). There should be an insignificant difference between technologies in the production of bottom ash if they are all processing the same composition of waste that has been subject to the same extent of pre-treatment. The latter includes ferrous separation and removal of other inerts such as metals and glass. This project has assumed that all options will process the same waste composition in each WDA area.

Table 22 shows that it is important to take into account fly ash transport, particularly when hazardous landfill facilities can be a significant distance from the WDA area. As discussed in Section 8.4.4, the Compact Power technology used to represent the pyrolysis/gasification options generates 75% less fly ash residues and hence, requires less transport in order to dispose of them. The degree of how great a proportion of transport can be allocated to residue transport depends on the technology used, but more importantly how close the landfill sites, (particularly those licenced to take the hazardous fly ash) are to the WDA area in which processing is conducted. Regarding Cornwall, the nearest hazardous landfill is situated in Gloucestershire and over 600 km from the WDA area. Despite tonnages of bottom ash being over 85% of the total ash residue from options, the costs of transporting the remaining 15% fly ash for disposal accounts for over 50% of total ash transport costs.

Since Pyrolysis/Gasification options generate 75% less fly ash, average savings are over £300k per annum compared to combustion options for Cornwall. In the case of Warwickshire, hazardous landfill sites are far more numerous and several are located within or just beyond the WDA boundary and routes range in distance between 4 and 26 km. This is 96% closer than the nearest hazardous landfill site to Cornwall with the result that savings are considerably less at around £15k per annum. These points show that it is important to take into account the specific socio-geographic characteristics of WDA's in formulating and appraising EfW policy.

Table 22 shows while all Warwickshire residue transport costs are significantly less due to the reasons discussed above, it should be noted that the proposed large-scale combustion plant at Judkins is on a site just 1.8 km from an existing hazardous and inert landfill site. Such co-location, (unique to this WDA) enables great transport cost savings and is certainly desirable, particularly in the case of a centralised large-scale EfW policy. This suggests that at least on this criterion, choice of technology may not be as important as in Cornwall, where the greater fly ash production of combustion technology results in significantly greater costs. While more distributed EfW facility options can be developed in proximity to dense areas of waste production from urban centres and save significant transport cost on this aspect, they may incur greater costs in the transport of ash to landfill as illustrated in Table 22. The costs of waste and fly ash transport presented in Table 19 and Table 22 have been input into the overall EfW option performance matrix (Table 42) for MCDA appraisal. This element of the DSS will ensure the differences discussed above are taken account of within the identification of preferred EfW implementation options.

7.3.3. COMPARISON OF RESULTS FROM ALTERNATIVE CUMULATIVE DISTANCE ESTIMATION METHODS

This more complex and demanding method of estimating transport impact using geometric networks provides a measure of the accuracy of using 'windage' factors (WFs) and makes it possible to judge whether the approach is worth the extra information it provides, in terms of programming expertise, data preparation and processing time,. Use of geometric networks enables the computation of county-specific WFs rather than values from the literature used to take account of the road network in the derivation of the planar distance based results. Table 23 shows the large-to-local ratios of the least-cost geometric network routing compared to the planar and WF analysis. The transport impact estimation results from both analyses were very similar for Cornwall, but differences between method results for Warwickshire were greater. All levels of modelling show that the large-scale options, (even when mitigated with the use of waste transfer stations) produce far higher levels of impact than the local-scale for both counties.

Table 23: Large-to-local ratios from 'least-cost' Geometric network routing vs Planar distance and WF analyses.

Area	Planar distance	Geometric network
Cornwall	1.5	1.49
Warwickshire	2.25	2.36

Table 24 shows that the use of static windage factors in estimating transport impact can underestimate impact typically in the range of 0.2 and 7.3%. The errors for Cornwall are lower than for Warwickshire. A difference of 27% between the two methods of estimation was identified for the Warwickshire large-scale option. This can be explained by the very high use of motorways, which favours longer-distance but higher-speed routes under cost-weighting within the routing analysis. In general, use of cost-weighting generated higher errors and these were reduced when shortest-path only routing is performed (-3.6% and 1.3%). Analysis in Cornwall, also generated smaller errors at between (-0.6 to +0.2%).

Table 24: Under- and over-estimates of travel impact against 'least-cost' and 'shortest-path' distance routing from Bastin and Longden (2007).

Using (a) a static winding factor of 1.2, (b) winding factors derived from the results (winding factor values shown in brackets).

	'Least-cost'		'Shortest-path'	
Method	a)	b)	a)	b)
Warwickshire				
Large option	-27.0%	+0.01% (1.799)	+1.3%	-0.01% (1.184)
Local option	-7.3%	+0.01% (1.294)	-3.6%	-0.02% (1.245)
Cornwall				
Large option	-3.1%	-0.07% (1.237)	-0.6%	+0.01% (1.204)
Local option	-3.2%	-0.02% (1.240)	+0.2%	-0.02% (1.197)

An advantage of using network routing analysis is that WFs can be derived for specific geographical areas to replace a more generic one chosen from the literature. Computed WFs ranged around 1.2 (between 1.197 and 1.294) but an exception to this was the 1.799 factor derived for the large Warwickshire option. This is due to the preference of the routing algorithm for using motorways which saves time but increases the distance travelled. Windage depends not just on the study area's roads and geography but also on the lengths of journeys within each option (Bastin and Longden, 2007), hence, the large-scale Warwickshire option derives a high factor. To conclude the discussion surrounding the use of WFs, it is clear that generic values predicted results for Cornwall reasonably well, while for Warwickshire, no consistent value was apparent.

Extending the project to include more sophisticated geometric network methods for transport analysis was worthwhile in terms of identifying the unpredictable accuracy of simpler straight-line methods for estimating what is an important aspect of EfW policy appraisal. However, using more complex network routing methods for any particular area is time and resource intensive in both programming expertise and data processing requirement. Bastin and Longden (2007) provide some judgment as to when to use either method:

- Use of the straight-line approach is necessary when road network data or routing software is unavailable.
- The accuracy of 'straight-line' approach estimates is limited. Hence, estimations of associated costs may be problematic.
- Network routing can produce results that the straight-line method cannot. Examples include maps that show the extent of cumulative traffic impact and the specific road links where this will occur.

The value of either the planar distance and windage factor method to estimate transport impact or the more complex geometric methods depends on the final use of the outputs. For example, if the weights attributed by the MCDA to transport are low, then it is unlikely that the difference in method estimates will impact the overall option preferences from the MCDA appraisal.

7.3.4. THE IMPACTS OF COLLECTION AND HAULAGE FROM MULTIPLE SERVICE AREAS

All transport impact estimation model results methods discussed in this Chapter, make the assumption that each Census Output Area (COA) waste production point represents a 'source' of residual waste that has been collected from within the area boundaries of the COA. A limitation of this approach to transport impact assessment may be identified in that it only takes into account the haulage 'transfer' of waste between service areas and final disposal destination with no account of the impacts arising from collection routing of residual waste *within* COA boundary 'service areas'. Further to this, is the question of how overall transport impacts are affected if it is assumed that more than one COA defines a collection service area and haulage transfer routes visit multiple COAs before reaching the final destination. These questions are discussed in this Section in turn. The concept of 'service collection areas' and haulage is shown in Figure 38 where collection routes serve a WTS before haulage transfer to final disposal point.

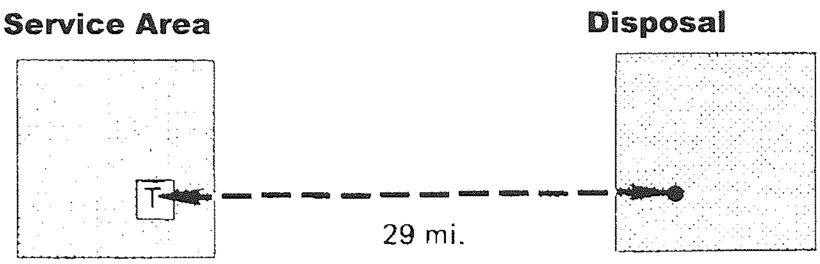

Figure 38: Service collection areas and haulage transfer to final disposal location (Gershman et al., 1986).

Of total waste management costs spent on the collection, transport and disposal of solid wastes, 50 to 70% is spent on collection (Tchobanoglous et al., 1993). The remaining costs are approximately of equal proportion (25-15%) on transfer and waste disposal (Gershman et al., 1986). Despite this, Gershman et al. (1986) state that the majority of waste management costs encountered in collection are unaffected by the construction of new EfW facilities, but, that the established transport network used for the delivery of waste to a final disposal facility is critical to the development process and costs associated with such a project. Savings can only be realised with the reduction of haul distances from the collection service area to the final unloading destinations.

For this reason, this project has estimated the transport impacts and costs associated with haul distance and not those relating to collection within COA service areas at street level, since, these would be unaffected between different EfW options of final disposal. Estimations of collection route impact at street level can be found by using vehicle routing problem (VRP) and vehicle routing problem with time windows (VRPTW) algorithms and heuristics. The reader is referred to Chapter 8 of Tchobanoglous et al (1993), Koushki et al (2004) and Salhofer et al (2007).

The assumption that there is only one COA 'source' for each haulage route as made by the Transport Impact estimation methods should be discussed further. COAs were recommended to include 125 households (National Statistics, 2007) and actually have an average of 110 households in the UK and 124 in England and Wales (Vickers and Rees, 2007). The mean average of households in the Warwickshire waste model is also 125. Of note, however, is that COAs can range from 40 to 200 households. Tchobanoglous et al. (1993) have suggested that a typical collection route may comprise of approximately 166 households. This number would suggest that any typical collection 'trip' would travel to not just one but two COAs in a circular haulage route.

To explore this further in the UK context, the author approached WDAs for data on the number of households that would be covered within a typical collection trip in an urban and rural context. Data from Chester City Council (Limb, 2008) are shown in Table 25 and these were supported by staff working on collection rounds for Bristol City Council (Money, 2008). Table 25 shows that each service collection area could include between three and six COAs. A key question arises: Does the assumption that haulage routes visiting three or more COAs within a circular trip produce significantly different annual transport impact estimates than the original two-way 'out and return' to one COA assumption applied in the Transport Impact methods, (whose results have already been discussed in Section 7.3.1. The difference in routing assumptions is shown in Figure 39.

Table 25: Typical UK household waste collection round data (Limb, 2008).

	Households/Day	Trips/Day	Households/Trip/Day	No of COA centroids/Trip
Urban	1400	2	700	6
Rural	700	2	350	3

Figure 39: Routes for testing original haulage assumptions against multiple COA circular haulage.

The 'source to sink' routes for the original TIM (out and return to single COA) and alternative circular round trip that visits multiple COAs are shown by the red and blue lines respectively. The purple lines denote the polygon boundaries of the COAs, and their population-weighted centroids represent are shown by the black triangles. The final disposal 'sink' location of an EfW facility is shown in the bottom right corner of both diagrams.

The original transport impact estimation methods did not take into account the requirement for greater frequency of collection rounds than the frequency derived by weight of the annual COA production. It is not acceptable for volumes of waste to be stored domestically for prolonged periods, hence, the minimum frequency of residual waste collection is weekly and associated haul transport to and from service areas are required. Tchobanoglous et al (1993) have assumed that collections are necessary for 52 weeks of the year and this is supported by current WDA policy (Bristol City Council, 2008; Limb, 2008).

To estimate the overall impact of circular multiple COA routes on haulage results, each EfW option's transport impact was re-calculated using the factors in Table 26. In order to derive the proportion of COAs in urban and rural areas of the study areas, a database query was executed within the GIS to identify how many COAs were located within Developed Land Use Area boundaries (DLUAs). Those not within DLUAs were assumed to be in rural areas. The percentage of 'urban' COAs for Cornwall and Warwickshire were 60 and 72% respectively.

Table 26: Comparing distances for singular and circular COA visits during haulage from COA collection service areas.

WARWICKSHIRE						
km/pa	**Urban**			**Rural**		
	Routes to 6 individual COAs and return	Circular route to 6 COAs (weekly)	% change	Routes to 3 individual COAs and return	Circular route to 3 COAs (weekly)	% change
Atherstone	329	222	33%	1166	1392	-19%
Stratford	466	246	47%	662	973	-47%
Rugby	808	473	41%	1416	1810	-28%
Nuneaton	551	328	40%	898	1248	-39%
Warwick	640	407	36%	1093	1163	-6%
Average CF		**40%**		**-28%**		
CORNWALL						
Camborne	1353	648	52%	758	904	-19%
Truro	2105	982	53%	656	789	-20%
Newquay	647	334	48%	562	658	-17%
St Austell	797	428	46%	543	623	-15%
Lean Quarry	1024	502	51%	484	661	-37%
Average CF		**50%**		**-22%**		

Table 26 compares the annual distances in 20 routes of both urban and rural nature in Cornwall and Warwickshire. 'Collection haulage factors' have been derived by taking an average of the percentage difference between the two sets of results taken from the original method and circular haulage routing. It can be observed that original methods have over-estimated transport impact in urban areas of Cornwall and Warwickshire by 40 and 50% respectively, but under-estimated rural route impact by 28 and 22%. The effect of taking into account multiple COA visits is shown in Table 27, where transport impact estimates of monetary and external costs are 20% (Cornwall) and 21% (Warwickshire) less than the original estimates.

Table 27: Re-estimated EfW option transport impacts using collection haulage factors for haulage of MSW.

Area	Option	Description	External costs of transport (£/pa)	Cost of WTS (£/pa)	Costs of transport (£/pa)	Total costs (£/pa, K's)
Corn-wall	1	Large Indian Queens	407,566	807,540	1,245,988	2,054
	2 & 4	Medium	299,200	219,100	914,698	1,134
	3 & 5	Local	267,103	219,100	816,570	1,036
Warwick-shire	1a	Large Judkins	247,453	557,140	756,500	1,314
	1b	Alt Large L. Spa	240,195	369,340	734,312	1,104
	2 & 4	Medium	141,459	219,100	432,460	652
	3 & 5	Local	96,731	0	295,722	296

Since transport related criteria (costs and emissions) account for between 12 and 15% of the total weighting within the final Warwickshire and Cornwall MCDA models, the re-calculated estimates were used to replace the original score inputs to test for sensitivity. In both WDA models, one option scored an extra point - Medium-scale combustion in Cornwall and Local-scale combustion in Warwickshire. Despite the relatively high proportion of total weighting in the models being assigned to transport, the differences in scoring did not affect the final ranking of preferred EfW options.

7.4. CHAPTER SUMMARY

This chapter has presented and discussed the transport impact estimates for large, medium and local EfW options identified for Cornwall and Warwickshire using two different methods of distance estimation – planar routing and windage factor, as well as geometric networks. The implications of multiple visits to COA waste production points instead of the assumed one visit per journey assumption were also discussed. Although transport impacts are important, they represent just two of 14 criterions within the overall MCDA appraisal models that take into account EfW option performance on other aspects of EfW planning. This is the subject of Chapter 9. The next Chapter describes how the MCDA model was developed and option performance scoring of other criteria.

8. APPRAISING EFW OPTIONS USING MCDA: DEVELOPING THE MODEL

8.1. AIMS OF CHAPTER

The aim of this chapter is to present the Multi Criteria Decision Analysis (MCDA) component and Step 4 of the overall EfW decision support system. Section 8.2 describes how criteria were selected, while Section 8.3 provides an outline of the final structure of the model. Section 8.4 defines the criteria and how scores were derived. Section 8.5 describes how the performance scores derived for all EfW options. Section 8.6 describes the process of how the model's relative criteria weightings were obtained.

8.2. CRITERIA SELECTION

A list of criteria identified from the literature was discussed in Section 4.2. The majority of criteria used by previous studies relate to environmental impact usually include air emissions (Shmelev and Powell, 2006), displaced CO_2 emissions from fossil fuels (Consonni et al., 2005b; Corti and Lombardi, 2004), water discharges (Bergsdal et al., 2005), discharges to ground, (fly and bottom ash) (Azapagic and Camana, 2005; Dujim and Markert, 2002), dioxins and risks to human health (Harbottle et al., 2006; Porteous, 2005), transport (Maniezzo et al., 1998; Wey, 2005) and landtake (Dujim and Markert, 2002; Jainter and Poll, 2005). Economic criteria included indicators representing labour and capital expenditure (Greenberg et al., 2002), gate fee (Murphy and McKeogh, 2004), net present value (Nilsson et al., 2005), and transport costs (Cheng et al., 2003).

This list was presented to officers from both Warwickshire (WCC) and Cornwall County Councils (CCC). Workshops, organised and facilitated by the author were held in October and November (2005) to decide the criteria from ones typically used in other studies. Criteria chosen are summarised in Table 28. Following the method used by

Norese (2003), group discussions were held to determine which criteria were of the most interest to the officers in the decision making process. These workshops resulted in the following decisions:

- The CCC group decided that technology maturity should be added to take account of the need to use 'proven' technologies. Officers were also insistent that the criterion should be scored relative to the number of facility examples already operating in the UK, since they needed reassurance they could be commissioned in the UK market environment.
- The WCC group decided that strategy 'flexibility' be added to respect the need to address varying future waste disposal needs and the introduction of new technology options. This was particularly interesting since this criterion was not identified in the review of previous studies.
- Both groups believed that Criterion 1, 2 and 3 in Table 28 are described as social criteria and should be added due to concerns about the impact of such issues on the planning system and the need for eventual public acceptance of any EfW policy. Typically dioxin production is often included in environmental criteria, but due to the groups' opinion that such a parameter has health implications, it was re-classified as a social criterion. The groups also insisted that it should stand alone as a criterion in its own right to receive its own weight and not be classified as a sub-criterion within an overall air emissions criterion. Section 8.4.3 provides an explanation of criteria and sub-criteria.
- In order to assist policies pass through the planning system, both councils requested a visual impact criterion be added, since they believed this was a particularly important issue. This is not surprising since the perception of air pollution can be related to stack height and the 'sight' of substances leaving it. To this extent, a UK facility operator was obliged to fit expensive "stack heating" equipment in order to abate the appearance of emissions from the stack, reported to be water vapour produced in cold weather (Sita, 2005).

Table 28: List of chosen criteria and their indicators.

	Criteria	Indicators	Units
1	Lorry traffic impact on local communities	No of lorries arriving at the plant	Per day
2	Jobs created	No of full time jobs created by 2011	-
3	Health of local community	Dioxins/furan production	Ng ITEQ/pa
4	Emissions to air	Nitrous Oxide	Mg/pa
		Sulphur Dioxide	
		Carbon Monoxide	
		Particulates	
		Hydrogen Chloride	
		Hydrogen Fluoride	
		Mercury	
5	Emissions to land	Flyash	tpa
		Bottom ash	
6	Water discharge to sewer	Water discharge to sewer	tpa
7	Individual site footprint	Land required for development of EfW facility/facilities	Ha
8	Individual plant site visual impact	Height of building	m
		Height of stack	m
9	Displaced fossil fuel CO_2 emissions	Displaced fossil fuel derived CO_2 from electricity generation	t CO_2/pa
10	Total external costs of road transport	Annual monetarised environmental cost of transport including road wear, congestion and road traffic accidents	£/pa
11	Net cost per tonne of MSW processed	Total annualised capital and operating costs minus energy revenues	£/t (MSW)
12	Cost of Waste Transfer Stations and transport movements	Annual cost of building, owning and operating a WTS	£/pa
		Annual cost of transport movements of all residual MSW waste in option.	£/pa
13	Technical maturity	No of plants in UK operating on MSW at present (2007)	-
14	Flexibility and strategic value	No of plants in EfW option (Section 8.4.13).	-

Social criteria include 1, 2, and 3 in Table 28. The choice to include these was because of WDA concerns of public opposition. Reports that have been specifically commissioned to mitigate the public concerns surrounding dioxin production (Enviros et al., 2004) have not been helped by reports of emission exceedances (Sita, 2005). 'Job creation' was chosen by the WDAs, since officers are aware of its importance in gaining public support for EfW projects, particularly in less affluent socio-economic areas. Many of the criteria insisted upon by the working groups were ones that primarily arise in similar studies conducted in the UK (Juniper, 2003; Enviros, 2004; Jainter and Poll, 2005).

Environmental criteria include criterion 5, 6, 7, 8 and 9 (Table 28). These would typically be covered by a local Environmental Assessment which is required for any large EfW project to obtain planning permission (Williams, 2005). Criterion 10 reflects the external costs of road transport and includes impacts such as accidents, noise, community severance and road wear. These have been monetarised in order to allow quantitative analysis and limit subjectivity. Criterion 11 reflects the need to respect the contribution to global warming and climate change from CO_2 emissions. This has been done this by using the indicator of displaced fossil fuel that would otherwise have been used to produce electricity if the EfW facility/facilities were not built. This displaced CO_2 value was assumed as an average of that produced by gas, oil and coal, since this is believed to be a fairer indicator (Clift, 2007). Other studies typically displace coal (Higham, 1999; Jainter and Poll, 2005) and such a choice may over-estimate the displacement of CO_2 that can be accrued from using EfW (Eunomia, 2006).

The economic criteria includes the net cost per tonne of processing residual waste takes into account the capital and operating costs of the EfW infrastructure alongside the energy revenues. Since transport is often a substantial proportion of the cost of any waste management strategy (Gershman et al., 1986), a separate criterion was added to account for the costs. These include the costs of building, owning and operating waste transfer stations and the costs of residual waste transport movements represented as sub-criteria.

Much concern in EfW planning surrounds managing operational risk and this observation is supported by the 'technical maturity' weightings which can account for up to 18% of the total model weights shown in Section 8.6. Criterion 13 respects the need for technology maturity and this is quantified by the number of MSW plants already in operation in the UK. A key concern of officers was that solutions perform at an annual waste processing capacity that is great enough to meet their needs for landfill diversion targets to be successfully met (Patel, 2005). Criterion 14 reflects the need to respect uncertainty with respect to the degree of achievement to which recycling and waste minimsation targets are met, or fluctuating waste growth which can be affected by unpredictable population movement and other socio-economic conditions over a 25 year period. Such a period could include as many as 3 to 7 opportunities for multiple facility development depending on scale. Officers appreciated this aspect in EfW decision making where choices of scale and technology could effectively be 'staggered' over the 25 years rather than restricted to just one scale and technology in the case of a centralised single facility approach.

8.3. MODEL STRUCTURE

The model using criteria agreed between officers to be important in making EfW decisions was created and agreed in the first WDA workshops. Both WDA groups were given the opportunity to comment on each other's models and they both ultimately decided to use the same structure shown in Figure 40. To avoid the risk of double counting, the social (Criteria 1 to 3) as well as some of the environmental ones (Criteria 4,8 and 7) were decided by officers to represent elements that could affect planning permission, hence, no individual criterion has been defined as 'planning permission'.

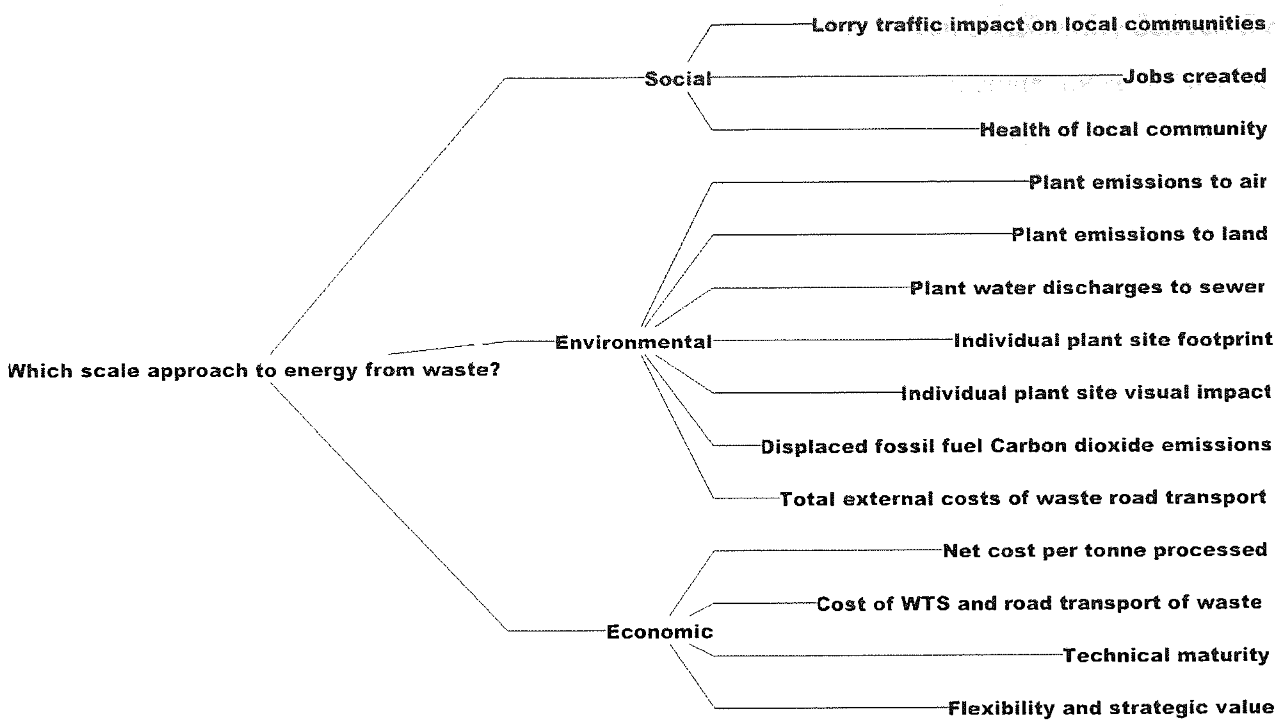

Figure 40: MCDA model decision tree.

8.4. CRITERIA SCORE DERIVATION

This Section describes how scores were derived for the criteria listed in Table 28 MCDA model development took place in early 2006. Data describing the performance of various real and modelled facilities has been collected from several sources including the Environment Agency's Waste Technology Data Centre (Environment Agency, 2006b), industry reports (Enviros, 2004, 2005; Fichtner, 2004) and journals (Brereton, 1996; Consonni et al., 2005a; Gershman et al., 1986; Murphy and McKeogh, 2004). To arrive at the input measurements for the MCDA model for 30, 60 and 180 ktpa combustion facilities, the sourced data was plotted between the scales of 30 and 250 ktpa and interpolated to produce best-fit curves with R^2 values which ranged between 0.75 and 0.99.

Efforts have been made to ensure that data sources have been derived by the same method. An example of this is the approach detailed in the WID directive for air emissions which provides some degree of consistency. Comparisons between scenarios have been kept valid by using the same interpolated relationship curves to derive scores for 180, 60 and 30 ktpa scale facilities. Indicator scores, such as those for criterion 1, 10 and 12 are not technology-dependent but geographically-dependent and have been consistently derived for all EfW options by the same GIS techniques. Such criteria include those related to transport. In contrast, criteria dependent on technical issues such as net costs and air emissions are very similar, if not exactly the same for both WDA areas.

8.4.1. No. 1: Lorry traffic impact on local communities

Methods used in Environmental Statement preparation for bio-energy planning applications have been adapted for use in this project (Scott Wilson, 2004). They estimate the number of Lorries arriving per day at any one particular scale of plant above that of the baseline traffic conditions. Impacts include poorer air quality, increased noise and potential of road traffic accidents (Strategic Rail Authority, 2003). There is also the issue of community severance which can occur if a congested road runs through a community's area. This can have the effect of placing a barrier in the community, which people are unwilling to cross in high traffic conditions (Strategic Rail Authority, 2003). These impacts may be described as a function of the number of Lorries arriving at the facilities per day.

Lorries delivering waste feedstock may be refuse collection vehicles (RCV), heavy goods vehicles (HGV) or both. These have different average payloads as indicated below. Calculations include deliveries at the Waste Transfer Stations in the EfW option, as well as for the EfW plants themselves.

Key assumptions include:

- All facilities (Waste Transfer Stations and EfW destinations) open for 5.5 days a week (Gershman et al., 1986).
- Average payloads for collection and transfer trucks are 7 and 21 tonnes respectively (Biffa, 2002).

At any facility, transfer station or EfW facility, the total lorry deliveries per day was calculated by dividing the planned throughput of residual waste by the number of working days in a year and by the average payload of the lorry. The total numbers of deliveries at the EfW plant/s were input into the MCDA model.

8.4.2. NO. 2: JOBS CREATED

This criterion is defined as the total number of jobs created by all facilities in any one EfW option by 2011 – the assumed operational year for all Option facilities. The data input into Figure 41 is shown in Table 29.

Table 29: Combustion capacity and job creation data.

Source	Capacity	No of Jobs created
Environment Agency (2006b)	265,000	53
WRG (2007a)	150,000	35
Environment Agency (2006b)	136,000	29
Sita (2005)	60,000	27
Talbott (2005)	24,000	10
Turner (2005)	230,000	70

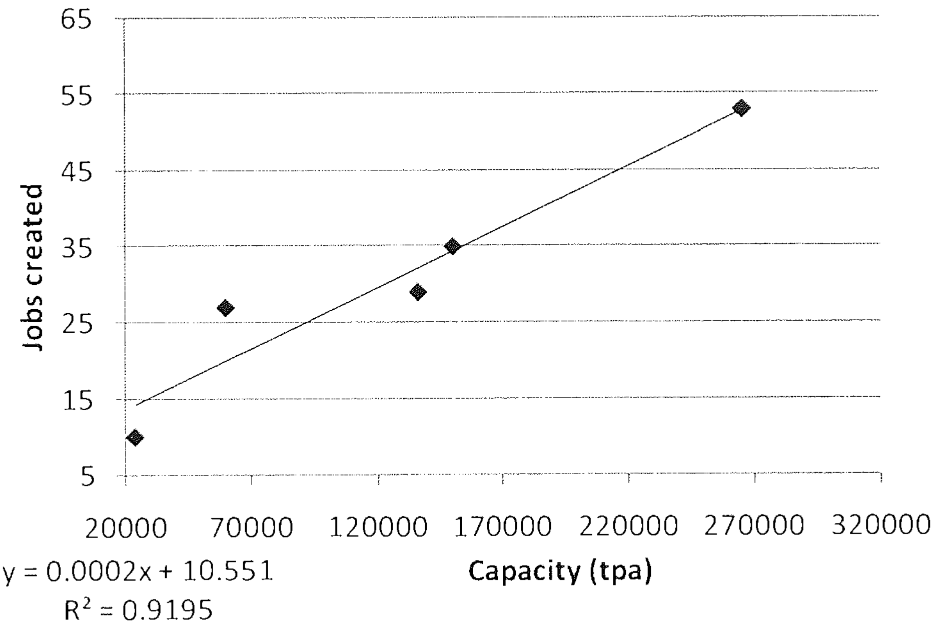

Figure 41: Regression model: Jobs vs Capacity for combustion technology.

Data obtained from some sources (Turner, 2005), was not included since the number of both full and part time jobs could not be distinguished. The model shown in Figure 41 was used to derive the number of jobs created for operating 180, 60 and 30 ktpa combustion plants. These values were aggregated by the number of plants in the option to calculate the total number of full time jobs created in any EfW combustion option. The number of full-time jobs required in the 60 and 30 ktpa ATT technology options were estimated by Compact Power and used directly.

8.4.3. Nos. 3 & 4: Health of local community (Dioxin production) and air emissions criteria

Scores were calculated by deriving the volume of flue gases (Nm^3) emitted by the combustion of all EfW option residual MSW throughputs in a year according to the waste composition assumptions in Table 6 of Section 5.3.2. The Combustion option has been characterised by Lurgi technology (Fichtner, 2004). The flue gas volume from the Compact Power process can also be assumed to be equal to that of combustion plant, since the gases produced by the Pyrolysis and Gasification stages are combusted in the final oxidation stage requiring excess air (Section 1.3.5.2). This volume was multiplied by the emissions concentration factors shown in Table 30 to calculate ng ITEQ of dioxins and furan production for the 'Health of the community' criterion and mg of other emissions for the 'Emissions to air' criterion. The latter includes Carbon Monoxide (CO) Sulphur Dioxide (SO_4), Particulate matter (PM_{10}), Nitrous Oxides in the form of Nitric Oxide and Nitrogen Dioxide (NO and NO_2), Hydrogen Chloride (HCL), Hydrogen Fluoride (HF) and Mercury (Hg). In order to meet their PPC (Pollution Prevention and Control) obligations, EfW facilities must meet MCERTS or an equivalent standard, which state that measurements must be within 4% error (Hardy, 2009). Therefore, the accuracy of using data from actually operating facilities is reasonable.

Table 30: Emission levels of dioxins and furans for Combustion and ATT technologies (Fichtner, 2004).

Corrected to WID reference condition of 11% O_2

Criteria	Indicator	Units	Lurgi Combustion	Compact Power Pyrolysis and Gasification
Health of local community	Dioxins and Furans	ng ITEQ/Nm^3	0.03	0.003
Air emissions	Carbon Monoxide	Mg/Nm^3	5	2
	Nitrous Oxides		200	37
	Sulphur Dioxide		20	1
	Particulates		1	2
	Hydrogen Chloride		7	2
	Hydrogen Fluoride		0.2	0.1
	Mercury		0.0034	0.005

To add detail to criteria such as those identified as being used in waste management appraisal tools in Section 4.2, it is possible to use sub-criteria in MCDA. It is possible to aggregate these sub-criteria scores, but to allow meaningful use; a method of aggregation must be defined. For example, the criterion 'Emissions to air' has included air emissions such as Sulphur Dioxide, Particulates and Nitrous Oxides which could be defined as sub-criteria with the aim of preference being to minimise production. Depending on EfW technology the quantities of these emissions will differ (as indicated in Table 30), and so will their impact. Emissions performance scores (metric tonnes/yr) were multiplied by equivalency factors from Hermann et al, (2007) and Baumann & Tillman (2004) to estimate their relative human toxicity potential (HTP) in terms of $C_6H_4CL_2$ (Dichlorobenzene). This is an organic compound and anticipated as a carcinogen (IARC, 2007). Acidification potential (AP) was estimated in terms of SO_2 (g Sulphur Dioxide/g) equivalent. Photochemical Oxidation potential (POCP) was estimated in terms of ethylene (kg Ethylene/kg). In demonstrating the approach, Table 31 provides an example of how equivalency factors have been applied to estimate and aggregate the overall impact of the emissions to air from combustion options.

Table 31: Human toxicity potential equivalency factors for air emissions from combustion EfW facilities.

	Metric tonnes/yr	Equivalency			Impact		
		p-$C_6H_4CL_2$	g-SO_2	kg-Ethylene	HTP	AP	POCP
Carbon Monoxide	4.2	-	-	0.03	-	-	0.11
Nitrous Oxide	168.3	1.20	0.7	0.03	201.97	117.82	4.71
Sulphur Dioxide	16.8	0.10	1	0.05	1.68	16.83	0.84
Particulates	0.8	0.82	-	-	0.69	-	-
Hydrogen Chloride	5.9	13	0.88	-	76.58	5.18	-
Hydrogen Fluoride	0.2	-	1.6	-	-	0.27	-
Mercury	0.034	6000	-	-	20.20	-	-
				Total	**301.12**	**140.10**	**5.63**

In examination of the emission levels in Table 30 for dioxin production, values from Porteous (2005) indicate that combustion technology can perform significantly better than the value from Fichtner (2004) at between 0.006 (measured best practice in the UK) and less than 0.01 (at the European mean level). Data from Williams (2005) shows that dioxin emissions can range between 0.0002 and 0.08 for European mass burn incinerators using combustion. These two different sources indicate that the values can range significantly and can be superior as well as inferior to the performance value provided for the CPL ATT technology. Like the range of data from references regarding combustion, other ATT performance values from Fichtner (2004) for dioxin production range from 0.0009 to 0.001 ng ITEQ Nm^3. Independent monitoring of dioxin production from the Energos ATT facility at Forus, Stavanger, Norway for due diligence purposes reported a value of 0.001 ng ITEQ Nm^3 (Fichtner, 2009). This suggests that the value used for Compact Power representing the ATT options is reasonable.

Using the same references, similar arguments are valid for the other emissions to air such as Nitrogen Oxides, Carbon Monoxide, Particulates, Sulphur Dioxide and Hydrogen Chloride. The range of values for both combustion and ATT suggest that emissions to air are not a factor of the overall technology but are related to the flue gas cleaning equipment that is generic to both thermal conversion technologies. That said, there is evidence that ATT facilities use less equipment to meet WID standards for emissions to air and this has been discussed in Section 1.3.5 where it is noted that the Compact Power and Energos ATT reference facilities use only a bag filter, have little or no use for De-NOx equipment and no electrostatic precipitators or scrubbers. The differences between ATT and combustion technology in an overall appraisal are therefore more likely to be in the capital costs rather than in operating emissions to air data.

During data collection, it was apparent that many other published sources providing operating plant data (Sita, 2005; Environment Agency, 2006b) for dioxins and other emissions to air from combustion incinerators were not the actual recorded amount, but simply that required by the Waste Incineration Directive (Appendix A.2.4). Since all EfW technologies must meet WID requirements, these sources could not be used to compare technology performance. The range of dioxin production performance values for both combustion and ATT from commercial and non-commercial sources suggest that a sensitivity analysis is appropriate, especially since the 'Health of the Community' criterion weighting is the second highest of all weightings in the overall MCDA model for both WDA areas. The sensitivity of assuming that all technologies run at WID requirements on the overall appraisal results is investigated in Section 9.3.1.2. In support of this approach, there is little incentive for operators to emit less emissions and dioxins to atmosphere than the WID limits although the data suggests that in practice this is not the case. Guarantees offered by developers are often to WID limits in order to ensure a safe margin to avoid litigation and to minimise operating costs.

8.4.4. NO. 5: EMISSIONS TO LAND

This criterion is defined as the annual tonnage of bottom ash and fly ash produced by all facilities operating in order to process the total amount of residual MSW in each WDA area. Figure 42 shows the derived relationship between fly ash produced and combustion facility capacity data provided in Table 32. In achieving an R^2 value of 0.943, it was necessary to omit the data from Fichtner (2004) at 100 ktpa.

Table 32: Combustion capacities and bottom/fly ash production.

Source	Capacity (tpa)	Bottom ash (tpa)	Fly ash (tpa)
Turner (2005)	230,000	48,000	8,000
Environment Agency (2006b)	130,000	31,163	5,712
	120,000	7,680	3,720
Fichtner (2004)	100,000	21,353	2,265
Sita (2005)	27,147	5,158	1,303

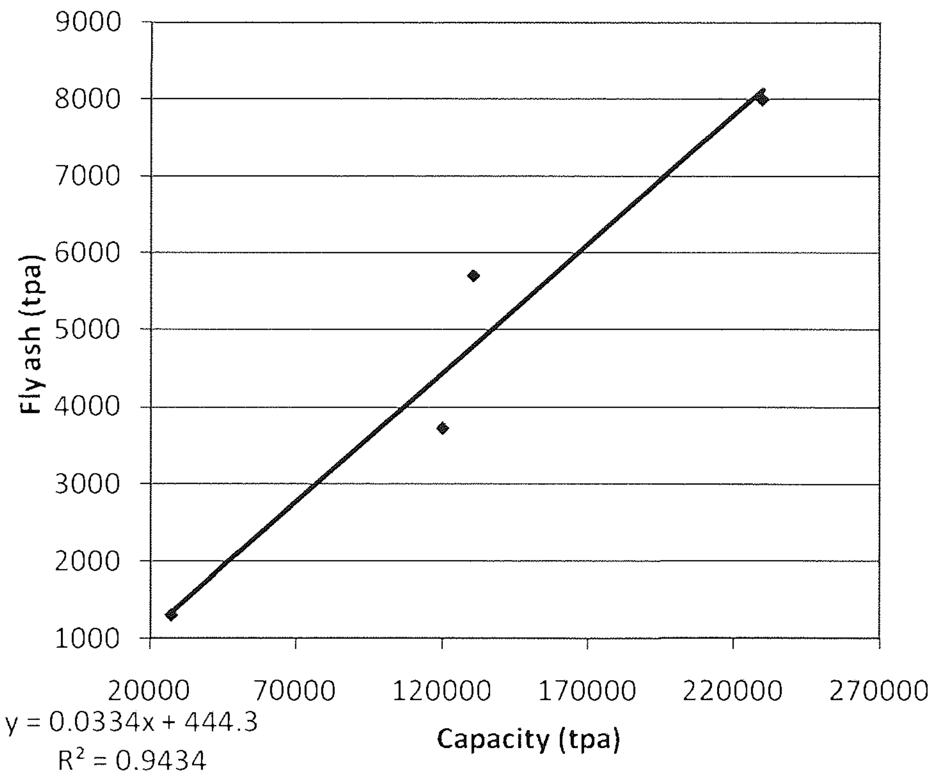

Figure 42: Regression model: Combustion Flyash vs Capacity.

The relationship shown in Figure 43 has been calculated with a reasonable R^2 of 0.998 but only by including data from moving grate combustion. At a 120 ktpa capacity, the FBC facility (Environment Agency, 2006b) produced only 7.7 ktpa of bottom ash – some 12 ktpa less than the model predicts for moving grate technology at the same scale.

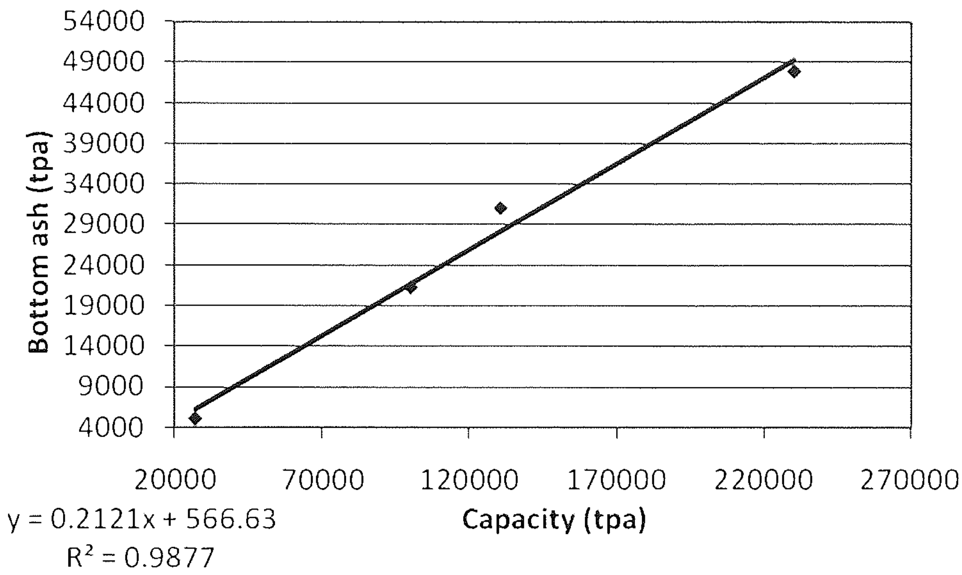

Figure 43: Regression model: Combustion Bottom ash vs Capacity.

Figure 44 shows a check of the Compact Power sourced data regarding flyash production with that from Fichtner (2004) in Table 33. The curve shows that the relationship is positive and linear with a good R^2 value of 0.998. In comparison, data from the operating Energos ATT facility at Forus, Stavanger, Norway shows almost the same ash residue production to that predicted by the linear regression model for combustion technology shown in Figure 42 when scaled to 60 ktpa. The Energos ATT gasification technology is significantly different to the Compact Power technology and has more similarities to combustion in that it re-circulates a similar proportion of flue gas combustion air through its secondary oxidation chamber. The Compact Power technology does not re-circulate combustion air before passing the flue gas to the bag filter for treatment. For this reason, together with the adequate crossreference to the independent Fichtner (2004) study data, the Compact Power data for fly ash production has been directly used from source.

Table 33: ATT Pyrolysis/Gasification bottom and fly ash production data.

Source	Capacity	Bottom ash	Fly ash
Fichtner (2004)	100,000	19,598	945
Compact Power (Beswick, 2006)	60,000	6,489	603
Compact Power (Beswick, 2006)	30,000	3,244	302

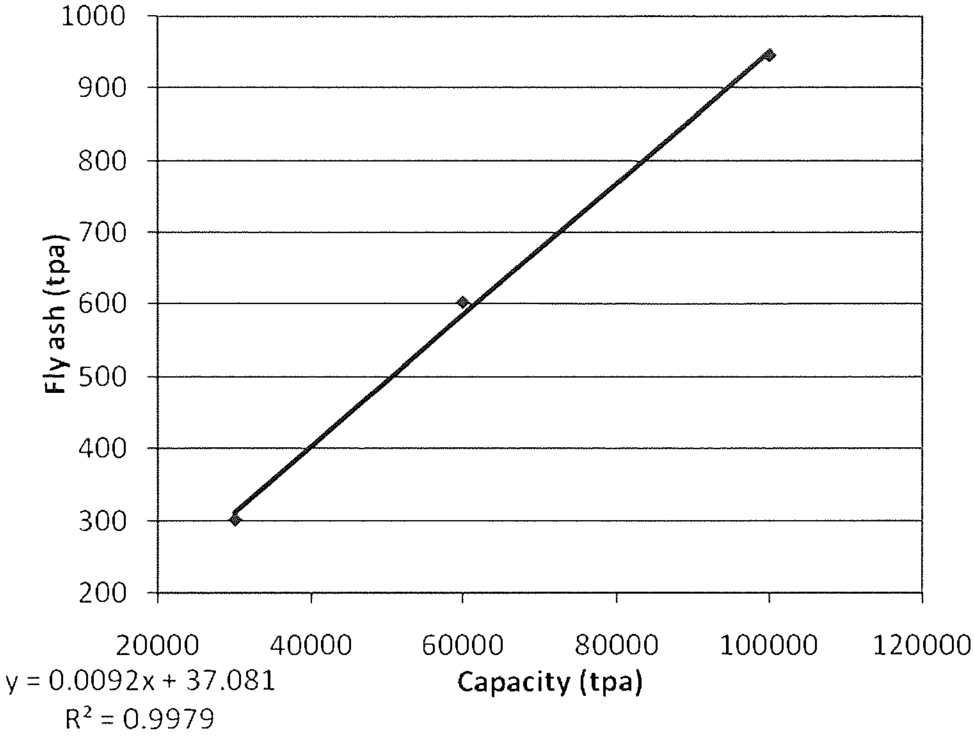

Figure 44: Regression model: Pyrolysis & Gasification (CPL) Fly ash vs Capacity.

Figure 45 shows a check of the Compact Power (CPL) sourced data regarding bottom ash production with that from Fichtner (2004). Fichtner (2004) predict that a much greater amount of bottom ash will produced at the 100 ktpa level compared to the CPL data. This may reflect assumptions on the feedstock, in that CPL may assume that inert recyclates have already been extracted from the waste feedstock before thermal conversion.

Using linear extrapolation with the combined Fichtner (2004) and in-house CPL data overestimates bottom ash generation at 60 ktpa and significantly underestimates at the 30 ktpa scale, therefore, the provided data point from Fichtner (2004) at 100 ktpa has been linearly scaled to calculate the impact implication of the need to dispose of bottom ash input into the MCDA at 60 and 30 ktpa capacity. This is viewed by the author as a more representative measure of performance, since the study assumes that residual MSW after recyclates have been extracted will be thermally treated. The Fichtner (2004) report has also been produced from an independent study; hence, this data has been used to represent the ATT options. The value from Fichtner (2004) is within 88% of the combustion value, while actual operating data from the Energos ATT gasification facility in Forus, Stavanger, Norway suggest a value of 77% that of combustion technology at 60 ktpa (Midtbust, 2009).

In contrast, the CPL data suggest a value of 49% that of combustion. This is not reasonable, since modern incineration methods for waste regardless of whether they are combustion, gasification or pyrolysis must ensure sufficient burn out of the carbon content to be within 3% Total Organic Carbon (TOC) as dictated by the Waste Incineration Directive (Appendix A.2.4). There should be an insignificant difference between technologies in the production of bottom ash if they are all processing the same composition of waste which has been subject to the same extent of pre-treatment. The latter includes ferrous separation and removal of other inerts such as metals and glass. To enable fair comparison of results, this project has assumed that all EfW options will process the same waste composition in each WDA area.

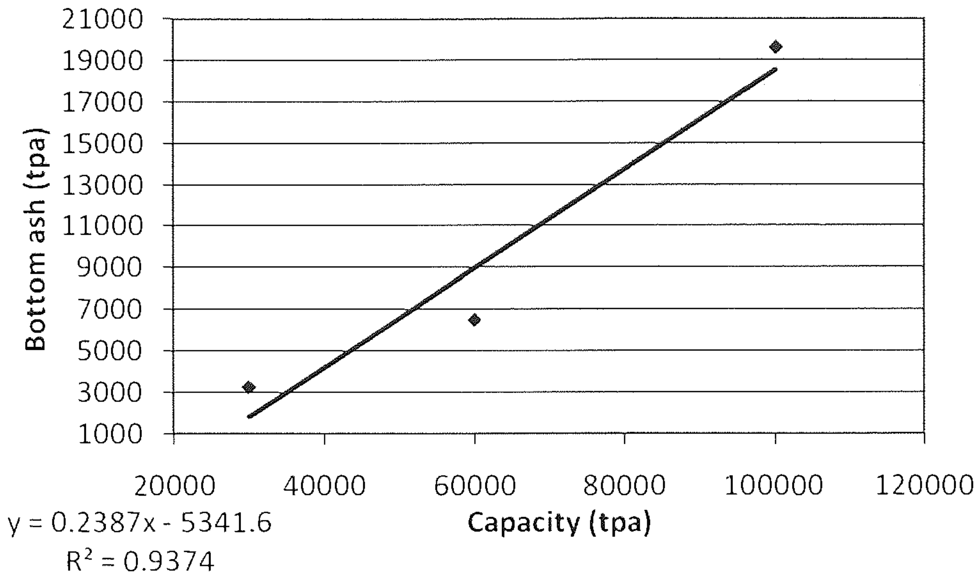

Figure 45: Regression model: Pyrolysis & Gasification (ATT) Bottom ash vs Capacity.

A monetary impact factor has been applied to each 'Emissions to land' sub-criterion in the aggregation and estimation of the potential impact of before input into the MCDA model. The different monetary values of £70/t and £185/t for bottom and fly ash respectively (Beswick, 2006) reflect the potential severity of impact. An example of monetary factors applied to a centralised combustion EfW option is shown with the final score (in bold) in Table 34. Fly ash arises from from particulate removal using air pollution control equipment and includes reagents such as lime that is used to remove pollutants from the flue gas streams. The hazardous nature of fly ash derives from the use of the lime which is alkaline and significantly higher fees are charged for its disposal. Bottom ash should be inert and is either disposed of to non-separated landfill or in some cases, used for building aggregate (Porteous, 2005). It was observed by the author that bottom ash from the ATT facility in Avonmouth was being sent to non-hazardous landfill, indicating that it has been fully oxidised.

Table 34: Example of monetary impact factors applied to 'Emissions to land' sub-criteria in the aggregation process.

Ash produced (Tpa)		Annual Cost of disposal (£)		Total annual cost (£) input into MCDA
Bottom ash	Fly ash	Bottom ash	Fly ash	
38,700	6,400	2,709,000	1,184,000	**3,893,000**

8.4.5. NO. 6: WATER DISCHARGE TO SEWER

Thermal treatment processes for waste use water for; continuous and intermittent blowdown of steam drums and boilers, equipment and facility washdown, pre-treatment filter backwater; humidification of flue gas for improved lime/Sodium Bicarbonate consumption; bottom ash quench, site drainage and sanitary water used by operatives (Gershman et al, 1995; McDougall, 2009). This criterion has been scored by using an average of the figure that combustion plants produce: between 0.15 and 0.3 m^3 of water for every tonne of MSW capacity (Williams, 2005). This method uses the assumption that scale has no effect on the volume of water required and the relationship is linear. Older estimates from Gershman et al, (1995) indicate that water to effluent is 0.1 m^3 of water for every tonne of MSW capacity, but this data has been rejected due to the fact that combustion has developed significantly since 1995 with higher operating temperatures and the introduction of the Waste Incineration Directive that calls for far improved emissions to air and therefore greater use of water in flue gas cleaning.

No supporting third party data regarding the Compact Power ATT process could be found, hence, discharges of 6.2 and 3.1 ktpa for 60 and 30 ktpa facilities respectively (Beswick, 2006) were input into the MCDA. As in the case of the emissions to land criterion scores, data supplied by CPL showed a positive linear relationship with scale. It is interesting, that on this basis the CPL ATT uses 0.1 m^3 of water for every tonne of MSW capacity throughput. These data certainly represent ATT as 'cleaner' technology and are supported by water consumption data describing other ATT technologies in Fichtner (2004) although it should be noted that with the exception of the Energos technology these are no longer available on the market. The Energos, Brighstar and Thermoselect technologies use 0.13, 0.14 and 0.07 m^3 of water for every tonne of MSW capacity. Although these data come from commercial sources and have been collated and compared by Fichtner (2004), they cross-reference well and this indicates that the data from CPL is reasonable.

8.4.6. NO. 7: INDIVIDUAL SITE FOOTPRINT

Data was more widely available for this criterion and less difficult to research than for others. Unfortunately, many had to be omitted due to the problem that the land area required in development sometimes included or excluded supporting buildings as well as the EfW technology itself. For example, car parks, office buildings or front-end Material Recycling Facilities (MRFs) and Refuse Derived Fuel (RDF) processing (Enviros, 2004) all add area to the site (Fichtner, 2004). For example, a 50 ktpa EfW facility described in Enviros (2004) had a landtake of 54,000 m^2 due to an RDF processing plant co-located on the same site. The derived relationship from the data in Table 35 is shown in Figure 46 with a reasonable R^2 value of 0.929.

Table 35: Combustion Capacity and Landtake data.

Source	Capacity (tpa)	Total landtake (m^2)
Gershman (1986)	18,250	8,094
Gershman (1986)	36,500	12,141
Enviros (2004)	50,000	15,000
Gershman (1986)	73,000	16,188
DEFRA (2007)	90,000	17,000
Gershman (1986)	91,250	20,235
Fichtner (2004)	100,000	15,000
Environment Agency (2006b)	136,000	20,000
Enviros (2004)	250,000	40,000

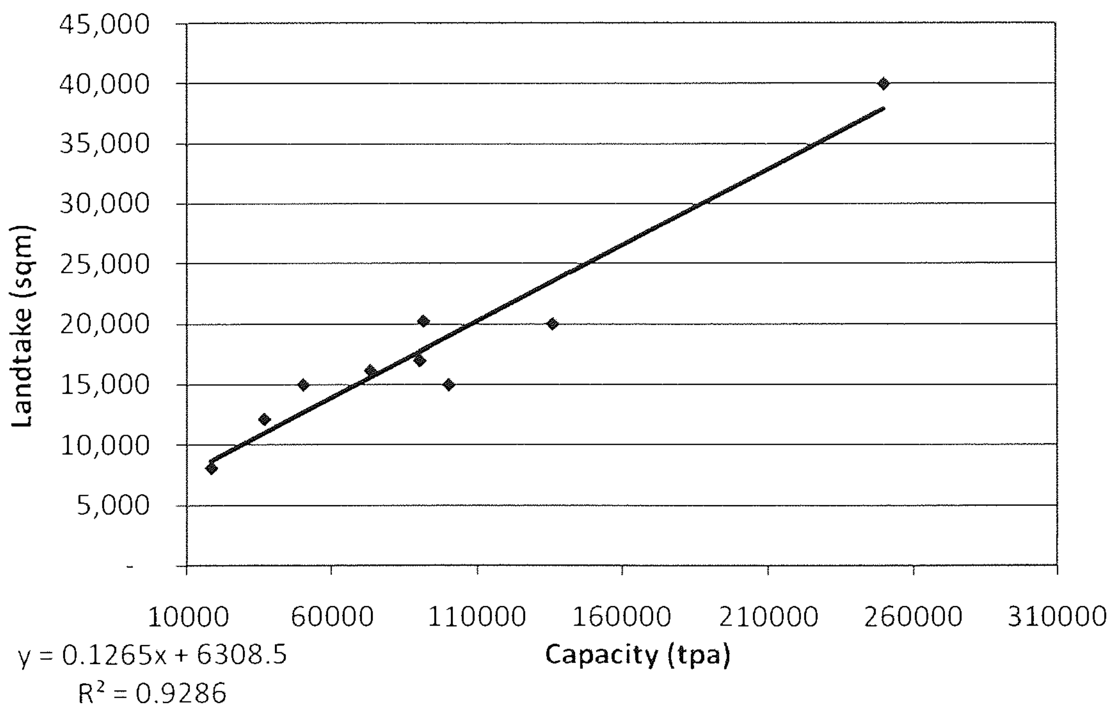

Figure 46: Regression model: Combustion Landtake vs Capacity.

Figure 47 shows a check of the Compact Power (CPL) sourced data regarding land take with that from Fichtner (2004). The relationship is positive and linear with an R^2 value of 0.998. This is not expected, since, theoretically plant size increases volumetrically. Therefore less land should be used for larger capacity throughput facilities. The provided data from CPL has been directly input into the MCDA at 60 and 30 ktpa. It is interesting to note that when using the models for Combustion and the ATT process, the land area required for combustion is more than twice that for ATT at a 30 ktpa scale. At 60 ktpa however, the models predict that combustion requires only a third more land area. This is not expected, since a modular system characterised by the low height of the components would use more land area, than a system of components with larger heights, such as the furnace of a combustion unit (Fichtner, 2004) processing the same waste tonnage. Alternative sources of data suggest that the ATT process actually requires 70% more land area at 30 and 60 ktpa (Enviros, 2004) but this is likely to be an overestimation taking into account pretreatment halls and visitor centres. The scores for the ATT process have therefore, been used since they correspond well with the check provided by the Fichtner data.

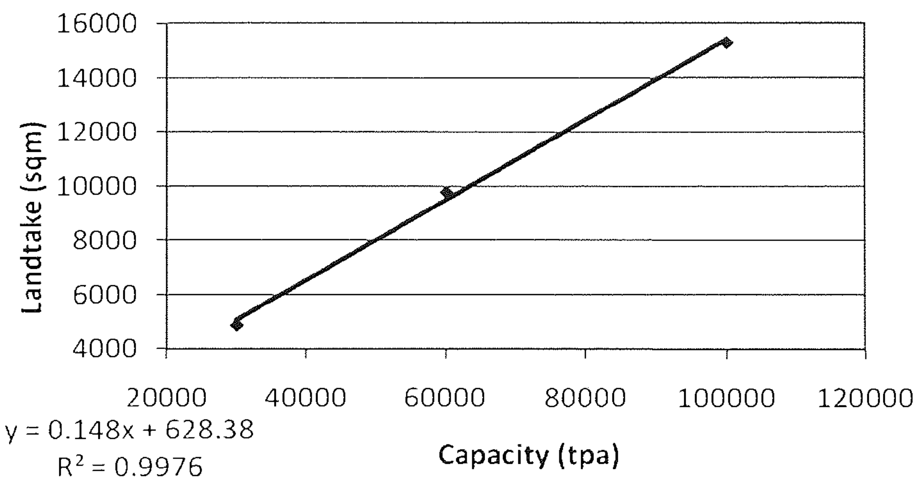

Figure 47: Regression model: Pyrolysis & Gasification (ATT) Landtake vs Capacity.

8.4.7. No. 8: Individual plant site visual impact

Building and stack heights are factors that heavily influence the degree of visual impact any EfW facility has within its environment. Visual impact is an important factor considered in any Environmental Impact Assessment (Appendix A.2.2) required in order to gain planning permission. Building heights are relatively standard for each technology and are influenced by scale in the case of combustion, with larger capacity plants demanding higher furnaces. Collected data is shown in Table 36.

Table 36: Building and stack height data of combustion plant.

Source	Capacity (ktpa)	Building height (m)	Stack height (m)
Enviros (2004)	50	20	75
Enviros (2004)	50	-	40
Enviros (2004)	56	-	55
Sita (2005)	60	-	67
Enviros (2004)	90	-	65
Fichtner (2004)	100	30	-
Environment Agency (2006b)	135	-	93
Turner (2005),	230	-	92
Enviros (2004)	250	27.5	100
Enviros (2004)	250	40	70

Figure 48 shows that a relationship may exist between scale and the height of building or stack. The diagram and R^2 values indicate however, that the relationship is greatly influenced by other factors. The stack height is a function of the emissions in the flue gas, the volume, and also of the geographical surroundings, which are unique to every site (Fichtner, 2004). If a facility was located in a valley, for example, a higher stack would be required, related to the technology used. The derived regression models shown in Figure 48 have not been used to derive the inputs for the MCDA model. Instead the data in Table 36 has been grouped into plants that are less or greater than 100 ktpa. Averages of 20 and 60 metres have been taken to represent building and stack height for combustion plants smaller than 100 ktpa. Averages of 33 and 89 metres have been taken to represent building and stack height respectively of combustion plants larger than 100 ktpa.

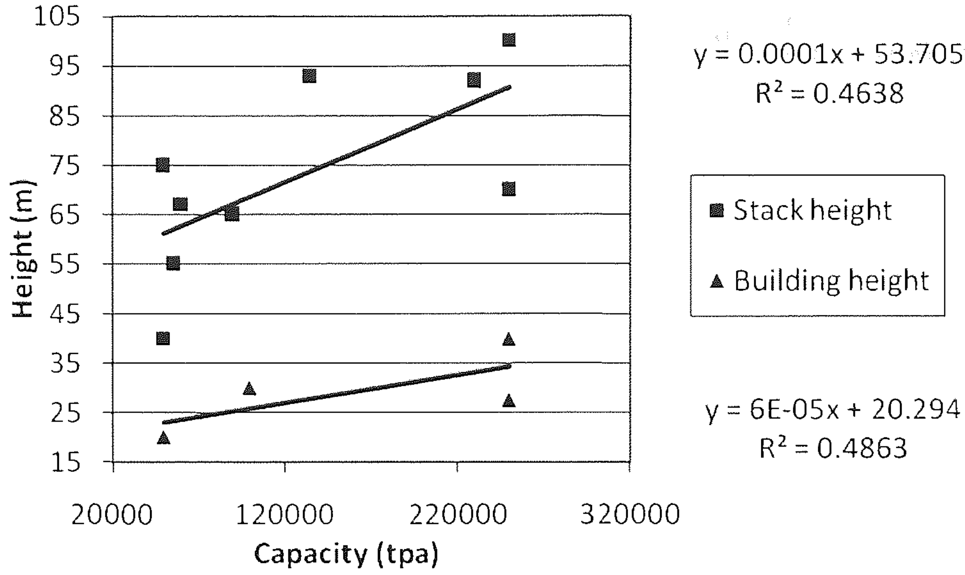

Figure 48: Combustion Building and Stack Height regression models.

To represent ATT, the Compact Power building height of 10m was used for both 30 and 60 ktpa facilities (Fichtner, 2004). Stack heights of 20 and 25m was assumed for 30 and 60 ktpa facilities respectively, sourced from company data (Beswick, 2006). Where overall EfW options of either ATT or combustion technology had a combination of 30 and 60 ktpa facilities, averages of all facility stack and building heights were input to represent the EfW option in the MCDA model.

8.4.8. NO. 9: DISPLACED FOSSIL FUEL CO_2 EMISSIONS

In order to calculate the displaced fossil fuel derived CO_2 emissions, from generating electricity in EfW plants instead of conventional power stations, it is necessary to know the electrical conversion efficiencies of plants at different scales of capacity. These are shown in Table 37. Typically, it has been argued that the larger the plant, the greater the efficiency (Consonni et al., 2005b; Wheeler and Jainter, 2006). Figure 49 suggests that this may be true to a point, since efficiencies do increase with scale overall. It is notable that two plants at the 150 ktpa scale are more efficient than what the model predicts. This may be explained by the fact that they have recently been commissioned and the age of the technology may be more of an influencing factor than scale of facility.

Table 37: Combustion facility efficiencies.

Source	Capacity (ktpa)	Net electrical capacity (MW)	Electrical Efficiency
Environment Agency (2006b)	245	20	26%
Ilex Energy (2005)	215	18	26%
Ilex Energy (2005)	90	7	24%
Ilex Energy (2005)	105	8	24%
Ilex Energy (2005)	150	13	27%
Ilex Energy (2005)	130	10	24%
Environment Agency (2006b)	135	12	28%
Fichtner (2004)	100	-	23%
Consonni et al, (2005a)	65	-	21%
Consonni et al, (2005a)	390	-	29%
Sita (2005)	60	-	22%

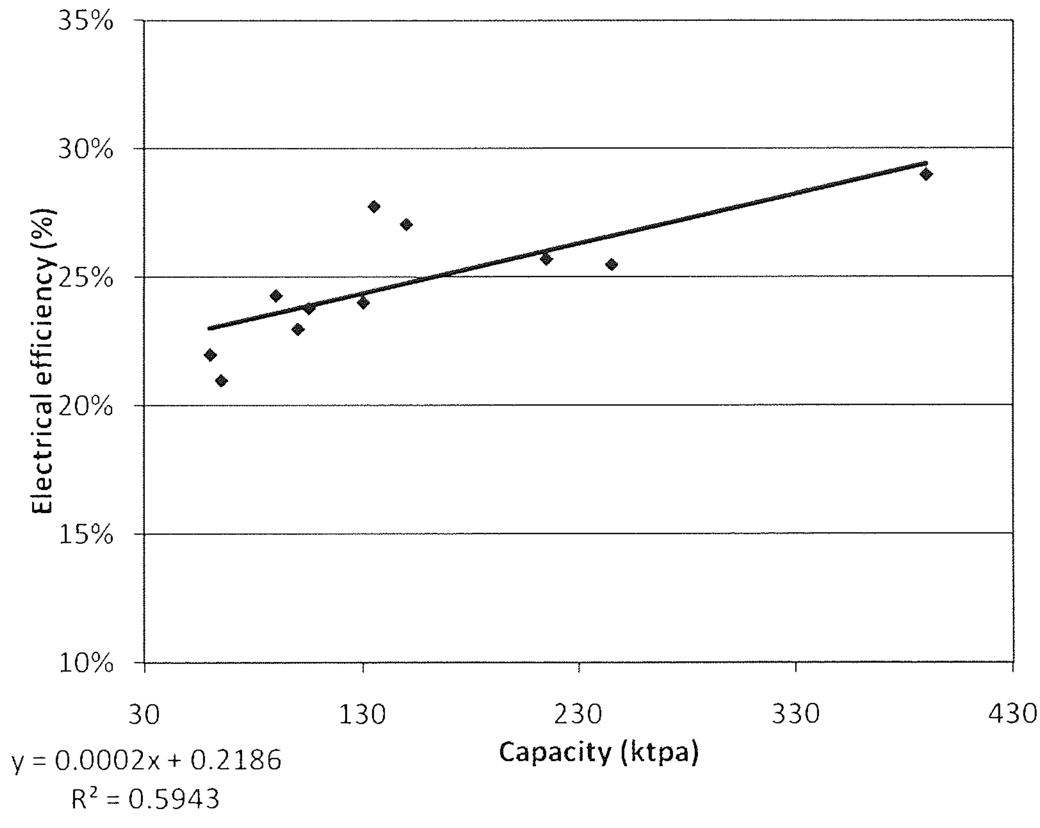

Figure 49: Regression model: Combustion electricity generation efficiency vs capacity.

The electrical efficiency for the Compact Power ATT process at 30 and 60 ktpa was assumed to be 14%, as published by Fichtner (2004) at 100 ktpa. Interestingly, Compact Power predicts a net electrical efficiency of 21% (Beswick, 2006). It has been argued, however, that this figure did not take into account the additional loads of pre-treatment and shredding of the waste before thermal conversion (Fichtner, 2004). In avoiding commercial sources of data, the more conservative estimate of 14% was used in calculations of scores for the MCDA model

The calorific value of the input MSW for all EfW options was assumed to be a lower heating value (LHV) of 10.11 MJ/kg (Consonni et al., 2005a). The gross primary energy of the fuel was multiplied by the electrical conversion efficiency, dictated by the model for the relevant scale to derive electrical output in MWh for each combustion EfW option. No assumption was made for plant availability since calculations were derived for a fixed amount of waste feedstock throughput.

Other studies have assumed that EfW displaces coal-fired electricity generation (Higham, 1999; Jainter and Poll, 2005), however, using this assumption can accentuate the true carbon-saving worth of using waste to produce electricity (Hogg, 2002). Instead an average of all the fossil fuel-derived CO_2 emissions from electricity generation from coal, oil and gas was used (see Table 38). Displaced fossil-fuel CO_2 emissions from all plants in any one EfW option were aggregated and input into the MCDA model.

Table 38: Grams of carbon per kWh of electrical output (DTI, 2000).

Fuel	gC/kWh
Coal	263
Gas	119
Oil	268
Average	183

8.4.9. No. 10: Total external costs of road transport

These external costs include accidents, road repair, noise, air pollution, as well as community severance and the visual impact of HGVs. The value has been inflated from the 2003 level of 51p (Strategic Rail Authority, 2003) to 56p per lorry mile (2006) using the RPI. This parameter was chosen because the WDA officers reported that weighting the criteria scores based on monetary values was easier that weighting quantities of emissions for example. In addition this parameter includes further externalities (impacts on third-parties) such as road traffic accidents, congestion, road wear and noise. The value per lorry-mile is multiplied by the distance required to supply all facilities in the EfW option with residual waste feedstock from their respective catchments (Section 7.2).

8.4.10. No. 11: Net cost per tonne of MSW processed (NCT)

The NCT parameter describes the minimum 'gate fee' required to make a breakeven case for developing the facility and has been used as the key indicator to represent the economic cost of EfW process technology in each of the options examined. NCT accounts for capital and operating expenditures, as well as the costs of financing and revenues accrued from energy production as shown in Table 39. In the case, where ATT qualifies for Renewables Obligation Certificates (essentially a premium for green electricity described in Appendix A.1.1), this extra value has also been taken into account.

Table 39: Factors taken account of in the derivation of NCT values from the literature.

CAPEX	OPEX	REVENUES
Process equipment	Plant manning	Gate fee for waste management
Civils engineering	Auxillary fuel	Materials recovery
Labour costs in project design, construction and commissioning	Water consumption	Sale of heat energy (steam or hot water)
Building engineering	Flue gas cleaning consumables	Sale of electricity
Project development costs	Operating and maintenance contracts	Sale of residues
Insurance, licence fees and bonds		
Site acquisition		
Financing		

Within Capital expenditure, process equipment includes all items of the working facility, the main components of which are; furnaces, boilers, turbines, flue gas cleaning and condensers. Another key area of expenditure can be the pre-construction development costs, which includes the need for an Environmental Impact Assessment (EIA) and achievement of planning and pollution control permitting. As part of these requirements, public consultation, emissions dispersal modelling, geo-technical studies and other data collection surveys will be necessary to commission.

Operating expeditures includes the labour costs of employing plant managers, operatives, fitters and maintenance engineers as well as consumables such as water, sodium becarbonate/lime and activated carbon. Operating and maintenance contracts are often outsourced but include the costs of spares, repairs and associated labour costs. The revenues on which EfW facilities depend on for favourable project economics are primarily the gate fee (per tonne of waste processed) and electricity sales. Other revenue streams include the recovery of ferrous materials, sale of bottom ash for aggregates recycling or heat production in the form of steam and hot water.

Using data from the literature (Murphy and McKeogh, 2004; Consonni et al., 2005b) it was possible to derive a relationship for combustion facilities between net cost per tonne (NCT) and scale with a reasonable R^2 value of 0.914 (shown in Figure 50). Values from other sources such as Enviros (2004) and Environment Agency (2006b) were rejected since they did not include detail as to how they had been derived and under what assumptions. In order to derive the NCT data in Table 40 on a consistent basis, total annualised capital and operating costs (minus energy revenues) were calculated assuming a 7% discount rate over a project lifetime period of 20 years (Consonni et al., 2005b).

Table 40: Combustion facility gate fees on an NCT basis.

Source	Capacity (ktpa)	Capital cost €/tpa	Operating cost €/t	NCT (£/t, 2006)
Murphy & McKeogh, (2004)	40	650	48.8	82.36
Consonni et al, (2005b)	65	-	-	90.73
Murphy & McKeogh, (2004)	120	560	42	70.92
Murphy & McKeogh, (2004)	230	560	36.5	63.89
Consonni et al, (2005b)	390	-	-	43.90
Murphy & McKeogh, (2004)	420	430	28	49.04

The original data were inflated to 2006 prices from 2003 prices (rates used are shown in Table 41). Exchange rate used in May 2006 was 0.671 Euro to 1 Pound Sterling.

Table 41: Interest rates used 2003-2006 (National Statistics, 2008).

Year	Inflation rate (%)
2002	1.7
2003	2.9
2004	3.0
2005	2.8
2006	1.9

Using the same assumptions as above, £54/t and £63/t for 60 and 30 ktpa facilities were calculated for ATT respectively (Beswick, 2006). No other sources of data for the ATT Compact Power process could be found to cross-check these values. This is because the technology has not yet been constructed at the 60 and 30 ktpa scale, and the NCTs used here are from commercial spreadsheet models. The values include the revenues from electricity generation but not the costs of site acquisition, which can vary significantly. Where facilities had a combination of 30 and 60 ktpa facilities, averages of both capacity prices (30 and 60 ktpa) were input to represent the EfW option in the MCDA model. It is acknowledged that the ATT NCT is below that expected in comparison with combustion values (shown as red square points in Figure 50). This may be due to commercial influences affecting conservative estimation. Therefore, in Section 9.3.1.1, MCDA models have been run using the same NCT values for both technology types in the sensitivity analysis to determine the effects of this on the final preferred option results.

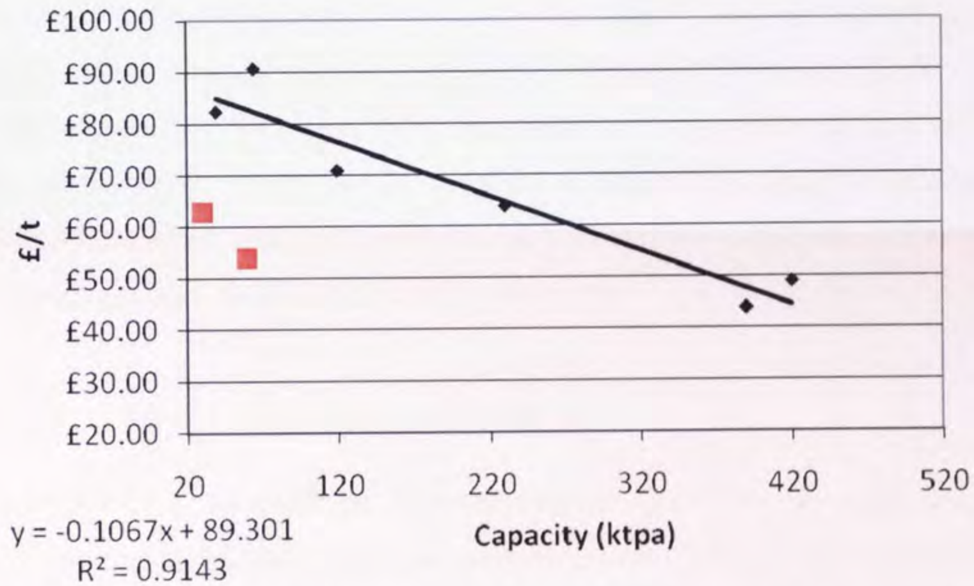

Figure 50: Regression model: Combustion Net cost per tonne of MSW processed vs Capacity.

8.4.11. NO. 12: COST OF WASTE TRANSFER STATIONS AND TRANSPORT MOVEMENTS

This criterion has two indicators. Sources suggest that the monetary cost for building, owning and operating a Transfer Station is £5.72/t (Biffa, 2002; US-EPA, 2002). This was derived from $10/t, converted by 2002 exchange rate ($1.75:£1) and inflated to 2006 prices (Table 41) and includes the costs of labour and capital and assumes that all WTS have not already been built. This value was multiplied by the total tonnage of waste bulked up for transport at Waste Transfer Stations in each EfW option. The total tonnage is dependent on the guidance of the case study areas waste planning documents (CCC, 2003; Jainter and Poll, 2005). The second indicator is the estimated monetary cost of transporting waste to the facilities in an EfW option as well as the ash to final disposal destinations. The average cost per lorry mile travelled is £1.72 (Biffa, 2002). This was derived from $10/t, converted by 2002 exchange rate ($1.75:£1) and inflated to 2006 prices (Table 41). This figure takes into account the cost of fuel, maintenance of the vehicle, tax and the wage of the driver. The value was multiplied by the distance required to supply all facilities in the EfW option with residual waste feedstock from their respective catchments. The derivation of these scores was the subject of Sections 7.2 and 7.3.

8.4.12. NO. 13: TECHNICAL MATURITY

Section 4.2.3.1 discussed the importance of proven technologies and what can be considered technically 'mature' (Malkow, 2004; Consonni et al., 2005a; Porteous, 2005). In the UK, a great amount of emphasis is placed on technologies that are already developed and operating within the country (Jainter and Poll, 2005; Poll and Oglivie, 2005; Wheeler and Jainter, 2006) and WDA officers indicated they needed confidence that technologies were deliverable within the UK market. This project has, therefore, defined this criterion as the number of facilities currently operating in the UK on MSW feedstock at a scale consistent with the options defined in this project at 180, 60 and 30 ktpa. In 2005, there were 17 EfW plants using combustion technology representing a range of scales in the UK (Williams, 2005). By 2006, there were 19 plants (ILEX Energy, 2005). There are no pyrolysis/gasification ATT facilities operating at the required scales of 60 and 30 ktpa in the UK at present, to satisfy the scenarios of this project. Values of 19 and zero for combustion and ATT options, respectively, have been input into the MCDA model. This is expected to change shortly however, since Energos and Compact Power expect to have new facilities to be built under the New Technologies Demonstration Programme (Appendix A.3.3). The sensitivity of this on the overall appraisal results is investigated in Section 9.3.1.1.

8.4.13. NO 14: FLEXIBILITY AND STRATEGIC VALUE

This has been defined by the number of facilities in any WDA EfW option derived in part from the assumptions regarding scale and technology, but also from the Final Site Identification GIS method. The importance of this criterion has been discussed in Jones (2006) where using a multiple-plant strategy assists the management of financial risk by allowing loans for capital expenditure to be awarded by banks in a more step-wise manner. Assuming a sensible step-wise development to building multiple plants, a 25 year contracting period could include as many as 3 to 7 opportunities for facility development depending on facility capacity scales. At each one of these development opportunities, a WDA should use the most up-to-date information on residual waste availability, taking into account variables such as waste growth or decline, and recycling diversion rates (Kondakor, 2007) when deciding scale and location.

This concept is shown graphically in Figure 51. The local-scale EfW option shows that there are five opportunities (represented by the five columns) to consider size and technology of the facilities to develop capacity over the 25 year period. The medium and large options have three and one opportunities, respectively. It can be argued, however, that the use of this criterion may bias the overall model results towards multiple, distributed plant and it may not be justified in that a single large plant may incorporate enough flexibility in its operation to meet varying waste production rates. Officers however, did not support this view, suggesting a multiple facility approach was not so vulnerable to periods of maintenance 'downtime'. The use of multiple facilities can result in lower operational risk, in that if one plant cannot operate, others can process waste and uphold contractural obligations.

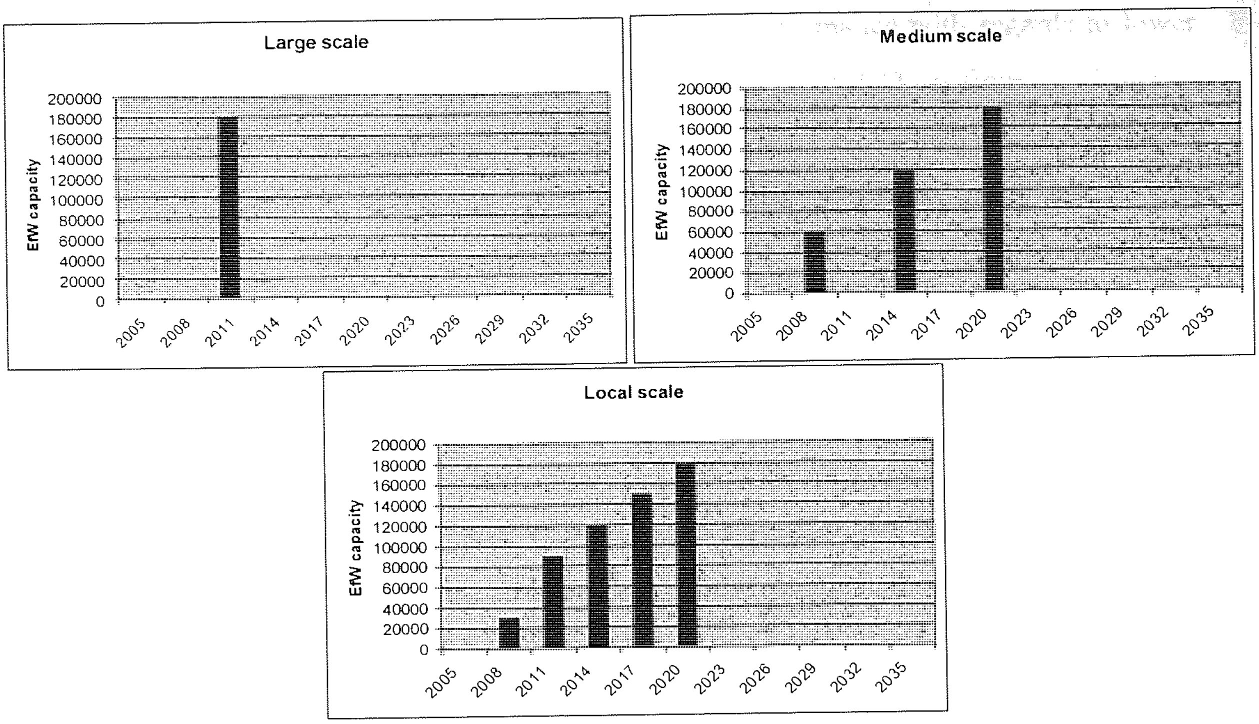

Figure 51: Flexibility and strategic value of multiple plants.

8.5. FINAL OPTION PERFORMANCE SCORES

Table 42 shows the Cornwall and Warwickshire option scores that have been derived for all criteria as described in Section 8.4. The scores show differences that result from the geographic characteristics of the two WDA areas. The greatest dissimilarity is shown in the costs of Waste Transfer Stations and road transport and external cost of transport scores. Table 42 indicates that the large-scale Warwickshire option has a 47% less impact than the corresponding Cornwall option. This can be explained by the fact that Cornwall has a weaker road network and lower waste production density. There are further differences derived from the GIS site identification techniques, which produced the result of 4 and 5 plants for the local options in Cornwall and Warwickshire, respectively. For example, the 'Flexibility and strategic value' and 'Lorry traffic impact' criteria derived their scores as a function of the number of plants per option.

Apart from geographically derived differences, the data in Table 42 shows that performance scores can differ significantly between the ATT and Combustion technology options. ATT shows a more favourable environmental performance with regards to lower emissions to air, land and water but does not displace as much CO_2 in from its electrical generation output. Interestingly, Azapagic and Camana (2005) identified that pyrolysis/gasification also resulted in lower local but higher global warming impacts and suggested that may result in greater public acceptance for EfW facilities in their communities. This supports the observation from Malkow (2004) that ATT designers face a trade-off between achieving high environmental performance, but at the cost of low energy efficiencies. Studies that include pre-treatment such as shredders and driers coupled within their assessment of EfW systems often show that the no pre-treatment option is the most worthwhile from an environmental and cost viewpoint (Corti and Lombardi, 2004, Consonni et al, 2005 a/b). Pyrolysis and gasification systems typically pre-treat their waste feedstock to a larger extent than traditional grate combustion systems. Fichtner (2004) notes that pre-treatment can increase parasitic load of the facility and reduce potential environmental benefits in the form of offsetting fossil-fuel fired energy generation.

Table 42: Criteria performance scores for each EfW option in the MCDA model.

Criteria	Indicator	Options									
		Warwickshire					Cornwall				
		L SC	M SC	Loc SC	M S ATT	Loc S ATT	L SC	M SC	Loc SC	M S ATT	Loc S ATT
Lorry traffic impact on local communities	Deliveries per site per day	62	27	19	27	19	49	28	21	28	21
Jobs created	Full time	47	69	91	66	90	47	69	80	66	78
Health of local community	Dioxins ITEQ mg/pa	25	25	25	3	3	25	25	25	3	3
Emissions to air	Tonnes/yr eq. $p\text{-}C_6H_4CL_2$ SO_2 kg ethylene	301 140 6	301 140 6	301 140 6	91 24 1	91 24 1	301 140 6	301 140 6	301 140 6	91 24 1	91 24 1
Emissions to land	Bottom ash and fly ash (£K/pa)	3907	4151	3764	2796	2758	3907	4151	4272	2796	2803
Water discharges to sewer	ktpa	40.5	40.5	40.5	18.8	18.8	40.5	40.5	40.5	18.8	18.8
Option site footprint	All sites total (ha)	2.9	4.2	5.1	2.9	3.0	2.9	4.2	4.8	2.9	3.0
Individual plant site visual impact	Building height average (m)	33	20	20	10	10	33	20	20	10	10
	Chimney stack average (m)	89	60	60	25	21	89	60	60	25	23
Displaced fossil fuel carbon dioxide emissions	CO_2 (ktpa) elec gen only	23.3	21.1	17.1	12.8	12.8	23.2	21.1	20.9	12.8	12.8
Total external costs of waste & ash road transport[a]	£ k/annum	248	147	101	143	98	497	405	380	325	293
Net cost per tonne processed	£/tonne	51	79	84	59	67	51	79	85	54	59
Cost of WTS & road transport of waste and fly ash[b]	£ million /annum	1.316	0.668	0.308	0.656	0.299	2.327	1.457	1.381	1.214	1.117
Technical maturity	No of operational plant in UK	19	19	19	0	0	19	19	19	0	0
Flexibility and strategic value	No of plants in option	1	3	5	3	5	1	3	4	3	4
		L SC	M SC	Loc SC	M S ATT	Loc S ATT	L SC	M SC	Loc SC	M S ATT	Loc S ATT

[a] Based on £0.35 per km traveled from the (Strategic Rail Authority, 2003) inflated to 2006 prices.
[b] Does not include collection costs, solely transit. Costs of owning and operating WTS at £6.26/ metric tonne. Cost of road transport at £1.07 metric ton/km (US-EPA, 2002) inflated to 2006 prices.

ATT has lower building and average stack heights, indicating that this technology (represented by the Compact Power design in Section 1.3.5.2) has a lower visual impact over combustion. This may lead to ATT being more politically acceptable, but Combustion is superior to ATT at all scales on its displaced fossil fuel CO_2 emissions. Wheeler and Jainter (2006), Jainter and Poll (2005) and Higham (1999) also show that large-scale conventional incineration using combustion technology for electricity generation can displace the most fossil fuel CO_2 emissions due to superior electrical conversion efficiencies. Caution should be taken however, since these studies are controversial in that they arrive at the result without taking account of heat product, unlike those such as Bergsdal et al. (2005) and Consonni (2005a). Murphy and McKeogh (2004) highlight this key issue by concluding that "in essence a thermal market for heat and power product is essential to improve sustainability" (for conventional incineration).

Key in deriving the displaced fossil fuel CO_2 emissions option performance is whether CHP is included within technology definitions. Consonni et al (2005b) and Murphy and McKeogh (2004) considered the effects of CHP generation. These authors concluded that CO_2 savings could be up to double that of options that were defined as electricity only. The importance of this has been discussed in Section 1.3.4 and to avoid its absence as in other studies (Wheeler and Jainter, 2006), this project has taken the potential for CHP into account in Section 9.3.1.3.

In terms of gate fee costs, the data in Table 42 supports the observation from Murphy and McKeogh (2004) that incineration proved to have the highest gate fee and greatest capital costs with gasification at the same scale. Porteous (2005), however, strongly advocated conventional incineration on the grounds of costs and reliability. The latter is a concern for new MSW processing pyrolysis/gasification technologies in that some are still only developed at the semi-commercial stage and have not been proven for reliability at a large enough scale to satisfy commercial and risk criteria (Fichtner, 2004). The need to minimise total cost and the need to meet the Landfill Directive is among the primary objectives of WDAs and should not be ignored. It is understandable that WDAs are risk adverse to technology in their approach to EfW planning, since they could incur fines if they do not meet their landfill diversion targets. This is reflected in Table 44 of Section 8.6 where mean average officer weights were between 10.4 and 8.7% of total weight applied in the MCDA models.

8.6. WEIGHTING CRITERIA

In order to obtain weightings sourced specifically from Cornwall and Warwickshire WDA officers, weighting 'workshops' using the HIVIEW software were held in October and November, 2005. The pre-organised work groups were comprised of officers directly involved in the EfW decision making process with responsibilities shown in Table 43.

Table 43: Working group officers' responsibilities

Officer	Cornwall	Warwickshire
1	Environmental Assessment Officer	Waste Manager
2	Waste Policy Manager	Sustainability Manager
3	Sustainability Officer	Energy Manager
4		Sustainability Intern
5		Climate change Manager

Each officer assigned a weight between 1 and 100 to each criterion, according to their perception of the importance of it in the overall decision. HIVIEW expects the criteria to be 'swing-weighted'; that is, the weightings should reflect not only the perceived importance of the criteria, but also the absolute range of scores obtained (an important criteria with a very narrow range of scores should receive less weighting than one with a very broad range). The mean average weightings obtained for each criterion are shown in Table 44, together with the standard deviations.

In both WDA counties, the highest mean weightings were 14.9% (Cornwall) and 12.7% (Warwickshire) and both were allocated to the 'Displaced fossil fuel carbon dioxide emissions'. This criterion also showed the greatest inconsistency in weighting with $\sigma = 11.3$ and 5.5 respectively. This suggests widely differing values about the importance of climate change between officers. The second most heavily weighted criterion in both counties was 'Health of the local community' (measured by dioxins produced) with weights of 11.3% and 3.3%. Community perceptions of risk, especially regarding health, can have a major effect on the extent of local opposition (Loosemore et al., 2006) despite attempts of studies to reassure the public that modern incineration poses very little risk (Enviros et al., 2004).

Table 44: Individual WDA officers' mean weightings

Shown as percent of total weighting in model.

Criteria	Cornwall					Warwickshire						
	Officer			σ	Mean	Officer					σ	Mean
	1	2	3			1	2	3	4	5		
Lorry traffic impact on local communities	7.7	8.8	11.6	2.0	9.4	8.0	11.3	8.4	5.6	7.6	2.0	8.2
Jobs created	5.8	2.2	4.8	1.9	4.3	3.9	8.5	7.3	9.2	5.2	2.2	6.8
Health of local community	9.6	8.8	15.4	3.6	11.3	5.6	14.0	11.9	12.7	12.3	3.3	11.3
Emissions to air	12.9	4.5	0.9	6.2	6.1	4.5	4.6	4.4	4.2	5.8	0.6	4.7
Emissions to land	2.6	4.5	0.9	1.8	2.7	4.5	4.6	3.2	4.2	3.2	0.7	4.0
Water discharges to sewer	1.3	4.5	0.9	2.0	2.2	2.2	4.6	4.4	4.2	3.2	1.0	3.7
Option site footprint	5.2	5.1	1.6	2.1	4.0	8.4	2.4	3.2	2.5	1.6	2.7	3.6
Individual plant site visual impact	7.8	6.2	3.5	2.2	5.8	4.5	1.6	3.6	2.8	3.2	1.1	3.2
Displaced carbon dioxide emissions	4.5	13.2	27.0	11.3	14.9	6.7	9.8	10.3	20.1	16.5	5.5	12.7
External costs of road transport	7.4	5.6	5.6	1.1	6.2	9.3	7.9	9.3	4.7	8.5	1.9	8.0
Net cost per tonne processed	9.3	6.8	6.0	1.8	7.4	11.1	12.3	9.9	8.0	10.0	1.6	10.3
Cost of WTS and road transport	7.4	5.6	7.4	1.0	6.8	10.1	3.9	7.0	8.0	8.1	2.3	7.4
Technical maturity	7.4	18.4	5.4	7.0	10.4	12.4	9.1	8.4	6.6	7.0	2.3	8.7
Flexibility and strategic value	10.7	5.6	9.6	2.7	8.6	8.8	5.6	8.4	6.6	7.7	1.3	7.4

The next most heavily weighted criteria were 'Net cost per tonne' (of MSW processed), 'Flexibility' and 'Technical maturity'. These reveal a high level of monetary awareness and officers' regard for the need to carry forward cost-effective solutions that have a good track record. The least weighted criteria in both counties include 'Individual site footprint', 'Emissions to land' and 'Plant water discharges' indicating that officers do not view these criteria as particularly important within EfW decision making.

The 'Emissions to air' criterion represented a weighting in the middle of the range provided and reflects that this is still of importance despite the use of modern air pollution control (APC) technologies and regulation by the Waste Incineration Directive (WID). Other medium range weights were given to 'Costs of WTS and road transport' and 'External costs of road transport'. This indicates that officers understand the importance of minimising waste transport impacts and related costs in any waste management strategy (Gershman et al., 1986). Transport impact too, is often of concern to the public and often presents a challenge to acquiring planning permission (Upreti & Van der Horst; 2004).

Some participants were reluctant to submit weightings in case the final results did not agree with the centralised EfW approach. It should be noted that at the start of this project in 2004, neither Council had officially publicised its final EfW policy decision. At the time of writing, Warwickshire still has not, but Cornwall has publicised its decision for a large-scale centralised EfW strategy. Attempts were made to engage personnel higher up the decision-making hierarchy than the participants listed in Table 43 who work in support of senior officers and politicians. It was not possible to engage these individuals for the overall project, but they were prepared to receive the results and conclusions of this study. Their comments are presented in Section 9.4.

8.7. CHAPTER SUMMARY

This chapter has presented the central elements of the MCDA appraisal component of the proposed EfW DSS. The overall structure of the models and how the criteria were chosen has been outlined. Descriptions of the criteria and their data indicators have been provided together with details on how the performance scores of options have been derived. The process in which weightings from WDA officers have been obtained together with the challenges faced has also been described. The results of the MCDA appraisal for formulated EfW options in both WDA test areas are presented in Chapter 9, where discussion and sensitivity analysis has been made on key criteria.

9. APPRAISING EFW OPTIONS USING MCDA: APPLYING THE MODEL

9.1. AIMS OF CHAPTER

The aim of this chapter is to present the results of applying Step 5 of the DSS to identify the preferred EfW options for each WDA area, discuss and relate them to the actual UK EfW decision making situation. The overall MCDA output scores for each EfW option are presented and compared in Section 9.2. These results are discussed in Section 9.3.1 with respect to sensitivity analysis. Sections 9.3.2 and 9.3.3 explain how the results reported from the MCDA models relate to the currently dominant centralised UK EfW policy and discuss the implications. Section 9.4 presents the response of members of WDAs in which the DSS was applied.

9.2. RESULTS

9.2.1. FINAL MCDA SCORES FOR EFW OPTIONS

Table 45 shows the final scores for each option derived from mathematically combining option criteria performance scores (Section 8.5) and weights (Section 8.6) using the weighted-sum MCDA technique described in Section 2.8. For Cornwall, the mean-weighted results ranked local ATT as preferred option, followed by medium ATT and then local combustion in third place. At the individual level, Officer 1 and 3 followed the same pattern, but Officer 2 results presented an alternative set of scores still ranking local ATT first, but followed by local combustion, and medium ATT, respectively.

Table 45: Final overall weighted MCDA scores.

Each preferred option's score is shown in bold, second in italics. A higher numerical score indicates superior preference to a lower score.

WDA	Weighting	Option				
		L SC	M SC	Loc SC	M S ATT	Loc S ATT
Cornwall	Officer 1	22	31	34	*53*	**58**
	Officer 2	36	44	*47*	45	**49**
	Officer 3	38	47	50	*55*	**59**
	Mean	33	42	45	*50*	**54**
Warwickshire	Officer 1	28	39	*49*	45	**56**
	Officer 2	28	38	46	*52*	**61**
	Officer 3	27	38	50	*51*	**62**
	Officer 4	34	43	50	*56*	**66**
	Officer 5	29	40	48	*53*	**63**
	Mean	31	41	*48*	*48*	**58**

For Warwickshire, the mean-weighted group results again ranked local ATT as the preferred option, followed by local combustion and medium ATT in second place. With the, exception of Officer 1, remaining officers ranked local ATT in first place, but medium ATT in second, with local combustion third. Officer 1 ranked local ATT in first place but local combustion in second place. All officers from both county WDAs ranked medium and large combustion options in fourth and fifth rank, respectively. It is interesting to note that the large combustion option is most typical of currently applied WDA EfW policy.

9.2.2. MEAN-WDA GROUP WEIGHTING RESULTS AND CRITERIA CONTRIBUTION

Figure 52 and Figure 53 (generated using the HIVIEW program) show the contribution that each criterion of value and weight make to the overall EfW option score. Each criterion has been assigned a colour. The pattern of the option scores for Cornwall show a general preference in terms of both scale and technology, with local-scale being dominant for both combustion and ATT options. Regarding technology, ATT is preferred to combustion at both medium and local-scale. For the Warwickshire model, however, the pattern of scores show that scale-related criterion have more influence than in the Cornwall model, since local-scale combustion and ATT are dominant over medium-scale combustion and ATT respectively. Local-scale combustion is preferred to medium-scale ATT.

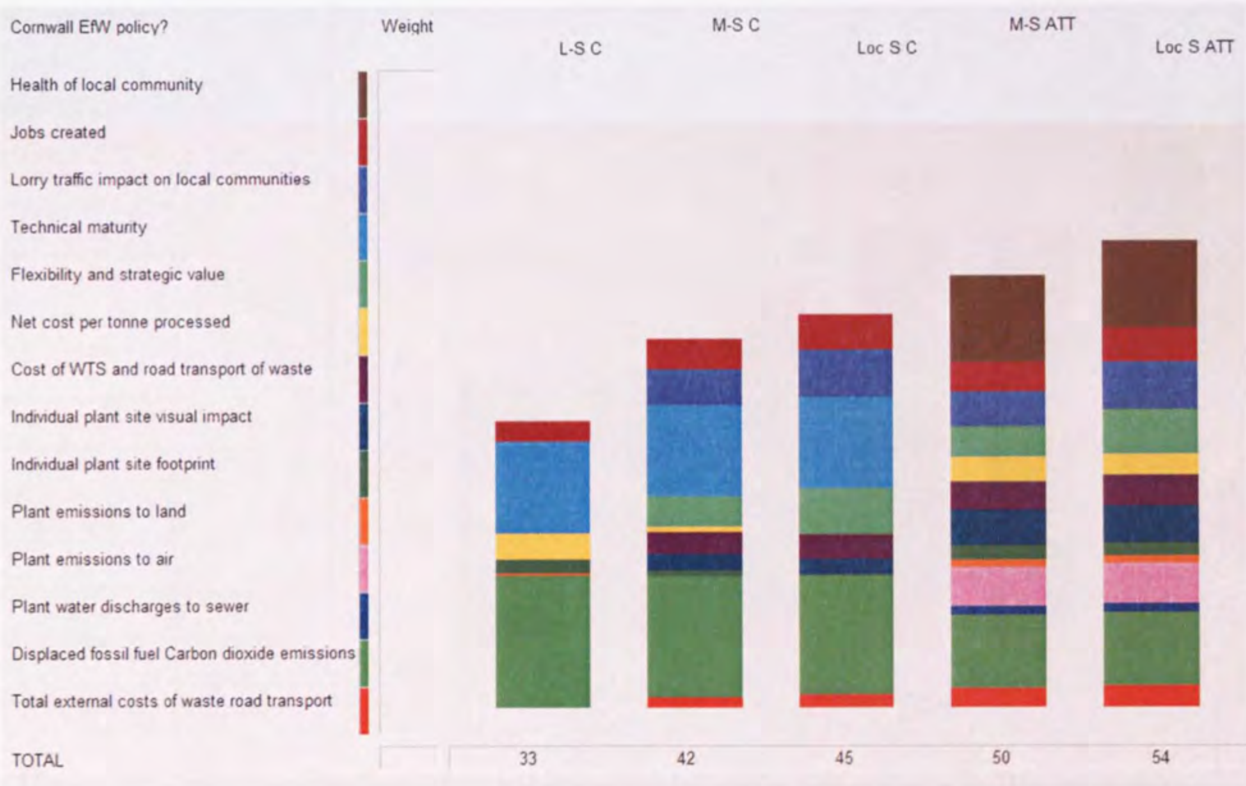

Figure 52: Criteria contribution to mean-weighted score for options in Cornwall.

Figure 53 shows that the alternative large-scale option (LSC Alt) derived for Warwickshire, which essentially represents a shift in location to minimise the need for haulage and costs of transport infrastructure has improved the score of the large-scale option by one point, but this is not enough to change the overall pattern of option scores, with the next least preferred – medium-scale combustion 9 points higher. This illustrates that in the this case, the transport savings that could be accrued as a result in changing the current large-scale site from Judkins in North Warwickshire (Jainter & Poll, 2005) to Leamington Spa (Central Warwickshire) or 20 km is of relative insignificance within the overall decision model. An alternative large-scale site option for Cornwall was not modelled since the chosen site of Indian Queens in the Waste Local Plan (CCC, 2003) was just 3 km from the preferred location as indicated by the site identification GIS method used in this project (Section 6.4.1.1).

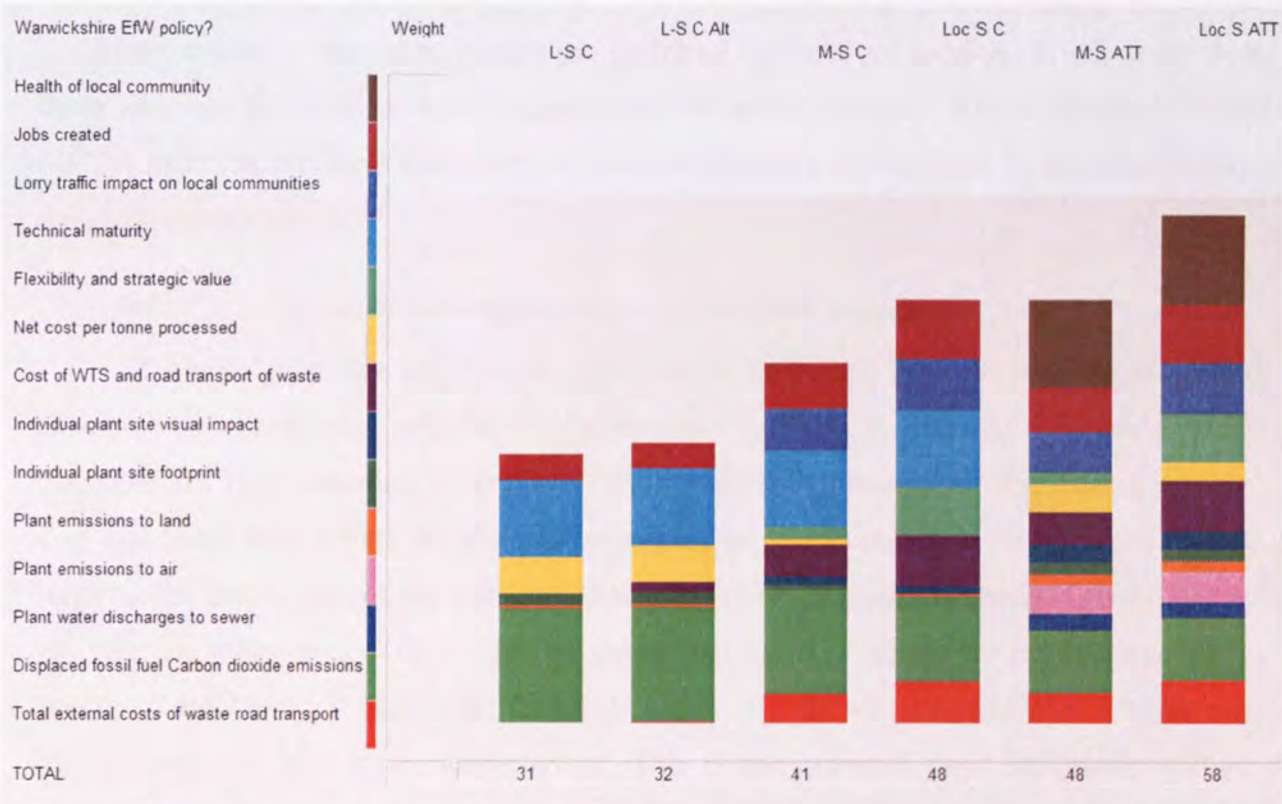

Figure 53: Criteria contribution to mean-weighted score for options in Warwickshire.

9.3. DISCUSSION

9.3.1. SENSITIVITY ANALYSIS OF KEY CRITERIA

Sensitivity analysis can be used to investigate how important uncertainties are by highlighting areas in the model that influence the overall preference ordering of options. There was significant debate between officers in defining weights during the weighting workshop shown by the variation in Table 44. There were no criteria, however, on which a small change (<5%) in total model weighting would change the preferred option of the local-scale ATT in Cornwall or Warwickshire. The software indicated that the preferred option would only change to medium-scale ATT option if jobs created and displaced CO_2 criteria weighting was increased to greater than the HIVIEW sensitivity threshold of 15%. No amount of weighting adjustment on the 'Individual plant site visual impact' or 'Plant emissions to land' would also change the preferred option from local ATT indicating that these were not important criteria in appraising EfW options overall. Further analysis of the MCDA model results have been performed in the following sub-sections by adjusting highly weighted criteria scores.

9.3.1.1. Technical maturity and net costs per tonne processed

Technical maturity and data on costs are related since it is not possible to obtain accurate cost estimates without commissioned facilities. Indeed, DEFRA's New Technologies Demonstration Programme (NTDP) has the primary aim of gathering reliable cost and performance data for the new emerging waste management technologies. It is unfortunate, that at present there are no existing examples of commissioned ATT facilities at the relevant scales in the UK. Table 42 shows that the ATT scores for net cost per tonne processed are 25 and 20% cheaper than their technically mature combustion counterparts at the medium and local-scales respectively. This is not expected since technically mature technology may have lower costs due to the benefit of previous experience gained in building, operating and commissioning (IEA, 2000). That said, developers may present high prices for facilities in a market of high demand but relatively low number of proven suppliers and technologies. There is also no incentive for developers of technologies with lower capital costs, (such has been discussed in Section 8.4.3 regarding ATT and the evidence that this technology uses less flue gas cleaning equipment) to offer sale prices at less than the market value for thermal treatment. To explore the sensitivity of the preferred option on this basis, Figure 54 shows there is no effect of increasing the ATT 'Net cost per tonne processed' criterion performance scores to the same values as combustion at medium and local-scale while retaining the same officer weighting (approx 8% of total weighting in the model). The overall pattern for the results is the same with local-scale ATT still the most preferred option, although ATT scores are decreased by three points at both medium and local-scale relative to Combustion.

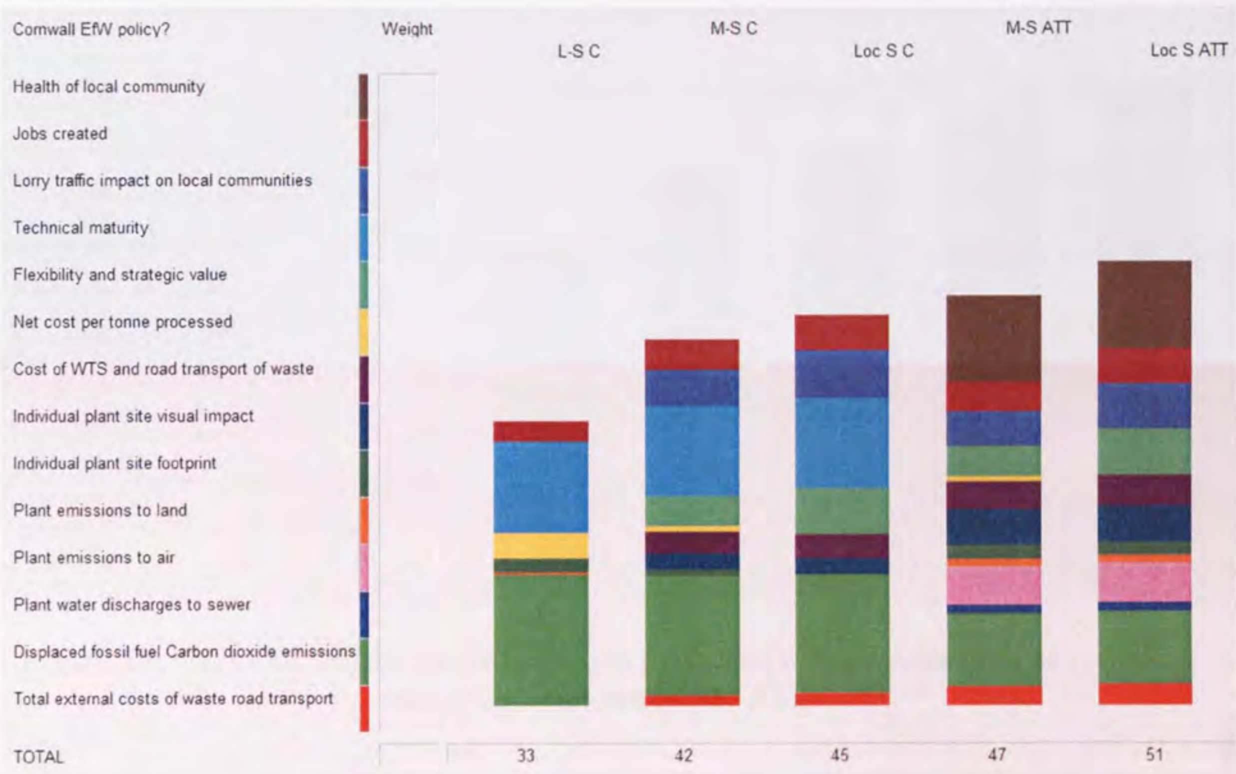

Figure 54: Cornwall MCDA results showing preferred options with ATT costs equal to combustion.

ATT technology is still at the development phase and it can be assumed that costs will become more comparable with combustion within the completion of the NTDP, which proposes that four ATT plants will be built before the end of 2009 (DEFRA, 2007). It is interesting that only two ATT pyrolysis facilities have beensuccessfully commissioned before the 2009 deadline of the programme but the other two are delayed indefinitely due to financing and permitting problems (Eminton, 2009a). To examine the effects of this, the model in Figure 54 has been further altered by changing the score for ATT technical maturity from 0 to 2. Figure 55 shows that ATT increases its score over Combustion by two and one points respectively for medium and local scale ATT; this to some extent cancels out the uncertainty in the ATT cost inputs. The same trend is shown in the Warwickshire model.

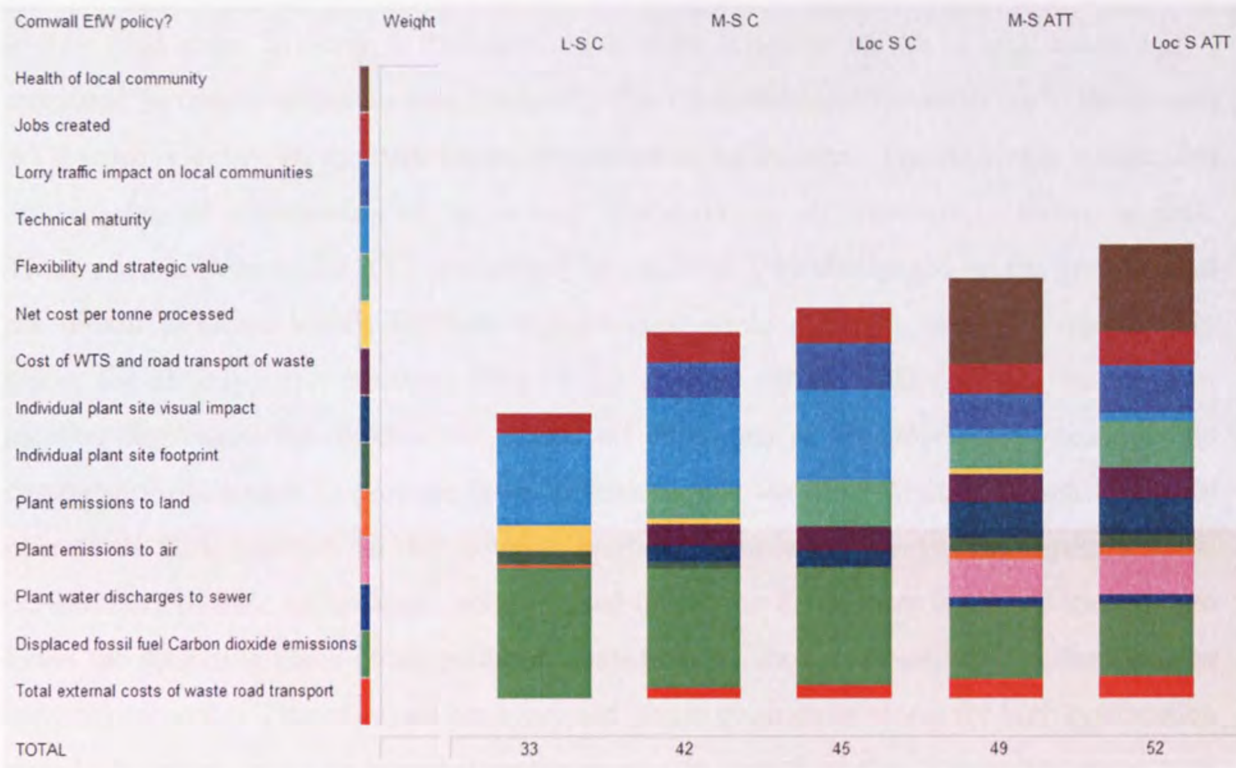

Figure 55: Cornwall MCDA results showing preferred options with greater technical maturity score applied to ATT.

9.3.1.2. Health of local community and emissions to air

Even with the adjustment of assumptions in scoring the criteria discussed in the previous two sections, the ATT options continue to outperform combustion options overall. A larger number of criteria, notably in the environmental categories contribute to the overall score (shown by the greater number of colour bars in the score column). The largest factor in their final score, however, is the contribution of the criterion 'Health of local community', measured by dioxin emissions (see Table 42). The contribution of this criterion to the overall ATT score is shown by the dark brown proportion of its column. The relatively smaller but still substancial contribution of the overall 'Emissions to air' criterion is shown in pink. These contributions to the ATT scores may be reasonably be challenged on the grounds that the dioxin emission values for both technologies, while different, are both significantly below the already strict emission limit of 0.1 ng/Nm^3 set by WID (A.2.4). In terms of meeting legislation for dioxins and indeed all emissions to air, developers are under no compulsory obligation to produce fewer emissions that the WID limit, although they may operate at this position in for limited periods in order to prove the environmental performance of their technology. As discussed in Section 8.4.3, there is also an incentive to lower the operating costs of air pollution abatement by using less activated carbon/lime or sodium carbonate. Therefore, air emission and dioxin production scores for both combustion and ATT option could be regarded as the same. In regard of this, Figure 56 shows how assigning the same dioxin production and overall air emissions scores to both ATT and combustion in the Cornwall model produces a significant effect on the ranking of preferred options with local and medium-scale combustion replacing their ATT counterparts. Medium and local scale ATT overall scores decrease by a considerable 14 and 15 points respectively. A ten point difference is due to the strength of the dioxin 'Health of community' with a further four or five point difference attributable to the 'Emissions to air' criterion. This shows how signficant these criteria's scores and weights affects the outcomes of the model. Medium-scale ATT is now only one point higher than large-scale incineration.

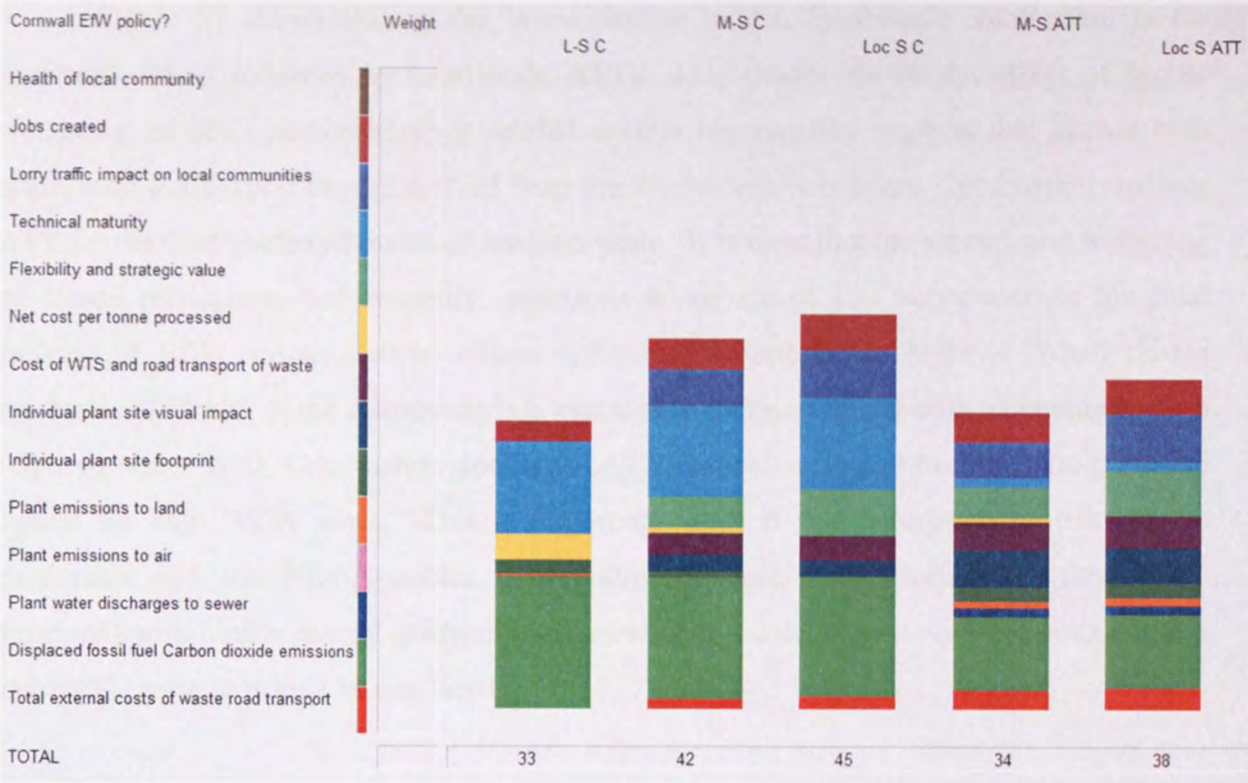

Figure 56: Cornwall MCDA results showing preferred options when dioxin production scores for ATT and combustion are constant.

Figure 57 shows that in the Warwickshire model, local-scale combustion is the preferred option followed by local-scale ATT. This model shows the effect of higher weighting on other non-technology related criteria representing impacts that accrue with scale, such as transport impact derived from the Warwickshire officers. Combustion replaces ATT for the third preferred option at medium-scale. It is clear that the scoring and weighting of dioxin production, and secondly, emissions to air are of key importance in the final ranking of EfW options, when officers weight these criteria so highly. When dioxin production ('Health of the community') is assumed to be the same for both technologies as is required under WID, Combustion dominates ATT at local-scale and becomes the preferred option for both WDA areas. This is important, since if this perception of risk can be moderated with the WDA's public, it may allow a more mature technology (and easily financed) with higher energy generation efficiencies to be developed with the outcome that more CO_2 emissions may be displaced.

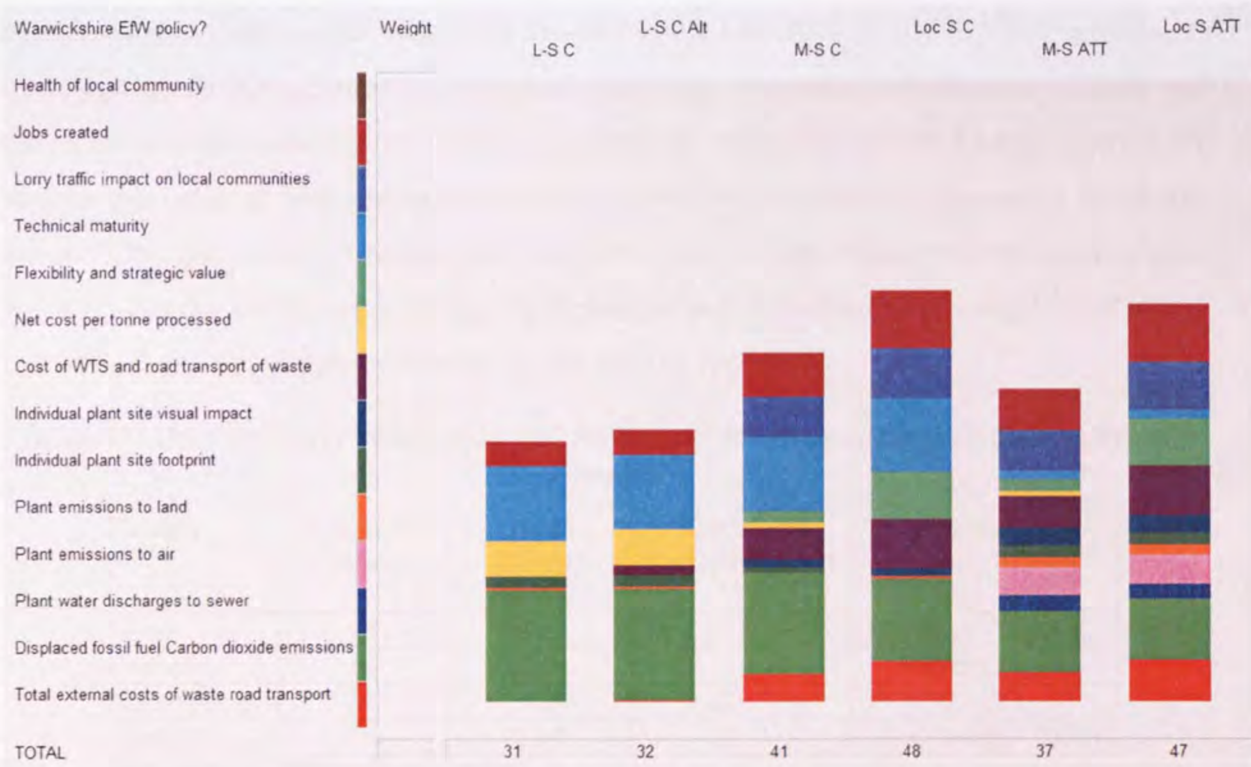

Figure 57: Warwickshire MCDA results showing preferred options when dioxin production scores for ATT and combustion are constant.

9.3.1.3. *Displaced fossil fuel CO_2 emissions*

In the unadjusted model, the criterion 'Displaced fossil fuel CO_2 emissions' considers electricity generation only and not the supply of heat in a combined heat and power operation. Combustion plant at larger scale perform particularly well on this definition of the criterion since it becomes more cost-effective to invest in plant features that raise electrical efficiency, for example, steam turbines can be more efficient as scale increases (Porteous, 2005). Figure 56 and Figure 57 show this, since it can be observed that the large-scale combustion option makes a larger contribution to its overall score on this criterion than its medium and local-scale counterparts. Similarly the lower efficiencies associated with ATT are apparent with lower score contributions shown at medium and local-scale compared with combustion. It is clear, therefore, that energy efficiency regarding electricity generation is a matter of both technology and scale.

But these factors, often specific to electricity generation and large-scale do not consider combined heat and power, which may be more suitable for lower-scale deployment in undeveloped heat markets as is often the case in the UK (AEAT, 2005). CHP efficiencies can reach up to 80% compared to typical electricity generating efficiencies of 26% and therefore have the potential to displace significantly more CO_2 (ILEX Energy, 2005). To explore the issue of heat production within the MCDA models, the 'Displaced fossil-fuel derived CO_2 emissions' criterion was redefined, and its performance scores re-calculated. Since the displaced CO_2 criterion has the highest of any individual total weighting of all (17 and 14%) it has a significant influence on the MCDA models.

Table 46: Heat to power ratios of actual EfW CHP facilities supplying district heating schemes.

Facility	Capacity (ktpa)	Heat Output (MWth)	Electricity Output (MWe)	Source
Forus	45	4.6	1.7	Midtbust (2009)
Grimsby	56	3*	3	Heath (2007).
Nottingham	150	7.9	22.7	WRG (2007b)
Sheffield	225	20.0	32.0	Ilex Energy (2005)

*Based on industrial process not district heating

Values of heat recovery have been based on the actual data from operating plant, shown in Table 46 and it is clear that increases in scale can lead to greater energy production efficiencies, this being defined by the actual output of CHP schemes. At the time of writing, while Grimsby and Nottingham are large-scale UK EfW CHP facilities, the only operating EfW CHP plant which more closely represents the 30 ktpa project option is the Energos ATT facility at Forus, Stavanger, Norway. The Grimsby EfW CHP currently supplies 3MWth to industrial process and this is not representative of district heating which can use lower quality steam production. To overcome this, the linear relationship in Figure 58 was used to recalculate the heat output from the 60 ktpa facility for district heating to ensure consistency between the options. Figure 58 was derived from data in Table 46.

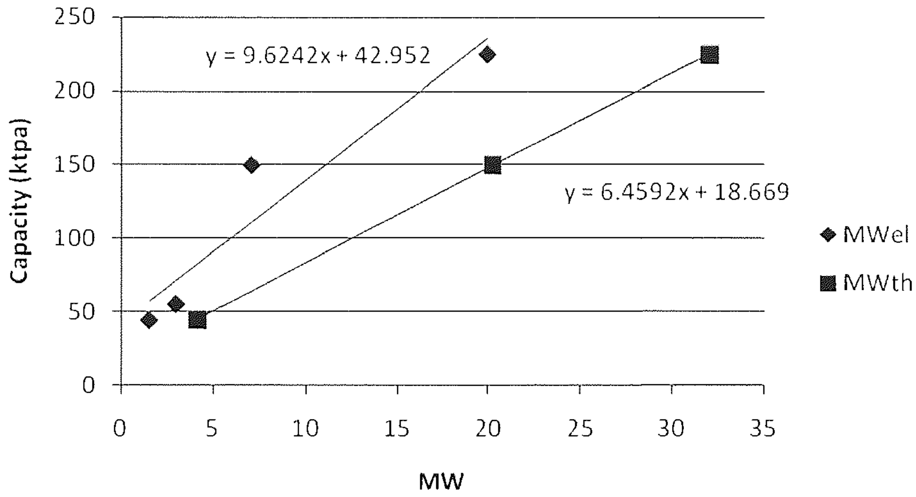

Figure 58: Linear regression: CHP schemes – Capacity vs MWel and MWth.

Table 47: Heat to power ratios of project option EfW CHP facilities supplying district heating schemes.

Based on Facility	Heat Output (MWth)	Electricity Output (MWe)	Applied to project option (ktpa)
Forus	3.1	1.1	30
Grimsby	7.0	3.0	60
Nottingham	27.3	9.5	180

The total Option scores include the displaced emissions from electrical generation, as in former models but additionally include the recovery of heat according to the scale assumptions made in Table 47 that are based on the operational data of Table 46. No assumption was made for plant availability since calculations were derived for a fixed amount of waste feedstock throughput. 62% of total heat consumption in the UK is based on the use of natural gas (DTI, 2007). Therefore, the heat recovered in each option is assumed to displace natural gas use at 0.19 kg CO_2 per kWh (NEF, 2007). Table 48 shows the total CO_2 emissions scores used in the revised MCDA model and these indicate that large-scale EfW CHP schemes can save up to 37% more CO_2 emissions than EfW small-scale CHP schemes. The results of this analysis are shown in Figure 59 and Figure 60.

Table 48: Displaced CO_2 emissions taking into account heat production.

WDA	Option	MWh_{el}/pa	Max CO_2 emissions tpa (Electrical)	MWh_{th}/pa	Max CO_2 emissions tpa (Thermal)	**Total option CO_2 emissions (tpa)**
Cornwall	Large SC	74,100	13,560	212,940	40,459	**54,000**
	Medium SC	70,200	12,847	163,800	31,152	**44,000**
	Local SC	57,720	10,563	151,320	28,751	**40,000**
	Medium ATT	70,200	12,847	163,800	31,152	**44,000**
	Local ATT	57,720	10,563	151,320	28,751	**39,000**
Warwick-shire	Large SC	74,100	13,560	212,940	40,459	**54,000**
	Medium SC	70,200	12,847	163,800	31,152	**44,000**
	Local SC	51,480	9,421	145,080	27,565	**37,000**
	Medium ATT	70,200	12,847	163,800	31,152	**44,000**
	Local ATT	51,480	9,421	145,080	27,565	**37,000**

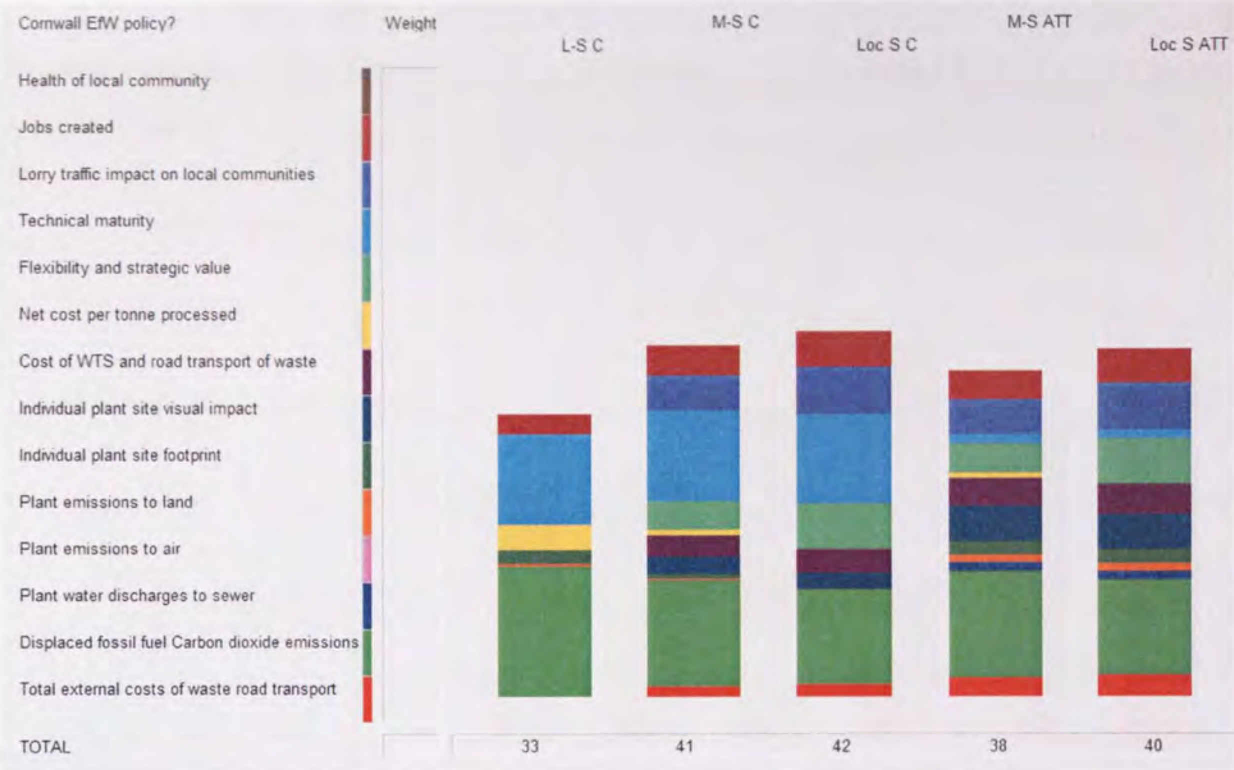

Figure 59: Cornwall MCDA results showing the effect of additional heat production credit to options for displaced CO_2 emissions.

Figure 59 and Figure 60 show that the contributions (shown in light green) in the medium and local-scales of combustion and ATT are significantly less than large-scale combustion when credit for heat production is made. This is because larger-scale facilities are typically more efficient in the production of both heat and power due to the use of higher efficiency boilers and turbines for energy production (Fichtner, 2004). In the case of the Cornwall MCDA model, this only results in a relative one and three point decrease for medium and local-scale combustion and also ATT. The main reason for this is the assumptions regarding CHP in this Section using plant operating data have negated the effect of lower electrical generation efficiencies associated with ATT relative to combustion technology discussed in Section 8.4.8. Assumptions based on the ratio of heat produced to power might have different outcomes. The overall ranking in the Cornwall model remains as in Section 9.3.1.2 with local and medium-scale combustion in first and second place. A similar effect can be observed in the Warwickshire MCDA model with local-scale combustion and ATT in first and second place respectively.

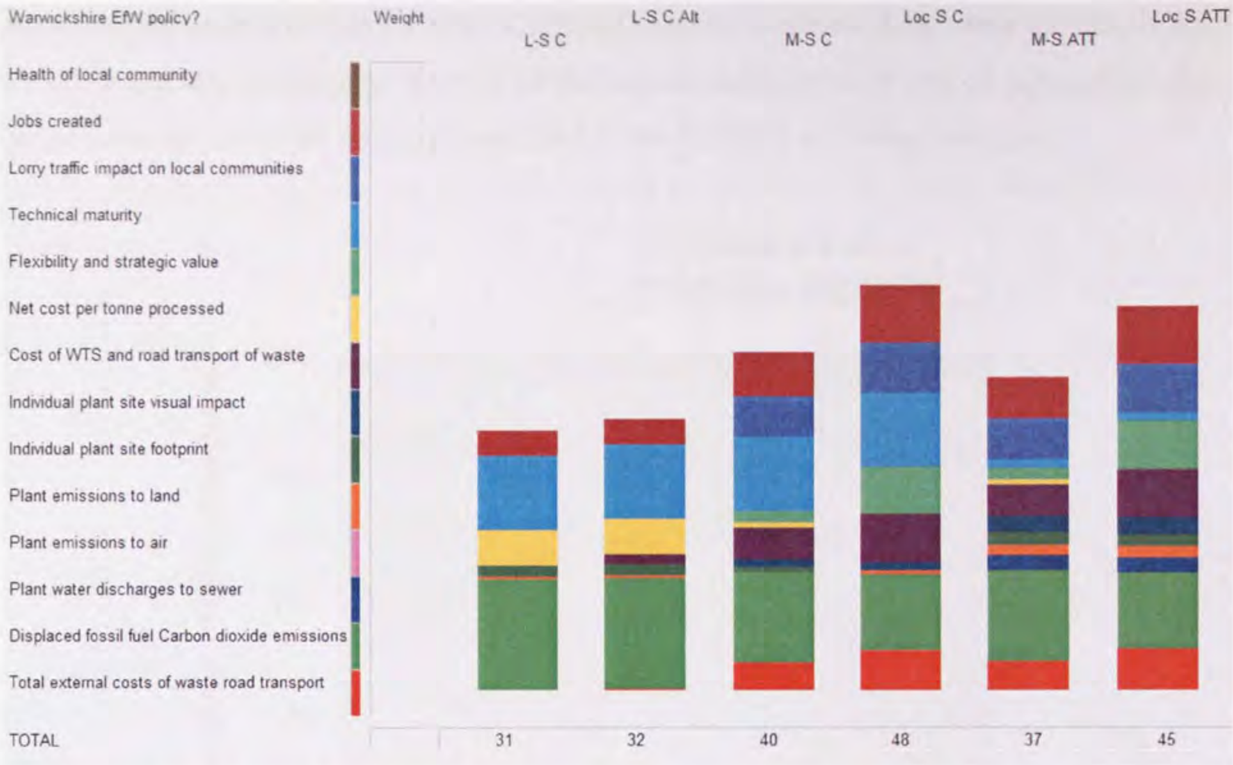

Figure 60: Warwickshire MCDA results showing the effect of additional heat production credit to options for displaced CO_2 emissions.

There are only three points difference between the two most preferred options in the Warwickshire model, where it can be observed that the input weights and scores produce a more distinctive set of preferred options than in Cornwall. The results in Figure 59 and Figure 60 show that while large-scale combustion is more efficient in overall energy production, particularly when deployed in a CHP configuration, this credit does not enable these options to dominate medium and local-scale of combustion or ATT options. While this observation is noted, only 4 of 19 UK EfW plants are CHP as discussed in Section 1.3.4. Large-scale EfW CHP schemes currently operating in the UK are situated in cities, such as Sheffield and Nottingham, where more numerous and large heat-users are more likely to be located nearby from the industrial and commercial sectors. Other large-scale schemes based in rural/suburban areas similar to Cornwall and Warwickshire such as Allington in Kent have no plans to recover heat, intending to waste all to atmosphere.

This is supported by Beggs (2002) who states that smaller heat loads with a suitable profile (more typical to rural/suburban areas) are more easily found than large ones, and require proportionately less investment. This is supported by the trends in Figure 61 that show that the growth of 1 to 10 MWe CHP installations is almost three times the rate of the 10 MWe and above category. 1 to 10 MWe include facilities of 30 and 60 ktpa, while 180 (large-scale option in this project) is included in the 10 MWe and above category.

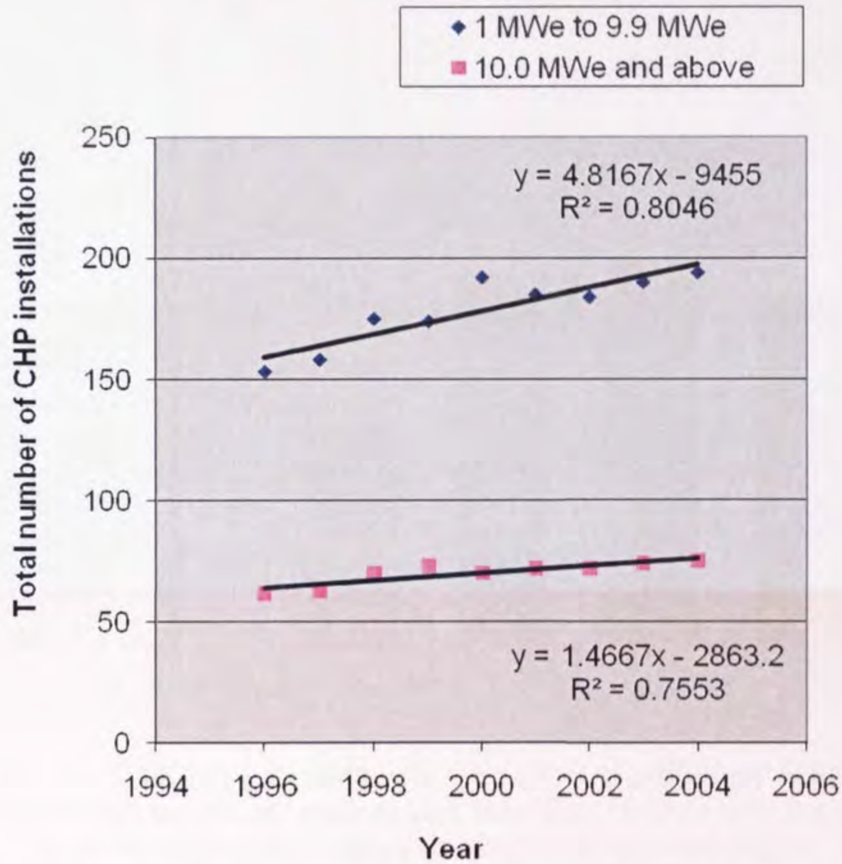

Figure 61: CHP installations growth between 1995 to 2005 (DTI, 2006a).

In the absence of established large district heating networks, heat can only be distributed over relatively short distances without significant losses or costs compared to electricity. AEAT (2005) argue that the scale of heat generation at any new potential facility location is limited by the cost of infrastructure to within a 2 km distance from the generating plant. These points suggest that the energy efficiencies attributable to CHP are more a matter of scale than technology. These arguments support the view that large-scale EfW schemes located in more rural/suburban areas such as Cornwall and Warwickshire are unlikely to be deployed in CHP configuration and should be awarded less credit for the associated displaced CO_2 emission savings (14 of the existing 19 UK EfW facilities are electricity only and 13 of these are over 150ktpa). Figure 62 and Figure 63 have been produced to examine the effect of these assumptions on the overall MCDA models for both WDA areas.

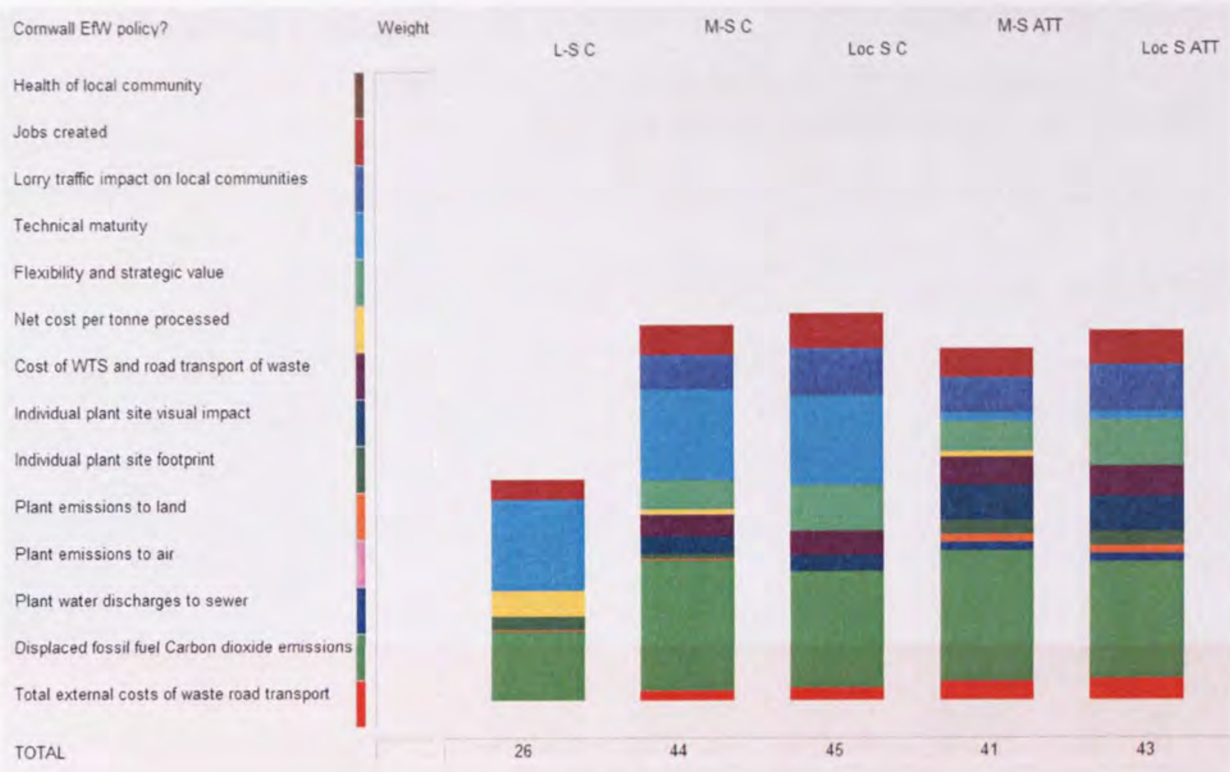

Figure 62: Cornwall MCDA results showing the effect of additional heat production credit to medium and local-scale options and the effect of electricity generation only credit to large-scale options for displaced CO_2 emissions.

Since the 60 ktpa facility is still in the category of 1 to 10 MWe, Figure 61 suggests that sufficient heat loads can still be found to a similar extent as for 30 ktpa facilities. The CHP credit for medium and local scale options have been kept constant as in the modelling in Figure 59 and Figure 60 but the large-scale combustion options are assumed to produce electricity only. As a result of the change in assumptions, large-scale combustion options in both WDA models decreases by a considerable 6 points. These assumptions on heat production are more representative of the actual situation in the majority of rural and suburban areas where new EfW capacity is increasingly being developed (Ilex Energy, 2005). That said, the potential of the large-scale schemes to deliver greater efficiency energy production at considerably less cost due to economies of scale should not be ignored. The degree to which any WDA can displace fossil-fuel derived CO_2 emissions when using EfW policies depends on the success of matching scales of facility with the appropriate heat demand loads within their jurisdictional areas. It is suggested that WDA decision makers and developers take greater efforts in identifying sites with suitable and realisable heat demands than is done at present.

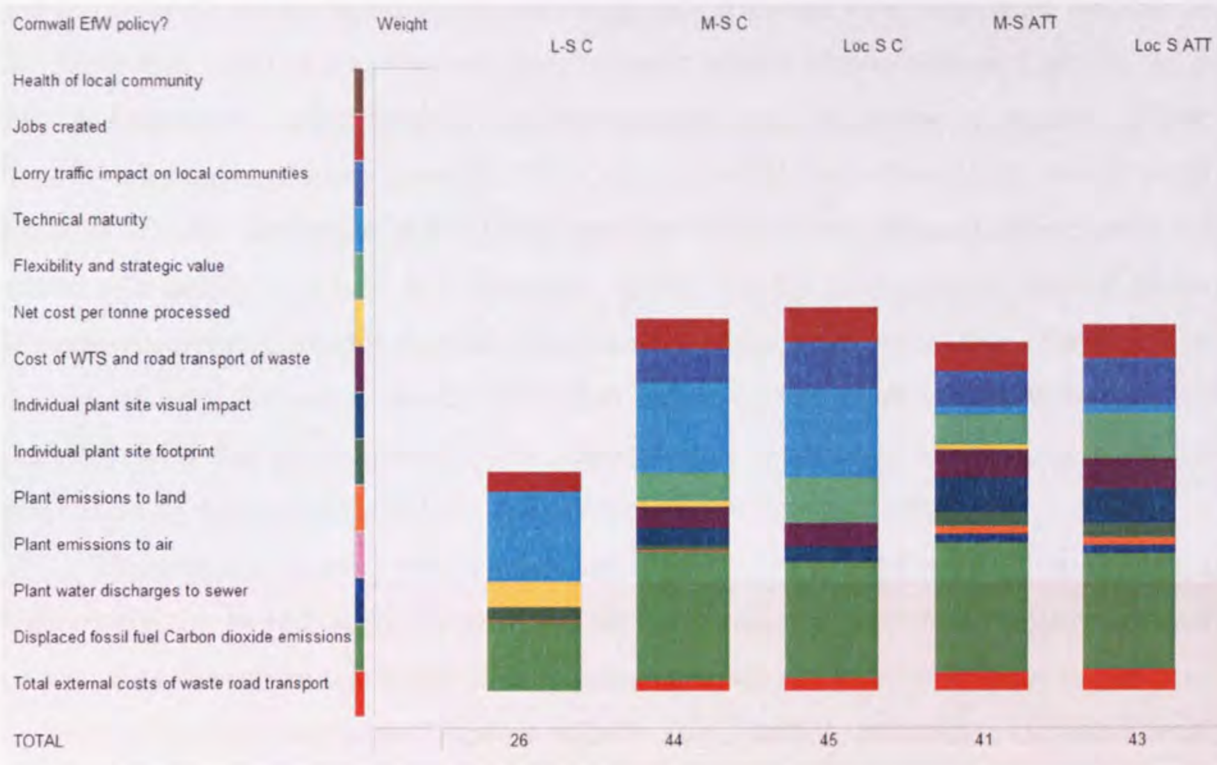

Figure 63: Warwickshire MCDA results showing the effect of additional heat production credit to medium and local-scale options and the effect of electricity generation only credit to large-scale options for displaced CO_2 emissions.

This Section has shown that displaced CO_2 emissions depend on the assumptions made on the EfW capacity of each option operating in a CHP configuration. An objective assessment of the implications between different options of EfW CHP across any WDA area is only possible with detailed site specific feasibility studies that have assessed the potential of heat production at all facility locations within a policy option. The use of CHP and its implications in EfW policy is difficult to assess since much uncertainty exists regarding the potential success of planned schemes. Developers are reluctant to accept the risks of additional capital build-out costs of heating networks and peak-load plant when it is difficult to be certain which industrial and commercial heat demands may remain over the typical EfW and CHP district heating project lifetime period of 25 years (AEAT, 2005).

9.3.1.4. Transport

The most important scale-related criteria are those related to transport. The medium and local-scale options, regardless of technology, are dominant over large scale because of the cumulative effect of contributions from transport related criteria such as 'Costs of WTS and road transport', 'Total external costs of transport' and 'Lorry traffic impact'. These three criteria represent approximately 25% of the total weighting of the models shown in the previous section. Gershman et al, (1986) state that 75% of total disposal system costs are related to collection of waste. It is interesting to note that the geographically derived scores of transport, where Cornwall showed a significantly higher road impact than Warwickshire did not influence the overall results, both areas indicating that small-scale EfW options are preferred. This can be explained by the relatively low weightings officers placed on the predominantly distance-derived costs and external costs of transport criteria.

However, as transport impact scores are relatively low in local and medium options, a higher weighting would only have increased their preference score over the large centralised option. It can be argued that future climate change policies and local compliance targets may combine to weight long-term transport impacts (e.g., carbon emissions, increased local traffic) even more strongly in an MCDA. For example, the criterion with the highest-weighting for both WDAs was 'Displaced CO_2 emissions' and with increasing awareness of the need to reduce CO_2 emissions, the emissions from transport, although only marginal compared with total emissions from plants (RCEP, 2004), may become more important in the future, thus increasing the significance of distributed options in EfW policy.

9.3.2. DOMINANCE OF THE LARGE SCALE COMBUSTION APPROACH IN UK EFW POLICY

In context of the results in Table 42 (which apply only to the WDAs considered), it is interesting that many UK WDAs, with the exception of Hampshire as discussed in Section 1.3.9 have rejected smaller-scale distributed facilities in favour of large-scale centralised ones. It is clear that decision-makers may not have considered the cost savings attributable to more distributed facilities that can accrue from: Reduction of waste transport distances; Closure of waste transfer stations or revenues from the sale of heat and steam in their decision-making process. There is also the possibility that decision makers do not attach enough weight to environmental and social criteria, which may be of greater concern to the public and their motivation for opposing planning applications.

In order to test this assumption, Figure 64 shows the model result when the effect of social criteria (top four) along with 'Flexibility and strategic value' and 'Cost of WTS and road transport' criteria have been removed, by assigning them a zero weighting. This may more closely match decision-making processes in real situations where cost calculations have typically focussed on the capital of plant (Wheeler & Jainter, 2006). The new system of weights provides a large cumulative weight for 'Displaced CO_2 emissions' (29%), and 'Technical maturity' (26%). The overall scores now show that the large combustion option is superior to options involving smaller scales of plant and ATT technology. The important point to note is that the overweighting of just two criteria (over 55% of all weighting in the model) and the omission of other important criteria could change the selected policy from smaller and distributed EfW systems to a large-scale, centralised one. This approach may be vulnerable to criticism as a narrow basis for decision-making.

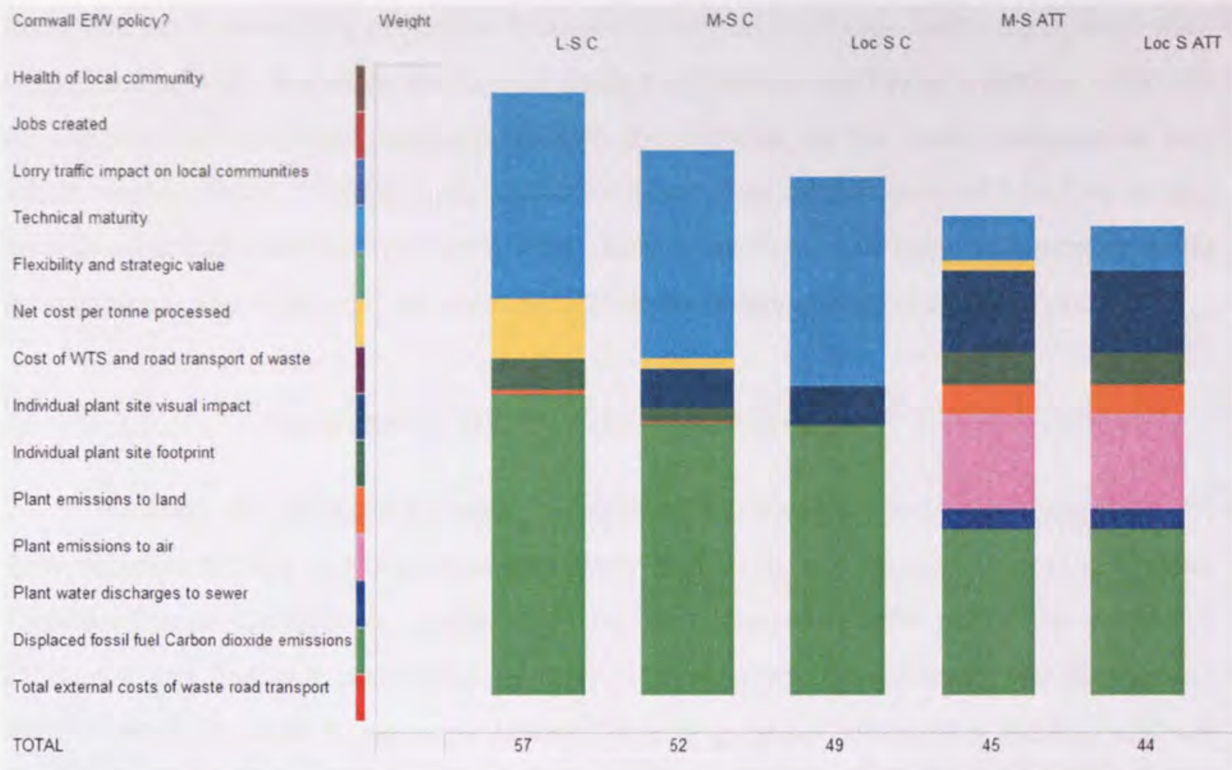

Figure 64: MCDA results with higher weight on high performing large-scale incineration criteria.

Authors who only present their argument in terms of displaced CO_2 emissions from electricity generation and net cost per tonne processed (Patel, 2005; Wheeler & Jainter, 2006) do not take enough account of a greater number of other criteria that have already been identified as important in Section 8.2 are potentially exaggerating the advantages of the large-scale combustion EfW option. Regarding scoring, it is clear that on 'displaced CO_2 emissions from electricity generation' and 'net cost per tonne' criteria, large facilities should always be superior to small ones due to scale economies and design, where the use of CHP is not assumed. When CHP is assumed, Kristiansen, (2006) states the superiority of large-scale EfW plants is often over-perceived and marginal by net present value calculations across project lifetimes.

Regarding weighting, it is apparent that the actual weights placed on technical maturity and costs are far higher in reality than those provided by WDA officers in this academic exercise. This is at the risk of disregarding other criteria that are important to take account of, in order to gain public support for the implementation of an EfW option. In the case of Cornwall, it was clear that the MCDA weightings provided by officers did not reflect the actual decision making procedure followed (Cornwall is already following a large-scale centralised policy). In reality, the Council made a decision to use PFI as a funding route (for reasons not disclosed) and produced an open specification for the waste management bid, which went to tender. Unfortunately all proposals received except one were based on using a centralised combustion facility, hence, CCC, were wary about how such DSS outputs might be used politically if they did not correspond with the policy already embarked upon.

9.3.3. A PROBLEM IN UK EFW DECISION MAKING

Relating the observations made in Sections 9.2 and 9.3.2 to the real world of UK EfW decision-making and other non-case study WDAs, it is interesting to note that while Cheshire County Council are considering a regional large-scale EfW policy for reasons of efficiency and financial cost, (Club recycle, 2006a), Surrey have already had to abandon such a policy because of planning failure for a large-scale combustion facility, and are currently carrying out a consultation on the number and type of small or medium scale plants required to replace the large-scale proposal (Club recycle, 2006b). Other cancelled or delayed UK large-scale EfW projects include Norfolk (Faulkner, 2006b), Belvedere and Aberdeen (Faulkner, 2006a).

Despite the difficulty in gaining planning permission for large-scale EfW facilities, some WDAs continue to pursue this policy. This appears to be because in reality, decision makers place far higher weights on the investment cost of the facility and on 'technical maturity' than the officers have done in this academic exercise (Section 8.6). Interestingly, these factors are strongly related to political risk (Paynter, 2006). This risk-averse attitude to new and emerging technology is understandable when WDAs can be fined at £150 per tonne if they exceed their landfill allowances (Eminton, 2005). Annual £3/t rises in Landfill tax also present financial penalties and this has been recently superceded by annual £8/t increases in the Chancellor's 2007 budget (Eminton, 2007).

To increase chances of success in EfW development, UK WDAs should adopt a flexible decision-making approach that can take into account the cost and benefits of several EfW solutions tailored specifically for the WDA area. The latter should include an assessment of more distributed scenarios, considering issues such as; the need to operate Waste Transfer Stations, road transport impact, and potential for local heat use. Assessment should not focus purely on the project economics and the technical maturity of EfW technology, but take greater account of overall sustainability by including socially important criteria such as health of the community and lorry delivery impact. Environmental criteria should be extended in order to include the implications of using heat. EfW planning should be supported by decision-assistance tools; such as the ones used and developed by this project, which are transparent, can be easily updated as new technologies (and options) become available and take into account the factors above. Use of this DSS could lead to more widely supported WDA EfW policies by ensuring the factors above are considered from policy inception and could reduce the problems described in Section 1.3.8. Most importantly, decision makers should ensure that weights represent not just internal political and economic concerns but also those of the public whose acceptance is required in developing EfW facilities

9.4. WDA FEEDBACK

Since WDAs were identified as the target end-user for the EfW DSS proposed by this thesis, the feedback from Councillors and Officers is important. Applications of this DSS to Cornwall and Warwickshire, were successful in that high-level Councillor decision makers at the Leader and Portfolio-holder level, as well as Senior Officers reported their support for the methods and techniques and they appreciated the insight it provided into the EfW decision making process (Whalley, 2006). It is however, unclear as to whether, the results of the DSS will be taken into formal account within the actual decision making process. It is perhaps unlikely, given the discussion regarding the fear of officers in providing weights. That said, it is likely that Cornwall may have renewed interest if their current centralised EfW policy is successfully challenged. This has already encountered difficulties in the decision making process (BBC, 2009).

Decision makers from both Councils reported that the methods used in this thesis would also be of significant value in the identification of new landfill site capacity, albeit with the use of different criteria and corresponding GIS datasets. Workgroup members acknowledged that such a desk top model analysis proposed by this EfW DSS enables identification of potential site areas for both EfW and landfill that may otherwise be missed in other planning studies that do not use GIS.

9.5. CHAPTER SUMMARY

The results of the MCDA were presented and the overall trends identified. Local-scale ATT was the preferred option for both county areas, with local-scale combustion and medium-scale ATT in second place. Criteria related to scale (such as transport and displaced fossil-fuel CO_2 from heat and power production) as well as technology (technical maturity and dioxin production), made greater contributions overall to deriving preferred options. The assumptions regarding the scoring of these criteria were altered in order to test for their sensitivity on the results. Finally, the overall MCDA model was adjusted with weight alterations designed to represent what may be happening in actual UK EfW decision making conducted at present. This activity was used to explain why large-scale combustion has been the dominating policy adopted in the UK and the implications of this. The next chapter presents the conclusions of this project.

10. CONCLUSIONS

This chapter presents the conclusions of this thesis. They are divided into those that concern: The DSS methods specifically and its elements (Section 10.1), results of the overall DSS analysis (Section 10.2) and implications for UK EfW policy (Section 10.3).

10.1. METHODOLOGY

Section 1.6 outlined the requirements for a useful EfW DSS and goals of the Energy White Paper for distributed generation in Section 1.3.2. In response, the points below show how the DSS (and its underlying methods) developed in this thesis meet those demands.

1. Since WDAs were identified as the key end-user, the GIS and MCDA elements of the overall EfW DSS are repeatable within the authorities' resources, since they have the in-house expertise and access to ArcView GIS and HIVIEW MCDA if required (Lea, 2006a; Holmes 2005a).
2. GIS methods can successfully formulate EfW options of local, medium and large-scale, within the context of a WDA's unique geography.
3. The results of both the Potential Site Identification and Final Site Identification models produce useful indications of suitable EfW sites that allow transport requirements of feedstock to facility (or facilities) to be minimised. Use of these modelling techniques at the beginning of an EfW planning project could identify areas where site visits and supporting investigative efforts should be concentrated, and lead to more cost-effective identification of multiple sites.
4. Both transport impact assessment methods can provide estimates of impact that clearly distinguish between EfW option performances. Where the decision maker

weightings on transport are high, the more complex geometric network methods can be used.

5. MCDA can be used to compare GIS-derived EfW options in a combined method DSS, that essentially exploits the advantages of both techniques.
6. MCDA can allow the importance (value) of WDA officer weightings to be attached to criteria in the decision making process. It can also be used as a tool to justify and support any policy route taken and may be easily updated as new information, regarding new technology for example, becomes available.
7. However, as is often found in MCDA, the results may be vulnerable to error in that the specified weightings may not accurately reflect the real situation. There may also be genuine disagreement over what weights to apply. This does present an opportunity to enhance further the value of modelling in this DSS, since option scenarios can be run with officers to show the impact of their choices until a consensus is reached.
8. MCDA has value in demonstrating that an auditable and transparent method has been followed in decision-making. Weightings and scores can be independently reviewed and subjected to sensitivity analysis.

10.2. RESULTS OF DSS ANALYSIS

1. The mean-weighted MCDA results identified local-scale ATT as the preferred option for both WDA areas. All officers from both counties ranked medium and large-scale combustion options in 4th and 5th rank, respectively (Section 9.2).
2. The Final Site Identification results indicate that, contrary to many waste planners belief, there are enough sites at the county level for distributed EfW facilities. 33 and 31 potentially suitable sites for EfW were identified in Cornwall and Warwickshire respectively (Section 6.3).
3. Regardless of estimation method used, transport savings in hauling waste using a local-scale approach to EfW were 34 and 60% lower than large-scale options in Cornwall and Warwickshire respectively, but medium-scale

facilities may present the best marginal benefit results with regard to minimising impact vs. the number of plants (Section 7.3).

4. Implications of the differences in WDA area geographic characteristics are significant. For the same scale option, Warwickshire's waste transport costs were between 37 and 62% of Cornwall's. Cornwall being a long peninsula, for example, required greater transport radii for collecting feedstock to facilities compared to Warwickshire which also has urban areas more evenly distributed across the county. This suggests that the effect of geography at the sub-regional level should certainly be taken into account in all EfW planning studies, regional or local (Section 6.4.3).
5. Most studies reviewed with the exception of Consonni et al, (2005a) did not take into account the impacts from the transport of fly ash residues. The pyrolysis/gasification options generated 75% less fly ash and hence, require less transport in order to dispose of them. Section 7.3.2 showed that the significance of this factor depended on the technology used, but more importantly on how close landfill sites, (particularly those licenced to take the hazardous fly ash) are situated to the WDA area in which processing is conducted.
6. There were significant differences in ATT and Combustion EfW option performance scores. On the basis of collected data, ATT performed more favourably on environmental criteria such as emissions to air, land and water and visual impact. Combustion was superior to ATT, however, in terms of its electrical energy generation efficiency and technical maturity. Overall, however, the choice mostly depends on weightings used in the evaluation (Section 8.6) and the assumptions made on how facilities are operated, since performances of all technology options legally only have to meet WID conditions.
7. In both WDA areas, the most significant weightings from WDA officers were allocated to the 'Displaced carbon dioxide emissions' criterion indicating that climate change issues are important within EfW decision making. Other heavily weighted criteria include: 'Health of the local community' (measured

by dioxins produced) 'Net cost per tonne' (of MSW processed), 'Flexibility' and 'Technical maturity'. All of which have significant political implications as discussed in Sections 4.2.1.1, 4.2.2.4, 8.4.13 and 4.2.3.1 respectively.

8. The least important criteria in both counties include 'Individual plant site footprint', 'Plant emissions to land', 'Plant water discharges' indicating that despite their use within studies from the literature, they are of little concern to WDA officers in the context of this project.
9. When 'Health of the community' (dioxin production) predominantly and 'Emissions to air' are assumed to be the same for both technologies as is required under WID, Combustion dominates ATT at local-scale and becomes the preferred option for both WDA areas. As discussed in Section 4.2.2.4, the scoring of this criterion is important, since if this perception of risk can be moderated with the WDA's public, it may allow a more mature technology with arguably higher energy generation efficiencies (Fichtner, 2004) to be developed with the outcome that more CO_2 emissions may be displaced.
10. Reasons for why large-scale combustion options are most typically followed in real decision making processes can be explained in the context of the modelling undertaken in this project by rejecting social criteria. This results in a heavy weighting on just two criteria 'Net cost per tonne' and 'Technical maturity'. As discussed in Section 9.3.2, this could be criticised by non-governmental organisations, interested in minimising environmental impact as a narrow basis for decision-making and may be difficult to defend further into the planning process.
11. In a rural/suburban context, credit provided to medium and local scale-options for the production of heat can potentially provide even greater strength to local and medium-scale options over large-scale. Further CO_2 emission savings from transport would also strengthen the case for small-scale distributed EfW options, particularly if the weight of this aspect was increased as discussed in Section 9.3.1.4.

10.3. POLICY IMPLICATIONS

A DSS comprising of modified methods from the literature has been developed to assist sub-regional decision-makers formulate and appraise EfW policy implementation options, tailored to the socio-geographic characteristics of WDA areas. This tool and its implementation has been reported to be useful to WDA decision makers (Whalley, 2006) and the insights gained from its application make a useful contribution to the UK EfW planning arena, (Porritt, 2006 in Appendix D). Use of both GIS and MCDA techniques allow the DSS to successfully to take into account transportation, technology and siting issues simultaneously in a far more holistic manner. The DSS offers a streamlined assessment of EfW policy implementation options that may be implemented using the skills and software of in-house WDA personnel (Lea, 2006a; Holmes 2005a). In addition, the project has identified if smaller, multiple or large-scale centralised systems of either Combustion or Advanced Thermal Treatment technology are preferred options within specific WDA areas and has identified the key criteria that may affect this outcome.

Relating the observations made in Section 9.2 to the real world of UK EfW decision-making and other non-case study WDAs as indicated by the case of Hampshire discussed in Section 1.3.9, local authorities are investigating more distributed EfW facility options due to public pressure. Such policies are increasingly being studied but for traditional incineration only. The degree of 'centralisation' differs between reports with two facilities representing decentralised generation (Jainter and Poll, 2005) and increasing to three and five (Wheeler and Jainter, 2006). These references support the view that decentralisation in the UK is only beginning to be recognised as a potentially attractive strategy to successfully implement EfW policy.

An EfW DSS such as that developed in this thesis might have saved much time, effort and money and ensured a far greater diversity of EfW options were formulated and appraised for the very WDA context in which they are to be actually implemented. While appreciating its limitations, its use by WDAs could mean that area-tailored projects may begin to experience fewer failures and delays in the planning process. EfW may then realise its potential to make a significant contribution to sustainable development in the UK by achieving national landfill diversion and renewable energy targets.

11. RECOMMENDATIONS FOR FURTHER WORK

11.1. DSS METHODS

- The residual MSW model could be further developed by taking into account the differences in waste generation that are attributable to socio-economic groups and also by taking account of seasonal variability that may be a result of tourism, for example.
- Other resource models could take account of study area arisings of biomass and commercial/industrial waste. Multiple layers could be combined to identify opportunities for co-firing feedstock, and hence, increase the size of the plant and acquire economies of scale, whilst still retaining the 'local' collection of resources which is perceived to be important by the public.
- The site identification results could be developed by deriving them from more layers of GIS data. Such layers might include derelict land, areas of previous waste management sites and electrical grid zones identified as suitable for distributed generation by network operators.
- Regarding transport, the implications of rail or water could be considered if suitable within the WDA context. In order to accomplish this, use could be made of the Environment Agency's WRATE software that has become available since the completion of this project.
- Regarding the MCDA options, other ATT design options could be considered to cross-reference the Compact Power performance data with other ATT technologies on the market. Such data has been difficult to obtain in this project due to its commercial sensitivity and the lack of developers' willingness to supply. While its introduction occurred after the completion of this project, one of the primary functions of the Environment Agency's

WRATE software is to appraise different technology options on a life-cycle analysis basis and such data could be combined with decision maker weights within an MCDA approach. It should be noted, however, that such a study might be limited by the reluctancy of WDA officers to consider any technology option that did not already have a facility operating in the UK. It may also not be possible due to the prohibitive cost of obtaining a fully licenced version of the software.

11.2. DSS SCOPE

Further study could investigate the optimum number of plants in terms of maximising revenues, (such as those from heat sales) while achieving the savings accruing from economies of scale in plant development and the savings from transport. Such a study, if performed to serve the real needs of county decision makers, would need to take into account many WDA area location-specific variables and its results would probably not be generally applicable. The annual savings in transport discussed in demonstrated Section 7.3.1 could make a significant impact on the overall cost of waste management over a typical 25 year contracting period and may make smaller, more distributed EfW options more economically attractive than previously perceived.

The Wheeler & Jainter (2006) study concluded that transport savings were marginal from a multiple plant strategy and that they are outweighed by the savings from developing a centralised, single plant option. Further work should investigate which technology gate fee cost curves are more accurate and under what circumstances (such as the inclusion of heat revenue), and which haulage cost is most reliable. This study also did not assume the use of WTS for local EfW options. An area of further work would be to exclude all WTS and re-run Cornwall's local option. This would also allow more meaningful comparison with the Wheeler study results.

Further work could investigate the effect of spatial change in the distribution of option locations due to changes in residual waste generation parameters. A range of different urban suburban or rural areas may be considered in terms of their jurisdictional boundary, population distribution. Conclusions could be made as to which type and characteristics of areas indicate to what degree of centralised or distributed, EfW policies may be of greatest suitability.

This study has applied its methods to two WDA areas which are not currently planning on sending their residual waste outside of their jurisdictional boundaries for management. Further work could compare the costs of all in-county options against those of transporting waste outside of the administrative boundaries to other existing EfW recovery destinations. To expand this, the Resource Recovery Centre concept (where recycling and energy recovery are co-located) could be investigated and compared to identify the extent this may have in mitigating site scarcity and transport impact by ensuring the majority of waste management is conducted *within* the study area. More generally, it would be interesting to compare the costs of *all* in-county waste management options against those of exporting waste (recyclable or residual) outside of the WDA boundaries to other existing or proposed regional scale facilities.

Applications of the DSS could also be extended to include formal estimates of potential heat demand by building type and number for case study areas in order to respect the true extent of how more CO_2 emissions can be displaced by using CHP at any one location identified as suitable for an EfW facility. Such an approach has been carried out in Norway (Bergsdal et al, 2005) but be currently difficult in the UK due to data availability.

It is of interest to obtain weightings from the public and other interested parties such as other experts or stakeholders actively involved in EfW decision making. These could be acquired and the resulting MCDA model results compared to those with WDA officers. Such stakeholders might include central government civil servants, resident opposition groups, environmental groups, consultants and academics. This was not undertaken in this project due to WDA concerns at the sensitivity of the issues investigated by this project and its high political profile, particularly in Cornwall. Concentration was, therefore, made on obtaining officer weights for testing the DSS. This was justified, since they are in a key position to influence and guide EfW planning policy in any one administrative area and have a good knowledge of the issues at hand and the relative importance of the criteria and scores that represent MCDA option performance. Officers were also identified as the targeted end-users for the overall DSS in Section 1.3.6

In the collection of weights for MCDA modelling from Local Authority Officers a number of issues arose. One of the most important ones was the observation that some officers seemed to fear that there weights would lead to identifying a preferred EfW option that was not currently supported within the Council and that the weights they supplied for different criteria may not be consistent. It was observed that on some criterion, due to the uncertainty of the implications of some of the more complex criterion such as 'Displaced CO_2 emissions', a minority of officers simply repeated their peers' weights. Assigning weights is challenging when changes in the range of variation and the different degrees of importance being attached to these variation ranges most be accounted for (Kirkwood, 1997). Weighting sessions were held in an open forum and while this had the benefit of knowledge sharing and debate, it was clear that the collection of swing-weightings as required by HIVIEW should also have been done privately and the end results compared.

To help overcome these difficulties in the event that this research be repeated or extended, alternative methods to swing-weighting could be used. The latter is a "rating" method on a scale of 0 to 100 but simpler "ranking" methods could be used. In using a rating method, every criterion under consideration is ranked in the order of the decision maker's preference (E.g. most important = 1, second important = 2 etc). Once done, several techniques such as rank sum, rank reciprocal and rank exponent methods (Stillwell et al, 1981) are available. These methods may prove less challenging to use in the local authority context and provide a greater degree of consistency. While ranking methods are attractive due to their simplicity, Voogd (1983), note that they are limited by the number of criteria to be ranked (the larger the number, the less appropriate these methods are). They have also been criticised for their lack of theoretical foundation but may be used as weight approximation methods (Malcewski, 1999).

Another worthwhile approach for investigation is to use the pairwise comparison method to weighting developed by Saaty (1980) as part of the Analytic Hierarchy Process (AHP) discussed in Section 2.7.3. This would essentially involve running a second MCDA approach but a comparison of the results from the different models would be worthwhile to investigate if the preferred EfW options were sensitive to choice of MCDA and weighting approach. One of the greatest strengths of AHP is that a consistency index can be computed to assess if the pairwise comparisons are consistent. This method of weighting has, however, been criticised for its vulnerability to erroneous interpretation by decision makers of the numerous questions that must be asked in order to derive the relative importance of evaluation criteria, without reference to the scales on which the criteria are measured (Malcewski, 1999). The most popular software that may be used for the pairwise comparison procedure is EXPERT CHOICE (Expert Choice, 2009).

The concept of communities 'owning' their EfW facilities could be investigated and how this could be best incorporated in the MCDA models. This might be of interest to WDAs in winning public support but unlikely to be of interest to large waste management companies interested in maximising the profit in return for their investment. It would be necessary to define 'community ownership' of any particular energy generation project is and has been described as when the 'local' community is given the opportunity to own shares and receive dividends from the sales of energy the plant produces (Baywind, 2005). It has been argued, however, that community ownership is not just related to the number of plant opportunities that may be viewed as 'local', but more do to with how the schemes are run and financed (Nabney, 2007).

At the time of writing it is apparent that Private Finance Initiative (PFI) is having a significant effect on EfW policy in the UK. It has been argued that the PFI mechanism and the financial criteria that must be satisfied for projects to receive Government credits are encouraging proven, large-scale solutions thus ensuring that large proportions of the UK MSW market will be taken up by conventional combustion EfW technology over the next 25 years at the cost of encouraging the development of the emerging ATT technologies. The only ATT technology currently on the market with an acceptable track record and chance of PFI funding is that offered by Energos acting as technology provider in a consortium of large utility or waste management companies.

It is important to undertake further research to investigate how PFI affects decision making and include this in future versions of the DSS. This could be done by interviewing various key members of DEFRA who are responsible for running the scheme for WDAs to obtain PFI credits, Project Managers of large waste management/utility companies and technology providers. It is interesting that at a local level, the strength of influence of PFI on decision making is often unknown and misunderstood by the wider public and interested parties on which planning permission may depend. This can also differ on a political and geographic basis, where local authorities in less affluent areas of the UK, such as Cornwall, may depend on PFI credits more than in other areas such as Surrey and Bristol.

Finally, the influence of the Secretary of State and Central Government should also be investigated and understood in the context of local EfW decision making since there are a growing number of large-scale EfW schemes whose developers are strategically offering as 'merchant' facilities and building them independently of any local authority waste contract procurement process. Examples include the 600 ktpa of Peel Holdings near Runcorn in Cheshire (Eminton 2009b) which has just been given permission from the Secretary of State and Sita UK's proposal for 400 ktpa intended for commercial wastes but strategically sited across the administrative boundary of Bristol (Eminton 2009c) to be well placed to win a proportion of the West of England's residual MSW contract by offering low gate fees.

In addition, developers of large-scale combustion schemes for residual MSW such as in Cornwall who have been refused planning permission by the local authority (despite winning the PFI contract), are increasingly appealing against the decisions, leaving final judgement to be made by the Secretary of State (Eminton 2009d). It is at this point that decision making power transfers from local political institutions to Central Government. Such actions may be argued not be in the interest of local democracy where people have a right to decide how the waste they generate is managed in the context of sustainable development (WCED, 1987) but perhaps necessary in ensuring the UK meets its landfill diversion targets set by the EU Landfill Directive.

REFERENCES

AEAT. (2005). "Renewable heat and heat from combined heat and power plants - Study and Analysis." Retrieved 22 June, 2006, from http://www.DEFRA.gov.uk/farm/crops/industrial/energy/pdf/fes-renewable-chp.pdf.

AEAT. (2007). "Industrial Heat Map." Retrieved 30th September, 2007, from http://www.industrialheatmap.com.

Ares, E. and Bolton, P. (2002). "Waste incineration." House of Commons Library Retrieved February 21st, 2006, from http://www.parliament.uk/commons/lib/research/rp2002/rp02-034.pdf.

Arrowsmith, G., Crampin, M. and Crowe, M. (2003). Unit 10: Prediction. Milton Keynes, Open University.

Assefa, G., Bjorklund, A., Eriksson, O. and Frostell, B. (2005). "ORWARE: and aid to environmental technology chain assessment." Journal of Cleaner Production **13**: 265-274.

Azapagic, A. and Camana, D. (2005). Municipal solid waste as an Energy Resource: Mass-burn incineration of small-scale Pyrolysis. 7th World Congress of Chemical Engineering, Glasgow.

Bastin, L. (2006). Circuity factors in routing and accessibility applications: a review. Birmingham, School of Engineering and Applied Science, University of Aston.

Bastin, L. and Longden, D. (2007). Comparing transport impact for energy recovery from domestic waste (EfW): large and local-scale options for two UK Counties. School of Engineering and Applied Science, University of Aston.

Baumann, H and Tillman, A. (2004). The Hitch Hiker's Guide to LCA: An orientation to life cycle assessment methodology and application. Sweden, Studentlitteratur.

Baywind. (2005). "Community Ownership." Retrieved 8th April, 2009 http://www.energy4all.co.uk/energy_community.asp

BBC. (2007). "Climate bill's 60% emission cut." Retrieved 29th December, 2007, from http://news.bbc.co.uk/1/hi/uk_politics/7080580.stm.

BBC. (2009). "Decision on incinerator delayed" Retrieved 24th April, 2009, from http://news.bbc.co.uk/1/hi/england/cornwall/7942370.stm

Beggs, C. (2002). Energy: Management, Supply and Conservation. Oxford, Butterworth-Heinemann.

Benoit, V. and Rousseaux, P. (2003). "Aid for aggregating the impacts in life cycle assessment." International Journal of Life Cycle Assessment **8**: 74-82.

Bergsdal, H., Stromman, A. H. and Hertwich, E. G. (2005). "Environmental Assessment of Two Waste Incineration Strategies for Central Norway." International Journal of LCA **10**(4): 263-272.

Berry, J. (1993). Cartographic modeling: the analytical capabilities of GIS. Environmental modelling with GIS. M. Goodchild, B. Parks and L. Steyaert. Oxford, Oxford University Press.

Beswick, J. (2006). Compact Power technology performance data. Bristol, 07810 354943: Personal Communication.

Biffa. (2002). "Future Perfect - Available tools logistics technologies." Retrieved September 20th, 2005, from http://www.biffa.co.uk/content.php?name=publications/futureperfect.html.

Boer, J., Boer, E. and Jager, J. (2007). "LCA-IWM: A decision support tool for sustainability assessment of waste management systems." Waste Management **27**: 1032-1045.

Boyle, G. (2004a). Renewable Energy. Milton Keynes, Open University Press.

Boyle, G., Everett, B. and Ramage, J. (2003). Energy Systems and Sustainability. Oxford, Oxford University Press.

Boyle, S. (2004b). "RCEP - Second consultant's report." Retrieved 27th July, 2007, from http://www.rcep.org.uk/papers/general04/119.pdf.

Brereton, C. (1996). "Municipal solid waste - incineration, air pollution control and ash management." Resources, Conservation and Recycling **16**(1-4): 227.

Bristol City Council. (2008). "Recycling and rubbish collection dates - December 2007 to January 2009." Retrieved 3rd January, 2008, from http://www.bristol.gov.uk/recycling.

Brown, R. (2003). Grid connection criteria of small and large generators. Northampton, Central Networks 01908 510453: Personal Communication.

Capita Symonds (2004). Waste by Rail Feasibility study. Truro, Cornwall County Council.

CCC (2003). Waste Local Plan. Truro, Cornwall County Council. Retrieved 24th April, 2006, from http://www.cornwall.gov.uk/default.aspx?page=15741#WasteDocuments

Chang, K. (2002). Introduction to Geographic Information Systems. New York, Mc-Graw Hill.

Cheng, S., Chan, C. and Huang, G. (2003). "An integrated multi criteria decision analysis and inexact mixed integer linear programming approach for solid waste management." Engineering applications of artificial intelligence **16**: 543-554.

Clift, R. (2007). "Climate change and energy policy: The importance of sustainability arguments." Energy **32**: 262-268.

Clift, R., Doig, A. and Finnveden, G. (2000). "The application of life cycle assessment (LCA) to integrated solid waste management, Part 1 - methodology." Transactions IChemE **78 (Part B)**: 279-287.

Club recycle. (2006a). "Cumbria nears decision on long-term waste partner." Retrieved 24th April, 2006, from. http://www.letsrecycle.com/do/ecco.py/view_item?listid=37&listcatid=238&listitemid=7467&section=info/localauth

Club recycle. (2006b). "Time running out for DEFRA's £30m Demonstrator Programme." Retrieved 29th March, 2006, from http://www.letsrecycle.com/do/ecco.py/view_item?listid=37&listcatid=239&listitemid=7402&section=info/waste_management.

Coggins, C. (2006). "What is a resource recovery park?" Retrieved 17th April, 2006, from http://www.resourcesnotwaste.org/EDEN/COGGINS(PPT).pdf.

Cole, N., Dagnall, S., Hill, J., Jenner, C., Pegg, D., Rushton, K. and Toplis, E. (1996). Resource mapping and analysis of potential sites for short rotation coppice in the UK - Assessing the opportunities for biomass-to-energy technologies. 9th European Biomass Conference, Copenhagen, Pergavon.

Consonni, S., Glugliano, M. and Grosso, M. (2005a). "Alternative strategies for energy recovery from municipal solid waste Part A: Mass and energy balances." Waste Management **25**: 123-135.

Consonni, S., Glugliano, M. and Grosso, M. (2005b). "Alternative strategies for energy recovery from municipal solid waste Part B: Emission and cost estimates." Waste Management **25**: 137-148.

Conway, N. (2006). Rethink, recycle, revolutionise. Birmingham Post. Birmingham: 9.

Cooper, N. (2003). Compact Power put Pyrolysis at the Heart of Sustainable Developments Optimising Value Recovery. Pyrolysis and Gasification of Biomass and Waste, Strasbourg, France, Cpl Press.

Cooper, R. (2006). GIS Electrical grid data. Nottingham, Central Networks, Robert.Cooper@central-networks.co.uk: Personal Communication.

Corti, A. and Lombardi, L. (2004). "End life tyres: Alternative final disposal processes compared by LCA." Energy **29**: 2089-2108.

CORWM. (2006). "Managing our radioactive waste safely: recommendations to government." Retrieved 26th August, 2006, from http://news.bbc.co.uk/nol/shared/bsp/hi/pdfs/310706_corwmfullreport.pdf#search=%22Hiview%20nuclear%20waste%22.

Coulson, M. (2006). Double counting in MCDA and the perceptions affecting overall planning permission. Birmingham, Aston University, m.coulson@aston.ac.uk: Personal Communication.

Curran, M. (1996). Environmental life cycle assessment. New York, Mc-Graw Hill.

Dagnall, S., Hill, J. and Pegg, D. (2000). "Resource mapping and analysis of farm livestock manures - assessing the opportunities for biomass-to-energy schemes." Bioresource Technology **71**: 225-234.

Dai, F., Lee, C. and Zhang, X. (2001). "GIS based geo-environmental evaluation for urban land use planning: a case study." Engineering Geology **61**(257-271).

Dawber, N. (2006). Small scale thermal treatment within an integrated waste management system. CIWM, Paignton, UK.

DEFRA. (2005). Our waste implementation programme - two years on. London, DEFRA.

DEFRA. (2006a). "Climate change agreements." Retrieved 3rd August, 2006, from http://www.DEFRA.gov.uk/environment/climatechange/uk/business/cca/index.htm.

DEFRA. (2006b). Review of England's waste strategy: a consultation document. London, DEFRA.

DEFRA. (2007). "New technologies demonstration programme -catalogue of applications 2007 update." Retrieved 30th July, 2007, from http://www.urbanmines.org.uk/assets/files/n/newtechnologiescatalogue2007_635.pdf.

DETR. (2000). Waste strategy for England and Wales. London, HM Government.

DTI. (2007) Estimates of heat use in the United Kingdom. Retrieved December, 15th February 2007 from http://www.berr.gov.uk/files/file43843.pdf.

DfT. (2005). "National Tranport Model, Forge: The road capacity and costs model research report." Retrieved 10th December, 2005, from http://www.dft.gov.uk/pgr/economics/ntm/etheroadcapacityandcosts3031.pdf.

DfT. (2007). "Accession." Retrieved 19th March, 2007, from http://www.citilabs.com/accession.html.

Dijikstra, E. W. (1959). "A note on two problems in connexion with graphs." Numerische Mathematik **1**: 269-271.

Dodgson, J., Spackman, M. and Pearson, A. (1999). "Multi-Criteria Analysis: a manual." Retrieved 27th August, 2006, from http://www.communities.gov.uk/publications/corporate/multicriteriaanalysismanual.

DTI. (2000). "Savings in carbon emissions from combined heat and power." Retrieved 1st March, 2006, from http://www.berr.gov.uk/energy/environment/efficiency/chp/index.html.

DTI. (2003). Energy White Paper - Our energy future - creating a low carbon economy. London, HM Government.

DTI. (2006a). Digest of UK Energy Statistics (DUKES). Retrieved 20th October, 2006 from http://www.berr.gov.uk/energy/statistics/source/chp/page18528.html.

DTI. (2006b). Our energy challenge - securing clean, affordable energy for the long-term. London, DTI.

Dujim, N. and Markert, F. (2002). "Assessment of technologies for disposing explosive waste." Journal of hazardous materials **A90**: 137-153.

Ecobilan. (2006). "Waste-integrated systems for assessment of recovery and disposal (WISARD)." Retrieved 16th June, 2006, from http://www.ecobalance.com/uk_wisard.php.

Edina. (2006a). "Digimap: Ordnance Survey Meridian data." 2006, from http://edina.ac.uk/digimap/.

Edina. (2006b). "UK Borders." from http://www.edina.ac.uk/ukborders/.

Ekvall, T., Assefa, G., Bjorklund, A., Eriksson, O. and Finnveden, G. (2007). "What life-cycle assessment does and does not do in assessments of waste management." Waste Management **27**: 989-996.

Elghali, L., Clift, R., Sinclair, P., Panoutsou, C. and Bauen, A. (2007). "Developing a Sustainability Framework for the Assessment of Bioenergy Systems." Energy Policy **35** (12) 6075-6083.

Eminton, S. (2005). "Limits set for disposal of waste in English landfills." Retrieved 22nd June, 2005, from http://www.letsrecycle.com/do/ecco.py/view_item?listid=37&listcatid=253&listitemid=6103&section=legislation.

Eminton, S. (2007). "Brown announces Landfill Tax rise to boost recycling." Retrieved 2nd April, 2007, from http://www.letsrecycle.com/do/ecco.py/view_item?listid=37&listcatid=226&listitemid=8565&section=legislation

Eminton, S. (2009a) "Deadline passes for New Technologies Demonstrator Programme" Retrieved 24th April, 2009, from http://www.letsrecycle.com/do/ecco.py/view_item?listid=37&listcatid=5270&listitemid=31320&section=waste_management

Eminton, S (2009b) "Government approves waste-fuelled power plant in Cheshire". Retrieved 1st November 2009 from http://www.letsrecycle.com/do/ecco.py/view_item?listid=37&listcatid=5358&listitemid=53154

Eminton, S (2009c) "Sita UK unveils plans for Bristol EfW facility". Retrieved 1st November 2009 from http://www.letsrecycle.com/do/ecco.py/view_item?listid=37&listcatid=5315&listitemid=52228&section=waste_management

Eminton, S (2009d) "Sita set to appeal Cornwall EfW planning refusal". Retrieved 1st November 2009 from http://www.letsrecycle.com/do/ecco.py/view_item?listid=37&listcatid=5377&listitemid=53323&section=local_authority

English Nature. (2006). "Magic." from http://www.magic.gov.uk/.

Environment Agency. (2006a). "Waste & Resource Assessment Tool for the Environment (WRATE)." Retrieved 6th Sept, 2006, from http://www.environment-agency.gov.uk/research/commercial/102922.aspx.

Environment Agency. (2006b). "Waste Technology Data Centre." Retrieved 20th March, 2006, from http://www.environment-agency.gov.uk/wtd/.

Environment Council. (2007). "Sustainable Waste Managment." Retrieved 17th March, 2007, from http://www.wasteonline.org.uk/resources/Wasteguide/mn_sustainable_wm.html.

Enviros (2004). Planning for Waste Management Facilities: A Research Study. London, ODPM.

Enviros, University of Birmingham, Risk and Policy Analysts, Open University and Thurgood, M. (2004). Review of environmental and health effects of waste management: municipal solid waste and similar waste. London, DEFRA.

ERM. (2005). Planning for sustainable waste management: companion guide to planning policy statement 10, ODPM.

Eunomia. (2006). "A changing climate for energy from waste." Retrieved 17th July, 2006, from http://www.foe.co.uk/resource/reports/changing_climate.pdf.

Expert Choice (2009) "Set prioirties and move your organisation forward" Retrieved 1st November, 2009 from http://www.expertchoice.com/

Fichtner. (2004). The viability of advanced thermal treatment of MSW in the UK. London, ESTET.

Fichtner. (2009). Energos Gasification Technology Report for Biogen Power. Confidential report administered by N. Dawber (Managing Director, Energos, n.dawber@Energos.com)

Finnveden, G., Johansson, J., Lund, P. and Moberg, A. (2005). "Life cycle assessment of energy from solid waste - part 1: general methodology and results." Journal of Cleaner Production **13**: 213-229.

Finnveden, G. and Moberg, A. (2005). "Environmental systems analysis tools - an overview." Journal of Cleaner Production **13**: 1165-1173.

FoE. (1995). "Briefing: Wildlife, Planning and Developments." Retrieved 10th November, 2006, from http://www.foe.co.uk/resource/briefings/wildlife_planning_develop.html.

FoE. (2002). "Incinerator Inquiries: A review of recent public inquiries considering planning permission for municipal waste incinerators." Retrieved 23rd May, 2006, from http://www.foe.co.uk/resource/briefings/incinerator_inquiries.pdf.

Freppaz, D., Minciardi, R., Robba, M., Rovatti, M., Sacile, R. and Taramasso, A. (2004). "Optimising forest biomass exploitation for energy supply at a regional level." Biomass & Bioenergy **26**(1): 15-25.

Geary, J. (2006). Secret talks on waste furnace. Birmingham Post. Birmingham: 1.

Gershman, H., Brickner, R. and Bratton, T. (1986). Small-scale municipal solid waste energy recovery systems. New York, Van Nostrand Reinhold Company.

Gill, B., Clayton, D. and Hartley, N. (2006). "Biomass task force: Report to Government." Retrieved 22nd June, 2006, from http://www.DEFRA.gov.uk/farm/crops/industrial/energy/biomass-taskforce/index.htm.

Goumas, M. and Lygerou, V. (2000). An extension of the PROMETHEE method for decision making in fuzzy environment: "Ranking of alternative energy exploitation projects". European Journal of Operational Research **123**: 606-613.

Graham, R., English, B. and Noon, C. (2000). "A geographic information system-based modeling system of evaluating the cost of delivered energy crop feedstock." Biomass & Bioenergy **18**: 309-329.

Greenberg, M., Lewis, D. and Frisch, M. (2002). "Local and interregional economic analysis of large US Department of energy waste management projects." Waste management **22**: 643-655.

Haggard, M. (2006). PFI credits and waste infrastructure. London, melville.haggard@DEFRA.gsi.gov.uk: Personal Communication.

Haramlambopoulos and Polatidis, H. (2003). "Renewable energy projects: structuring a multi-criteria group decision-making framework." Renewable Energy **28:** 961-973.

Harbottle, M., Tabbaa, A. and Evans, C. (2006). "A comparison of the technical sustainability of in situ stabilisation/solidification with disposal to landfill." Journal of Hazardous Materials **141**(2): 430-440.

Hardy, K. (2009) Air emissions and the accuracy required for MCERTS certification for PPC licences. k.hardy@Energos.com, Personal Communication.

Heath, J. (2007). NEWLINCS Case Study. Retreived on 6th January from http://www.fey.org.uk/site/LinkClick.aspx?fileticket=cwYje8XTESY%3D&tabid=228&mid=1070&language=en-GB

Hermann, B., Kroeze, C. and Jawjit, W. (2007). "Assessing environmental peformance by combining life cycle assessment, multi-criteria analysis and environmental performance indicators." Journal of Cleaner Production **15**: 1787-1796.

Higham, I. (1999). An assessment of municipal solid waste treatment options for Cornwall County Council. Harwell, AEA Technology.

Hogg, D. (2002). Maximising recycling rates: tackling residues. Bristol, Community Recycling Network.

Holmes, T. (2005a). Contact for GIS data from Warwickshire County Council. t.holmes@warwickshire.gov.uk. Warwick, Personal Communication.

Holmes, T. (2005b). Roads Windage factor for Warwickshire. t.holmes@warwickshire.gov.uk. Warwick, Personal Communication.

Hopkins, G (2008). Environment portfolio holder, Liberal Democrats: Politics using alternatives to incineration in Bristol. g.hopkins@bristol.gov.uk. Bristol, Personal Communication.

IARC. (2007). Overall evaluations of carcinogenicity on humans. Retrieved 27th October 2007 from http://monographs.iarc.fr/ENG/Classification/crthgr02b.php.

IEA. (2000). Experience curves for energy technology policy. Paris, OECD.

ILEX Energy. (2005). "Extending ROC eligibility to EfW from CHP." Retrieved 8th April, 2005, from http://www.berr.gov.uk/files/file22325.pdf.

Jainter, N. and Poll, J. (2005). Best Practicable Environmental Option for the management of municipal waste in Warwickshire. Harwell, Didcot, AEAT Environment.

Jones, P. (2006). "Renewable energy supply packages from the waste sector - dreams and realities." from peter.jones@biffa.co.uk. Personal Communication.

Juniper. (2003). "Pyrolysis and gasification factsheet." Retrieved 16th of February 2006, from http://www.juniper.co.uk/services/Our_services/P&GFactsheet.html.

Keen, P. G. W. and M. S. S. Morton (1978). "Decision Support Systems: An Organisational Perspective." Data Base **12**(1,2).

Keeney, R. (1980). Siting Energy Facilities. New York, London, Academic Press.

Keeney, R. (1992). Value-focused thinking - A path to creative decision making. London, Harvard University Press.

Keeney, R. and Raiffa, H. (1976). Decisions with Multiple Objecives. New York, Wiley.

Keeney, R., Renn, O. and Winterfeldt, D. (1987). "Structuring West Germany's energy objectives." Energy Policy: 352-362.

Khelifi, O., Giovanna, F., Vranes, S., Lodolo, A. and Miertus, S. (2006). "Decision support tool for used oil regeneration technologies assessment and selection." Journal of Hazardous Materials **137**(1): 437-442.

Kirkby, N. and Azapagic, A. (2004). Municipal solid waste management: Can thermodynamics influence People's opinions about incineration? Theory and practice of sustainable development: Case studies for Engineers and Scientists. Chichester, John Wiley & Sons: 118-200.

Kirkeby, J., Birgisdottir, H., Hansen, T. and Christensen, T. (2006). "Evaluation of environmental impacts from municipal solid waste managment in the municipality of Aarhus, Denmark." Waste Management Research **24**: 16-26.

Kirkwood, C.W. (1997) Strategic decision making:multiobjective decision analysis with spreadsheets. Belmont, CA: Duxbury Press.

Kondakor, K. (2007). "Meeting LATS in Warwickshire without having to build another giant incinerator." Retrieved 20th October, 2006, from http://www.greennuneaton.org.uk/waste/kk/WWMP_KK_Waste_talk_2.pdf.

Koushki, P., Al-Duaij, U. and Al-Ghimas, W. (2004). "Collection and transport cost of household solid waste in Kuwait." Waste Management **24**: 957-964.

Kristiansen, T. (2006). Small scale Energy from Waste facilities: Case studies from Denmark. CIWM, Paignton, UK.

Krukanont , P & Prasertsan, S (2004)."Geographical distribution of biomass and potential sites of rubber wood fired power plants in Southern Thailand. " Biomass & Bioenergy **26**. 47-59.

Larke, C & BBC. (2008). Concerns on centralised EfW development. Retrieved 22nd January 2009 from http://news.bbc.co.uk/1/hi/england/cornwall/7635289.stm

Lea, A. (2006a). Final presentation of results. alea@cornwall.gov.uk. Truro, Cornwall County Council: Personal Communication.

Lea, A. (2006b). Preferred options for waste in Cornwall. Truro, Cornwall County Council.

Limb, D. (2008). Typical household waste collection data. Chester, d.limb@chester.gov.uk: Personal Communication.

Lisney, R. (2001). Project Integra - a personal history by Robert Lisney, Hampshire County Council.

Livingston, W. R. (2002). Technical and economic assessment of energy conversion technologies for MSW. DTI sustainable energy programme. London, DTI.

Loosemore, M., Raftery, J., Reily, C. and Higgon, D. (2006). Risk management in projects. London & New York, Taylor & Francis.

Malczewski, J. (1999). GIS and Multi-criteria decision analysis. New York, John Wiley & Sons.

Malkow, T. (2004). "Novel and innovative pyrolysis and gasification technologies for energy efficient and environmentally sound MSW disposal." Waste Management **24**(1): 53-79.

Maniezzo, V., Mendes, I. and Paruccini, M. (1998). "Decision support for siting problems." Decision support systems **23**: 273-284.

Matejicek, L., Engst, P. and Janour, Z. (2006). "A GIS based approach to spatio-temporal analysis of environmental pollution in urban areas: A case study of Prague's environment extended by LIDAR data." Ecological Modelling **199**(3): 261-277.

Mc Lanaghan, S. R. B. (2002). Delivering the Landfill Directive: The role of new and emerging technologies. London, Government Strategy Unit (PIU).

McDougall, F. (2004). IWM case studies with the use of LCA in countries with developing economies. Integrated Waste Management & Life Cycle Assessment Workshop and Conference, Prague.

McDougall, A. (2009). Use of water in operation of Energos ATT facilities. a.mcdougall@Energos.com, Personal Communication.

Midtbust, H. (2009). Operating data for the Energos facility at Forus, Norway. h.midtbust@Energos.com, Personal Communication.

Moberg, A., Finnveden, G., Johansson, J. and Lund, P. (2005). "Life cycle assessment of energy from solid waste - part 2: landfilling compared to other treatment methods." Journal of Cleaner Production **13**: 231-240.

Moller, B. (2000). Using GIS for energy planning. ESRI User Conference, San Diego, California.

Money, T. (2008). Typical household waste collection data. Bristol, ECT, 0117 952 5100: Personal Communication.

Munda, G. (2004). "Social multi-criteria evaluation: Methodological foundations and operational consequences." European Journal of Operational Research **158**: 662-677.

Murphy, J. D. and McKeogh, E. (2004). "Technical, economic and environmental analysis of energy production for municipal solid waste." Renewable energy **29**: 1043 -- 1057.

Nabney, I. (2007). Assumptions on financing small-scale, multiple projects. Birmingham, Aston University, i.t.nabney@aston.ac.uk: Personal Communication.

National Statistics. (2007). "Census Geography." Retrieved 6th Jan, 2008, from http://www.statistics.gov.uk/geography/census_geog.asp.

National Statistics. (2008). RPI Inflation rates, Retrieved on 23rd November from http://www.statistics.gov.uk/cci/nugget.asp?id=19.

NEF. (2007). National Energy Foundation," Carbon Calculator" Retrieved January 2007 from http://www.nef.org.uk/greencompany/co2calculator.htm.

Nilsson, M., Bjorklund, A., Finnveden, G. and Johansson, J. (2005). "Testing a SEA methodology for the energy sector: a waste incineration tax proposal." Environmental Impact Assessment Review **25**: 1-32.

Noon, C. E. and Daly, M. J. (1996). "GIS-based biomass resource assessment with BRAVO." Biomass & Bioenergy **10**(2-3): 101-109.

Norese, M. (2003). "ELECTRE III as a support for participatory decision-making on the localistation of waste-treatment plants." Land Use Policy **23**: 76-85.

Nuberg, I. and Bugg, A. (2002). Bioenergy Atlas of Australia. JVAP Research Update Series. J. V. A. Program, University of Adelaide.

Oakdene Collins. (2005). "Quantification of the Potential Energy from Residues (EfR) in the UK." from http://www.ice.org.uk/downloads//energy_from_waste.pdf.

ODPM. (2005). Planning Policy Statement 10: Planning for sustainable waste management. London, The Stationary Office.

ODPM. (2006). Best Value Performance Indicators: 2005/2006. London.

Patel, N. (2005). Rationale for a single facility or multiple (dispersed) residual waste treatment facilities for Cornwall. Truro, Cornwall County Council.

Paynter, A. (2006). Political risk of EfW plants. Truro, apaynter@cornwall.gov.uk: Personal communication.

Perlack, R. D. and Turhollow, A. F. (2002). "Feedstock cost analysis of corn stover residues for further processing." Energy **28**: 1395-1403.

Pfeifer, S. (2006). Where there's muck, there's a £7bn market. The Daily Telegraph. Retrieved 14th December, 2007 from http://www.telegraph.co.uk/finance/2940280/Where-theres-muck-theres-a-7bn-market.html

PIU. (2002). The Energy Review. London, Strategy Unit.

Pokehar, S. and Ramachandran, M. (2004). "Application of multi-criteria decision making to sustainable energy planning - A review." Renewable & Sustainable Energy Reviews **8**: 365-381.

Poll, J. and Oglivie, S. (2005). Markets for products from waste treatment, AEA Technology.

Porritt, J. (2006). Contribution to EfW policy, mtrievnor@forumforthefuture.org.uk Personal Communication.

Porteous, A. (2005). "Why energy from waste is an essential component of environmentally responsible waste management." Waste Management **25**: 451-459.

Poslethwaite, A. (1980). CHP plant for whole city heating. Combined heat and power. W. Orchard and A. Sherratt. London, John Wiley & Sons.

Purser, E. (2003). The contribution of Wisard to the definition of BPEO in waste planning. Cardfiff, Cardiff County Council and ENTRUST.

RCEP. (2000). Energy: The Changing Climate. London, HM Stationary Office.

RCEP. (2004). Biomass as a Renewable Energy Source. London, Royal Commission on Environmental Pollution.

Rebitzer, G., Ekvall, T., Frischknecht, R., Hunkeler, D., Norris, G., Rydberg, T., Schmidt, W., Suh, S., Weidema, B. and Pennington, D. (2004). "Life cycle assessment - Part 1: Framework, goal and scope definition, inventory analysis and applications." Environment International **30**: 701-720.

Rozakis, S., Sourie, J. and Vanderpooten, D. (2001). "Integrated micro-economic modelling and multi-criteria methodology to support public decision making: the case of liquid biofuels in France." Biomass & Bioenergy **20**: 382-398.

Saaty, T. (1980). The analytic hierarchy process. New York, McGraw-Hill.

Salhofer, S., Schneider, F. and Obersteiner, G. (2007). "The ecological relevance of transport in waste disposal systems in Western Europe." Waste Management **27**: 47-57.

Schneider, L. C., Kinzig, A. P., Larson, E. D. and Solorzamo, L. A. (2001). "Method for spatially explicit calculations of potential biomass yields and assessment of land availability for biomass energy production in Northeastern Brazil." Agriculture Ecosystems & Environment **84**: 207-226.

Scott Wilson. (2004). "Winkleigh biomass electricity generator: Environmental Statement." Retrieved, from http://download.southwestrda.org.uk/projects/general/Front%20Matter.pdf.

Shmelev, S. and Powell, J. (2006). "Ecological-economic modelling for strategic regional waste management systems." Ecological Modelling **59**: 115-130.

Sita. (2005). "Sita Isle of Man annual public report." Retrieved 15th February from http://ec.europa.eu/environment/emas/pdf/es_library/90.2_uk_sita_iom_ltd_06_en.pdf.

Soares, S., Toffoletto, L. and Deschenes, L. (2006). "Development of weighting factors in the context of LCIA." Journal of Cleaner Production **14**: 649-660.

Spadaro, J. and Rabi, A. (2001). "Damage costs due to automotive air pollution and the influence of street canyons." Atmosphere Environment **35**: 4763-4775.

Stillwall, W.G., D.A. Seaver, and Edwards, W. (1981). "A comparison of weight approximation techniques in multiattribute utility decision making. Organisational Behaviour and Human Performance **28** (1); 62-77.

Strategic Rail Authority. (2003). Sensitive Lorry Miles: Results of Analysis. London, DfT.

Strategy Unit. (2002). Waste Not, Want Not - A strategy for tackling the waste problem in England. London.

Subramanian, P. M. (2000). "Plastics recycling and waste management in the US." Resources, Conservation and Recycling **28**: 253-263.

Sweeting, D. (2006). Throughputs for EfW plants and operational penalties. d.sweeting@ethosenergy.co.uk. Bristol: Personal Communication.

Tafdrup, S. (1994). 7th International Symposium on Anaerobic Digestion, Cape Town, South Africa.

Talbott, B. (2005). Combustion technology data. ben.talbott@talbotts.co.uk. Stafford: Personal Communication.

Tchobanoglous, G., Theisen, H. and Vigil, S. (1993). Integrated waste managment. New York, Mc Graw-Hill.

Thompson, J. and Anthony, H. (2006). The health effects of waste incinerators. London, British Society for Ecological Medicine.

Turban, E. and Aronson, J. (2001). Decision Support Systems and Intelligent Systems. New Jersey, Prentice-Hall.

Turner, G. (2005). Combustion technology data. graham@cswdc.co.uk. Coventry. Personal Communication.

Tyson, K., Rymes, M. and Hammond, E. (1996). "Future Potential for MSW Energy Development." Biomass & Bioenergy **10**(2-3): 111-124.

Upreti, U and van der Horst, D. (2004) National renewable energy policy and local opposition in the UK: the failed development of a biomass electricity plant.

UK Census. (2006). "Casweb." from http://www.census.ac.uk/casweb/.

US-EPA (2002). Waste transfer stations: A manual for decision-making. EPA.

Varela, M. and Saez, R. (2000). Energy crops integration using a multiple criteria decision making tool. Madrid, CIEMAT.

Varela, M., Saez, R. and Audus, H. (2001). "Large-scale economic integration of electricity from short-rotation woody crops." Solar Energy **70**(2): 95-107.

Vickers, D. and Rees, P. (2007). "Creating the UK National Statistics 2001 output area classification." Journal of the Royal Statistical Society **170**(2): 379-403.

Videl, J. (2005). Scandal as waste returns to Britain. The Guardian. London.

Voivontas, D., Assimacopoulos, D. and Koukios, E. G. (2001). "Assessment of biomass potential for power production: a GIS based method." Biomass and Bioenergy **20**: 101-112.

Voogd, H. (1983). Multicriteria evaluation for urban and regional planning. London: Pion.

WCED. (1987). Our Common Future. Geneva, Oxford University Press.

Weidema, B. and Wesnes, M. (1996). "Data quality management for life cycle inventories - an example of using data quality indicators." Journal of Cleaner Production **4**(3-4): 167-174.

Weisser, D. (2007). "A guide to life-cycle greenhouse gas (GHG) emissions from electric supply technologies." Energy **32**: 1543-1559.

Wenisch, S., Rousseaux, P. and Metivier-Pignon, H. (2004). "Analysis of technical and environmental parameters for waste-to-energy and recycling: household waste case study." International Journal of Thermal Sciences **43**: 519-529.

Wey, W. (2005). "An integrated expert system/operations research approach for the optimisation of waste incinerator siting problems." Knowledge-based systems **18**: 267-279.

Whalley, D. (2006). Final presentation of results. dwhalley@cornwall.gov.uk. Truro, Cornwall County Council: Personal Communication.

Wheeler, P. and Jainter, N. (2006). An assessment of options for the management of residual municipal solid waste in Cornwall. Harwell, AEA Technology.

White, P., Franke, M. and Hindle, P. (1995). "Integrated solid waste management: A lifecycle inventory."

Williams, P. (2005). Waste treatment and disposal. Chichester, John Wiley & Sons Ltd.

Wilson, D. (1981). Waste management - planning, evaluation, and technologies. Oxford, Oxford University Press.

Wiltshire, R. (2003). The UK Potential for Community Heating with Combined Heat and Power. London, Carbon Trust.

Wood, K. (2005). Not enough sites for small-scale, multiple scale facilities. k.wood@warwickshire.gov.uk. Warwick, Personal Communication.

WRG. (2007a). Eastcroft EfW CHP. Retrieved 3rd January from http://www.wrg.co.uk/eastcroft/eastcroft-energy-from-waste-facility.asp?link=85

WRG. (2007b). Eastcroft EfW Annual Report. Retrieved 11th October from http://www.earthresources.org.uk/pdf/stewarding_22.pdf

Wright, P. (2005). Climate change agreements - Results of the second target period assessment. London, DEFRA.

Zopoundis, C. and Doumpos, M. (2002). "Multicriteria classification and sorting methods: a literature review." European Journal of Operational Research **138**: 229-246.

APPENDIX A: POLICY DRIVERS INFLUENCING UK EFW DEVELOPMENT

In support of Chapter 1 and Chapter 3, this Appendix reviews background energy, waste management and climate change policy and instruments that must be taken into account in the design of any proposed EfW DSS.

A.1 CLIMATE CHANGE TARGETS AND INSTRUMENTS

The United Nations (UN) Kyoto Protocol requires the UK to meet its obligation of reducing CO_2 emissions by 12.5% of 1990 levels by 2010. The UK Government has itself, committed a goal of a 20% reduction over the same time period. The RCEP reports that radical changes will be required if such goals are met (RCEP, 2000). There is great concern that the UK Government's targets of achieving a 60% reduction in carbon emissions by 2050 and 10% of UK electricity from renewable sources by 2010 will not be achieved (PIU, 2002), but the 2050 target has recently been made legally binding (BBC, 2007).

A.1.1 RENEWABLES OBLIGATION AND CERTIFICATES

The Renewables Obligation (RO) is the key support mechanism for encouraging the expansion of electricity generation derived from renewable and low carbon sources. Its aim is to support new technologies currently unable to compete with nuclear or fossil-fuel derived sources of power because they have yet to achieve the favourable economics of mature technologies. Electricity suppliers must supply a percentage of their output from renewable sources. They obtain Renewables Obligation Certificates (ROCs) for the renewable electricity they supply, which they can sell if they have a surplus. If they have a shortfall, they must 'buy out' the shortfall at a fixed rate, currently 3p/kWh (ILEX Energy, 2005). Large-scale EfW generating electricity only from conventional combustion does not qualify for ROCs as this is seen as mature technology, although CHP schemes will qualify for the renewable fraction of their output (ILEX Energy, 2005).

On the other hand "new" EfW technologies (see Section 1.3.5) generating electricity, such as anaerobic digestion and pyrolysis/gasification plant, do qualify for ROCs for the renewable fraction of their electrical output (see Section 1.3.3). It is currently unclear precisely how this will impact on the economics of these technologies, but they could be significantly advantaged over conventional combustion (Livingston, 2002). The deployment of such technologies would contribute both to the Renewables Obligation and the Landfill Directive targets (see Section 1.4.1). The DSS should take account of the benefit attributable to ATT EfW from the RO, and this will most likely be in the form of gate fee estimates, where the RO in effect will provide a subsidy over conventional combustion.

A.1.2 CLIMATE CHANGE LEVY

The climate change levy is a tax on the use of energy in industry, commerce and the public sector. It is intended to promote energy efficiency, encourage employment opportunities and stimulate investment in new technologies. The Government returns the revenues from the levy to the non-domestic sector, through a cut in the rate of employers' National Insurance Contributions. Businesses also benefit from schemes aimed at promoting energy efficiency and the take-up of technologies that can exploit renewable sources of energy.

The levy was introduced on 1st April 2001. Rates of levy are currently 0.15p/kWh for gas, 1.17p/kg (equivalent to 0.15p/kWh) for coal, 0.96p/kg (equivalent to 0.07p/kWh) for liquefied petroleum gas (LPG), and 0.43p/kWh for electricity. The levy package is expected to lead to reductions in CO_2 emissions of at least 2.5 million tonnes of carbon a year by 2010 (DEFRA, 2006a). There are also several exemptions from the levy, including:

- Used electricity generated from new traditional large-scale combustion, unless CHP, is not exempt.
- Any fuel used in good quality combined heat and power schemes ("Good Quality CHP" - certified via the CHP Quality Assurance Programme CHPQA). "Good quality" is defined as when plant are run at greater than

35% overall efficiency for both heat and power production (ILEX Energy, 2005), although 80% overall efficiency is possible (AEAT, 2005).

A.1.3 EU EMISSIONS TRADING SYSTEM

The Emissions Trading System (ETS) of the European Union (EU) came into effect at the beginning of 2005. Companies are given carbon emission permits equivalent to a target level. Those who reduce carbon below their target may sell their permits to companies who fail to make the investment. Approximately 500 carbon-intensive installations are covered. The ETS creates a strong economic incentive for more energy efficiency and investments to reduce carbon emissions. Proposals for the next phase of this scheme with more ambitious targets are being made with the intention that companies will be given clear direction on which to make long-term investments, particularly in power generation. It has been reported that within the system, 21 out of 42 sectors have met their carbon emissions trading targets (Wright, 2005).

Existence of the CCL and EU ETS suggests that the DSS should aim to identify EfW sites on industrial locations, where large business energy consumers may be willing to provide investments in capacity, and hence, enjoy exemptions from the CCL on their fuel costs.

A.2 EU WASTE MANAGEMENT LEGISLATION

A.2.1 LANDFILL DIRECTIVE

The Landfill Directive 1999/31/EC (1999) is the principal driver for new EfW capacity and has the objective of reducing negative effects on the environment from the landfill of waste. "The European Commission regards landfilling of waste as the least favourable option due to the fact that landfilling does not make use of waste as a resource" (Williams, 2005). Under the Directive, the UK must reduce the landfill of biodegradable municipal waste (BMW) to 75% of its 1995 rate by 2010, 50% by 2013 and 35% by April 2020. The Landfill Allowance Trading Scheme (LATS) has been introduced in the UK to encourage the waste disposal authorities (WDAs) to meet the targets of the Directive.

WDAs that do not use their full allowance may sell the surplus to other WDAs. Failure to meet the targets nationally means that the UK could face up to £180 million of fines (Eminton, 2005), and the Department for Environment, Food and Rural Affairs (DEFRA) has stated that these fines will be passed on to the WDAs, so that a fine of £150 must be paid for every tonne by which an allowance is exceeded. Figure 65 shows the collective challenge that all the WDAs must meet with allowances dropping from 15.6 million tonnes in the base year of 1998 to just 5.2 million tonnes in 2020. The LATS scheme commenced in April, 2005 and leaves just 15 years to develop the necessary landfill diversion infrastructure required to meet the 2020 target. Such infrastructure includes reuse, recycling and energy recovery projects.

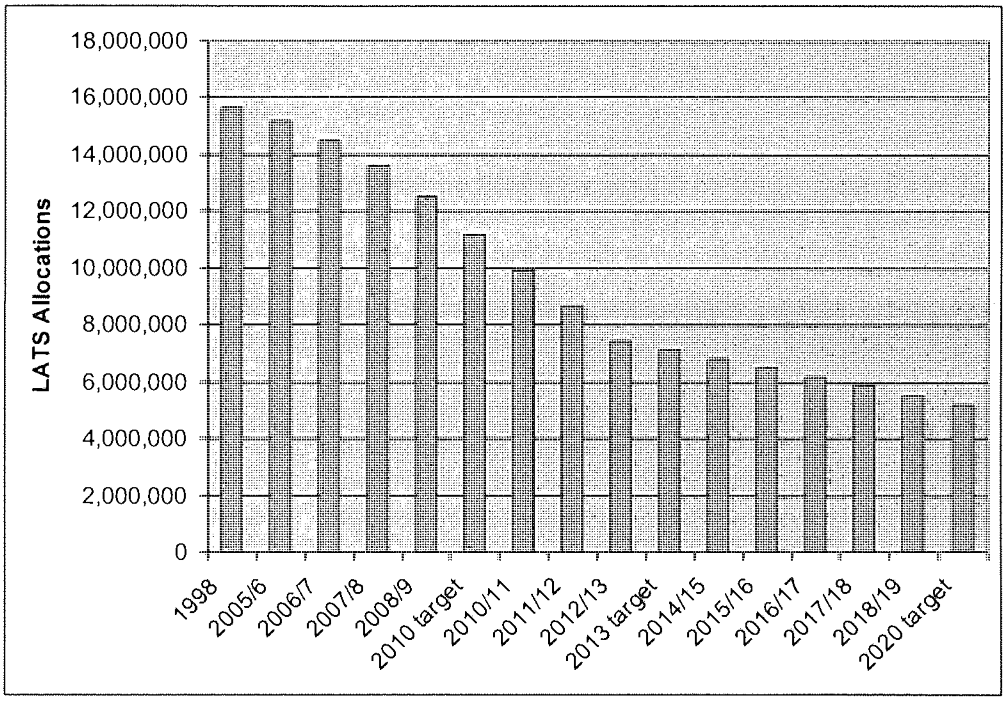

Figure 65: UK Landfill Allowances (DEFRA, 2006b).

The diversion of BMW from landfill is driven primarily by the need to reduce emissions of methane, a powerful greenhouse gas with 20 times the global warming potential (GWP) of CO_2. One tonne of biodegradable waste produces between 200 and 400m^3 of landfill gas containing about 50% methane. Landfills released 25% of the UK's methane emissions in 2001, about 2% of total greenhouse gas emissions (Strategy Unit, 2002). Hence, EfW has the capacity to mitigate climate change by diverting waste from landfill (and likely methane emissions) and offsetting the use of fossil-fuel (and related CO_2) in energy production. It is sensible that the proposed DSS will assume that all EfW options will be equal in their methane emission mitigation, and hence, this factor, may not be further considered. Any definition of EfW option capacity, must however, meet local LATS targets.

A.2.2 ENVIRONMENTAL ASSESSMENT DIRECTIVE

The Environmental Assessment Directive 85/337/EEC was introduced in 1985 and requires large-scale project proposals to undertake a full environmental assessment of their impacts. Projects within the scope of the Directive are those deemed likely to have a significant effect on the environment due to their nature, size or location (Williams, 2005). They include large-scale EfW facilities greater than 75 ktpa capacity.

Typical criteria for environmental assessment of a large-scale EfW project (Williams, 2005) are shown in Table 49:

Table 49: Typical criteria for environmental assessment of large-scale EfW facilities.

Criterion	Description
Visual impact	Of the facility upon the existing landscape and visual amenity
Air emissions	Existing air quality, concentration, volume and dispersal characteristics of pollutant gases, ground level concentrations, local topography and meteorology.
Water discharges	Treatment and disposal options for scrubber liquor and cooling water
Ash discharges	Treatment and disposal options for bottom and flyash.
Human health	Impacts and pathways of exposure to the pollutant emissions.
Fauna and flora	Impact of emissions or on local fauna and flora and loss of habitat, particularly for sites of special scientific interest (SSSI).
Site operations	Management and risk analysis of activity associated with plant operation and the consequence of operational failure. Impact of plant operation noise.
Traffic	The number of heavy goods vehicles and other vehicle movements, impacts on existing road networks and traffic flows, noise from increased traffic, accident statistics and routing considerations.
Socio-economic impacts	The effects of the project on adjoining residents and the existing industry, including benefits such as employment and investment.
Land-use and cultural heritage	Compatibility of the project with existing and proposed adjacent land-use and conformity with local development plans.

The assessment (executed by a team of experts for the developer) takes into consideration process design, size and location. Areas of mitigation are identified, and alternative sites and processes considered. The assessment process also involves full disclosure of information and consultation with the public. Environmental Assessment is complex, difficult, time-consuming and expensive. The process can cost up to 5% of the total capital costs of the project (but is often around 1%) and can take up to one year to complete (Williams, 2005). Table 50 summarises some of the main environmental impacts that can result from waste incineration (i.e. combustion for disposal only, without energy recovery).

Table 50: Environmental effects from incinerators (Williams, 2005).

Activity	Combustion	Heat Recovery	Gas Cleaning	
Source	Emissions of: Acid gases CO_2 Metals Organics	Discharge of cooling water	Scrubber effluent	Flyash
First order effects	Increase in ambient air concentrations and deposition of contaminants	Effect of receiving water temperature	Increase in chemical concentrations in receiving water	Possibility of fugitive emissions during transport
Second and higher order effects	Effects of CO_2 on global climate Effects of NO_X and SO_X on vegetation and human health Effects of metals and organics through the food chain	Effect on water resources, such as aquatic flora and fauna.	Effects on sewage treatment works and water resources	Effects of leachate discharge from landfill

The Directive was reviewed in 2001 and a new one adopted that makes provision for public participation procedures in waste management activities. These procedures require that the public is fully informed about the proposals for such projects and that decisions made concerning them should take into account the public's views and participation. This is required before any permit or licence for a project (such as an EfW facility) can be granted. Any EfW DSS should consider the types of criteria outlined in Table 49 in the appraisal of options and identification of preferred local policies. The method of appraisal should also be capable of taking account of the public's views.

A.2.3 INTEGRATED POLLUTION PREVENTION AND CONTROL DIRECTIVE

The Integrated Pollution Prevention and Control (IPPC) Directive 96/61/EC of 1996 is intended to protect the community from air, water and soil pollution occurring from emissions from potentially highly polluting industrial installations. This Directive aims to achieve greater environmental sustainability. Installations within the scope of the Directive include energy generation and waste management plants, as well as facilities from the metals, minerals and chemical industries. Within waste management, the Directive stipulates the need for permits for new and existing landfill and incineration facilities. In the UK, permits (operating licences) are issued by the Environment Agency. In order to gain these licences, facilities must be using the best available technology (BAT) and must operate at or below the WID defined emission limits for their specific activity (see next Section).

A.2.4 WASTE INCINERATION DIRECTIVE

The Waste Incineration Directive (WID) 2000/76/EC was introduced in 2000 and applied to new EfW plants from December 2002 and to existing ones from December 2005. The Directive imposes stringent emission limit values, as shown in Table 51.

Table 51: WID limits for large-scale municipal waste incineration (Williams, 2005).

Pollutant	**Emission limits (mg/m^3)**
Total Dust	10
Total organic carbon (TOC)	10
HCL	10
HF	1
CO	50
SO_2	50
NO_X	200
Metals	
Cd and TI	0.05
Hg	0.05
Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V (Total)	0.5
Dioxins and furans (TEQ) ng/m^3	0.1

The main objective of WID is to prevent air, water and soil pollution caused by the incineration of waste that may cause a hazard to human health. Due to the considerable concern from environmental groups and the public regarding the emissions from waste incineration, the Directive was implemented to achieve a high level of environmental protection through stringent operational conditions, technical requirements and emission-limit values (Williams, 2005). WID also imposes emission limits and regulations on the wastewater used to clean exhaust gases and the solid residues as well as their methods of transport. The complete process operation is covered including waste handling.

It is clear from this Section that any technology used to characterise an EfW option within the DSS must conform to BAT and WID requirements. It is assumed that all facilities within options will successfully obtain IPPC permits and pass through the planning process.

A.3 UK Waste management policy instruments

A.3.1 The UK National Waste Strategy and its principles

All national waste management strategies incorporate the principles laid out in the European document "A Community Strategy for Waste Management" (SEC (89) 934 Final). This strategy sets out the waste management hierarchy as a decision tool and the planning guidance principles of proximity of management to arising and self-sufficiency. In 1996, European Environment Ministers adopted a revised strategy (COM (96) 399) that emphasised the need for improved sustainable practice with high levels of environmental protection. It was recognised that a quantitative monitoring approach would be required to ensure that objectives were met. The most important of these is the Landfill Directive described in Appendix A.2.1. These principles, along with those in UK national and regional planning documents, are described in the National Waste Strategy, published as the Waste Strategy 2000 (DETR, 2000). Failure to adhere to these principles can lead to refusal of planning permission for EfW facilites. This may also result if the BPEO suggested EfW policy (outlined in Appendix A.3.1.4) has not considered enough technology options or if the assessment has been carried out without adequate public consultation (FoE, 2002).

A.3.1.1 Waste Hierarchy

The Waste Hierarchy provides a framework to prioritise methods of waste management. The first priority is to prevent waste and be more efficient in the use of virigin resources by using clean and improved technologies. The second is to re-use waste material where possible, and the third is to recycle it. The lower priorities involve the optimisation of final disposal and include options for energy recovery, concluding with the final option of landfill. The most up-to-date form of the Waste Hierarchy is shown in Figure 66.

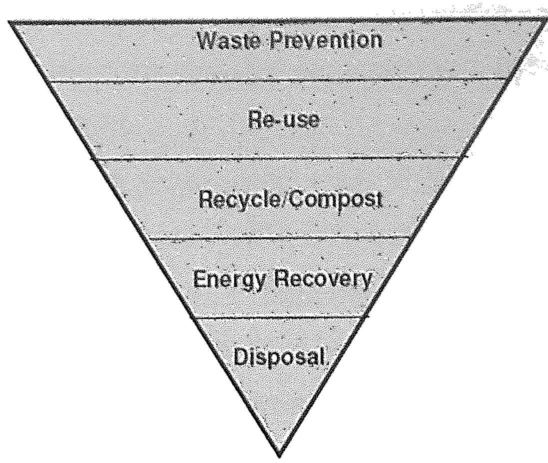

Figure 66: Waste hierarchy (DEFRA, 2006b).

The energy recovery and disposal categories in Figure 66 can be further divided into those prioritsing CHP (see Section 1.3.4) and energy production from the capture of methane in landfill sites (Strategy Unit, 2002). It is clear from this Section that any EfW option within the DSS must be formulated on the basis that obligations of waste minimisation, re-use and recycling are met. This has implications for the capacity/ies and number of plants which characterise each option.

A.3.1.2 Regional Self-sufficiency

At the European level, member states are required to be self-sufficient in waste disposal. The principle requires networks of integrated disposal installations to be developed at the regional and national level. The definition of self-sufficiency in the UK is made formal in the National Waste Strategy:

"In England, PPG 10 makes clear the Government's view that most waste should be treated or disposed of within the region in which it is produced. Each region should provide for facilities with sufficient capacity to manage the quantity of waste that they expect to have to deal with in that area for at least ten years."

A.3.1.3 Proximity Principle

Closely related to the concept of self-sufficiency, the Proximity Principle requires that waste should be disposed of (or managed) as close as possible to the location at which it is generated (Environment Council, 2007). It is therefore, expected that each region should provide sufficient facilities to manage the waste it generates. Following the Proximity Principle should lead to a more responsible approach to managing waste and limit the environmental impacts of transport.

The proposed DSS will be aimed at the local WDA (sub-regional) level rather than the regional to ensure the Proximity and Self-sufficiency principles are met. Although the Self-sufficiency principle is defined at a regional level, Government energy policy is arguably supporting distributed generation of a size more strongly related to locality and community (see Section 5.3.3). The stronger acknowledgement of locality at the sub-regional rather than regional level can only lead to greater adherence to the Proximity principle.

A.3.1.4 Best Practical Environmental Option

Best practical environmental option (BPEO) forms an integral part of the UK decision-making process on waste management options. The National Waste Strategy defines it as:

> *"The outcome of a systematic and consultative decision-making procedure which emphasises the protection and conservation of the environment across land, air and water. The BPEO procedure establishes, for a given set of objectives, the option that provides the most benefits or the least damage to the environment as a whole, at acceptable cost, in the long term as well as in the short term."*

The concept implies that different options have been investigated before a preferred option is chosen which gives the optimal environmental outcome without incurring unreasonable financial cost. All options that are feasible must be analysed for their disadvantages and advantages to the local and wider environment. The BPEO can be different for the same waste but in different areas, or could even be different for the same area and same type of waste at different times – such as recession (DETR, 2000).

The determination of the preferred BPEO option has been derived from life cycle assessment (LCA) methods such as WISARD (see Section 1.3.7). Also advocated is the use of multi-criteria decision analysis (MCDA). Such techniques can be formally used to analyse the trade-off between waste management options. Regardless of what specific tools are used, analysis of BPEO should be comprehensive, flexible, iterative and transparent (DETR, 2000). LCA and MCDA tools can quantify the environmental impacts of several waste management options on a consistent basis, including those associated with transport. Such tools should be considered as key methods within the proposed DSS for the appraisal of EfW options.

A.3.2 WASTE IMPLEMENTATION PROGRAMME

The WIP is run by DEFRA and was launched in May, 2004. It is the Government's response to the Strategy Unit report "Waste Not, Want Not" (Strategy Unit, 2002). This report stated that one of the key priorities was the need for the UK Government to ensure that adequate incentives are provided for the development and take-up of new technologies for waste management that offer an alternative to landfill. Although the WIP claims success in the areas of local authority support and in facilitating access to Private Finance Initiative (PFI) credits (DEFRA, 2005), it has been criticised for the delays in its New Technologies Demonstration Programme (Club recycle, 2006b).

A.3.3 NEW TECHNOLOGIES DEMONSTRATION PROGRAMME

The New Technologies Demonstration Programme (NTDP) is one of eight work streams of the WIP and its work covers four key areas, including two funding programmes worth £30 million announced in January 2004. It is designed to encourage the take up of new technologies in the treatment and diversion of BMW. The main purpose of this programme is to reduce the perceived risk of implementing new technologies that are considered 'unproven' in the UK, and to provide accurate technical and economic data. This project has already acknowledged this data availability difficulty by entering into a collaborative agreement with Compact Power – a 'new technology' EfW developer. The company has recently won £5 million funding for a 30 ktpa ATT facility to be operated as part of the NTDP scheme.

Table 52: List of technologies and projects bidding for NTDP support.

Company	Technology
WasteGen UK	Pyrolysis/gasification
Bristol City Council/Compact Power	Pyrolysis/gasification
Premier Waste Management Ltd	MBT/in-vessel composting
Greenfinch Ltd	Anaerobic digestion
Golder Associates	MBT/anaerobic digestion
ADAS Consulting	MBT/in-vessel composting
Fairport	Material separation/ MRF/ gasification.

The schemes in Table 52 are being run in partnership with local authorities and industry. They will assist in establishing the technical and commercial viability of emerging and near-market technologies and provide more confidence for industry and local authorities on the economic and environmental feasibility of these 'new' technologies. The DSS should be capable of accommodating additional technology options as new technologies are validated by the NTDP or other programmes.

A.3.4 PLANNING AND POLICY STATEMENT 10

Planning and Policy Statement (PPS) 10 replaced the previous Planning and Policy Guidance (PPG) 10 and advises how waste management issues should be treated in planning applications. A major change to the policy agenda by PPS 10 was the replacement of BPEO with the need to make a full Sustainability Appraisal and Strategic Environmental Assessment (SEA) in waste planning applications. PPS 10 makes it clear that its objective is to "help deliver sustainable development through driving waste management up the Waste Hierarchy". For a considerable time, local authority WDAs regarded BPEO as the major test to gain planning consent for their waste local plans (WLPs) and individual facilities, such as EfW plants. SEA now introduces a specific methodology by which to assess policies and identify how impacts can be avoided or mitigated. SEA will relate local EfW policy to the objectives of sustainable development and through SEA, PPS 10 objectives will be the key benchmarks in evaluating policy options. Since Sustainability appraisal includes environmental, social and economic criteria, the DSS appraisal element should also includes these groups of criteria that can identify preferred options that are more likely to to pass through SEA successfully.

PPS 10 advises that planned provision should uphold its key objectives. Sites should be situated at or close to where waste arises and opportunities for co-location of facilities should be considered. This latter concept is often described as a resource recovery park. Development of any facility sites should: be assessed against their potential to support PPS 10 policies; respect physical and environmental constraints; consider the well-being of the local community; consider the capacity of existing and potential transport infrastructure to support sustainable movement of waste and be located on appropriate land uses (ODPM, 2005). The DSS formulation of EfW option element must produce outputs that are consistent with PPS 10 objectives as much as possible, within the constraints of input data and method.

APPENDIX B: INTRODUCTION TO LIFE CYCLE ASSESSMENT

B.1 THE PROCESS

An LCA practitioner investigates the environmental impacts by tabulating the emissions and resources involved throughout the full life-cycle (cradle-to-grave) of a product or system (Rebitzer et al., 2004; Weisser, 2007) The stages in a life cycle can include raw material extractions, energy acquisition, materials production, manufacturing, use, recycling and ultimate disposal (Rebitzer et al., 2004). An application of LCA consists of four different phases that include: Goal definition and scoping. Life cycle inventory (LCI); Life cycle impact assessment (LCIA) and interpretation of the results (Curran, 1996). Specifically within the impact assessment, impact categories indicators and models are selected and the processes of classification, characterisation and weighting are carried out (Moberg et al., 2005). Contributions to the impact categories are quantified in the characterisation.

Characterisation is the assessment of the magnitude of potential impacts for the chosen impact categories and can be performed using equivalency. The latter is when models use derived factors to aggregate inventory data with the assumption that aggregated equivalency factors measure potential impacts. Aggregation of criteria scores is an area of LCA that can be used within MCDA, for example, the aggregation of sub-criteria to give an overall score of 'equivalent' impact. Such a technique will be used for environmental criteria such as emissions to air as outlined in Section 8.4.3.

LCA has also been described as attributional and consequential (Rebitzer et al., 2004). In consequential LCA, the processes included are those that are expected to be affected in the short or long term by decisions to be supported by the study. Hence, this type of LCA is relevant to the context of this project, while attributional LCA includes the processes that are believed to contribute significantly to a studied product.

There are international standards for LCA in the ISO 14000, namely: 14040 (1997) on principles and framework, 14041 (1998) on goal and scope definition and inventory analysis, 14042 on life cycle impact assessment and 14043 on life cycle interpretation that have been developed (Ekvall et al., 2007). These are currently being reviewed (Wenisch et al, 2004), but are in general accepted (Rebitzer et al., 2004) and followed (Corti and Lombardi, 2004).

The result of the LCIA is an evaluation of a product or process life cycle impact on a functional unit basis (Rebitzer et al., 2004), the latter of which describes the quantities of resources required and emissions and waste generated identified by the LCI. Azapagic and Camana (2005) and Consonni et al. (2005b) have used life-cycle assessment to compare the two functional units of: reducing the volume of MSW, and energy recovery. Other studies that have used LCA on a volume of waste processed functional unit include Wenisch et al. (2004), Corti and Lombardi (2004) and Nilsson et al. (2005). Many LCA studies involve the calculation of mass-balance before the LC impact assessment can be made (Consonni et al. 2005a/b, Corti and Lombardi, 2004).

B.2 METHODS

Within the LCA procedure itself, LCI is a methodology for estimating the consumption of resources and the quantities of waste flows and emission caused by a product or process's life cycle, while LCIA provides the indicators and the basis for analysing the potential contributions of the resource extractions and wastes/emissions of an inventory to a number of potential impacts (Rebitzer et al., 2004). Examples of impacts are given in the next Section and this review has observed how indicators within an LCI are similar to indicators in MCDA studies discussed in Section 4.2

More specifically different methods can be used for both the LCI or LCIA stages of an LCA. For example, Moberg et al (2005) uses the Danish EDIP and Dutch USES-LCA methods for quantifying contributions to the impact categories. "Choices concerning data and methodology may depend on the intended goal of the study" (Finnveden and Moberg, 2005). Overall LCA methods are generally distinguished between process chain analysis (PCA) and I/O (Input/Output), although there is a growing trend towards using elements of both in a hybrid assessment (Weisser, 2007). The strengths and weaknesses of process, I/O and hybrid LCA are extensively discussed in Rebitzer et al (2004).

Within the more detailed context of integrated waste management Bergsdal et al. (2005) applied LCA using the CML 2 method which includes the implications of transport, district heating and plant construction. Matrices were used to aggregate the various datasets for scenario impacts. Consonni et al. (2005b) used the CML 1 method, including two district heating scenarios, but omitted the implications of transport.

B.3 Criteria and Impact Categories

Bergsdal et al (2005) used seven criteria groups including global warming potential, aquatic freshwater and sea water toxicity, terrestrial toxicity, photochemical oxidation, acidification, and eutrophication. Consonni et al. (2005b) have restricted their criteria to atmospheric emissions because the technologies they considered did not discharge water and classified them into global warming potential (GWP), human toxicity potential (HTP), acidification potential (AP), and photochemical ozone creation potential (POCP). Most authors use some or all of these listed above together with further criteria such as: resource depletion – thus respecting the need to recover materials for re-use (Wenisch et al, 2004), water consumption and summer/winter smog (Corti and Lombardi, 2004), energy consumption (Nilsson et al, 2005), agricultural suitability (Barda et al. 1990; Cheng et al., 2003) and risks of major accident (Maniezzo et al, 1998).

B.4 Weighting factors

After characterisation in LCIA, results are further processed by weighting. This means converting and aggregating results across impact categories into a single score (Soares et al., 2006). Weights can be based on different methods and has always been a controversial area in developing an LCIA. Different methods are discussed in Soares et al (2006) and include 'distance-to-target', monetary evaluation and public opinion. The latter is the preferred LCA community approach and involves a 'panel approach' which establishes a hierarchy of impacts followed by a value allocation. Monetary evaluation weighting is made on the basis of costs related to environmental consequences. Monetarisation can include 'willingness to pay' (WTP) surveys or taxes to value the significance of criteria and has been noted as a convienient method for aggregating health impacts (Spadaro and Rabi, 2001). Finnveden et al (2005) used monetary weights in the form of taxes and fees characterised by the Swedish Ecotax 98. MCDA is also a method for developing weighting factors and this is an area in which MCDA has been combined with LCA (Soares et al., 2006; Hermann et al., 2007) and this is discussed further in Section.

B.5 Data and Life cycle inventories

One of the typically stated weaknesses of using LCA is the quality of data and the uncertainty involved in using it within inventories (Finnveden et al., 2005). The reliability and therefore, the applicability of the results of an LCA is dependent on the quality of the original data (Weidema and Wesnes, 1996). To help mitigate this Weidema and Wesnes (1996) have developed a set of quality indicators and present examples on how these may be applied. The indicators included reliability, completeness and temporal, geographical and technological correlation.

B.6 Tools and software

Many software tools have been developed for LCA in various national and include EASEWASTE (Kirkeby et al., 2006), IWM2 (McDougall, 2004), LCA-IWM (Boer et al., 2007) and ORWARE (Assefa et al., 2005). Specifically for the appraisal of waste management policy in the UK, the WISARD LCA tool has been criticised by Purser (2003) for the following reasons: The tool informs only BPEO (at least just the environmental aspect) and not other EU decision making tools such as the proximity principle and waste hierarchy. The main criticism is that it does not take account of several increasingly important waste processing routes, such as those offered by pyrolysis, gasification and anaerobic digestion. Often reliable transport impact data on which significant LCA impacts occur are not easy to secure and use within the tool. There is also no coverage in the standard databases of EfW plant below the 250 ktpa capacity. This implies that WISARD-based studies such as those by Higham (1999), Jainter and Poll (2005) and Wheeler and Jainter (2006) may be based on non-standardised LCA data to model effects of scale and technology. To overcome the deficiencies of the WISARD LCA tool, the UK Environment Agency (2006a) has (after the completion of this project) introduced the WRATE software.

APPENDIX C: GIS METADATA

Warwickshire and Cornwall

Title	Author	Date	Description		Scale	Data	Format	Projection	Spatial reference		Attributes (used in modelling)
			Abstract	Purpose					Coordinates Warks	Coordinates Cornwall	
County boundaries	Ordnance Survey	Jan 2006	This data layer was derived from the OS Meridian dataset downloaded from the Digimap website administered by Edina.	The purpose of the county administrative boundary dataset was to act primarily as the spatial extent for all modelling. All input datasets were clipped to this data layer.	1:10000	Vector - Polygon	Shapefile	British National Grid	L: 402695 R: 456472 T: 310029 B: 228615	L: 134116 R: 246070 T: 117556 B: 011073	
District boundaries	Ordnance Survey	Jan 2006	This data layer was derived from the OS Meridian dataset downloaded from the Digimap website administered by Edina. There are 5 districts in Warwickshire and 6 in Cornwall.	The purpose of the district boundary data was to assist the application of the decision rules in the final identification of potential EfW sites.	1:10000	Vector - Polygon	Shapefile	British National Grid	L: 402695 R: 456472 T: 310029 B: 228615	L: 131950 R: 246070 T: 117556 B: 011073	
SSSI	English Nature	Feb 2006	This data layer was downloaded from the Magic website administered by English Nature. There are 94 and 1005 records for Warwickshire and Cornwall respectively.	The purpose of these data are to form criterion layers within the spatial model for identifying potential suitable sites for EfW facilities. These locations provide indications of unsuitable locations that should be avoided and at least provided a proximity buffer.	1:1250	Vector - Polygon	Shapefile	British National Grid	L: 404792 R: 446677 T: 305124 B: 228884	L: 134480 R: 302305 T: 151257 B: 011086	

SPA	English Nature	Feb 2006	This data layer was downloaded from the Magic website administered by English Nature. There are 0 and 11 records for Warwickshire and Cornwall respectively.		1:1250	Vector - Polygon	Shapefile	British National Grid	N/a	L: 150229 R: 302305 T: 089627 B: 031129
NNR	English Nature	Feb 2006	This data layer was downloaded from the Magic website administered by English Nature. There are 3 and 64 records for Warwickshire and Cornwall respectively.		1:1250	Vector - Polygon	Shapefile	British National Grid	L: 409430 R: 411400 T: 298991 B: 295206	L: 165885 R: 198304 T: 061525 B: 011736
RAMSAR	English Nature	Feb 2006	This data layer was downloaded from the Magic website administered by English Nature. There are 0 and 1 records for Warwickshire and Cornwall respectively.		1:1250	Vector - Polygon	Shapefile	British National Grid	N/a	L: 293898 R: 302305 T: 089627 B: 077871
A Roads	Ordnance Survey	Jan 2006	This data layer was derived from the OS Meridian dataset downloaded from the Digimap website administered by Edina. There are 1328 and 1854 records for Warwickshire and Cornwall respectively.	The purpose of this data is to add a criterion layer to the spatial model for identifying potential suitable sites for EfW facilities. These locations provide indications of suitable locations of the road network that would be suitable for the traffic movements of HGVs.	1:10000	Vector - Line	Shapefile	British National Grid	L: 404491 R: 455684 T: 300716 B: 228876	L: 134805 R: 244148 T: 117556 B: 012545
B Roads	Ordnance Survey	Jan 2006	This data layer was derived from the OS Meridian dataset downloaded from the Digimap website administered by Edina. There are 1169 and 1423 records for Warwickshire and Cornwall respectively.	The purpose of this data is to add a criterion layer to the spatial model for identifying potential suitable sites for EfW facilities. These locations provide indications of suitable locations of the road network that would be suitable for the traffic movements of HGVs.	1:10000	Vector - Line	Shapefile	British National Grid	L: 404572 R: 454415 T: 309091 B: 238802	L: 135249 R: 245392 T: 111182 B: 017900

Population-weighted centroids	Casweb	2001	This data layer was derived from linking tabular population data from the 2001 Census at the Output Area level with their associated population-weighted centroid. Tables and centroids were downloaded from the Casweb website. There are 1740 and 1776 records for Warwickshire and Cornwall respectively.	The purpose of this layer is to create georeferenced waste production and projection models to 2011. Household waste production is estimated using household data, waste growth and recycling rates.	1:50000	Vector - Point	Shapefile	British National Grid	L: 405191 R: 454824 T: 308554 B: 231399	L: 135418 R: 244624 T: 116063 B: 012276	Total number of households. X and Y coordinates of calculated population weighted centroids.
Land Ranger background mapping	Ordnance Survey	Jan 2006	This data layer was derived from tiles of the 1:25000 Land Ranger raster mapping downloaded from the Digimap website administered by Edina. 98 and 72 tiles were used to complete for layer for Warwickshire and Cornwall respectively.	The purpose of this data is to provide background contextual mapping on which to reference and check the outputs of the PSI and FSI modelling. It is also a means to check the quality of the input data layers. Substations, electricity lines, roads and industrial areas can be identified at the 1:25000 scale resolution.	1:25000	Raster	TIN	British National Grid			N/a

Warwickshire only

Title	Author	Date	Description		Scale	Data	Format	Spatial reference		Attributes (used in modelling)
			Abstract	Purpose				Projection	Coordinates	
Industrial sites	WCC	April 2004	These sites were captured by on-screen digitising based on O.S. 1:10000 LandPlan maps, carried out in ARCINFO v 7. There are 86 sites in the dataset.	To collate information on the spread of industrial sites in Warwickshire, there were some difficulties in some cases where adjacent sites have grown and merged - it is not always clear were one site begins and the other ends. It was not possible to obtain a comprehensive list of industrial sites in Warwickshire. The sites selected for digitising were chosen on the basis of various publicity documents and local knowledge.	1:10000	Vector - Polygon	Shapefile	British National Grid	L: 406152 R: 456967 T: 300933 B: 239057	Land area (Ha)
BSPs/ Primary substations	Central Networks	Nov 2005	These data were provided by Central Networks who employed a consultant to extract the data from the company's SmallWorld GIS system and convert it for use in ArcView. There are 57 records.	The purpose of this data is to add a criterion layer to th spatial model for identifying potential suitable sites for EfW facilities. These locations provide indications of suitable grid connection points for injections of power within the distribution grid - ie where voltage levels and grid strength is acceptable.	1: 10000	Vector - Point	Shapefile	British National Grid	L: 412452 R: 456012 T: 305393 B: 252155	N/a
Motorway junctions	Ordnance Survey	Jan-2006	These locations were extracted as a layer from the OS Meridian dataset to be merged with the additional layers of A and B roads. The county boundary data was used to clip them.	The purpose of this data is to add a criterion layer to th spatial model for identifying potential suitable sites for EfW facilities. These locations provide indications of suitable locations of the road network that would be suitable for the traffic movements of HGVs.	1:10000	Vector - Line	Shapefile	British National Grid		N/a

Cornwall only

Title	Author	Date	Description		Scale	Data	Format	Spatial reference		Attributes (used in modelling)
			Abstract	Purpose				Projection	Coordinates	
BSPs/ Primary substations	Western Power Distribution	Jan 2006	These data were digitised from hard copy paper maps covering the whole of Cornwall purchased from Western Power Distribution. There are 80 records in this dataset.	The purpose of this data is to add a criterion layer to th spatial model for identifying potential suitable sites for EfW facilities. These locations provide indications of suitable grid connection points for injections of power within the distribution grid - ie where voltage levels and grid strength is acceptable.	1:50000	Vector - Point	Shapefile	British National Grid	L: 137598 R: 249812 T: 114485 B: 018416	N/a

Appendix D: Letter from Sustainable Development Commission

Forum for the Future

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21st April 2006

Dear David

Firstly, thank you very much indeed for your letter of March 28th, and for a copy of your report to CIWEM.

As you might imagine, I read this with great interest! It seems to me to be very timely given just how difficult people are finding it to address this whole issue of Energy from Waste, and how intractably polarised people's views are!

I have passed this on to both colleagues in Forum for the Future and in the Sustainable Development Commission, and I just wanted to thank you again for such a valuable input.

I am assuming that you yourself have fed this in to the Defra consultation on its Waste Management Strategy, as I know that this is one of the areas where they are having greatest difficulty reconciling different perspectives.

Best wishes

Jonathon

JONATHON PORRITT
Founder Director

The mission of Forum for the Future is to accelerate the building of a sustainable way of life, taking a positive, solutions-oriented approach.

ISO 14001 EMS 59526

Appendix E: Transport model code

```
Private Sub Add_X_Plant_Click()

Dim pMXDoc As IMxDocument
   Set pMXDoc = ThisDocument

   Dim pFLayer As IFeatureLayer
   Set pFLayer = pMXDoc.ContextItem

   Dim pFClass As IFeatureClass
   Set pFClass = pFLayer.FeatureClass

   Dim pFields As IFields
   Set pFields = pFClass.Fields

   Dim intPosX As Integer
   intPosX = pFields.FindField("XPlant")

   If intPosX = -1 Then
      Dim pFieldEdit As IFieldEdit
      Set pFieldEdit = New Field

      pFieldEdit.Name = "XPlant"
      pFieldEdit.Type = esriFieldTypeDouble

      pFClass.AddField pFieldEdit

      intPosX = pFields.FindField("XPlant")
   End If

   Dim dblXPlant As Double

   dblXPlant = InputBox("Enter the X Coordinate of the plant location.", "Enter X
Coordinate")


   Dim pFCursor As IFeatureCursor
   Set pFCursor = pFClass.Update(Nothing, True)

   Dim pFeature As IFeature
   Set pFeature = pFCursor.NextFeature
```

```
  Do Until pFeature Is Nothing
    pFeature.Value(intPosX) = dblXPlant


    pFCursor.UpdateFeature pFeature

    Set pFeature = pFCursor.NextFeature
  Loop


End Sub



Private Sub Add_Y_Plant_Click()
Dim pMXDoc As IMxDocument
  Set pMXDoc = ThisDocument

  Dim pFLayer As IFeatureLayer
  Set pFLayer = pMXDoc.ContextItem

  Dim pFClass As IFeatureClass
  Set pFClass = pFLayer.FeatureClass

  Dim pFields As IFields
  Set pFields = pFClass.Fields

  Dim intPosY As Integer
  intPosY = pFields.FindField("YPlant")

  If intPosY = -1 Then
    Dim pFieldEdit As IFieldEdit
    Set pFieldEdit = New Field

    pFieldEdit.Name = "YPlant"
    pFieldEdit.Type = esriFieldTypeDouble

    pFClass.AddField pFieldEdit

    intPosY = pFields.FindField("YPlant")
  End If

  Dim dblYPlant As Double
   dblYPlant = InputBox("Enter the Y Coordinate of the plant location.", "Enter the Y
Coordinate")
```

```
    Dim pFCursor As IFeatureCursor
    Set pFCursor = pFClass.Update(Nothing, True)

    Dim pFeature As IFeature
    Set pFeature = pFCursor.NextFeature

    Do Until pFeature Is Nothing
        pFeature.Value(intPosY) = dblYPlant

        pFCursor.UpdateFeature pFeature

        Set pFeature = pFCursor.NextFeature
    Loop


End Sub

Private Sub Distance_Click()

    Dim pMXDoc As IMxDocument
    Set pMXDoc = ThisDocument

    Dim pFLayer As IFeatureLayer
    Set pFLayer = pMXDoc.ContextItem

    Dim pFClass As IFeatureClass
    Set pFClass = pFLayer.FeatureClass

    Dim pFields As IFields
    Set pFields = pFClass.Fields

    Dim IntPosDist As Integer
    IntPosDist = pFields.FindField("DistanceKM")

    If IntPosDist = -1 Then
        Dim pFieldEdit As IFieldEdit
        Set pFieldEdit = New Field

        pFieldEdit.Name = "DistanceKM"
        pFieldEdit.Type = esriFieldTypeDouble

        pClass.AddField pFieldEdit

        IntPosDist = pFields.FindField("DistanceKM")
    End If

    Dim intPosXCent As Integer
```

```
    intPosXCent = pFields.FindField("XCentroid")

    Dim intPosYCent As Integer
    intPosYCent = pFields.FindField("YCentroid")

    Dim intPosXPlant As Integer
    intPosXPlant = pFields.FindField("XPlant")

    Dim intPosYPlant As Integer
    intPosYPlant = pFields.FindField("YPlant")


    Dim pFCursor As IFeatureCursor
    Set pFCursor = pFClass.Update(Nothing, True)

    Dim pFeature As IFeature
    Set pFeature = pFCursor.NextFeature

    Do Until pFeature Is Nothing
        pFeature.Value(IntPosDist) = _
Sqr((pFeature.Value(intPosXCent) - pFeature.Value(intPosXPlant)) ^ 2 +
(pFeature.Value(intPosYCent) - pFeature.Value(intPosYPlant)) ^ 2) / 1000 * 1.2

'Sqr ( ([XCentroid] - [XPlant] )^2 + ([YCentroid] - [YPlant])^2 )/1000*1.2

        pFCursor.UpdateFeature pFeature

        Set pFeature = pFCursor.NextFeature
    Loop

    Dim dblTotal As Single
    Set pFCursor = pFClass.Search(Nothing, True)
    Set pFeature = pFCursor.NextFeature

    Do Until pFeature Is Nothing
    dblTotal = dblTotal + pFeature.Value(IntPosDist)
    Set pFeature = pFCursor.NextFeature
    Loop

    MsgBox "The total straight line distance including windage factor is " & (Chr(13) &
Chr(10)) _
    & (Chr(13) & Chr(10)) _
    & dblTotal & " Kms.", vbInformation

End Sub

Private Sub Lorry_C02_Emiss_Click()
```

```
Dim pMXDoc As IMxDocument
Set pMXDoc = ThisDocument

Dim pFLayer As IFeatureLayer
Set pFLayer = pMXDoc.ContextItem

Dim pFClass As IFeatureClass
Set pFClass = pFLayer.FeatureClass

Dim pFields As IFields
Set pFields = pFClass.Fields

Dim intPosCarbon As Integer
intPosCarbon = pFields.FindField("LorryCO2")

If intPosCarbon = -1 Then
   Dim pFieldEdit As IFieldEdit
   Set pFieldEdit = New Field

   pFieldEdit.Name = "LorryCO2"
   pFieldEdit.Type = esriFieldTypeDouble

   pFClass.AddField pFieldEdit

   intPosCarbon = pFields.FindField("LorryCO2")
End If

Dim intPosLorry As Integer
intPosLorry = pFields.FindField("LorryKms")

Dim pFCursor As IFeatureCursor
Set pFCursor = pFClass.Update(Nothing, True)

Dim pFeature As IFeature
Set pFeature = pFCursor.NextFeature

Do Until pFeature Is Nothing
   pFeature.Value(intPosCarbon) = _
   pFeature.Value(intPosLorry) * 1.1


   pFCursor.UpdateFeature pFeature

   Set pFeature = pFCursor.NextFeature
Loop
```

```
    Dim dblTotal As Single
    Set pFCursor = pFClass.Search(Nothing, True)
    Set pFeature = pFCursor.NextFeature

    Do Until pFeature Is Nothing
    dblTotal = dblTotal + pFeature.Value(intPosCarbon)
    Set pFeature = pFCursor.NextFeature
    Loop

     MsgBox "The total Carbon Dioxide emissions are " & (Chr(13) & Chr(10)) _
    & (Chr(13) & Chr(10)) _
    & dblTotal & " Kilograms per year.", vbInformation

End Sub

Private Sub Lorry_Fuel_Consump_Click()

    Dim pMXDoc As IMxDocument
    Set pMXDoc = ThisDocument

    Dim pFLayer As IFeatureLayer
    Set pFLayer = pMXDoc.ContextItem

    Dim pFClass As IFeatureClass
    Set pFClass = pFLayer.FeatureClass

    Dim pFields As IFields
    Set pFields = pFClass.Fields

    Dim intPosConsump As Integer
    intPosConsump = pFields.FindField("FuelCons")

    If intPosConsump = -1 Then
        Dim pFieldEdit As IFieldEdit
        Set pFieldEdit = New Field

        pFieldEdit.Name = "FuelCons"
        pFieldEdit.Type = esriFieldTypeDouble

        pFClass.AddField pFieldEdit

        intPosConsump = pFields.FindField("FuelCons")
    End If

    Dim intPosLorry As Integer
    intPosLorry = pFields.FindField("LorryKms")
```

```
    Dim pFCursor As IFeatureCursor
    Set pFCursor = pFClass.Update(Nothing, True)

    Dim pFeature As IFeature
    Set pFeature = pFCursor.NextFeature

    Do Until pFeature Is Nothing
      pFeature.Value(intPosConsump) = _
      pFeature.Value(intPosLorry) / 3

      pFCursor.UpdateFeature pFeature

      Set pFeature = pFCursor.NextFeature
    Loop

    Dim dblTotal As Single
    Set pFCursor = pFClass.Search(Nothing, True)
    Set pFeature = pFCursor.NextFeature

    Do Until pFeature Is Nothing
    dblTotal = dblTotal + pFeature.Value(intPosConsump)
    Set pFeature = pFCursor.NextFeature
    Loop

    MsgBox "The total transport fuel consumption of serving " & (Chr(13) & Chr(10)) _
    & "this plant from catchment is " & (Chr(13) & Chr(10)) _
    & (Chr(13) & Chr(10)) & _
     dblTotal & " litres per year.", vbInformation

End Sub

Private Sub Lorry_Fuel_Costs_Click()


    Dim pMXDoc As IMxDocument
    Set pMXDoc = ThisDocument

    Dim pFLayer As IFeatureLayer
    Set pFLayer = pMXDoc.ContextItem

    Dim pFClass As IFeatureClass
    Set pFClass = pFLayer.FeatureClass

    Dim pFields As IFields
    Set pFields = pFClass.Fields

    Dim intPosCost As Integer
```

```
    intPosCost = pFields.FindField("FuelCost")

    If intPosCost = -1 Then
      Dim pFieldEdit As IFieldEdit
      Set pFieldEdit = New Field

      pFieldEdit.Name = "FuelCost"
      pFieldEdit.Type = esriFieldTypeDouble

      pFClass.AddField pFieldEdit

      intPosStandValue = pFields.FindField("FuelCost")
    End If

    Dim intPosConsump As Integer
    intPosConsump = pFields.FindField("FuelCons")

    Dim pFCursor As IFeatureCursor
    Set pFCursor = pFClass.Update(Nothing, True)

    Dim pFeature As IFeature
    Set pFeature = pFCursor.NextFeature

    Do Until pFeature Is Nothing
      pFeature.Value(intPosCost) = _
      pFeature.Value(intPosConsump) * 0.8866


      pFCursor.UpdateFeature pFeature

      Set pFeature = pFCursor.NextFeature
    Loop

    Dim dblTotal As Double
    Set pFCursor = pFClass.Search(Nothing, True)
    Set pFeature = pFCursor.NextFeature

    Do Until pFeature Is Nothing
    dblTotal = dblTotal + pFeature.Value(intPosStandValue)
    Set pFeature = pFCursor.NextFeature
    Loop

    Dim pCurrency As INumberFormat
    Set pCurrency = New CurrencyFormat

    MsgBox "The total cost of fuel consumed is " & (Chr(13) & Chr(10)) & (Chr(13) &
Chr(10)) _
```

```
  & pCurrency.ValueToString(dblTotal) & " per year."
End Sub

Private Sub Lorry_Transp_Kms_Click()

  Dim pMXDoc As IMxDocument
  Set pMXDoc = ThisDocument

  Dim pFLayer As IFeatureLayer
  Set pFLayer = pMXDoc.ContextItem

  Dim pFClass As IFeatureClass
  Set pFClass = pFLayer.FeatureClass

  Dim pFields As IFields
  Set pFields = pFClass.Fields

  Dim intPosLorry As Integer
  intPosLorry = pFields.FindField("LorryKms")

  If intPosLorry = -1 Then
     Dim pFieldEdit As IFieldEdit
     Set pFieldEdit = New Field

     pFieldEdit.Name = "LorryKms"
     pFieldEdit.Type = esriFieldTypeDouble

     pFClass.AddField pFieldEdit

     intPosLorry = pFields.FindField("LorryKms")
  End If

  Dim intPosCurWas As Integer
  intPosCurWas = pFields.FindField("EfR")

  Dim IntPosDist As Integer
  IntPosDist = pFields.FindField("DistanceKm")

  Dim pFCursor As IFeatureCursor
  Set pFCursor = pFClass.Update(Nothing, True)

  Dim pFeature As IFeature
  Set pFeature = pFCursor.NextFeature

  Do Until pFeature Is Nothing
     pFeature.Value(intPosLorry) = _
     (pFeature.Value(intPosCurWas) / 21) * _
```

```
    pFeature.Value(IntPosDist)

    '([EfR]/21)* [DistanceKm]
    pFCursor.UpdateFeature pFeature

    Set pFeature = pFCursor.NextFeature
  Loop

  Dim dblTotal As Single
  Set pFCursor = pFClass.Search(Nothing, True)
  Set pFeature = pFCursor.NextFeature

  Do Until pFeature Is Nothing
  dblTotal = dblTotal + pFeature.Value(intPosLorry)
  Set pFeature = pFCursor.NextFeature
  Loop


  MsgBox "The total lorry transport distance including windage factor is " & (Chr(13) &
Chr(10)) _
  & (Chr(13) & Chr(10)) _
  & dblTotal & " kms per year."


End Sub
```

APPENDIX F: JOURNAL PAPERS ASSOCIATED WITH THIS PROJECT