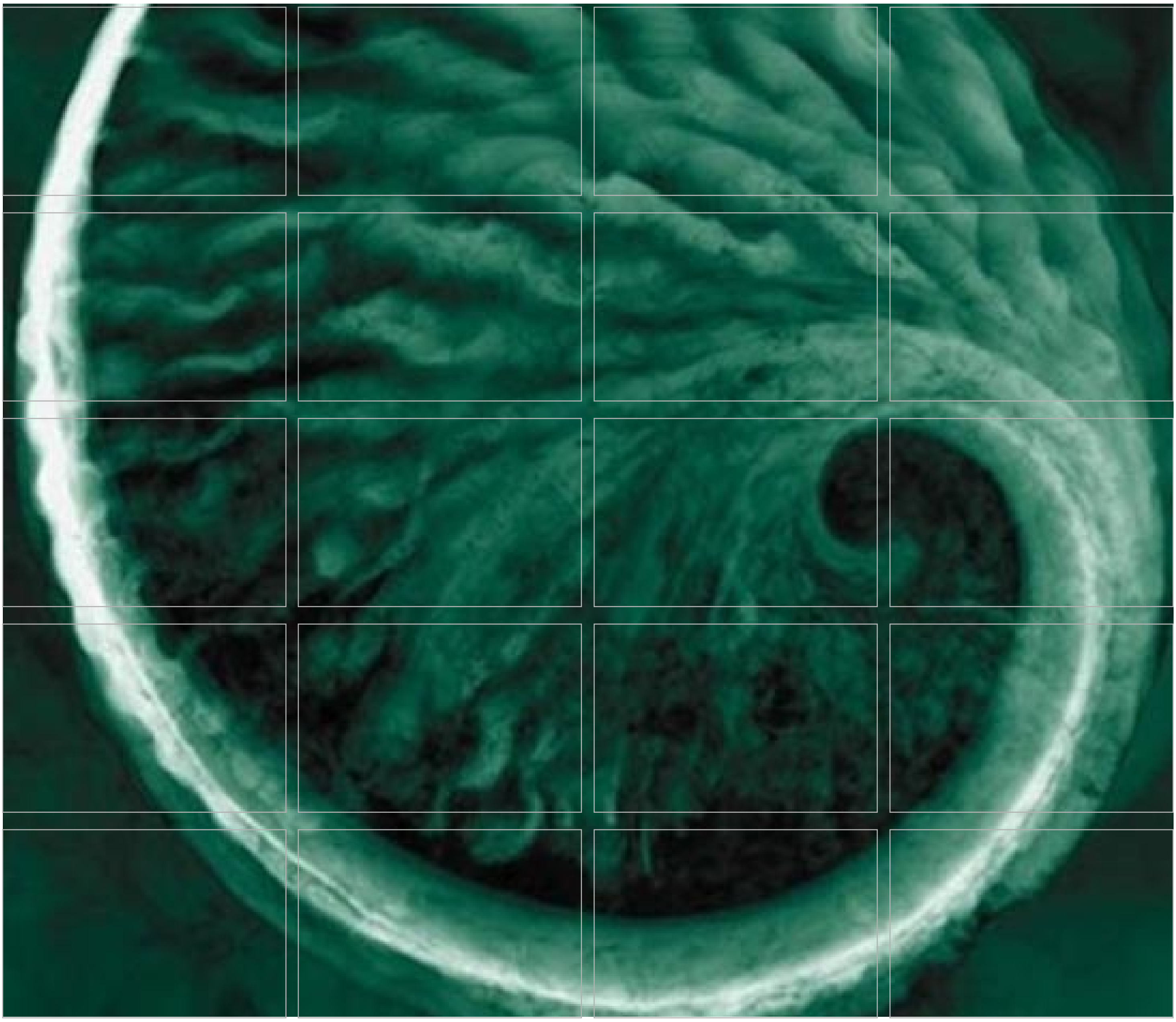

Carbon Balances and Energy Impacts of the Management of UK Wastes

Defra R&D Project WRT 237

Final Report

December 2006

Delivering sustainable solutions in a more competitive world

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Final Report

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For and on behalf of
Environmental Resources Management

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Date: 18th December 2006

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We would also like to thank Terry Coleman (Environment Agency), the material managers at WRAP and the attendees of the *'What the Future holds for Commercial and Industrial Waste?'* workshop for their assistance with waste arising data and the development of the scenarios.

1 EXECUTIVE SUMMARY

This project undertook a macro-level investigation of the carbon flows, energy and greenhouse gas benefits and impacts associated with alternative management routes for the predominant waste materials arising in the UK. The research examines the scale of benefits and impacts resulting from different process and recovery routes, traces carbon flows through alternative systems and identifies the most significant wastes and management methods.

Findings illustrate that some materials and management routes show significant potential for greenhouse gas emission and fossil energy demand savings. Although there are a number of uncertainties (see below), the largest potential, over and above current recovery efforts, is with regard to:

- **energy recovery via anaerobic digestion of agricultural manures/slurries**;
- **energy recovery via combustion of waste wood**;
- **recovery of both resources (through recycling) and energy (through combustion) from waste paper and card**; and
- **recycling of non-ferrous metals.**

The energy benefits estimated for these materials and management routes equate to a combined saving in the region of 88 to 202 PJ-equivalents per year over the period assessed. This is equivalent to approximately 1-3% of UK energy consumption in 2003 (1).

Discounting the influence of relative material arisings, on a tonne-for-tonne basis the **recycling of textiles and plastics** and **energy recovery via anaerobic digestion of kitchen and green wastes** and **combustion of crop and other organic wastes** (2) also show significant potential for benefit.

It was our objective to assess the broad alternatives for managing waste materials and identify where potential benefits might lie. Four core scenarios were developed to assess the management of waste arisings over the period 2005 to 2031:

1. *baseline scenario* – reflecting best current estimates of waste material arisings and management, and assuming that this will not change;
2. *high resource recovery scenario* – reflecting increased rates of recycling and composting over the period;
3. *high energy recovery* – reflecting increased rates of energy recovery via thermal processing technologies (with energy recovery) or anaerobic digestion; and
4. *combined recovery* – reflecting a combination of both resource and energy recovery.

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(1) DTI Energy Statistics http //www dti gov uk/energy/statistics/regional/index html

(2) Predominantly sewage sludge

Each scenario was designed to assess the maximum performance theoretically achievable for each waste material, in the absence of current policy or infrastructural barriers. The maximum limit was set based on best performance demonstrated across Europe – under the proviso that if it has been achieved elsewhere, it is 'theoretically achievable' in the UK.

The major flows of both carbon/greenhouse gases and energy through waste management systems result from:

- ancillary requirements for fuel and energy in processing and transporting materials;
- direct releases from waste fractions on processing (eg biological processing or combustion) or disposal in landfill;
- avoidance of greenhouse gas emissions or energy use elsewhere in the economy; and
- sequestration of carbon in soils.

For each material and scenario these flows were quantified in each year from 2005 to 2031 and were combined with estimates of time-lagged landfill gas release and capture over 100 years. Carbon and greenhouse gas balances were drawn up, outlining the flow and fate of all carbon over this period. Both direct and indirect greenhouse gas releases were accounted for.

The work further explored the range of potential performance for alternative materials by assessing a set of 'maximum' and 'minimum' avoided burdens.

For energy recovery processes, these maxima and minima were based on the range of conversion efficiencies reported in literature:

- *Combustion*: minimum – 20% electricity only; maximum – combined power at 70% total efficiency (40% electricity, 30% heat); and
- *Anaerobic Digestion*: minimum – 30% electricity only; maximum – combined power at 85% total efficiency (40% electricity, 45% heat).

For resource recovery, maxima and minima were based on the range of potential fates for recovered materials. As a general rule, the potential savings are higher where recovered materials are of higher quality, material integrity can be maintained and virgin material production is avoided. The relationship is not a straightforward one for all materials, however, and so maxima and minima were developed on a material-by-material basis.

Figure 1.1 shows a carbon and greenhouse gas balance for all UK wastes, according to best estimates of current arisings and management for the materials assessed (1).

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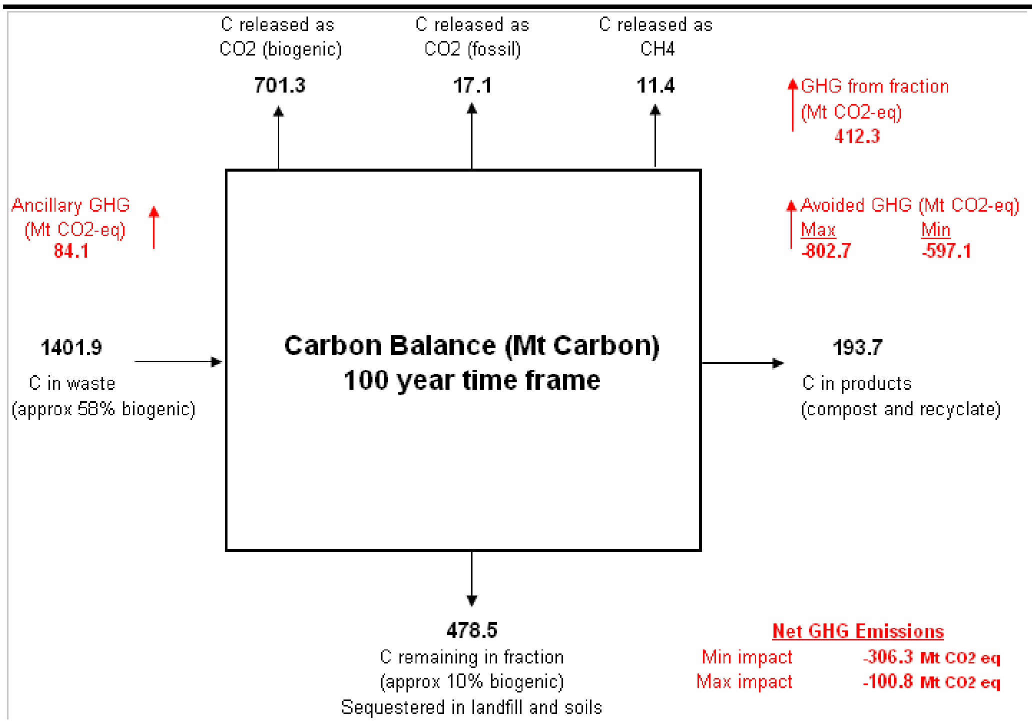
(1) Those listed in *Table 1.1* and *Table 1.2.*

Figure 1.1 *Carbon and Greenhouse Gas Balance over Study Period – Baseline Scenario*



Maximum and minimum net greenhouse gas emissions and fossil energy demand per tonne of material and by scenario are shown in *Table 1.1* and *Table 1.2*. These are expressed in terms of net impact over the baseline (1) to highlight opportunities for improvement on a unit basis.

Table 1.1 *Net Greenhouse Gas Emissions (kg CO_2-eq) per Tonne of Waste Material – Net Impacts over Baseline*

Material	**Net GHG Emissions over Baseline (kg CO_2-eq/ tonne)**	**Net GHG Emissions over Baseline (kg CO_2-eq/ tonne)**	**Net GHG Emissions over Baseline (kg CO_2-eq/ tonne)**
	High Resource	*High Energy*	*Combined*
Paper/Card	-104.1 to -143.0	-181.7 to -311.7	-123.3 to -170.9
Kitchen/ Food Waste	-27.0 to -51.5	-85.7 to -168.0	-40.8 to -75.4
Green Waste	-11.2 to -16.4	-87.7 to -158.7	n/a
Agricultural Crop Waste	9.6 to 16.9	-69.5 to -205.0	n/a
Manure/ Slurry	4.7 to 5.5	-28.9 to -70.3	n/a
Other Organics	17.6 to 38.0	-65.8 to -193.7	-29.7 to -72.3
Wood	-23.2 to -26.2	-255.8 to -558.0	-149.1 to -295.3
Dense Plastic	127.5 to -455.0	163.8 to 561.1	-404.0 to 342.3
Plastic Film	132.1 to -324.1	192.1 to 482.6	-274.9 to 319.3
Textiles	-178.2 to -276.6	-61.2 to 143.6	-138.3 to -361.7
Ferrous Metals	-64.7 to -93.5	n/a	n/a
Non-ferrous Metals	-798.9 to -852.9	n/a	n/a
Silt/Soil	0.6 to 2.3	n/a	n/a
Minerals/Aggregate	0.1 to 0.1	n/a	n/a

(1) A range, showing the maximum estimate for scenario minus maximum estimate for baseline; and minimum estimate for scenario minus minimum estimate for baseline

Table 1.2 Net Fossil Energy Demand (MJ-eq) per Tonne of Waste Material – Net Impacts over Baseline

Material	**Net Energy Demand over Baseline (MJ-eq/ tonne)**	**Net Energy Demand over Baseline (MJ-eq/ tonne)**	**Net Energy Demand over Baseline (MJ-eq/ tonne)**
	High Resource	*High Energy*	*Combined*
Paper/Card	-206.8 to -755.8	-764.7 to -3172.3	-245.1 to -943.1
Kitchen/ Food Waste	318.9 to 389.5	-349.0 to -1357.1	65.6 to 330.9
Green Waste	203.0 to 286.4	-764.1 to -2104.3	n/a
Agricultural Crop Waste	101.7 to 401.8	-1199.7 to -3236.5	n/a
Manure/ Slurry	57.7 to 176.5	-502.0 to -994.5	n/a
Other Organics	227.3 to 651.3	-1231.4 to -2939.5	-243.3 to -691.0
Wood	194.9 to 205.1	-2513.8 to -7732.2	-927.5 to -3393.2
Dense Plastic	2977.4 to -12693.7	-4215.1 to -10,623.2	1493.0 to -16,997.0
Plastic Film	2561.7 to -11654.2	-3906.4 to -7671.6	1321.0 to -15,262.6
Textiles	-1535.2 to -5208.3	-1373.7 to -4086.1	-2544.7 to -8348.6
Ferrous Metals	-113.4 to -873.7	n/a	n/a
Non-ferrous Metals	-8581.2 to -9297.6	n/a	n/a
Silt/Soil	11.0 to 33.3	n/a	n/a
Minerals/Aggregate	2.7 to 3.2	n/a	n/a

Uncertainties and Areas for Further Investigation

A number of assumptions have been made in quantifying the carbon, energy and greenhouse gas flows for each waste material and process assessed. Sensitivity analyses were carried out to examine which of the assumptions have the greatest influence. These pointed to a number of areas where findings should be treated with caution, or where we are currently lacking in information on which to derive accurate estimates:

- average estimates show energy recovery to be favoured over recycling for waste paper and card. In fact, there is a fine balance between these alternative recovery methods;
- estimates show net energy and/or greenhouse gas impacts associated with soil and minerals recycling. This was found to be sensitive to the transport assumptions made during modelling;
- all findings were based on, or drawn from, baseline estimates of current arisings and management and so are inhibited by limitations in data quality;
- for some organic materials we found increased greenhouse gas and/or energy demand impacts associated with composting. In practice it is considered that the balance of greenhouse gas potential may swing either way. However, little data or information exists to enable us to explore this further;
- results for all biodegradable materials were found to be highly sensitive to assumptions regarding landfill gas capture; and
- the scale of avoided greenhouse gas emissions and energy demand associated with recycling of the majority of materials, but chiefly plastics,

textiles and paper/card, varies widely with assumptions regarding the routes via which they may be processed.

Combining both the scale of potential impacts/benefits quantified and the known limitations of the study, we have identified a number of key areas in which further research could aid our understanding of the greenhouse gas and energy impacts from managing waste materials:

- the development of a long term strategy to collect and collate data regarding the availability, sources and current management of materials (building on the Defra waste data strategy (1));
- a more sophisticated approach to assessing the fertiliser, sequestration, and other benefits of composting activities, relative to landfill, landspread and other waste management activities;
- the development of an improved understanding of the relative importance of alternative reprocessing routes for plastics, textiles and paper and card;
- the development of more sophisticated impact factors to describe the potential benefits and avoided burdens of soil/minerals recycling;
- further consideration of the potential for capture and utilisation of landfill gas; and
- the development of a method to quantify the greenhouse gas and energy benefits of reducing and re-using waste materials. The current work did not attempt to quantify the potential for reduction and re-use. There is undoubted benefit associated with these routes and future studies would benefits from their inclusion.

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(1) Defra (2006) *The Defra/WAG Waste Data Strategy for Waste Streams across the UK* Department for Environment, Food and Rural Affairs

CONTENTS

ACKNOWLEDGMENTS

EXECUTIVE SUMMARY

1 INTRODUCTION

There are over 430 million tonnes of waste materials produced annually in the UK (see *Annex A*). The sources and composition of these wastes vary considerably, and there is a wide range of activities that may be employed in managing them, from collection and transport, through treatment, recycling and energy recovery, to final disposal.

Each of these activities has a consequence for the flow of carbon and is associated with a greenhouse gas and energy burden, be it the result of a direct release from degrading waste, or through electricity and fuel consumption. Some activities also convey a greenhouse gas and energy benefit through materials recycling or energy recovery. The balance of impacts and benefits can be a fine one and can vary from material to material, such that the relative benefits of different waste management routes are uncertain.

As UK waste and energy policy moves to take account of the ever-increasing problem of climate change, there is need for greater clarity with respect to these flows to inform policy choices. A detailed analysis of the carbon flows, energy and greenhouse gas consequences of landfill and its alternatives, and the relative benefits of different routes, for different wastes, has seldom been explored in detail and reported in a single, comparative, study.

This project undertakes a macro-level investigation of the energy and greenhouse gas benefits and impacts associated with alternative management routes for the predominant waste materials arising in the UK. The research examines the scale of benefits and impacts resulting from different process and recovery routes, traces carbon flows through alternative systems and identifies the most significant wastes and management methods. Opportunities for improvement, in terms of avoided greenhouse gas emissions and reduced energy consumption, are also highlighted.

The research was commissioned by the Defra Waste Research Team as part of a wider, three year waste and resources R&D programme. The programme was developed in response to an identified need for better coordinated waste-related research in the UK. Its aim is "*to deliver a sound evidence base for better-informed policy development, implementation, monitoring and evaluation for sustainable waste management at both the national and local levels, which incorporates an effective mechanism for access to, and dissemination of, research results*". This research falls primarily under the programme themes, 'environment and health' and 'sustainable resource consumption and management'.

The work has been carried out by Environmental Resources Management Ltd. (ERM) and Golder Associates (UK) Ltd. and builds on three previous studies commissioned by Defra:

- *Impact of EU Landfill Directive and National Strategies on UK Greenhouse Gas Emissions* (ERM, 2004);
- *UK Landfill Methane Emissions: Evaluation of Waste Polices and Projections to 2050* (Golder Associates, 2005); and
- *Impact of Energy from Waste and Recycling Policy on UK Greenhouse Gas Emissions* (ERM, 2006).

1.1 THE APPROACH TAKEN

The project was undertaken in a series of tasks, over a nine month timescale. The results of each task were written up in Phase Reports, which have formed the basis of the annexes to this report. In brief, the tasks undertaken were to:

- review information pertaining to the range of waste streams arising across the UK,
- compile arisings and composition data for these waste streams in order to determine the quantity of discrete material fractions (for example, paper and card, kitchen/food waste, wood, ferrous metals, minerals etc.);
- carry out a screening exercise in order to streamline the research towards those materials with greatest potential for carbon and energy impact or benefit;
- develop alternative scenarios for the management of the selected materials;
- characterise the fuel and energy requirements, emissions and mass, carbon and energy flows through alternative management routes;
- translate inputs and outputs into net greenhouse gas emissions (expressed as CO_2-equivalents) and fossil -energy demand (expressed as energy [joule]-equivalents);
- translate materials and energy recovered from management processes into net greenhouse gas emissions and fossil energy demand savings; and
- combine impacts and savings to quantify net greenhouse gas and energy demand estimates for the alternative scenarios.

The following sections describe this approach further.

Climate change is one of the major challenges facing the global community and, as such, is becoming increasingly important in driving waste policy in the UK.

The Government is currently conducting a review of its UK Climate Change Programme (1). The programme contains a package of policies and measures to meet the Kyoto commitment, the domestic goal of reducing carbon emissions to 20% below 1990 levels by 2010 and to prepare the UK to make more significant cuts in the longer term. There is increasing agreement that the UK should be aiming to reduce carbon emissions by 60% by 2050 - a challenging target.

Waste management makes a significant contribution to UK emissions of greenhouse gases, through transport, processing, treatment and, of particular importance, releases of methane from degrading wastes in landfill. In 2004, the waste sector contributed 2.5% to the national total greenhouse gas inventory (2).

Other forms of waste management have the potential to result in net reductions in greenhouse gas emissions, by recovering materials or energy and avoiding the requirement for, and production of, primary resources. Waste policies aimed at reducing climate change impact predominantly focus on the EU Landfill Directive (3), which aims to reduce the negative effects of landfilling waste. Article 5 of the Directive progressively limits the quantity of biodegradable municipal waste (BMW) (4) that can be landfilled, with the aim of reducing the emission of gases that affect the global climate.

Beyond direct waste policy, measures are being taken to reduce greenhouse gas emissions across all industry sectors. A key area is with regard to energy policy and, in particular, renewable sources of energy. Biomass is playing a role of increasing importance and, in response to the 2003 Energy White Paper (1) , a Biomass Task Force was launched to assist Government in optimising the contribution of biomass energy to meeting renewable energy targets. This has implications for the potential management of waste biomass materials, such as wood and agricultural animal or crop wastes.

With these moves, clarity on the energy and greenhouse gas impacts of alternative management routes for waste materials is invaluable. Furthermore, energy impacts are an extremely good analogue of overall environmental impact, and provide a sound basis for consideration of other

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(1) Defra (2004). *Review of the UK Climate Change Programme. Consultation Paper*. Defra, London.

(2) Baggott, *et al* (2006). *UK Greenhouse Gas Inventory 1990 to 2004*. ISBN 0-9547136-8-0

(3) Council Directive 99/31/EC on the Landfill of Waste, European Commission (1999).

(4) The Directive defines BMW as that which is capable of undergoing anaerobic or aerobic digestion, such as food and garden waste, paper and cardboard.

energy-related emissions and resource impacts. The reduction of energy consumption is an important pre-requisite for sustainable development, and can serve as a benchmark for improvement (2).

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(1) Energy White Paper: Our Energy Future - Creating a Low Carbon Economy. DTI, February 2003, CM 5761

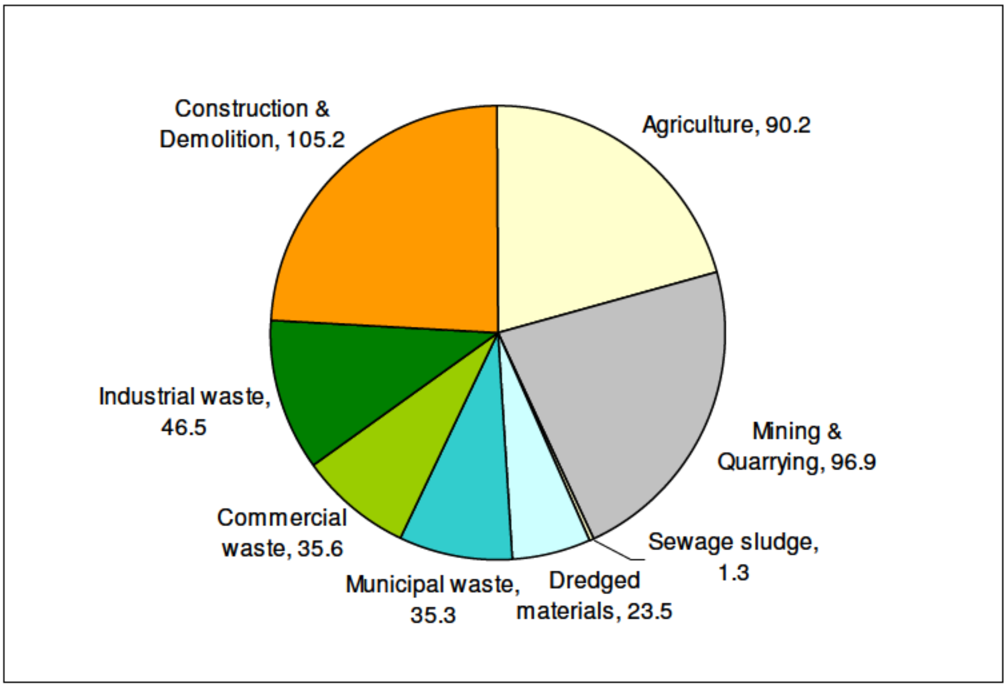
(2) Frischnecht F and Jungbluth N. (2004). Implementation of Life Cycle Assessment Methods. Ecoinvent Report No. 3.

3 WASTE IN THE UK

The first step in quantifying the impacts and benefits associated with managing wastes is to determine how much waste there is, what it is comprised of and how it is currently dealt with. To fill this need, a review was carried out of the best and most complete published sources of waste arisings and management data.

It is commonly considered that UK waste management statistics are in want of improvement and findings of the review further highlight the absence of coordinated and consistent data across the UK (1). Data are predominantly collated by source stream, and best available estimates are presented in *Figure 3.1*. Together, these total approximately 430 million tonnes of waste per year.

Figure 3.1 *UK Waste Arisings by Source Stream (Million Tonnes, 2005 (2))*



Note: The European Commission judged in September 2005 that livestock effluent may fall outside of the classification of waste if it is used as a soil fertiliser as part of a lawful practice of spreading. The Environment Agency comment that this would not be classed as waste. However, other legal controls such as the Nitrate Vulnerable Zones (NVZ) Action Programme and the Groundwater Regulations would still need to be complied with. The quantity and fate of livestock effluent is therefore included within estimates of waste arisings

Consultation was also carried out as part of filling the information gap for waste arisings in the research. A workshop was held with policy makers, significant waste producers and key players in the waste management

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(1) Defra have undertaken recent consultation to address this need: Defra (2004). *A Consultation Document on the Development and Implementation of a Three-Year Strategy to Improve Data across all Waste Streams in the UK.* Defra, London.

(2) Latest available estimates were sourced and correspond to different years for different source streams. Refer to *Annex A* for further detail.

industry, to try to identify future trends in waste production and management. This was illuminating in that it unearthed a general feeling that managing wastes according to where they come from, rather than their composition is a flawed approach. It was recommended that the research seek to identify the potential associated with discrete materials within wastes, rather than according to their source.

To this end, and as part of the ongoing review of wastes in the UK, best available data regarding the composition of each waste stream were also compiled, and collated in order to quantify arisings of specific waste materials.

The findings of this work are shown in *Table 3.1* and are presented in more detail in *Annex A*. This approach is somewhat inhibited by the quality of available waste statistics, as some waste streams are disaggregated by material fraction more than others, and some materials are defined in greater detailed. However, estimates were cross-checked against alternative sources wherever possible. As always, the quality of the available data remains a limitation to the accuracy of results.

Table 3.1 Best Estimates of UK Waste Arisings by Material (2005)

Waste Fraction	**Total UK Arisings (Million Tonnes)**	**% of Total Arisings**
Paper & Card	13.7	3.2%
Kitchen/Food Waste	11.8	2.6%
Garden/Plant Waste	17.2	4.0%
Other Organic Waste (manure, slurry, sewage sludge)	87.0	20.2%
Wood	7.5	1.8%
Textiles	1.4	0.4%
Fines	2.3	0.5%
Glass	3.5	0.8%
Plastic (dense)	2.8	0.4%
Plastic (film)	3.1	0.3%
Ferrous Metal	4.1	1.0%
Non-Ferrous Metal	2.0	0.5%
WEEE	2.1	0.4%
ELVs	2.0	0.02%
Tyres	0.5	0.1%
Batteries	0.2	0.04%
Oils/Fuels	0.5	0.1%
Organic Chemicals	0.8	0.2%
Inorganic Chemicals	1.0	0.2%
Mixed Chemicals	1.2	0.3%
Aqueous. Chemical Effluents	0.6	0.1%
Organic/Inorganic Sludges	0.6	0.3%
Mixed Sludges	2.4	0.7%
Absorbent Hygiene Products	0.8	0.2%
Combustion Residues	11.9	1.9%
Silt/Soil	110.7	26.0%
Aggregate/Mineral Materials	119.9	28.1%
Other, Miscellaneous Non-combustible Materials	6.8	1.3%
Miscellaneous Combustible Materials	12.7	4.4%
Total	**431.3**	**100%**

Refer to *Annex A* for data age and sources. Percentages total 100.1% due to rounding

3.1 *WITH SUCH A RANGE OF WASTE MATERIALS, WHERE SHOULD WE FOCUS OUR RESEARCH..?*

Table 3.1 details all of the material fractions identified in the compositional analyses reviewed as part of the research. With such a wide range of fractions specified it was clear that there was a need to focus the scope of the research to reduce the number of materials assessed, whilst ensuring the majority of potential carbon and energy flows were captured.

As a result, we were interested not only in the total quantity of waste material arisings, but also in the carbon and energy content of these materials. Furthermore, the embodied energy and economic value of alternative materials is a useful indicator of the upstream burdens of their production, and thus the potential savings that might be achieved through their recovery.

A screening exercise was carried out to identify significant material fractions. Material streams were ranked according to their contribution to each of the following categories (as a % of the total for all wastes) and their ranks summed to generate a combined score:

- total biogenic carbon content;
- total fossil carbon content;
- total energy/calorific content;
- embodied energy; and
- economic/commodity value.

Those fractions with a combined score of less than 52 (half of a possible maximum of 104) were selected for inclusion in the study. In addition, those material streams contributing more than 5% to any one category were selected for inclusion on the basis of their importance within this parameter.

Results of this screening process are shown in *Table 3.2,* with material fractions included in the research shaded in grey. Data show that inclusion of these fractions accounts for:

- 91% of total waste arisings;
- 97% of total biogenic carbon:
- 75% of total fossil carbon;
- 89% of total energy content;
- 77% of total fossil embodied energy (82% of total embodied energy); and
- 92% of total commodity value.

As such, we consider that quantifying the greenhouse gas and energy estimates on the basis of these materials alone will provide a good estimate of the potential scale of impacts and benefits for all UK wastes.

Table 3.2 Waste Fraction Screening Matrix

Waste Fraction	Biogenic Carbon Content (%) [1]	% of Total Waste Biogenic Carbon	Biogenic Carbon Score	Fossil Carbon Content (%) [1]	% of Total Waste Fossil Carbon	Fossil Carbon Score	Calorific Value [1] (MJ/kg)	% of Total Waste Energy Content	Energy Content Score	Embodied Energy (MJ fossil energy/ kg)[2]	% of Total Waste Fossil Embodied Energy	Fossil Embodied Energy Score	Approx Commodity Value (£/tonne)[3]	% of Total Waste Commodity Value	Commodity Value Score	Total Score
Paper & Card	31.9%	12%	3	-		20	12.6	8%	5	20	13%	2	25.5	7%	5	**35**
Kitchen/Food Waste	13.5%	4%	7	-		20	5.3	3%	10	19	10%	5	6	1%	13	**55**
Green/Plant Waste	17.2%	8%	5	-		20	6.5	5%	7	0.7	1%	19	6	2%	10	**61**
Other Organic Waste	13.5%	33%	1	-		20	5.3	21%	1	-	-	24	6	10%	4	**50**
Wood	43.8%	9%	4	-		20	18.3	6%	6	2	1%	18	-	-	16	**64**
Textiles	19.9%	1%	9	19.9%	1%	14	15.9	1%	13	151	10%	6	52.5	1%	11	**53**
Fines	6.9%	<1%	11	6.9%	1%	17	4.8	1%	22	-	-	24	-	-	16	**90**
Glass	0.3%	<1%	14	-		20	1.5	<1%	25	11	2%	15	11.5	1%	14	**88**
Plastic (dense)	-		15	54.8%	8%	3	26.7	3%	8	100	13%	1	112.5	6%	6	**33**
Plastic (film)	-		15	47.8%	8%	4	23.6	3%	9	80	11%	4	210	13%	3	**35**
Ferrous Metal	-		15	-		20	-		28	15	3%	11	60	5%	7	**81**
Non-Ferrous Metal	-		15	-		20	-		28	126	12%	3	800	31%	1	**67**
WEEE	-		15	15.8%	2%	11	7.6	1%	17	45	4%	8	75	3%	8	**59**
ELVs	-		15	15.8%	2%	13	7.6	1%	20	42	4%	9	75	3%	9	**66**
Tyres	-		15	74.0%	2%	10	31.7	1%	18	90	2%	14	-	-	16	**73**
Batteries	-		15	-		20	-		28	45	<1%	21	30	<1%	15	**99**
Oils/fuels	-		15	80.4%	2%	7	37.7	1%	14	54	1%	16	-	-	16	**68**
Organic Chemicals	-		15	38.4%	2%	12	15.6	1%	21	63	2%	12	-	-	16	**76**
Inorganic Chemicals	-		15	38.4%	2%	8	15.6	1%	19	19	1%	17	-	-	16	**75**
Mixed Chemicals	-		15	38.4%	3%	6	15.6	1%	15	41	2%	13	-	-	16	**65**
Aq. Chem Effluents	-		15	38.4%	1%	16	15.6	<1%	23	-	-	24	-	-	16	**94**
Organic Sludges	30.9%	<1%	13	-		20	12.0	<1%	27	-	-	24	-	-	16	**100**
Inorganic Sludges	-		15	30.9%	1%	20	12.0	<1%	26	-	-	24	-	-	16	**101**
Mixed Sludges	15.5%	1%	8	15.5%	2%	9	12.0	1%	12	-	-	24	-	-	16	**69**
Absorbent Hygiene	14.8%	<1%	12	3.7%	<1%	19	8.0	<1%	24	86	3%	10	-	-	16	**81**
Combustion Residues	-		15	7.00%	4%	5	2.8	2%	11	-	-	24	6	1%	12	**67**
Silt/Soil	7.0%	22%	2	-		20	2.8	14%	3	0.03	<1%	23	-	-	16	**64**
Agg/Minerals	-		15	7.0%	45%	1	2.8	15%	2	0.8	4%	7	6	14%	2	**27**
Other Non-comb	3.5%	1%	10	3.5%	1%	15	2.8	1%	16	0.8	<1%	22	-	-	16	**79**
Misc. combustibles	19.2%	7%	6	19.2%	13%	2	15.6	9%	4	0.8	<1%	20	-	-	16	**48**
Total		**100%**			**100%**			**100.0%**			**100%**			**100%**		

1. Source: ERM & Environment Agency Data (2003-2005)
2. Source: Ecoinvent Database version 1.2[redacted])
3. Source: [redacted] – accessed on 01/03/06

3.2 *WASTE GROWTH*

As part of the review of waste arisings, some consideration was made of how wastes might change in the future, both in terms of arisings and management. It was found that reliable historic data are lacking and information regarding potential future change incomplete. For this reason, and to aid clarity of results, it was decided that carbon flows, greenhouse gas and energy impacts would be modelled on the basis that waste arisings will remain static over the period and the most up to date estimates of arisings, as shown in *Table 3.1*, were used.

4 MANAGING WASTE MATERIALS AS A RESOURCE

'Waste' has historically been viewed as something that we must get rid of in the easiest, cheapest way possible and the definition of waste reinforces this view. However, there is an increasing move towards policies that reduce the impact waste materials have on the environment, by reducing, re-using or recovering value from them (1),(2) . In this way, we begin to view waste as something that is of value; something that is, in fact, a resource.

Waste materials have inherent value in two principal ways. They can be recovered as a product, or 'secondary' resource. This can reduce the requirement for, and avoid the production of, virgin (primary) materials with the same, or similar, function. Alternatively, they can be processed in such a way as to recover the energy they contain.

In streamlining the direction of this research we focused on these broad alternatives for managing waste materials and have developed scenarios that alternatively maximise:

- '**resource recovery**' - through recycling and recovery of secondary materials, and composting and recovery of organic matter; or
- '**energy recovery**' - through combustion of materials with high calorific value, or anaerobic digestion of wet materials with lower net calorific content.

Processes and technologies for treating waste materials according to these broad management routes are many and varied. They have different operating parameters and have different product and emission outputs. *Annex B* provides detail with regard to modelling assumptions for alternative waste management routes and processes. To aid interpretation of results, the predominant management methods assessed are outlined below.

Landfill - There is a general understanding that landfill of biodegradable wastes is of minimal benefit in terms of energy and climate change because little value is recovered from the wastes. Furthermore, the organic portion of the waste degrades to produce landfill gas – comprising approximately 50% methane and 50% carbon dioxide. Methane in landfill gas is of particular concern because it is 23 times as powerful a greenhouse gas as carbon dioxide. Landfill sites can contribute significantly to UK greenhouse gas emissions through their uncontrolled release of methane emissions to atmosphere. This is considerably reduced, however, where gas is collected and burned in a gas engine to produce electricity or flared.

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(1) DETR (2000). *Waste Strategy 2000: England and Wales*. DETR, London.

(2) Defra (2006). Review of England's Waste Strategy. A Consultation Document. Defra, London

Landspread – Land application, void fill, or landscaping is a common management method for wastes derived from agriculture (manure, slurry, crop waste), mining and quarrying and soil or mineral materials from construction and demolition activities. We assume that inert materials deposited in this way will have neither benefit nor burden, save for the fuel used in their transport and application. Organic fractions, when spread on land, will degrade over time and the majority of carbon they contain will be converted to carbon dioxide by biological activity. Like compost, we assume that they also have a benefit as fertiliser, and displace the production of alternative soil conditioning and fertiliser materials.

Recycling – Recycling processes vary widely according to the type of material recovered and the type of secondary product recyclate is converted to. This will depend on the quality of the material recovered, and we make different assumptions for 'high value' and low value' recovery routes. *Annex B* describes this approach in more detail. In general, energy is required to convert waste materials into secondary products. However, this is typically less than the energy required to make the primary materials they displace, so net benefits accrue. We assume that the carbon and energy inherent within the waste materials remains in the secondary products recovered.

Composting - The composting of organic matter is an aerobic process and converts around half of the carbon content to carbon dioxide. If the resulting compost product is spread on the land, the majority of the remaining carbon will also be converted to carbon dioxide by biological action over time. The product is also assumed to have a fertiliser and/or soil improvement, avoiding the production of alternatives, such as mineral fertilisers, peat and wood mulch.

Combustion – Methods of treating waste by combustion include incineration with energy recovery (Energy from Waste (EfW)), gasification and pyrolysis. All have different operating parameters, efficiencies and generate different products. Importantly, each has the capability of thermally degrading waste, converting the majority of carbon to carbon dioxide and recovering energy, as electricity and/or heat, in the process. Not all of the carbon is lost, as some will remain in ash residues. Any energy recovered in the process can be used to generate electricity exported to the national grid, or used for localised heating systems, and displaces the production of either a marginal electricity source (we assume combined cycle gas turbine (CCGT)), or heat production by natural gas.

Anaerobic Digestion - Anaerobic digestion is an alternative technology for recovering energy from biodegradable organic waste. The digestion recovers energy from organic materials by enhancing degradation in the absence of oxygen and the production of 'biogas' (methane and carbon dioxide) through biological activity. This gas can be combusted to generate electricity and/or heat, and thereby displace fossil energy sources. The remaining digestate can be used as a compost product, with an associated fertiliser benefit.

5 WHAT IS THE SCALE OF ENERGY AND GREENHOUSE GAS IMPACTS AND BENEFITS?

5.1 HOW DID WE MODEL GREENHOUSE GAS AND ENERGY IMPACTS AND BENEFITS?

Scenario Development

Four core scenarios were developed, aimed at assessing the broad alternatives for managing waste materials and identifying where potential benefits might lie:

1. **baseline scenario** – reflecting best current estimates of waste material arisings and management;
2. **high resource recovery scenario** – reflecting increased rates of recycling and composting;
3. **high energy recovery** – reflecting increased rates of energy recovery via thermal processing technologies (with energy recovery) or anaerobic digestion; and
4. **combined recovery** – reflecting a combination of both resource and energy recovery (1).

Each scenario was designed to assess the maximum performance *theoretically achievable* for each waste material, in the absence of current policy or infrastructural barriers. The maximum limit was set based on best performance demonstrated across Europe – under the proviso that if it has been achieved elsewhere, it is 'theoretically achievable' in the UK. Assumed recycling and energy recovery maxima for alternative materials are shown in *Table 5.1* (refer to *Annex B* for sources). *Annex B* outlines each scenario in further detail.

Scenarios assess the management of waste arisings over the period 2005 to 2031. It was assumed that 'maximum performance' would be reached in the final year of assessment (2031), with recovery rates increasing linearly from baseline levels. Similarly, current treatment capacities were phased out linearly over this period wherever applicable.

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(1) Note – this scenario assesses upper limit recovery rates, as set out in *Table 5.1*, being achieved through recycling & composting to maximum recycling rates and additional thermal processing/anaerobic digestion, where applicable. For some materials, such as garden waste, upper recycling and recovery limits are the same. For these materials, the high resource recovery and combined scenarios will be the same and so the latter was not assessed.

Table 5.1 Recycling and Recovery Upper Limits

Material Fraction	Recycling Upper Limit (Collected Material)	Energy Recovery Upper Limit
Paper & Card	85%	90%
Kitchen/Food Waste (non-agriculture)	75%	90%
Agricultural Manure/Slurry	50%	50%
Other Organic Waste (predom sewage sludge)	55%	90%
Garden/ Plant Waste (non-agriculture)	90%	90%
Agricultural Crop Waste	50%	50%
Wood	50%	90%
Textiles	50%	90%
Plastic (dense)	60%	90%
Plastic (film)	60%	90%
Ferrous Metal	95%	n/a
Non-ferrous Metal	95%	n/a
Aggregate/Mineral Materials	95%	n/a
Silt/Soil	95%	n/a

Describing the Performance of Alternative Waste Management Routes

The major flows of both carbon/greenhouse gases and energy through waste management systems result from:

- the use of fuel and energy in processing;
- the transportation of waste to and from sites (including collection);
- direct releases from waste materials on processing (eg biological processing or thermal treatment) or disposal in landfill;
- avoidance of greenhouse gas emissions or energy use elsewhere in the economy; and
- sequestration of carbon in landfill and soil.

Annex B sets out the assumptions we have made in quantifying such flows for each waste material and process assessed. These include assumptions regarding process mass balances, carbon balances, ancillary requirements (fuel, energy and transport) and outputs (emissions and products).

It is a common difficultly in quantitative studies, such as this, to collate data that are representative of a generic management route, given the variation demonstrated in each. It is therefore necessary to make a number of assumptions, based on the best available data wherever possible, and, critically, to identify where the results are most significantly influenced by these assumptions.

Through previous research in this area (1), (2) we have found factors such as direct process emissions from waste management facilities, fuel consumption in waste processing and transport to be of lesser importance. The key

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(1) ERM (2006). *Impact of Energy from Waste and Recycling Policy on UK Greenhouse Gas Emissions.*

(2) ERM (2004) *Impact of EU Landfill Directive and National Strategies on UK Greenhouse Gas Emissions.*

influencing factors relate to assumptions regarding the quantity of materials recovered via recycling and composting processes and, more importantly, the uses to which they are put (and hence the materials production displaced). For energy recovery processes, the key influencing factors relate to the properties of waste inputs, and the efficiency at which calorific content can be converted into usable electrical energy or heat.

In essence, it is assumptions regarding the 'avoided' burdens of waste management processes that tend to have most influence on their net performance. As such, we have explored this range of potential performance by assessing both 'maximum' and 'minimum' avoided burdens. *Annex B* describes this approach further and the key assumptions made are detailed in *Table 5.2*.

Table 5.2 ***Maximum and Minimum Avoided Burdens – Basis for Modelling***

Recovery Route	**Basis of Max/Min Avoided Burdens**
Energy Recovery (Thermal)	Maximum and minimum energy conversion efficiencies are based on findings in literature of approximately 20-27%(1) for conventional incineration with steam cycle electricity generation, 40-45%(2) for gasification with combined cycle gas turbine and up to 50-70% for combined heat and electricity recovery (CHP)(3). A minimum of 20% (electricity only) and a maximum of 70% combined power (40% electricity, 30% heat) were modelled.
Energy Recovery (Anaerobic Digestion)	Maximum and minimum conversion efficiencies are based on those quoted in the Biomass Task Force Report to Government (2005). A minimum of 30% (electricity only) and a maximum of 85% combined power (40% electricity, 45% heat) were modelled.
Resource Recovery (Recycling and Composting)	Maxima and minima are based on the range of potential fates for recovered materials, for example recovery of plastics and reprocessing into granulate to replace virgin material versus recovery of plastics and reprocessing into plastic lumber for use in street furniture and replacement of wood inputs. As a general rule, the potential savings are higher where recovered materials are of higher quality, material integrity can be maintained and virgin material production is avoided. The relationship is not a straightforward one for all materials, however, and so maxima and minima have been developed on a fraction-by-fraction basis.

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(1) C-Tech Innovation Ltd (2003). Thermal Methods of Municipal Waste Treatment. Biffaward

(2) C-Tech Innovation Ltd (2003). Thermal Methods of Municipal Waste Treatment. Biffaward

(3) http://www.environment-agency.gov.uk/wtd/981058/981100/?version=1&lang=_e

Extensive sensitivity analyses have also been carried out to find out where results are sensitive to these, and other, modelling parameters, and to appreciate the influence these have on the findings.

Modelling Landfill Greenhouse Gas Emissions and Energy Demand

Modelling of carbon flows and greenhouse gas emissions from landfill was undertaken using the GasSim model.

The GasSim model assesses landfill gas emissions via lateral migration (terrestrial) or surface (fugitive and combustion plant) pathways. The surface emissions of methane, carbon dioxide, and other greenhouse gases can be assessed on a year by year basis, or cumulatively for greenhouse gas impact.

As one of its key inputs, GasSim will accept a detailed description of the composition of waste, in terms of tonnages and sources of the waste (for example municipal solid waste, commercial, civic amenity, industrial, etc). In the model, these waste streams are defined by the different amounts of degradable cellulosic materials they contain, the water content of each fraction, the amount of cellulose and hemicellulose, and the degradability of that cellulose. The alternative properties each have an influence on material degradation. For example, both paper and food waste have high cellulose contents and degradabilities, but food waste contains a significantly higher percentage of water and so, on a per tonne basis (as deposited to landfill), there will be a greater yield of methane from the paper waste stream than from the food waste stream.

GasSim models the degradation of the individual waste components of all the different waste streams represented in the model according to rates of degradation and other modelling rules defined in the user manual (1), (2) . Thus, it is a relatively straightforward task for GasSim to simulate the fate of, for example, all the residual paper and card deposited to landfill in a given waste management scenario.

The result of waste degradation is landfill gas generation. The generated gas can be managed by active gas management systems, to a level determined by the collection efficiency for the gas. This has been set at 75% over a 100 year period, and the rationale for this is discussed further below and in *Annex B*. The remainder of the landfill gas generated is lost to the atmosphere. It is this component which is used to predict the greenhouse gas impact, along with the 1% of the collected gas which is not destroyed in the combustion processes of flaring or gas utilisation. GasSim assumes that 10% of all the methane lost through fugitive surface emissions is oxidised, according to the IPCC default for a well-managed landfill in a developed economy (3) .

(1) Environment Agency (2006). GasSim2 User Manual. Available a [redacted]

(2) Degradation rates can be either default, or user defined. The degradation rates assumed in this assessment are set out in *Annex B*.

(3) IPCC (1996). *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*. IPCC, Geneva, Switzerland.

Annex B shows the degradation, and resultant greenhouse gas emissions associated with alternative materials in landfill, as calculated in GasSim.

As well as forecasting gas generation, GasSim can determine the amount of degradable cellulose which has not yet undergone degradation in a given year. Of the pool of degradable carbon, not all is released as landfill gas in the year of deposition. Some remains in the landfill, sequestered for subsequent degradation. This pool of sequestered carbon will eventually become depleted. There is also a pool of sequestered carbon which will not be depleted, as it is unavailable for microbial degradation. Both forms of sequestered carbon have been quantified in the assessment.

Net greenhouse gas emissions and energy demand were quantified for residual waste materials sent to landfill over the period 2005 to 2031. Due to the time-lag associated with the degradation of biodegradable materials in landfill, greenhouse gas emissions (and energy generation from methane capture) over a period of 100 years following the initial landfill of waste (to 2105) were also quantified.

The one hundred year timeframe is useful measurement window on two counts. Firstly, IPCC consider a one-hundred year timeframe as one of the relevant greenhouse gas markers, and these data are embedded in the GasSim model for greenhouse gas impact assessment. Secondly, the bulk of the degradation from any of the degradable waste components will have taken place in that timeframe. The degradation rates under average waste moisture contents in landfills range from a five year half-life for putrescible wastes to a fifteen year half-life for slowly degradable materials. Five half-lives of even the slowest degradation rate represented in the model results in the assumed loss of 98.4% of the degradable material. As a result we observe the release of the bulk of methane committed to release from the landfilled waste within this timeframe.

Developing and Applying Greenhouse Gas and Energy Impact Factors

Greenhouse gas emissions (expressed as CO_2-equivalents) and cumulative fossil energy demand (expressed as energy [joule]-equivalents) associated with waste management activities were quantified for each scenario using a series of steps, as follows.

1. Ancillary impact factors (greenhouse gas emissions/energy demand per tonne of diesel produced and combusted, per kWh of electricity generated, per tonne-kilometre of waste transported) were sourced from published life cycle inventory databases (sources presented in *Annex B*).
2. The ***ancillary inputs*** (tonnes of diesel, kWh of electricity, tonne-kilometres of residues transported, etc) and ***direct emissions*** associated with the management of wastes were determined for each treatment process and waste material (as discussed above).

3. ***Avoided burdens*** (tonnes of material separated for recycling, kWh electricity recovered, etc) were calculated using both mass balance assumptions and further calculations.
4. Ancillary impacts, direct process emissions and avoided burdens were combined and multiplied by process throughputs to give a total net greenhouse gas/energy demand.

Combining Estimates

Net greenhouse gas emissions and energy demand were quantified for the management of waste materials in each year from 2005 to 2031. These were combined with time-lagged landfill impacts (capturing gas release over 100 years), to give a total for the assessment period.

Net emissions and energy demand were also quantified on a year-by-year basis to understand the long term climate change and energy impacts of managing waste materials. We have not discounted these future emissions. There is no consensus on whether it is appropriate to do so, or on what positive, or negative, discount rate should be used (1).

Results

Results are presented in full in *Annex C* and *Annex D*, detailing:

- carbon and greenhouse balances over the 100-year assessment timeframe for each waste material and scenario (*Annex C*);
- maximum and minimum net greenhouse gas emissions over time for each waste material and scenario (*Annex D*);
- maximum and minimum net fossil energy demand over time for each scenario and waste material (*Annex D*); and
- specific impacts associated with the landfill of residual materials (*Annex D*).

A summary and interpretation of results is presented in the following sections. The aim of this is to identify key findings and trends and to identify areas in which estimates of impact/benefit are sensitive to the assumptions made during modelling.

A selection of graphs and tables presenting 'average' estimates for greenhouse gas and energy demand have been included. We have taken this average to be the median value between maximum and minimum estimates. It must be noted that this average is useful for presentational purposes only – it represents the midpoint of the range of theoretical savings associated with recycling or recovering energy from alternative materials. It is not intended to

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(1) Discussed, for example, in Hellweg *et al* (2002). *Discounting and the Environment. Should Current Impacts be Weighted Differently than Impacts Harming Future Generations?* Int. Journal LCA (OnlineFirst).

be representative of, for example, an average thermal treatment plant, or recycling route.

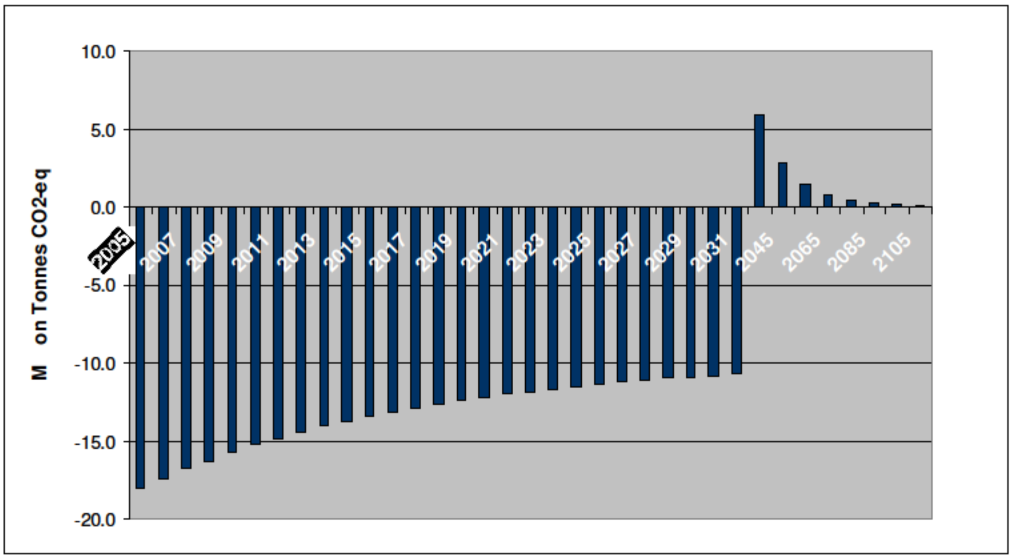
Further, maximum avoided burdens, in particular for energy recovery, are purely theoretical, and would be practically achievable only in the framework of significant change, for example for regard to infrastructure for heating systems. Thus it is important that results are interpreted in this context, and efforts have been made to highlight where the presentation of average burdens is ambiguous.

5.2 UK WASTES – BUSINESS AS USUAL

5.2.1 *Net Emissions and Energy Demand*

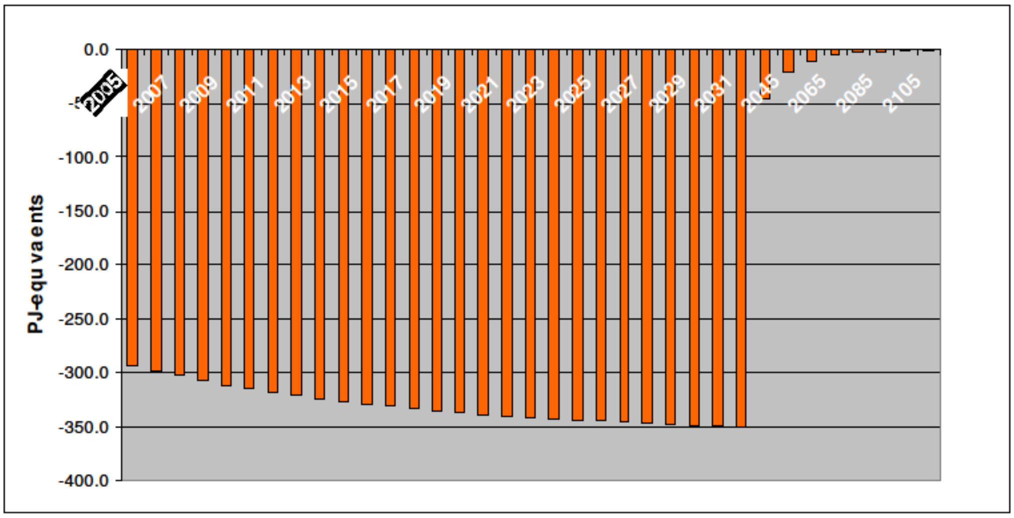
A timeline of results, showing average net greenhouse gas emissions and energy demand associated with the baseline case in the UK, is shown in *Figure 5.1* and *Figure 5.2*. The graphs show that, under the assumptions modelled, current recovery and recycling of materials, such as metals, plastics and paper, result in a net greenhouse gas and energy benefit, achieved across all waste streams. The benefit ceases beyond 2031 because we are only examining **committed** consequences of the landfill of waste over the 2005 – 2031 period beyond this point.

Figure 5.1 Average Net Greenhouse Gas Emissions (Mt CO_2-equivalents)



Note – includes committed emissions from the landfill of waste over the period 2005-2031

Figure 5.2 Average Net Energy Demand (PJ-equivalents)



Note – includes committed emissions/consequences of the landfill of waste over the period 2005-2031

Although we assumed that both waste arisings and management routes will remain constant from 2005-2031, we see that that greenhouse gas benefits decrease over time, whereas net energy demand benefits increase over time. This is a consequence of the legacy and cumulative release of methane and other greenhouse gases from landfill. A considerable proportion of this methane is captured for energy recovery and is assumed to avoid and to offset the production of grid electricity. The implication of this is that net energy demand is reduced.

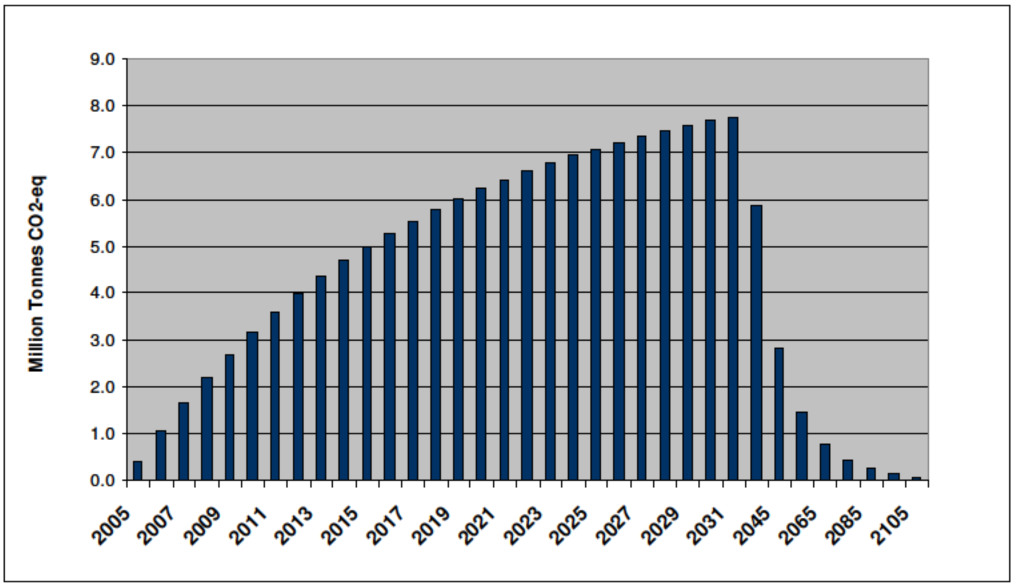
Note that the time lag of organic waste degradation is such that landfill sites will continue to release (and capture and put to use) methane and other greenhouse gases over a significant period following disposal. This is evident from the 'tail' of greenhouse gas emissions, post 2031, that we see in *Figure 5.1*.

The impact of the committed tail is interesting to observe conceptually. In reality, however, continued materials recycling beyond 2031 will shift the net balance of greenhouse gas release such that it is consistent with previous years. Further, the scope of this study was to address the management of wastes as they arise today, and from this point forward (for the next 25 years). The presented estimates do not, therefore, take account of the committed greenhouse gas releases associated with organic wastes that were deposited in landfill prior to 2005.

5.2.2 *Landfill Contributions*

To further understand the contribution of landfill to net greenhouse gas emissions, *Figure 5.3* shows the greenhouse gas releases from landfilling baseline quantities (approximately 300 million tonnes) of degradable waste inputs each year, over the period 2005-2031.

Figure 5.3 *Residual Waste to Landfill - Net Greenhouse Gas Emissions (Mt CO_2-equivalents)*



Note: These net emissions include energy generation and consumption at landfill sites

The greenhouse gas releases follow a curve which is directly proportional to the rate of degradation of the degradable-carbon containing substances in the waste. GasSim models three degradation rates, for slowly degradable material, moderately degradable material, and rapidly degradable material.

Newspaper remains can often be found in landfills, since the lignin content of newspaper effectively slows down the decomposition process, and makes more of the cellulose unavailable for degradation. Newspapers therefore are assumed to degrade slowly (typically with a 15 year half-life). Other paper and card are simulated with a 75% slow degradability and a 25% moderate degradability (typically with a nine year half-life). Textiles are also considered as slowly degradable material. At the other end of the spectrum, food wastes, green waste, fines, sewage sludge, and the residual carbon in ash are all readily degradable, typically with a five year half-life. Stabilised compost and miscellaneous combustibles are considered to be moderately degradable.

While degradability is important in determining when the carbon is released from the landfill, so also is the amount of degradable carbon in the waste material and the moisture content. Putrescible wastes were for a long time considered to be the major source of landfill gas. In reality, however, they typically contain 70% water, and currently the most significant source of carbon emissions is from paper and card.

Annex B shows the degradation of alternative materials and resultant greenhouse gas releases, as calculated in GasSim, and provides some further detail on the modelling approach.

5.2.3 *Carbon and Greenhouse Gas Balance*

A carbon and greenhouse gas balance, outlining the flow and fate of all carbon in managed wastes over the period 2005-2031, and subsequent releases from landfill over the 100-year period is shown in *Figure 5.4*. This details:

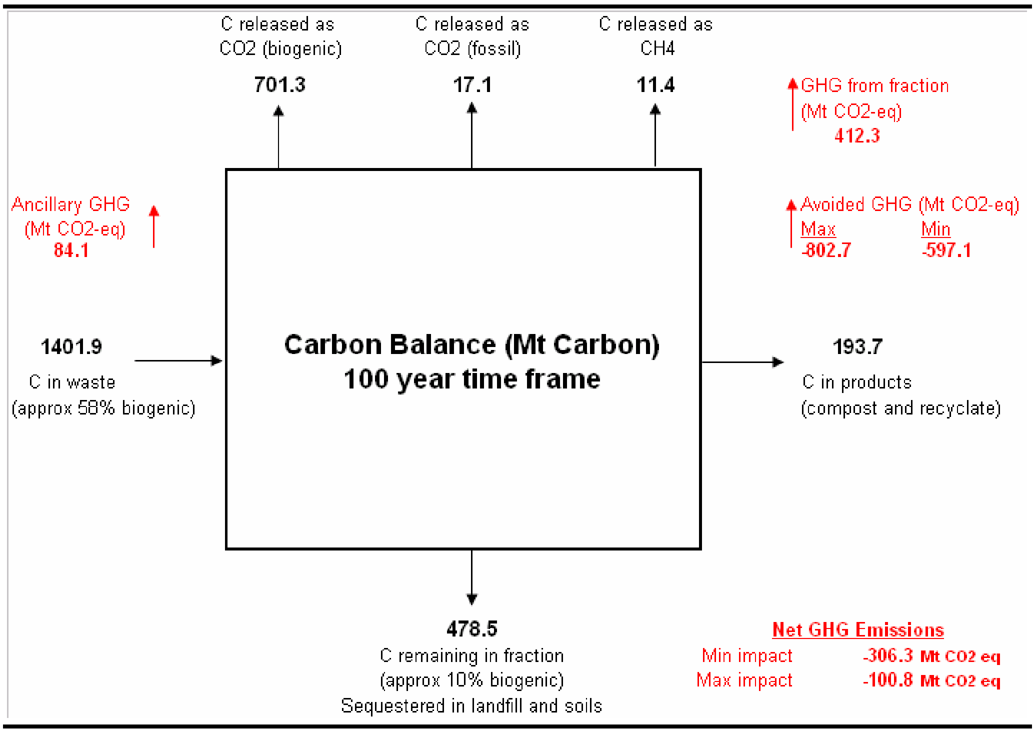
- the carbon that remains in the material fraction following treatment or disposal (both carbon in inert fractions that have been deposited in land, as well as organic carbon that has not degraded but is sequestered in landfill or other soil carbon sinks);
- carbon that is contained in products, such as recyclate or composts; and
- carbon that is released to atmosphere, as carbon dioxide (fossil/biogenically derived), or methane.

A greenhouse gas balance is shown in red, detailing:

- 'ancillary' greenhouse gas emissions predominantly associated with fuel, energy and transport;
- greenhouse gas releases directly associated with the degradation of waste materials (eg on biological processing or landfill of biogenic wastes, or combustion of fossil-derived materials); and
- avoided greenhouse gases through resource and energy recovery.

Note that both the maximum and minimum avoided benefits are presented, and so we also see a range for resulting net emission estimates.

Figure 5.4 *Carbon and Greenhouse Gas Balance over Study Period – Baseline Scenario*



5.2.4 *Sensitivity of Results*

The results depend on the assumptions made in calculating these estimates (the assumptions are set out in *Annex B*). Sensitivity analyses were carried out to examine which of the assumptions have the greatest affect on the results.

Landfill Gas Capture

Figure 5.4 shows that the predominant greenhouse gas impact associated with the management of waste materials in the baseline scenario is that of direct releases. The major contribution in this respect is methane and other greenhouse gases from waste degrading in landfill. Consequently, it is useful to look first to landfill in sensitivity analyses.

A key modelling assumption with regard to landfill was that, on average over the 100 year period, 75% of all landfill gas emissions will be captured and combusted or oxidised. This is assumed to be for current, PPC-permitted landfills and takes account of both the high rates of capture currently achieved with a high gas generation rate and the much lower capture likely to be achieved when yields are low (1).

Table 5.3 presents net greenhouse gas emissions over the 100 year assessment period should only 50% or 60% of landfill gas be captured over this timescale. This shows the results to be highly sensitive to the assumed gas capture, such that if 100-year collection efficiencies of less than 60% (approximately) are achieved, and assuming the same rates of oxidation, the average net greenhouse gas benefits shown for the UK in *Figure 5.1* and *Figure 5.4* become net impacts (average net greenhouse gas estimates over the 100-year period increase from the –203 Mt CO_2-eq shown in *Figure 5.4* to -16 Mt CO_2-eq at 60% capture and 117 Mt CO_2-eq at 50% capture).

Table 5.3 Alternative Landfill Gas 100-Year Collection Efficiencies (Net Greenhouse Gas Emissions over Period)

Gas Capture over 100 Years	Max Net GHG Emissions over Period (Mt CO_2-eq) – Total for Baseline	Min Net GHG Emissions over Period (Mt CO_2-eq) - Total for Baseline
50%	219.8	14.2
60%	86.4	-119.2

Annex E presents additional analyses that explore the use of 75% as a 100-year gas collection value. This modelling shows that a 100-year gas collection value of 75% could result in a lower lifetime (150 year) collection efficiency of approximately 59%. There are periods at the start and end of a landfill's life during which gas collection is technologically impractical (at the end of a site's life) or challenging (at the start of a site's life). It should be realised that the nature of gas generation and emissions in the late stages of a landfill's life are

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(1) *Annex B* provides more background to this assumption.

very site specific, and are not well understood. The modelling assumes first order decay but this is a simplification.

The additional work also shows that, in terms of lifetime gas collection, scenarios comparing 75% gas collection over 100 years with a permitting regime of 85% collection efficiency during the active gas management phase (1) – as is currently the case – equate very closely.

The permitting regime expects 85% collection efficiency in the operational period of landfilling when active gas management is practicable. This means that during landfilling of individual cells, gas management may not be practicable. In the model example in Annex E, a landfill with a modelled average of 75% gas collection efficiency, over a 100 year timeframe behaves similarly to a model of the same landfill site where the individual cells are represented and an 85% gas collection efficiency is expected where such gas can be collected by the gas collection infrastructure (but not during filling of the individual cells). On this basis, a 75% gas collection efficiency over 100 years would seem to be a reasonable assumption with regard to current landfill technologies and management. However, the results have been shown to be particularly sensitive to this assumption, and future estimates of climate change impacts associated with landfill would benefit from further work in this area.

Further, the additional analyses presented in *Annex E* show that if losses of methane occur as a result of inabilities to collect gas at the tail end of production, overall lifetime collection efficiencies would be reduced, resulting in increased net greenhouse gas emissions from landfill.

Landfill Degradation Conditions

Another factor that influences greenhouse gas and energy demand estimates for landfill is the assumed rate of degradation of wastes in landfill. This is, in turn, influenced by moisture conditions in the landfill itself.

Moisture has an effect on waste degradation because the microbially mediated reactions which take place to degrade cellulose-containing wastes take place on wetted surfaces. The rate-determining step for all the many complex microbially mediated reactions that can take place in the landfill is the rate of hydrolysis of cellulose to glucose (all subsequent microbial degradation processes will occur at faster rates than these). A consequence of this is that a well-wetted (but not saturated) waste, well-shredded with lots of active broken surfaces for hydrolysis to be initiated, is the ideal medium for landfill gas generation.

In the UK, the majority of landfills can be represented using either average moisture content or wet moisture content degradation rates. For the core

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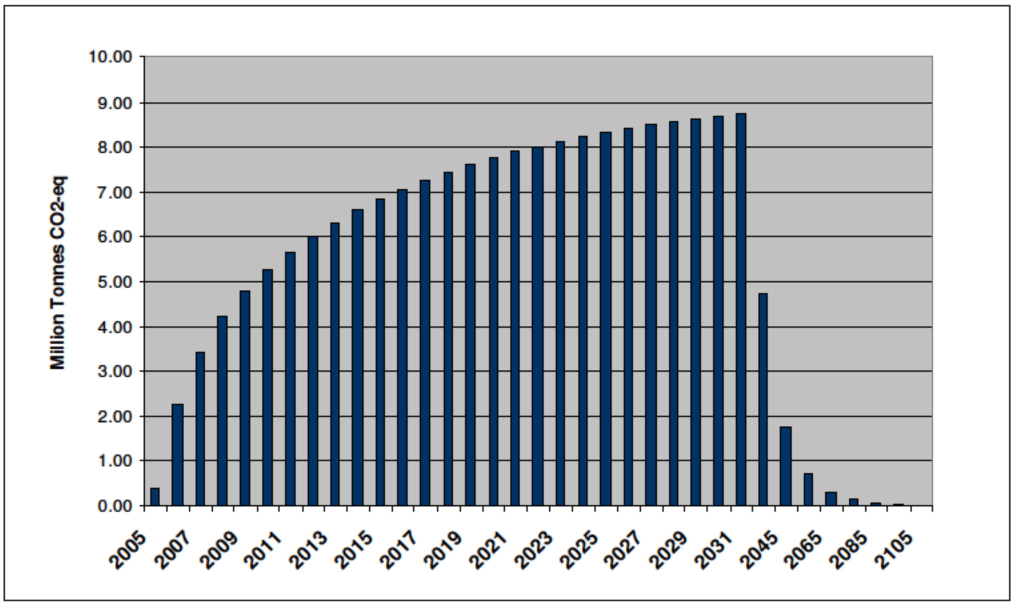
(1) Environment Agency (2004) Guidance on the management of landfill gas. Environment Agency, Bristol.

analyses in the research, we used average moisture conditions (resulting greenhouse gas emission estimates are shown in *Figure 5.1* and *Figure 5.3*). *Figure 5.5* and *Figure 5.6* show greenhouse gas emissions from landfill, and resulting average net greenhouse gas emissions over time, should a wet degradation rate be assumed.

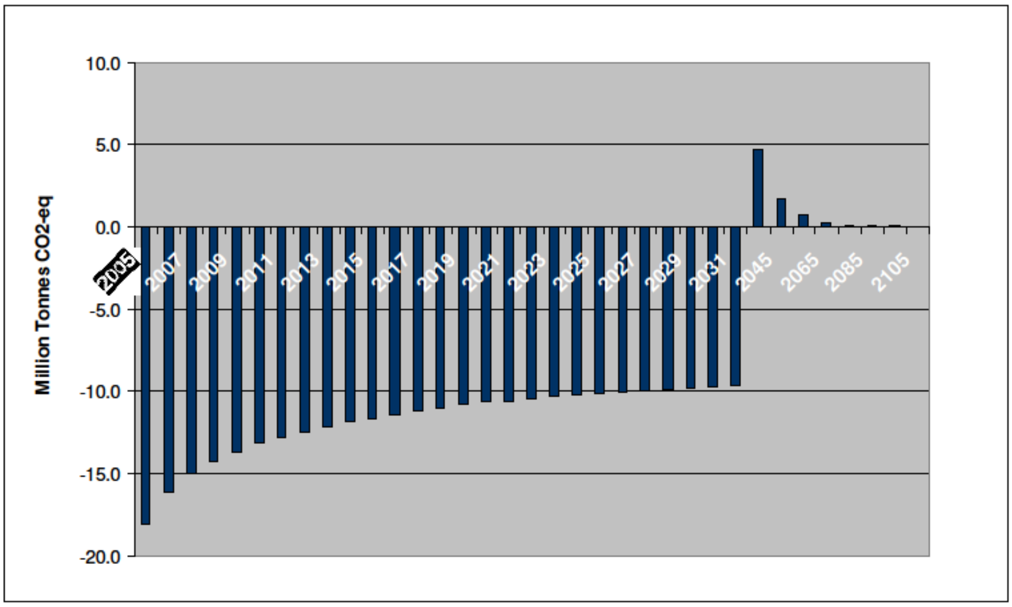
Figure 5.6 shows a steeper curve of decreasing greenhouse gas benefit in early years, as a result of faster degradation of materials in landfill, and associated gas emissions. However, the impact of this assumption on net greenhouse gas emissions over the 100 year period is minimal (average net emissions of -212.5 Mt CO_2-eq in comparison with -216.7 Mt CO_2-eq), as it is not the quantity of gas release that is influenced, but its rate of release.

Figure 5.5 ***Wet Degradation: Residual Waste to Landfill - Net Greenhouse Gas Emissions (Mt CO_2-equivalents)***



Note: These net emissions include energy generation and consumption at landfill sites

Figure 5.6 ***Wet Degradation: Average Net Greenhouse Gas Emissions (Mt CO_2-equivalents)***



Note – includes committed emissions from the landfill of waste over the period 2005-2031

Other Sensitivities?

Analyses of material fractions, presented in subsequent sections of this report, show that, for the most part, results are not sensitive to the majority of other modelling assumptions, save for the range and scale of avoided burdens. The exception is the transport of soil and mineral materials, derived predominantly from construction and demolition activities. This is discussed further in *Section 5.3.7*. It was found that assuming reduced transport of these waste materials has the potential to reduce ancillary greenhouse gas impacts, and thus overall baseline estimates, by up to 25-30 Mt CO_2-equivalents over the period assessed.

5.2.5 *Estimates of Future Change*

A key consideration in modelling was how the baseline case should be defined. As a core scenario, we opted for the 'business-as-usual', or no change over the period. However, it is also useful to look at what change might reasonably be expected to occur over the period that we have assessed.

As part of the 2006 national Waste Strategy review, Defra have estimated the rates of recycling, composting and energy recovery that might be expected to be achieved under the current policy climate. One scenario, the 'baseline policy scenario' was modelled to reflect this. Defra have made further estimates of how different waste sources might increase over time and how the management of waste materials will change accordingly. An additional scenario, the 'policy growth scenario', was developed to reflect these estimates.

The resulting carbon and greenhouse gas balances are shown in *Figure 5.7* and *Figure 5.8*. These show the scale of potential benefit should current policy drivers result in the changes expected. For the baseline policy scenario, we see that the increased recycling and composting rates expected result in greater quantities of carbon accumulating in products, and there is the potential for greater avoided burdens in displacing primary products. Furthermore, diversion of waste from landfill results in reduced direct greenhouse gas emissions and less carbon also remains undegraded in landfill.

The policy growth scenario presents an oxymoron, of sorts, in that increasing quantities of waste will result in increased greenhouse gas benefit, through greater materials and recycling. In reality, it is not meaningful to compare this scenario with either of the baselines. Static growth, as assumed in the baseline scenarios, can only be a function of either reduced consumption, and thus reduced subsequent waste, or re-use of waste materials. Both of these routes will have significant associated greenhouse gas and energy benefits, through avoiding primary materials production. However, it is not possible to quantify the relative proportion of materials that might pass via these routes and so we have not attempted to do so.

Whilst not quantified, the overarching benefit of reducing, or avoiding, consumption should be noted.

Figure 5.7 *Carbon and Greenhouse Gas Balance over Period – Baseline Policy Scenario*

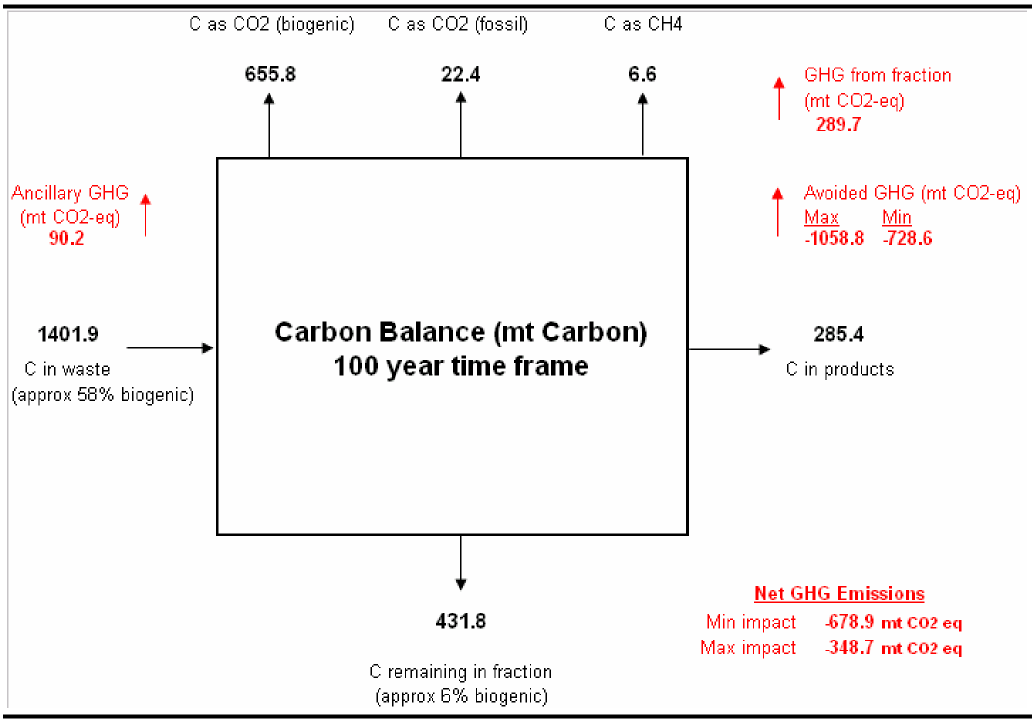
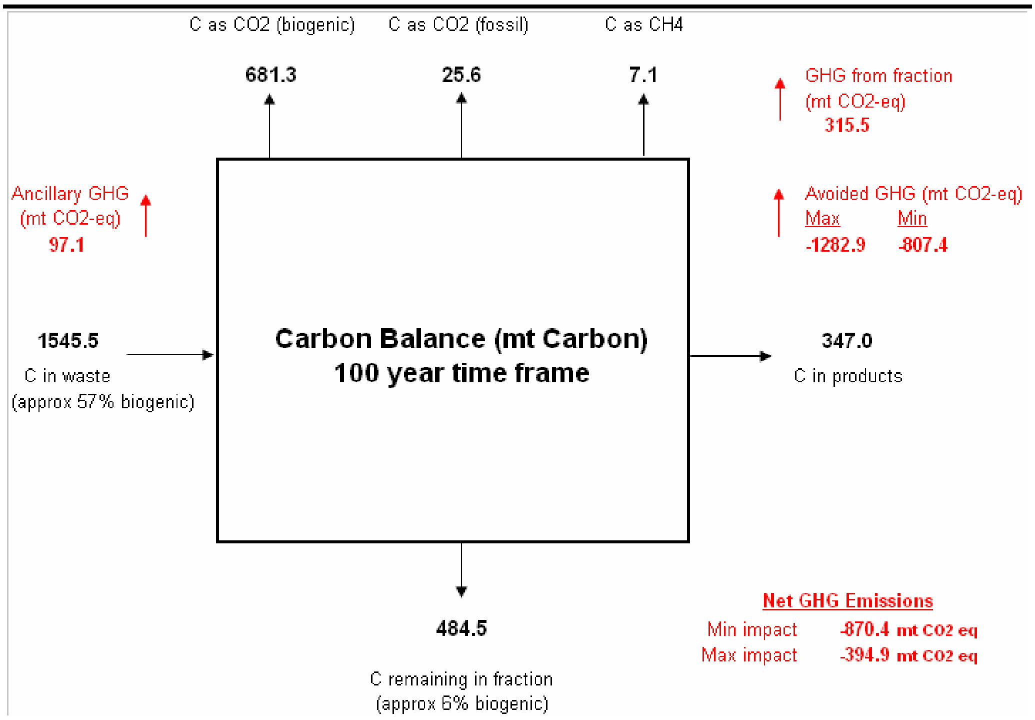


Figure 5.8 *Carbon and Greenhouse Gas Balance over Period – Policy Growth Scenario*



5.2.6 *How Should Landfills be Managed as Waste Composition Changes?*

So far, we have considered the effect of individual waste materials being landfilled in the UK. The reality is that landfill operators will experience the consequences of the Landfill Directive Article 5 biodegradable MSW diversion targets. The result in the composition of waste received will be a decrease in the biodegradable material sent to landfill. It is of interest to investigate the implications that this will have on resulting greenhouse gas emission and energy recovery estimates.

Annex E presents a discussion and results of additional analyses that were carried out in this respect. It is shown that the construction of large biodegradable landfill sites, which would receive a larger proportion of degradable waste than the current typical MSW composition, shows potential environmental benefit. This is in comparison with reducing the biodegradable MSW content at all landfills at an equal rate.

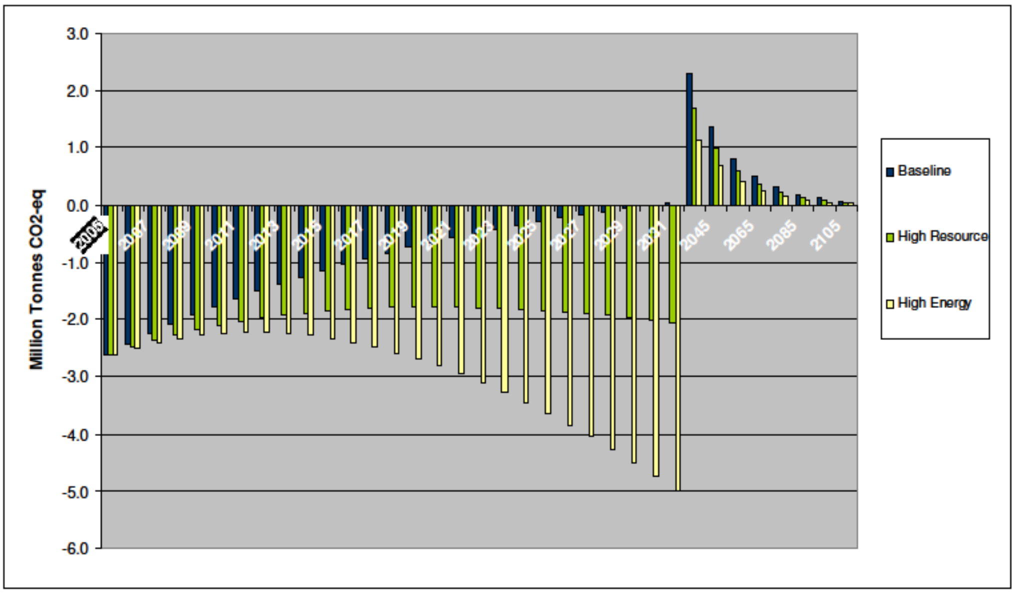
A number of alternative scenarios were modelled, including: one reflecting a landfill that follows Landfill Directive targets to the letter (Scenario C); and another that represents the concentration of bioactive waste components at a degradable waste landfill, where additional gas utilisation plant could be employed (Scenario E). Scenario results were normalised by calculating emissions and energy generation potential per tonne of biodegradable waste sent to landfill in each scenario. Resulting estimates show scenario E to have both reduced greenhouse gas emissions (0.42 tonnes CO_2-eq per tonne of biodegradable waste, in comparison with 0.52 for Scenario C) and increased potential for energy generation (0.21 MWh per tonne of biodegradable waste in comparison with 0.17 MWh for Scenario C), leading to further greenhouse gas savings.

5.3 THE SCALE OF POTENTIAL BENEFITS FOR INDIVIDUAL MATERIALS

5.3.1 *Paper and Card*

Average net greenhouse gas emissions and fossil energy demand associated with the management of waste paper and card arisings over the period 2005-2031 are shown in *Figure 5.9* and *Figure 5.10* (1).

Figure 5.9 Paper and Card - Average Net Greenhouse Gas Emissions (Mt CO_2-equivalents)



- Baseline = business as usual. High resource = moving from 47% recycling in 2005 to 85% in 2031. High energy = moving from 7% thermal treatment in 2005 to 90% in 2031.
- Estimates include committed emissions from the landfill of waste over the period 2005-2031

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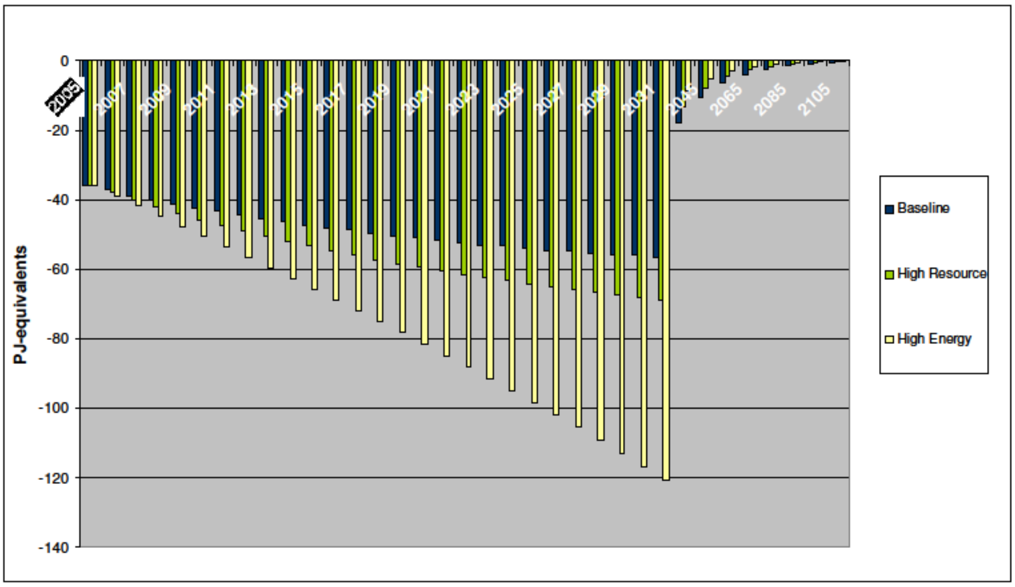
(1) Results for the combined scenario are intermediate in profile and so, in an attempt to aid clarity, have not been presented. Results for this scenario can be found in full in *Annexes* C and D.

Figure 5.10 Paper and Card - Average Net Energy Demand (PJ-equivalents)

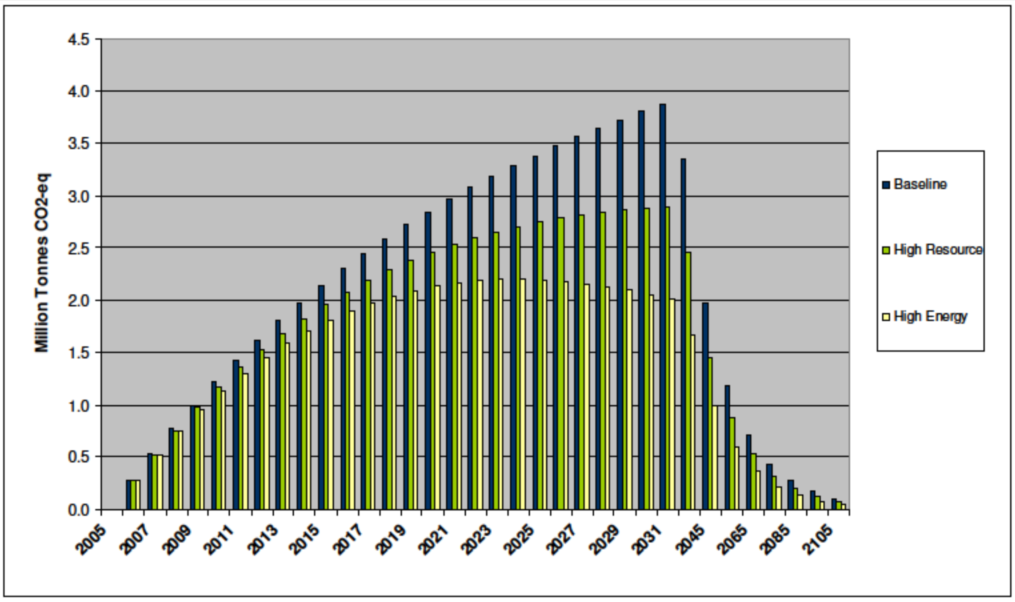


- Baseline = business as usual. High resource = moving from 47% recycling in 2005 to 85% in 2031. High energy = moving from 7% thermal treatment in 2005 to 90% in 2031.
- Estimates include energy recovery from committed consequences of the landfill of waste over the period 2005-2031

A number of findings are immediately apparent:

- all scenarios show net greenhouse gas and energy benefits in each year between 2005-2031, as a result of current and enhanced levels of recycling or combustion with energy recovery;
- the high resource recovery and energy recovery scenarios both confer net greenhouse gas and energy benefits over the baseline scenario;
- greenhouse gas benefits for all scenarios initially decrease with time as residual material in landfill degrades and emissions from landfill increase (see *Figure 5.11*). As material is diverted from landfill in the recovery scenarios, and the increased benefits of resource and energy recovery are realised, greenhouse gas benefits begin to increase;
- after 2031, residual paper in landfill continues to degrade and generate landfill gas, some of which is captured and used to generate energy, resulting in the tail evident in *Figure 5.10*. The remainder escapes to atmosphere and causes the impact shown in *Figure 5.9*. Sending less of this material to landfill reduces the associated impact, as is shown in *Figure 5.11*; and
- for the average case presented, and under the assumptions modelled, energy recovery from paper and card conveys a greater greenhouse gas and energy benefit than recycling. It must be noted that this 'average' represents the midpoint of a range of theoretical savings associated with recycling or recovering energy from paper/card. It is not intended to be representative of an average UK thermal treatment plant, or recycling route. Its interpretation should therefore be treated with caution and is considered further in sensitivity analyses.

Figure 5.11 *Paper and Card Residuals to Landfill - Greenhouse Gas Emissions (Mt CO_2-equivalents)*



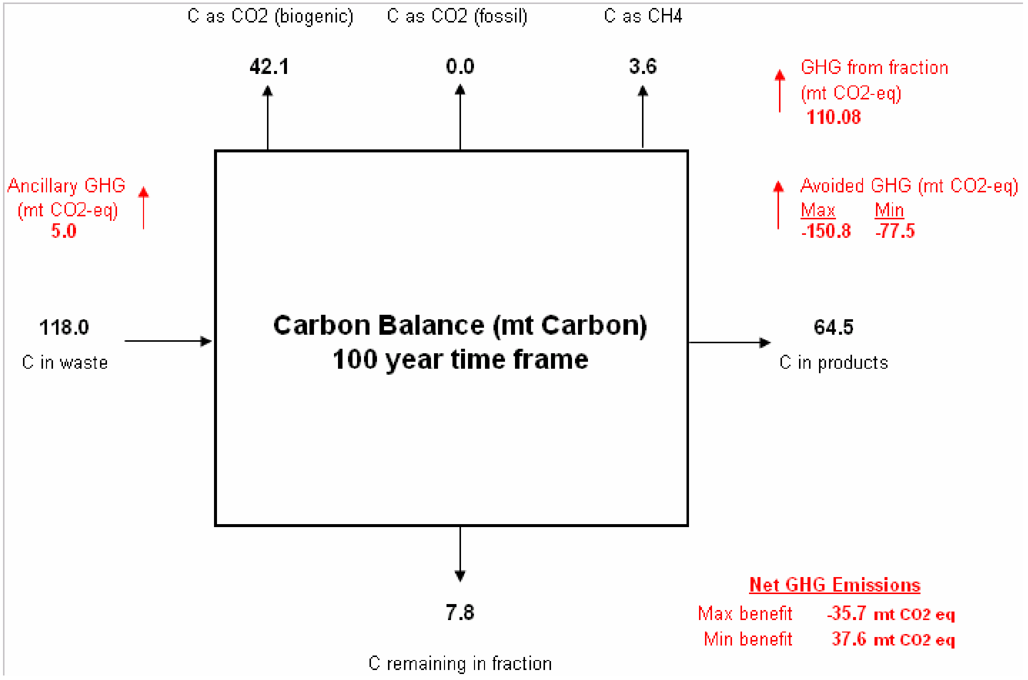
Baseline = business as usual. High resource = moving from 47% recycling in 2005 to 85% in 2031. High energy = moving from 7% thermal treatment in 2005 to 90% in 2031.

Less apparent are the factors that contribute most significantly to the relative benefits seen – and in particular, to the differences between resource and energy recovery scenarios. To understand these further, it is useful to look to the carbon and greenhouse gas balances calculated for both scenarios over the 100-year period (*Figure 5.12* and *Figure 5.13*).

Balances show the majority of greenhouse gas impact to be associated with direct releases of methane and other greenhouse gases when the material degrades (the 'GHG from fraction'). The majority of this impact derives from residual paper in landfill and so it follows that the high energy recovery scenario, which achieves 90% diversion of paper/card from landfill by 2031, results in lower emissions than the high resource recovery scenario, which assumes a maximum recycling (and therefore diversion) rate of 85%.

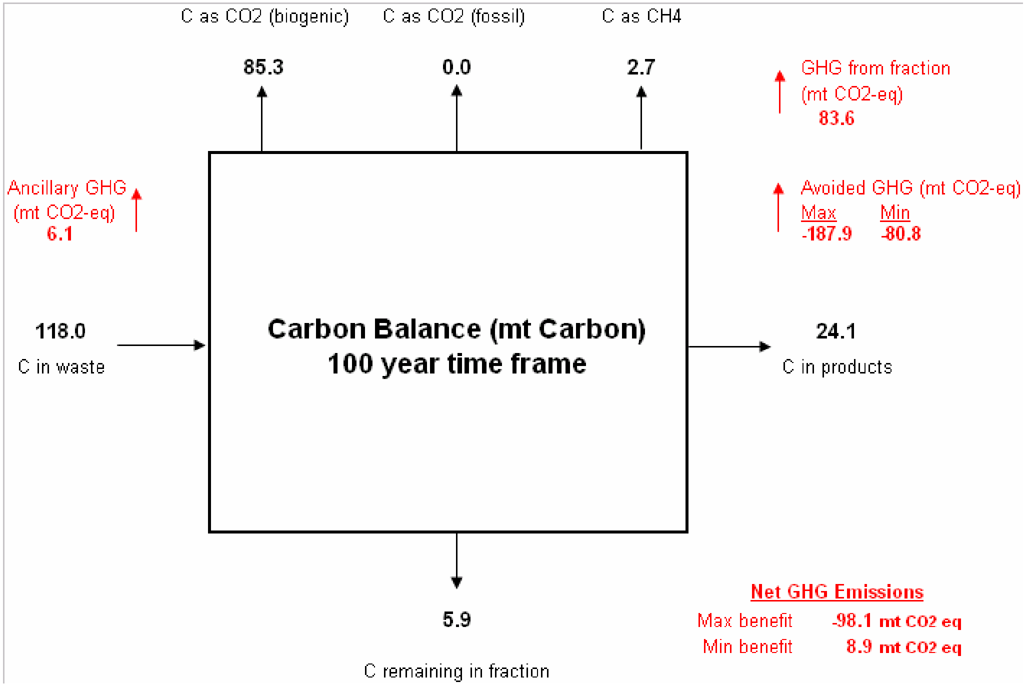
Balances also show that ancillary impacts (process fuel/energy consumption, transport etc.) contribute much less to net greenhouse emissions than direct impacts. We can conclude from this, and confirm through sensitivity analysis, that assumptions relating to process energy consumption and transport distances do not significantly influence the results.

Figure 5.12 *Paper and Card - Carbon and Greenhouse Gas Balance over Period (High Resource Recovery)*



High resource recovery = moving from 47% recycling in 2005 to 85% in 2031.

Figure 5.13 *Paper and Card - Carbon and Greenhouse Gas Balance over Period (High Energy Recovery)*



High energy recovery = moving from 7% thermal treatment in 2005 to 90% in 2031.

The most significant factor influencing net greenhouse gas profiles is the quantification of avoided benefits. We see from *Figure 5.9* that, assuming average avoided burdens, the high energy scenario performs favourably. However, *Figure 5.12* and *Figure 5.13* show that, if only a minimum energy recovery efficiency (20%) is achieved, average recycling confers the greater benefit. Conversely, if average energy recovery efficiency is achieved and all recovered materials are assumed to follow the high value (maximum benefit) reprocessing route, the balance between energy recovery and recycling becomes extremely close.

Given the sensitivity of the results to these parameters, and the wide range of climate change and energy benefits potentially achievable, further assessment was made of the relative performance of scenarios under different assumptions. For example, how would a change in the energy recovery efficiency of combustion over time influence results? Similarly, what would the resource recovery profile look like if we assume that the quality of materials recovered changes as more paper and card is collected?

It is reasonable to consider that as paper/card recovery increases, the quality of the materials recovered will change as new sources are tapped. It is also reasonable to consider that, as time and throughputs increase, combustion technologies are likely to improve in efficiency.

With these considerations in mind, three alternative profiles of net greenhouse emissions were calculated. Both assume that current, low levels of energy recovery in the UK are predominantly low efficiency technologies and that, as the proportion of energy recovery for paper/card increases, technology will develop and new plant will comprise increasing proportions of medium and high efficiency (combined heat and power (CHP)) energy conversion. The changing mix of technology efficiency is shown in *Table 5.4*.

Table 5.4 Paper and Card Energy Recovery Sensitivity Assumptions

Energy Recovery Rate	% High Efficiency Conversion (CHP - 40% elec, 30% heat)	% Medium Efficiency Conversion (40%, elec)	% Low Efficiency Conversion (20%, elec)
0-20%	5%	5%	91%
21-40%	12%	12%	77%
41-60%	22%	22%	56%
61-80%	27%	27%	45%
81-100%	33%	33%	33%

The differentiation between the alternative scenarios is with respect to the relative split of paper and card recycling routes. (1) assumes that current recycling is predominantly via high value reprocessing routes and that, as recycling rates increase, the proportion of medium and low value routes will increase accordingly. (2) assumes that current recycling is initially split equally across categories and, as recycling increases, there will be increased captured of office and other high value paper types. (3) assumes an equal weighting between the three categories (33%) across the period. *Table 5.5, Table 5.6* and *Table 5.7* show the performance assumptions for each scenario.

Table 5.5 Paper and Card Recycling Performance Sensitivity Assumptions (1)

Recycling Rate	% High Value Recovery	% Medium Value Recovery	% Low Value Recovery
0-20%	90%	5%	5%
21-40%	77%	12%	12%
41-60%	56%	22%	22%
61-80%	45%	27%	27%
81-100%	33%	33%	33%

Table 5.6 Paper and Card Recycling Performance Sensitivity Assumptions (2)

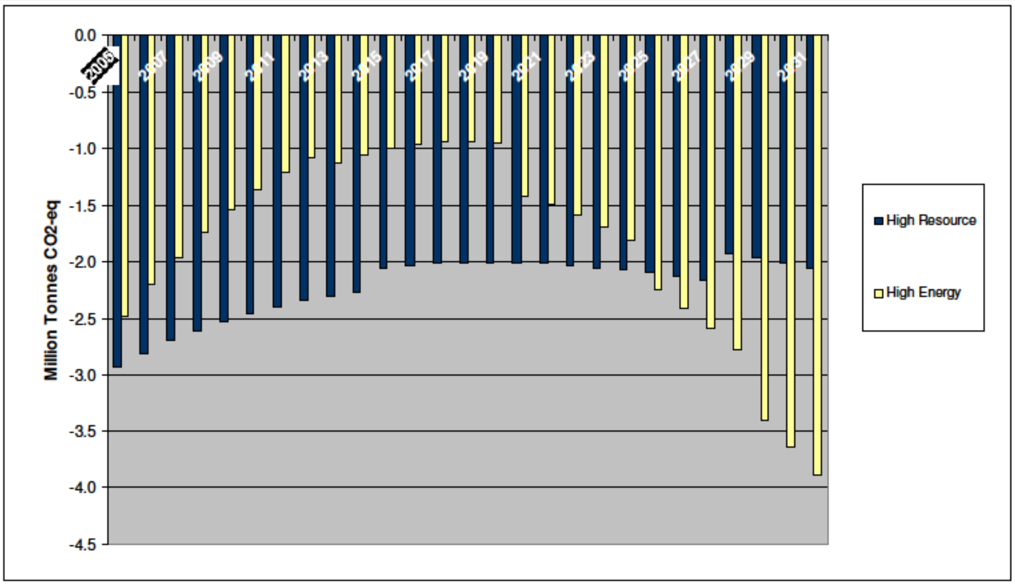
Recycling Rate	% High Value Recovery	% Medium Value Recovery	% Low Value Recovery
0-20%	33%	33%	33%
21-40%	42%	30%	27%
41-60%	52%	27%	22%
61-80%	61%	23%	16%
81-100%	70%	20%	10%

Table 5.7 Paper and Card Recycling Performance Sensitivity Assumptions (3)

Recycling Rate	% High Value Recovery	% Medium Value Recovery	% Low Value Recovery
0-20%	33%	33%	33%
21-40%	33%	33%	33%
41-60%	33%	33%	33%
61-80%	33%	33%	33%
81-100%	33%	33%	33%

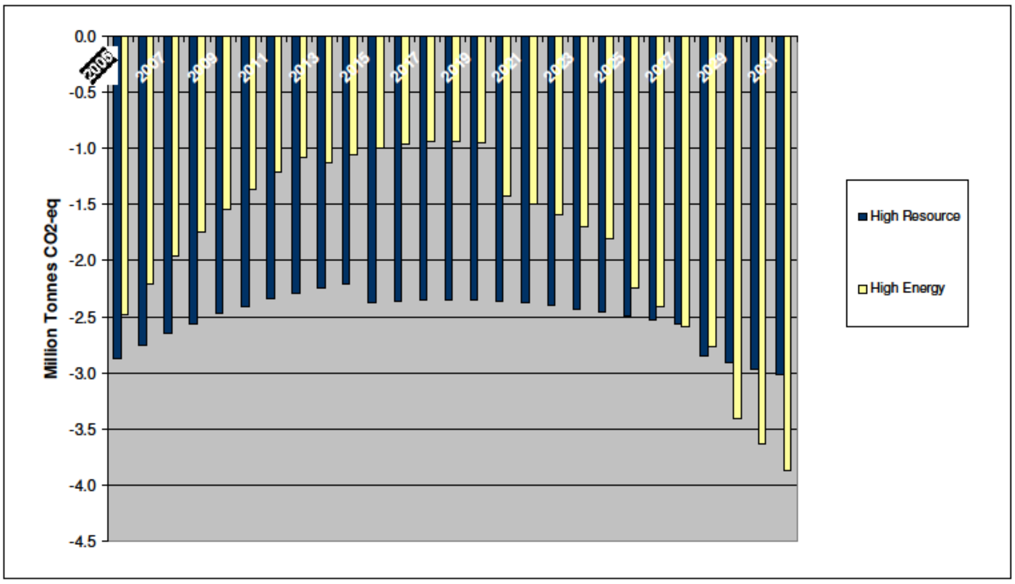
The resulting profiles are shown in *Figure 5.14, Figure 5.15* and *Figure 5.16*.

Figure 5.14 *Paper and Card Average Net Greenhouse Gas Emissions (Mt CO_2-equivalents) – Alternative Recovery Assumptions (1)*



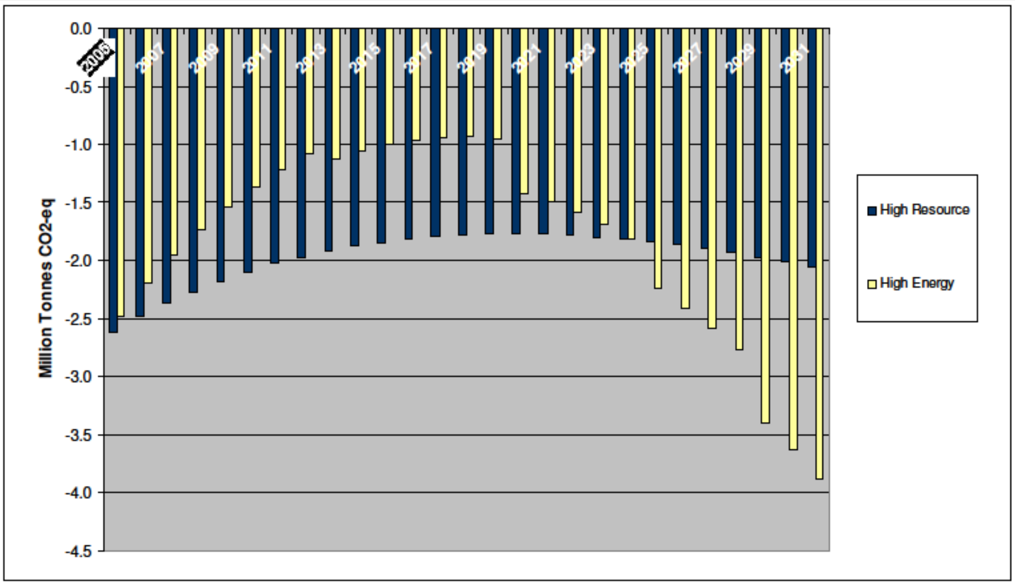
Increasing energy efficiency and decreasing recycling value

Figure 5.15 *Paper and Card Average Net Greenhouse Gas Emissions (Mt CO_2-equivalents) – Alternative Recovery Assumptions (2)*



Increasing energy efficiency and increasing recycling value

Figure 5.16 *Paper and Card Average Net Greenhouse Gas Emissions (Mt CO_2-equivalents) – Alternative Recovery Assumptions (3)*



Increasing energy efficiency and fixed recycling value

Comparing *Figure 5.14*, *Figure 5.15* and *Figure 5.16* with *Figure 5.9* shows that the results are highly sensitive to future developments in the efficiency of energy recovery technologies in particular, and the use and interpretation of estimates should be seen in that light. If we assume recovery is initially of low efficiency and increases over time, it is only in later years that energy recovery is favoured over resource recovery.

It is interesting to note that for all sensitivity scenarios, the point at which energy recovery becomes favoured over resource recovery is reached where the proportion of medium or high efficiency conversion exceeds 50% (a combined net conversion efficiency across the UK of approximately 36% (28% electricity, 8% heat)) .

Figure 5.15 further shows that, if the quality of materials recovered for recycling increases over time, energy recovery shows only very small benefit over resource recovery, and only in the very final years of assessment. It is conceivable that over this time period, the efficiency of the fossil energy generation technologies that are offset by recovering energy from wastes will also increase. In the core analyses it was assumed that electricity generation by CCGT operating at the current UK average of 46.7% would be offset. If the average efficiency of these plant was increased to 53.2% (representative of UK F Class CCGT plant), it was found that energy recovery is no longer favoured in these final years (it is still favoured over lower quality recycling routes, however).

Paper/Card Results Summary

The high resource recovery and energy recovery scenarios both confer net greenhouse gas and energy benefits over the baseline scenario and we can conclude from this that increasing the recovery of paper/card and either recycling or combusting it has significant potential for benefit over the status quo of landfill.

The balance between the two recovery routes is extremely close and is dependent predominantly on two factors – the quality of materials recovered for recycling and the efficiency at which energy recovery plant operate. Of these, energy recovery efficiency is key. If maximum efficiency CHP plant (operating at an overall efficiency of 70%) were sourced as an outlet, the greenhouse gas and energy benefits of this route dominate. Across the UK, this level of efficiency is unlikely to be achieved.

Sensitivity analyses investigated the influence of assuming a mix of energy recovery technologies, with increasing efficiency over time, as might be expected. Results showed energy recovery only to be favoured over recycling where the proportion of medium or high efficiency conversion exceeds 50% (a combined net conversion efficiency across the UK of approximately 36% (28% electricity, 8% heat)). This is clearly not currently the case across the UK and it remains to be seen whether it is achievable in the future.

Coupled with other uncertainties, such as the likely improvement in efficiency of both fossil energy generation processes (that are offset through energy recovery) and paper recycling technologies (potentially leading to decreased residue rates and/or increasing the number of times fibres can be recovered), leads us to conclude that no firm inference can be drawn as to the benefit of one recovery route over the other on the basis of this analysis.

5.3.2 *Organics*

In the context of this assessment, ‘organics’ comprise those fast-degrading biogenic materials, including kitchen and food wastes, green, garden and crop-derived waste materials, manures and slurries from agriculture and other wastes, such as sewage and other organic process sludges.

Given the similar nature and degradation properties of these materials, it is reasonable to consider that scenario results for each will show similar profiles of greenhouse gas emission and energy demand over time. As such, it is interesting to note differences between the scenarios assessed and to understand the parameters that have influenced them.

Table 5.8 presents average, and the range of, net greenhouse gas emissions for each material over the period assessed. The high energy recovery scenario performs favourably for each material, and this is discussed further below. Two distinct groupings are apparent with respect to the performance of the resource recovery (composting) scenario:

- for kitchen/food and green waste the baseline scenario results in a net greenhouse gas impact over the assessment period and resource recovery (composting) results in reduced greenhouse gas emissions; and
- for crop wastes, manure/slurry and other organics there is a net greenhouse gas benefit associated with baseline management and the resource recovery scenario (composting/stabilisation) results in increased net emissions.

Table 5.8 Organic Materials – Summary Results (Average Net Greenhouse Gas Emissions over Period)

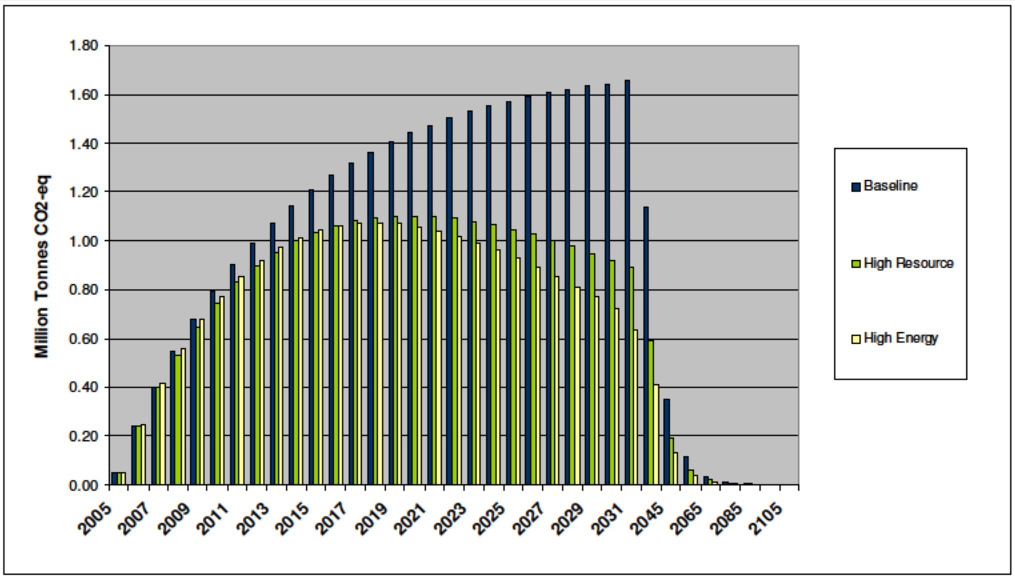
Material	**Total Waste Arisings over Period (Mt)**	**Ave Net GHG Emissions over Period (Mt CO_2-eq)**	**Ave Net GHG Emissions over Period (Mt CO_2-eq)**	**Ave Net GHG Emissions over Period (Mt CO_2-eq)**	**Ave Net GHG Emissions over Period (Mt CO_2-eq)**
		Baseline	**High Resource**	**High Energy**	**Combined**
Kitchen/ Food Waste	318	49.6 (47.0 to 52.0)	37.0 (35.6 to 38.4)	8.9 (-1.5 to 19.7)	31.0 (28.0 to 34.0)
Green Waste	286	22.9 (21.2 to 24.6)	19.0 (18.0 to 19.9)	-12.5 (-24.2 to -0.5)	n/a
Agricultural Crop Waste	177	-2.3 (-3.9 to -0.7)	0.05 (-0.9 to 1.0)	-26.6 (-40.2 to -13.0)	n/a
Manure/ Slurry	2242	-1.8 (-8.8 to 5.2)	9.6 (3.5 to 15.7)	-113.0 (-166.3 to -59.6)	n/a
Other Organics (eg sewage sludge)	108	-1.2 (-3.6 to 1.2)	1.8 (0.5 to 3.1)	-15.2 (-24.5 to -5.9)	-6.7

Note: estimates include emissions from landfill over the 100 year period

It seems counter-intuitive that a scenario with elevated levels of resource recovery should perform less well than current management systems. However, these findings are directly dependent on assumptions relating to baseline material management.

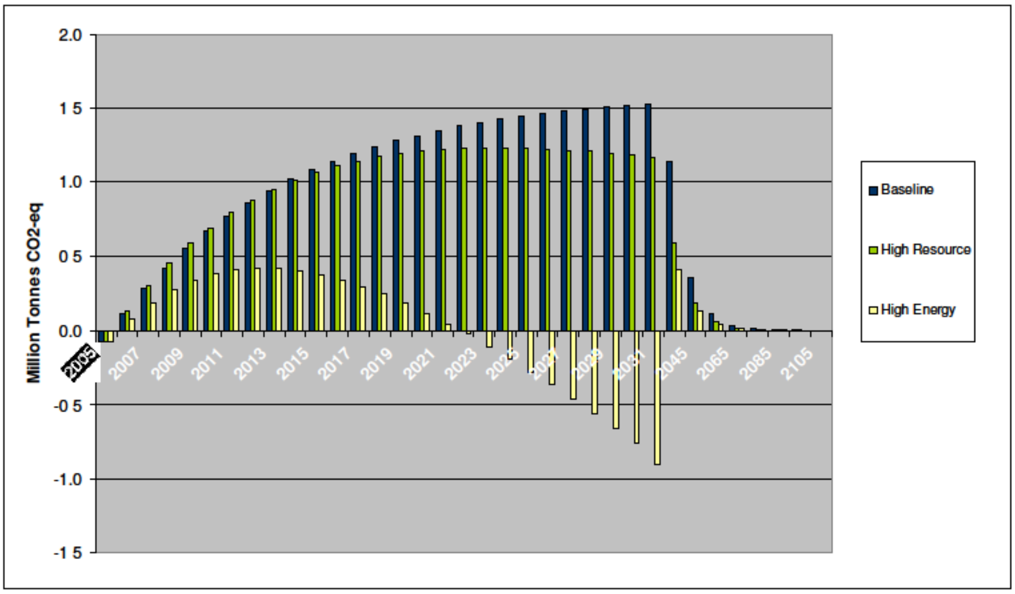
Where the baseline management system is predominantly landfill (kitchen/food and green wastes), any change in management to divert wastes from landfill results in reduced greenhouse gas emissions. To illustrate the impact of landfill on overall estimates further, *Figure 5.17* and *Figure 5.18* show the greenhouse gas emissions associated with landfilled kitchen/food waste and the resultant net greenhouse gas emissions for the baseline and resource recovery scenarios.

Figure 5.17 *Residual Kitchen Waste to Landfill - Greenhouse Gas Emissions (Mt CO_2-equivalents)*



Baseline = business as usual. High resource = moving from 7% composting in 2005 to 75% in 2031. High energy = moving from 14% energy recovery (AD and thermal) in 2005 to approx 90% anaerobic digestion in 2031.

Figure 5.18 *Kitchen Waste - Average Net Greenhouse Gas Emissions (Mt CO_2-equivalents)*

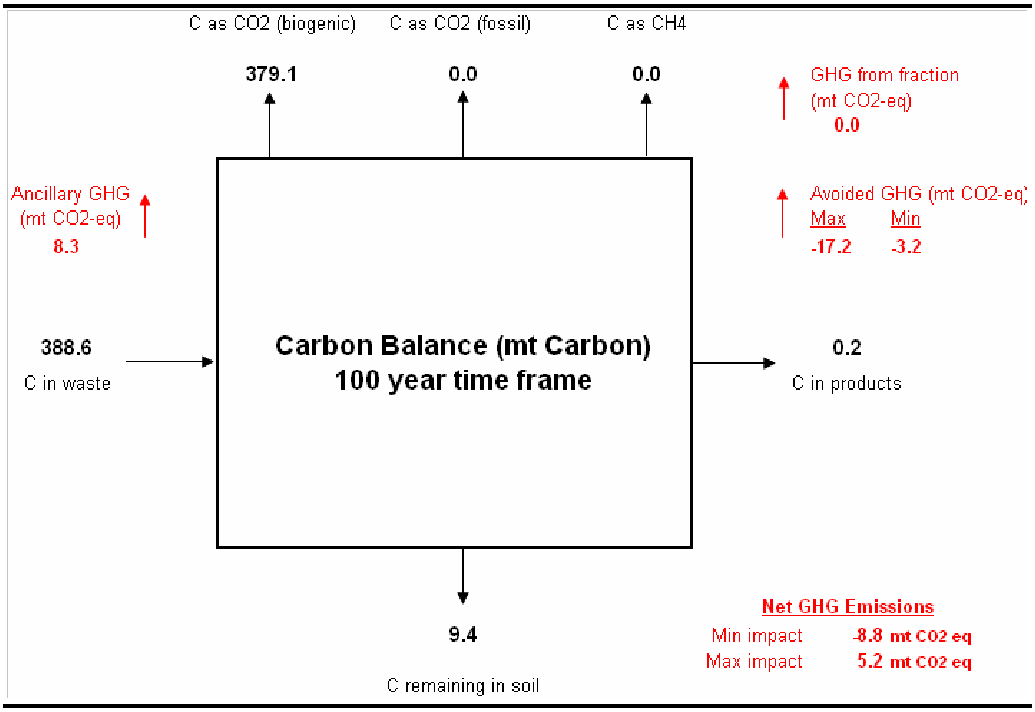


- Baseline = business as usual. High resource = moving from 7% composting in 2005 to 75% in 2031. High energy = moving from 14% energy recovery (AD and thermal) in 2005 to approx 90% anaerobic digestion in 2031.
- Estimates include committed emissions from the landfill of waste over the period 2005-2031

Where the baseline management system relies heavily on the landspread of waste materials (agricultural crop wastes, manures and slurries and other organic wastes such as sewage sludge), a shift towards composting results in a net increase in greenhouse gas emissions.

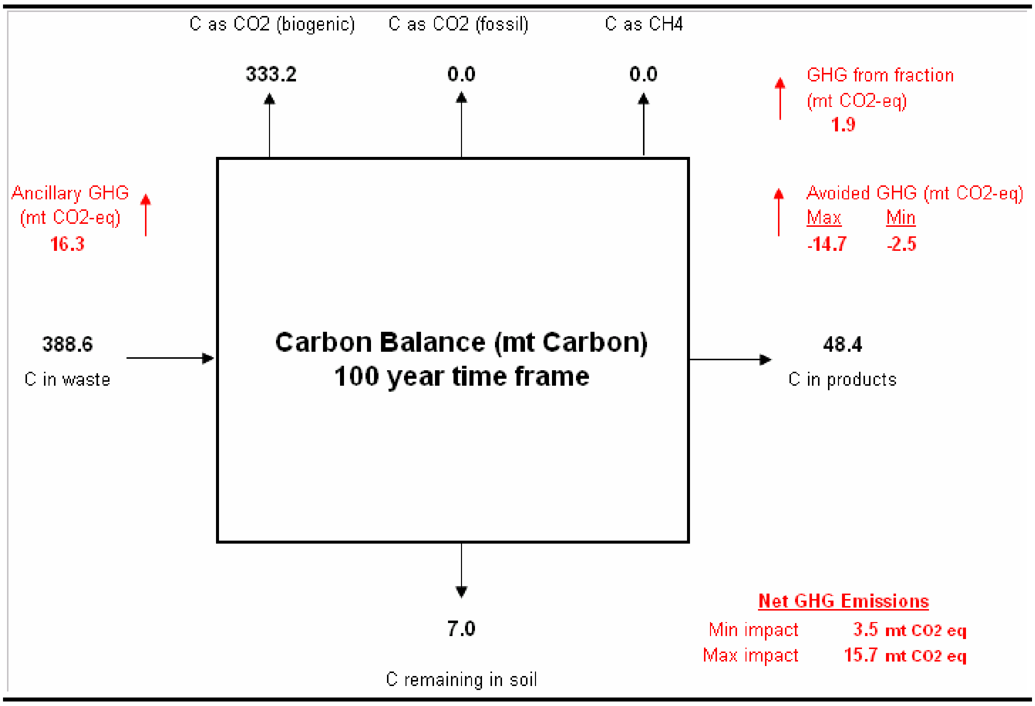
To understand the reason behind this, it is useful to look at carbon and greenhouse balances for the alternative scenarios. As an example, balances for the baseline and high resource-focused management of manure/slurry are presented in *Figure 5.19* and *Figure 5.20*.

Figure 5.19 Manure/Slurry – Baseline Scenario



Baseline = business as usual (predominantly landspread)

Figure 5.20 Manure/Slurry – High Resource Recovery Scenario



High resource recovery = moving from predominantly landspread in 2005 to 50% composting, 50% landspread in 2031

These balances highlight key differences with respect to greenhouse gas impacts/benefit estimates:

- landspreading (baseline management) confers lower ancillary process impacts associated with fuel/electricity consumption (zero transport is assumed for both);
- modelling assumed negligible methane and other greenhouse gas emissions associated with landspread wastes, whereas there are known releases associated with composting. These have some impact, but are not significant; and
- modelling assumed an equivalent fertiliser benefit for both landspread and composted organic wastes. However, loss of mass during composting reduces both the quantity of compost product and resulting benefit.

In this case, the impacts associated with the fuel and energy requirements of composting have the greatest influence on results. It is reasonable to conclude that passing waste through such a process confers greater impact than directly spreading the waste onto land. However, what can not be determined with any degree of certainty is the relative benefit that can be awarded to raw waste materials in comparison with a stabilised compost product. We have assumed an equal benefit for each, on a mass for mass basis, as very little data or information exist to enable us to explore this further. However, in practice the balance of greenhouse gas potential may swing either way and this is an area in which further research would aid interpretation considerably.

Regardless of these uncertainties, it was unequivocally found that energy recovery from separated organic materials, be it through anaerobic digestion of materials with high moisture content and low calorific value (kitchen/food waste, green waste, manure/slurry), or combustion of wastes with higher calorific value (crop wastes, dried sewage sludge), resulted in net greenhouse gas and energy benefit. This was found even where minimum energy recovery efficiencies (30% recovery of electricity only) and maximum resource recovery benefits (high quality compost production) were assumed, and where composting processes were maximised to increase the rate of compost production and reduce residues to landfill.

An area of sensitivity is with regard to the quantity of methane that is emitted from degrading wastes and would be available for recovery. We have based this calculation on the quantity of carbon lost from waste materials on degradation (see *Annex B* for further information). No comprehensive data are available regarding this loss and so it was assumed to be set at 50% across all materials. This is likely to representative, or even conservative, for faster degrading materials, such as kitchen waste, or manures/slurries, but may not be so for slower degrading materials, such as green waste, or mixed organic wastes. Sensitivity analyses show that if carbon loss were instead in the region of 20%, the net greenhouse gas benefit seen for the green waste high energy recovery scenario (*Table 5.8*) becomes a net impact. The scenario still performs favourably in comparison with current management and increased composting (both maximum and minimum estimates), however.

A further area of methodological sensitivity with regard to the comparison of biological and thermal processing routes for biogenic materials is the issue of whether, and how, to count residual carbon which remains fixed, or sequestered, in landfilled, composted or landspread materials. Carbon sequestration in landfills, for example, is not currently included in the IPCC methodology for estimating land and carbon sinks. Fawcett *et al*, in their work for Carbon UK (1) further conclude that more work is needed on the legitimacy of counting undegraded wastes as a carbon store.

Sensitivity analysis was used to infer what the implications for results might be should we allocate a 'sequestration benefit' to biogenic carbon that does not degrade, but is stored in landfill, or another soil sink. Quantities of biogenic carbon remaining stored in landfill after 100 years were calculated in GasSim (see *Annex B* for calculation assumptions) and are shown in the carbon balances presented in *Annex C*. We further assumed that 2% of the carbon in composted and landspread wastes would remain in soil on application over this period (2). An additional benefit of 3.6 (44/12) tonnes of CO_2 per tonne of carbon was given to this 'sequestered' biogenic carbon.

The resulting average net greenhouse gas emissions for kitchen and food waste scenarios are shown in *Figure 5.21*. Comparing these with the estimates presented in *Figure 5.18* shows the difference between resource and energy recovery scenarios now to be less wide, but with energy recovery still favoured. The baseline scenario now performs comparatively much better, as a result of landfill being given an additional carbon sequestration benefit.

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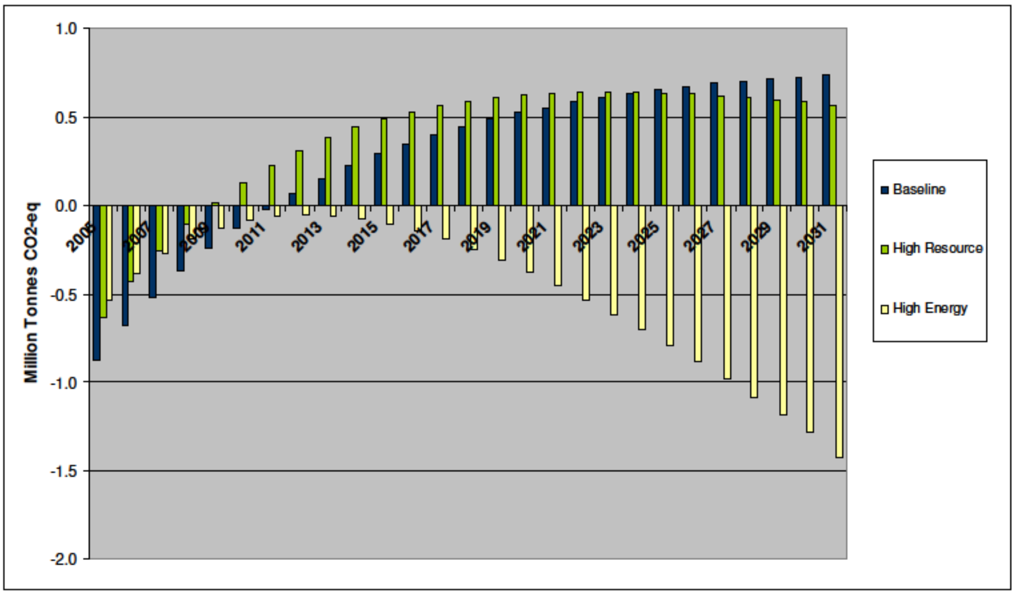
(1) Fawcett T, Hurst A and Boardman B (2002). *Carbon UK*. Environmental Change Institute, University of Oxford. ISBN 1 874370 1.

(2) Smith *et al* (2001). *Waste Management Options and Climate Change.* Final Report to DGENV. AEA Technology.

Figure 5.21 *Kitchen/Food Waste plus Sequestration Benefit - Average Net Greenhouse Gas Emissions (Mt CO_2-equivalents)*

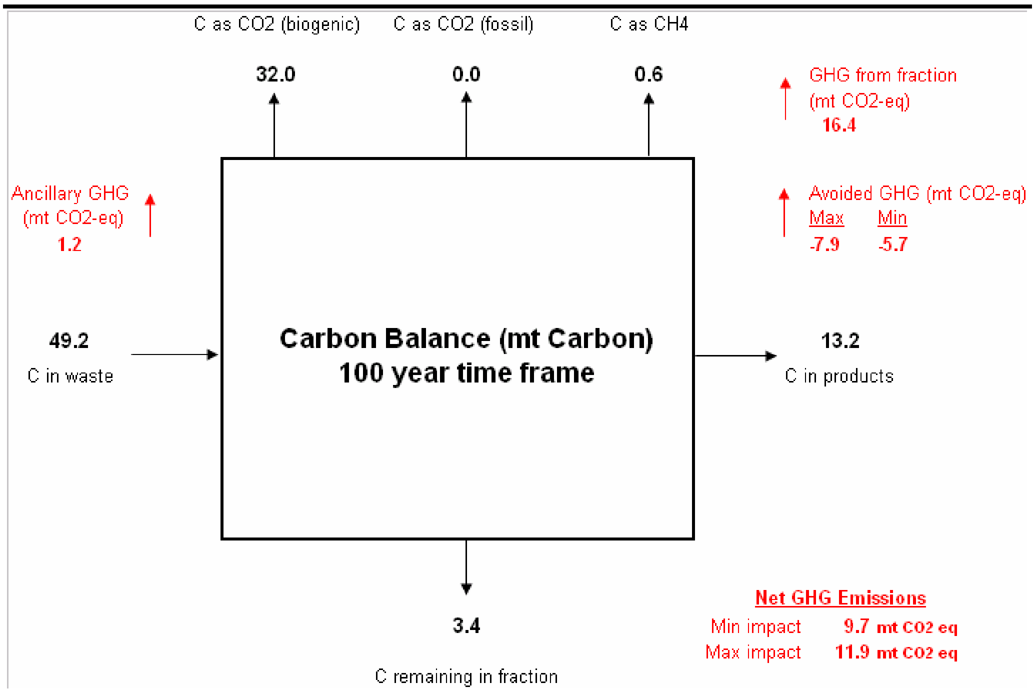


Baseline = business as usual. High resource = moving from 7% composting in 2005 to 75% in 2031. High energy = moving from 14% energy recovery (AD and thermal) in 2005 to approx 90% anaerobic digestion in 2031.

Another sensitivity analysis exercise was carried out to investigate the implications of home composting green wastes, as an example, as opposed to composting within a local, or regionally-coordinated facility. This was simulated by discounting all transport and processing impacts associated with composted materials.

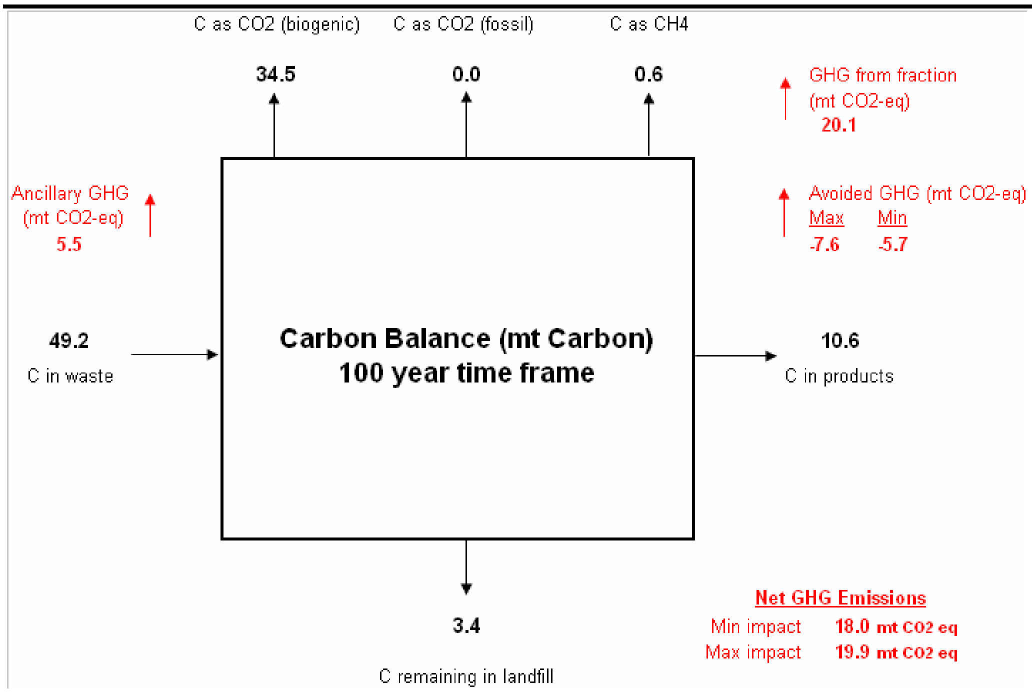
Resulting carbon and greenhouse gas balances are shown in *Figure 5.22* and, in comparison with *Figure 5.23*, show home composting to result in lower net greenhouse gas emissions, to the order of approximately 50%. This is achieved through reduced tonnages of sorting and process residues being sent to landfill (avoiding 3.7 Mt CO_2-eq through reduced methane emissions), reduced emissions from fuel consumption at sorting and composting facilities (2.3 Mt CO_2-eq) and reduced transport emissions (2.0 Mt CO_2-eq).

Figure 5.22 Green Waste – High Resource Recovery through Home Composting



High resource recovery = moving from 16% composting in 2005 to 90% in 2031

Figure 5.23 Green Waste – High Resource Recovery with Wastes to Composting to Facilities



High resource recovery = moving from 16% composting in 2005 to 90% in 2031

Organics Results Summary

Results show energy recovery from separated organic materials, be it through anaerobic digestion of materials with high moisture content and low calorific value (kitchen/food waste, green waste, manure/slurry), or combustion of wastes with higher calorific value (crop wastes, dried sewage sludge), to convey a greenhouse gas and energy benefit in comparison with either baseline management routes (predominantly landfill or landspread), or composting.

This was found even where minimum energy recovery efficiencies (30% recovery of electricity only) and maximum resource recovery benefits (high quality compost production) were assumed. It also held where key assumptions and modelling sensitivities were investigated to take account of: the potential sequestration benefits of composting and landfill; the potential for improvement in composting processes to reduce residue rates and increase compost product; the potential for improvements in the efficiency of (offset) fossil energy generation; the potential for reduced carbon loss, and thus reduced energy recovery, resulting from digestion of less well degrading materials; and alternative assumptions regarding the quantity of compost product resulting from anaerobic digestion processes.

Comparative results for the baseline and high resource recovery scenarios are less clear cut. In general it was found that, where the baseline management system is predominantly landfill (kitchen/food and green wastes), any change in management to divert wastes from landfill results in reduced greenhouse gas emissions.

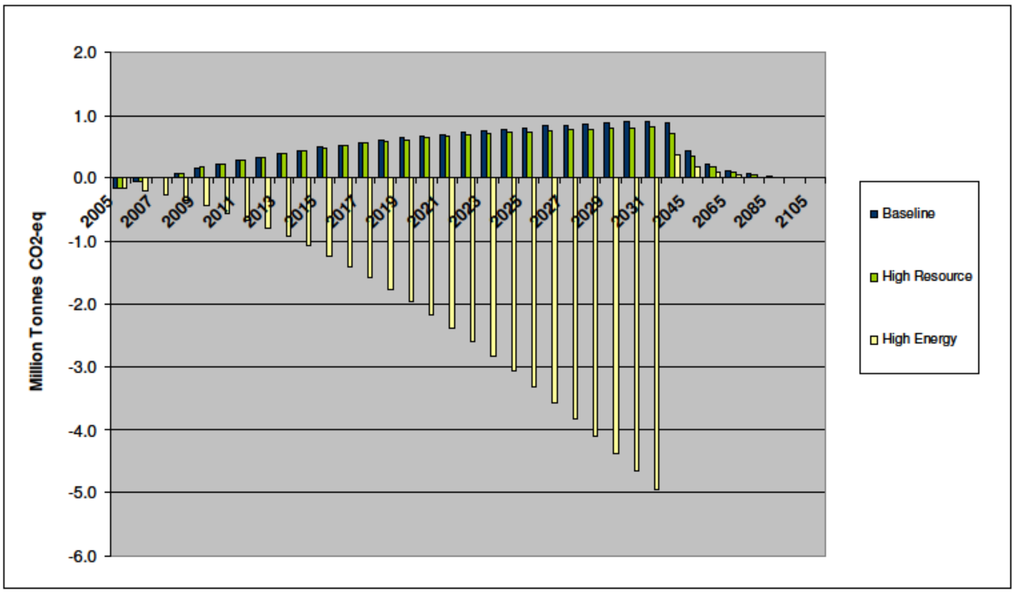
In comparison, where the baseline management system relies heavily on the landspread of waste materials (agricultural crop wastes, manures and slurries and other organic wastes such as sewage sludge), a shift towards composting resulted in a net increase in greenhouse gas emissions. However, uncertainties exist with regard to the balance of direct emissions and avoided burdens for these materials and recovery routes, and further work is required to reliably make comparisons.

Composting performs relatively poorly in carbon and energy terms as the use of compost products displaces alternatives which tend themselves to be organically-derived (with the exception of inorganic chemicals fertilisers) and are therefore not energy or carbon intensive to produce in the first place. The use of compost is likely to convey additional benefits, for example in terms of soil structure, fertility or the maintenance of carbon sinks, but these factors are difficult to quantify in carbon terms and it was not within the scope of this work to do so (further than the crude sensitivity analysis applied). An additional piece of research has been commissioned by Defra to investigate this further.

5.3.3 Wood

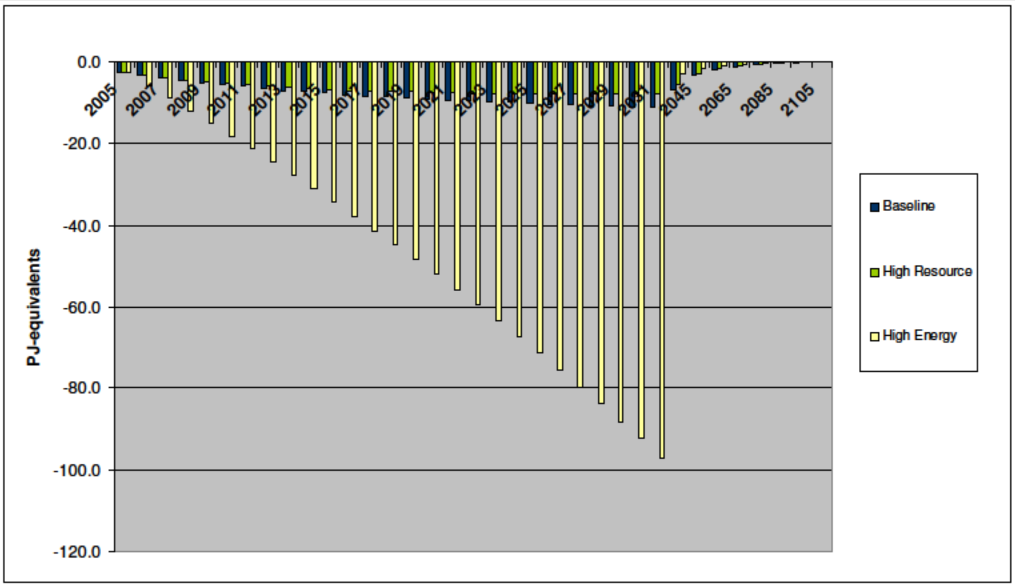
Average net greenhouse gas emissions and energy demand for the baseline, high resource recovery (recycling) and energy recovery scenarios for waste wood arisings are presented in *Figure 5.24* and *Figure 5.25* (1).

Figure 5.24 *Wood - Average Net Greenhouse Gas Emissions (Mt CO_2-equivalents)*



- Baseline = business as usual. High resource = moving from 16% recycling in 2005 to 50% in 2031. High energy = moving from 4% thermal treatment in 2005 to 90% in 2031

Figure 5.25 *Wood - Average Net Energy Demand (PJ-equivalents)*



- Baseline = business as usual. High resource = moving from 16% recycling in 2005 to 50% in 2031. High energy = moving from 4% thermal treatment in 2005 to 90% in 2031

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(1) Results for the combined scenario are intermediate in profile and so, in an attempt to aid clarity, have not been presented. Results for this scenario can be found in full in *Annexes* C and D.

As a material resource, wood has a relatively low embodied energy (2 MJ fossil energy/kg (1), its extraction having a relatively low requirement for fossil fuels, energy or other materials. As such, it is not surprising that the recovery and use of the inherent calorific value in the material confers a greater greenhouse gas and fossil energy benefit than passing the waste material through a recycling process and avoiding the extraction of wood from alternative sources (this is true even where minimum energy recovery efficiencies and maximum recycling benefits were assumed).

However, it is interesting to note that results show, on average, an overall greenhouse gas impact associated with landfilling or recycling wood waste, but an overall fossil energy demand benefit. This stems from the energy benefit attributed to the capture and recovery of energy from landfill gas. As such, it is likely that the scale of this benefit will be proportional to the rate of gas recovery assumed. Indeed, results for all materials have been shown to be sensitive to this parameter.

Carbon and greenhouse gas balances for the high resource and energy recovery scenarios are presented in *Figure 5.26* and *Figure 5.27*, showing the fate of carbon and the scale of potential impact and benefit. Differences for the alternative scenarios arise predominantly due to the structure of the scenarios and what was considered 'theoretically achievable' for alternative recovery routes. The high energy recovery scenario was assumed to achieve 90% diversion from landfill by 2031, whereas only a 50% maximum recycling rate was considered achievable. As such, less carbon ends up in landfill for the former and less is emitted as methane. However, high biogenic CO_2 emissions are evident as the majority of carbon is lost on combustion.

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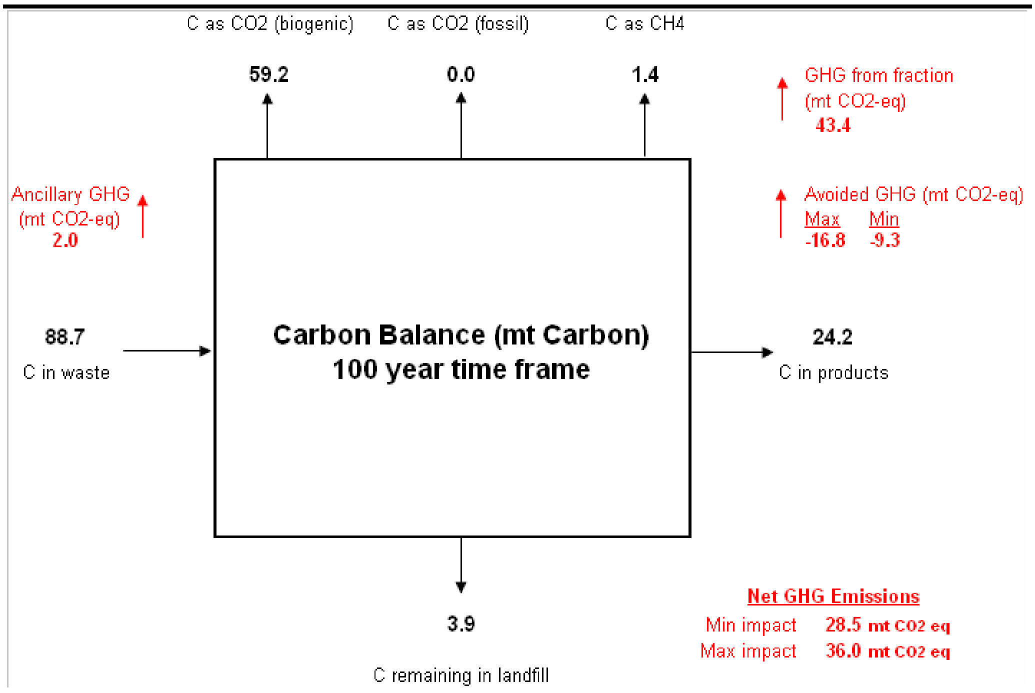
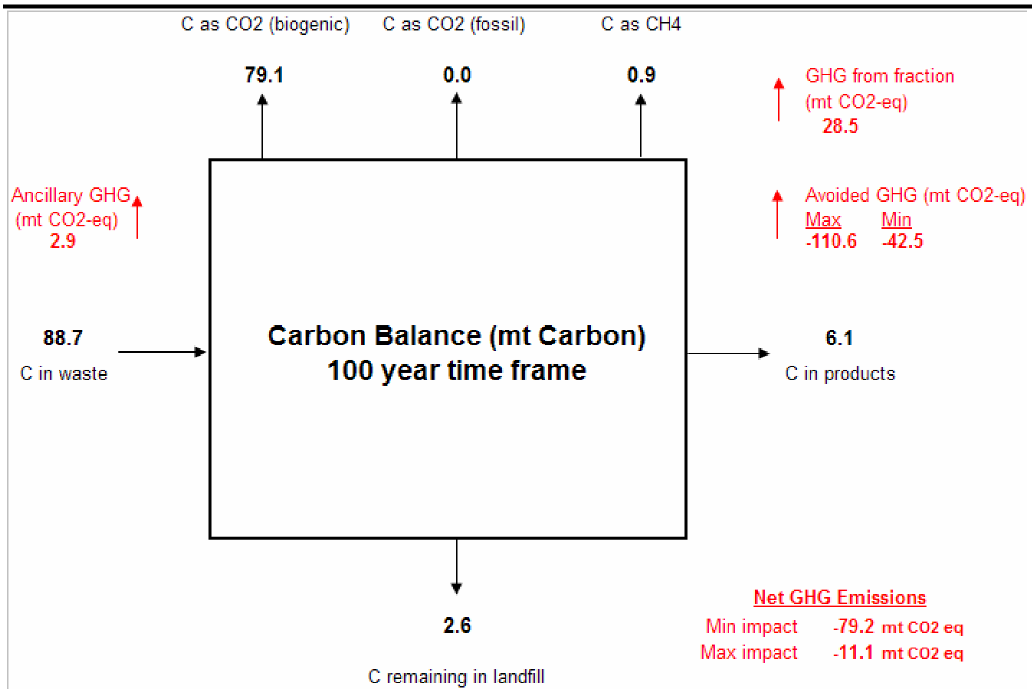
(1) Average for kiln dried rough sawn timber, from [redacted]

Figure 5.26 *Wood - Carbon and Greenhouse Gas Balance over Period (High Resource Recovery)*



High resource recovery = moving from 16% recycling in 2005 to 50% in 2031.

Figure 5.27 *Wood - Carbon and Greenhouse Gas Balance over Period (High Energy Recovery)*



High energy recovery = moving from 4% thermal treatment in 2005 to 90% in 2031.

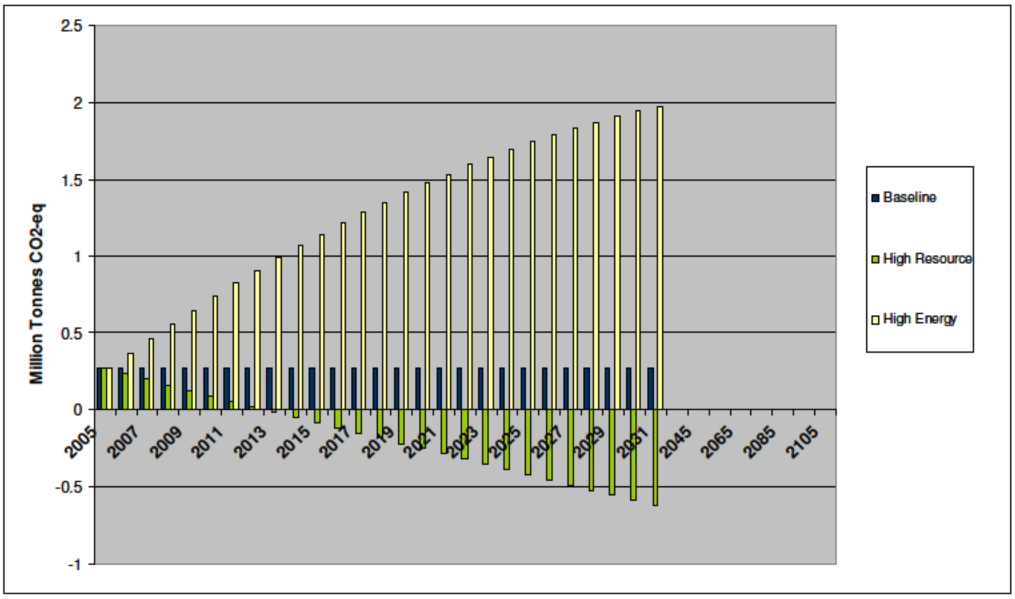
5.3.4 *Plastics*

Scenarios for the management of waste plastics present an altogether different picture to those for organic materials. *Figure 5.28* and *Figure 5.29* show the profile of average net greenhouse gas emissions over time for dense and film plastic wastes. These highlight the greenhouse gas implications of burning plastics and releasing fossil carbon into the atmosphere. This release of carbon is greater than the carbon savings achieved through energy recovery, and an overall impact associated with thermal treatment is seen.

Note that emissions and net energy demand cease in 2031, as it was assumed that these materials do not degrade on disposal in/on land and there is no associated impact (or benefit) of residual materials in landfill.

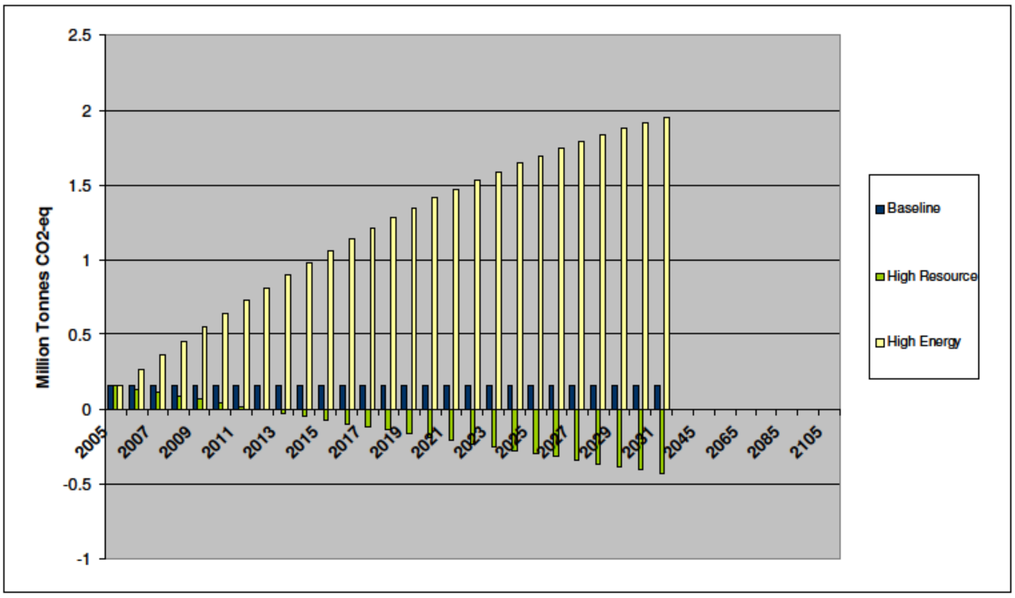
Note also that the story with respect to energy demand is somewhat different, as the benefits of recovering energy are seen, but with no associated burden. *Figure 5.30* shows net energy demand estimates for alternative scenarios for dense plastic waste management. It is useful to note this wide disparity between the results for greenhouse gas emission and energy demand, as it highlights the risks of making conclusions with regard to environmental impact on the basis of one indicator only. It is further useful in reminding us that this assessment is of climate change and energy impacts only, it does not assess other categories of environmental impact, such as toxicity, or eutrophication – and, as such, does not attempt to present the complete story.

Figure 5.28 ***Dense Plastic - Average Net Greenhouse Gas Emissions (Mt CO_2-equivalents)***



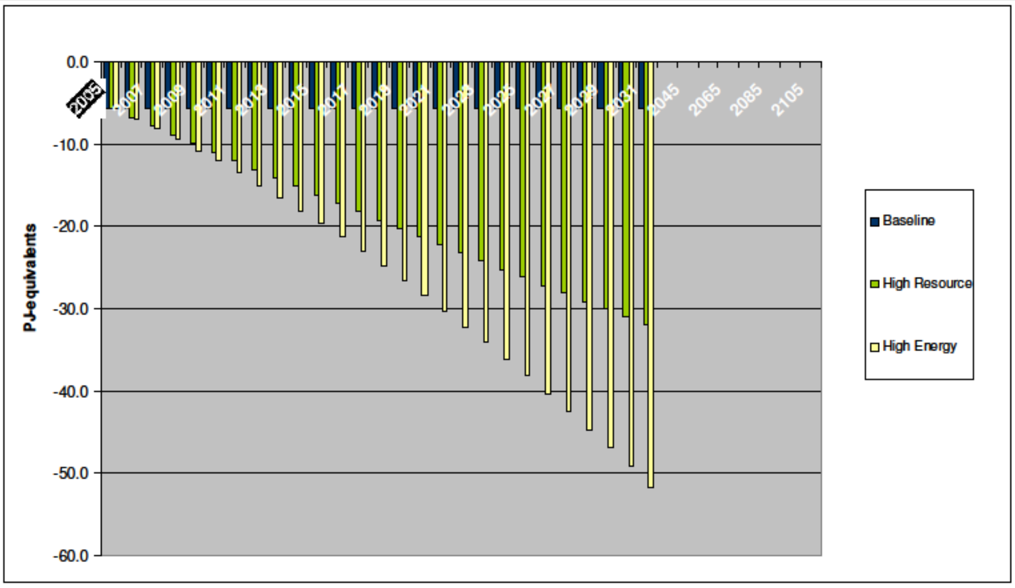
Baseline = business as usual. High resource = moving from 4% recycling in 2005 to 60% in 2031. High energy = moving from 9% thermal treatment in 2005 to 90% in 2031

Figure 5.29 *Plastic Film - Average Net Greenhouse Gas Emissions (Mt CO_2-equivalents)*



Baseline = business as usual. High resource = moving from 9% recycling in 2005 to 60% in 2031. High energy = moving from 7% thermal treatment in 2005 to 90% in 2031

Figure 5.30 *Dense Plastic- Average Net Energy Demand (PJ-equivalents)*



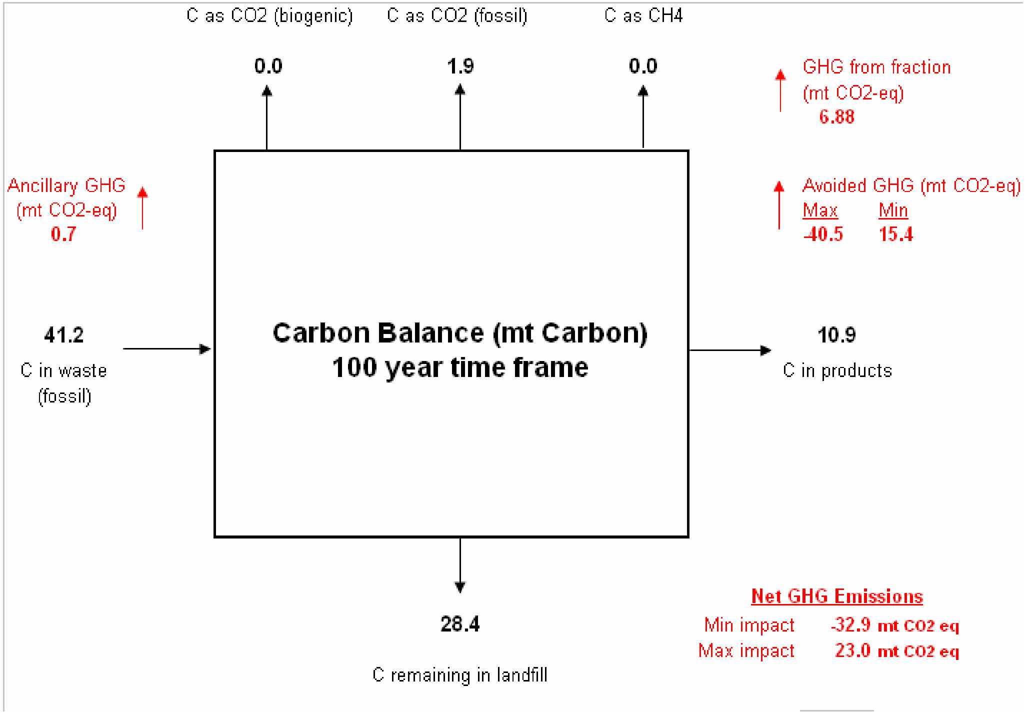
Baseline = business as usual. High resource = moving from 4% recycling in 2005 to 60% in 2031. High energy = moving from 9% thermal treatment in 2005 to 90% in 2031

Both *Figure 5.28* and *Figure 5.29* show a greenhouse gas impact associated with baseline of waste plastics management. This is incurred predominantly as a result of current levels of plastics combustion (mainly in mixed municipal waste). Processing and transport requirements were less significant.

Figure 5.28 and *Figure 5.29* also show that high resource recovery profiles for plastic materials both have a 'crossover point' at around 2012, whereby the benefits associated with recycling outweigh those associated with processing. This coincides with an approximate 20% recycling rate. However, it should be noted this is true for 'average' recycling benefits only. If all recovered materials were used to displace virgin plastic production, a net benefit would be seen across all years. Conversely, if a lower value material was displaced, a net impact would be seen in each year (this is further demonstrated in the results tables presented in *Annex D*).

The balance diagram in *Figure 5.31* also shows that the scale of avoided greenhouse gas emissions associated with plastics recycling varies widely with the assumptions regarding the routes via which they may be processed. If plastics are recycled via the assumed low-value route, to produce lumber, it was found that reprocessing requirements were greater than the avoided burdens of wood production, and recycling shows a net greenhouse gas impact. In comparison, the recovery of materials that can be reprocessed to avoid virgin material (the 'high value' route), as expected, conveys considerable net greenhouse gas savings.

Figure 5.31 Dense Plastic - Carbon and Greenhouse Gas Balance over Period (High Resource Recovery)



High resource recovery = moving from 4% recycling in 2005 to 60% in 2031.

Given the influence of these assumptions on results, a sensitivity analysis was carried out. Of interest was to demonstrate how a change in the quality/reprocessing potential of recovered materials had influence on net greenhouse gas estimates. More importantly – where does the balance between impact and benefit lie?

We saw that for the 'average' benefit the crossover point, at which net benefit was achieved, was reached at 20% recycling. *Figure 5.32* shows the results of the sensitivity analysis. As the proportion of high value recycling, assumed to be synonymous with high quality materials recovery to displace virgin production, decreases, a much higher recycling rate must be achieved to result in net greenhouse gas benefit (1).

Figure 5.32 *Dense Plastic Sensitivity Analysis*

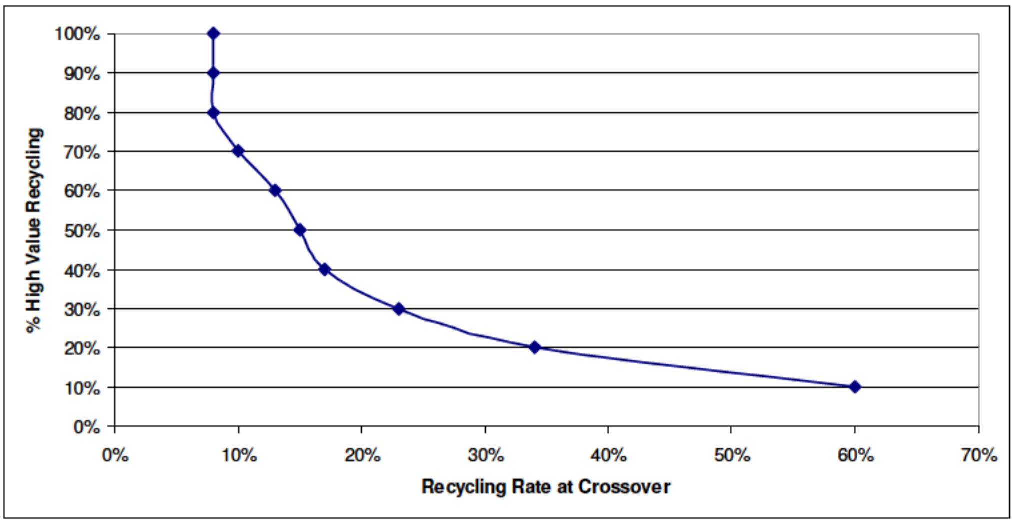


Figure 5.31 shows the ancillary (fuel, energy, transport) impacts associated with dense plastic management to be of relatively lower significance. We can conclude from this, and confirm through sensitivity analysis, that results are not sensitive to assumptions regarding these parameters. Similarly, sensitivity analyses looked at assumptions regarding processing residues during recycling and this was not found significantly to influence the results. Assuming that no primary sorting of residues during recycling reduced the average impacts over the assessment period to -5.8 Mt CO_2-eq, in comparison with the -4.9 Mt CO_2-eq average inferred from *Figure 5.31*.

Plastics Results Summary

Scenarios for the management of waste plastics show a net greenhouse gas impact associated with burning plastics and releasing fossil carbon into the atmosphere. This release of carbon is greater than the carbon savings achieved through energy recovery.

In comparison, plastics recycling shows significant potential for both greenhouse gas and energy savings. The scale of these potential savings varies widely with assumptions regarding the routes via which they may be processed. Sensitivity analyses showed that, as the proportion of high value recycling, assumed to be synonymous with high quality materials recovery to

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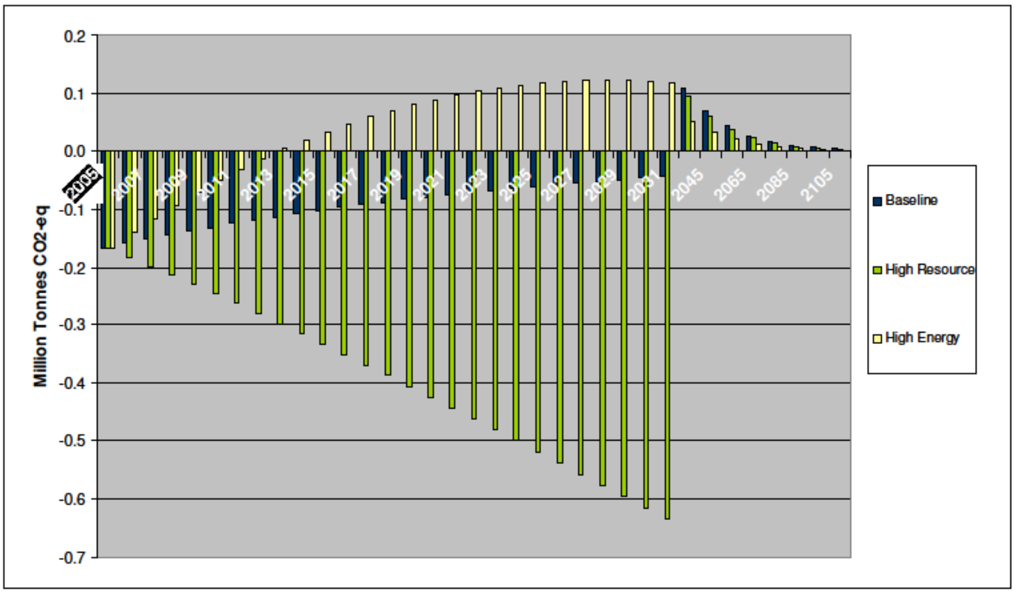
(1) This assumes that the remainder of materials will either be processed via a low value, or intermediate route

displace virgin production, decreases, a much higher recycling rate must be achieved to result in net greenhouse gas benefit (*Figure 5.32*).

5.3.5 *Textiles*

Textiles show an interesting profile in terms of net greenhouse gas emissions, as the waste stream is assumed to comprise 50% synthetic material and 50% natural fibres. A time series of average net greenhouse gas emissions is shown in *Figure 5.33*. The high resource recovery scenario performs well in terms of both greenhouse gas emissions and energy demand. Of note is the curve evident for greenhouse gas emissions from the high energy recovery route. As recycling, and associated benefits, decrease over time for this scenario, combustion of the waste material and its release of fossil CO_2 increases.

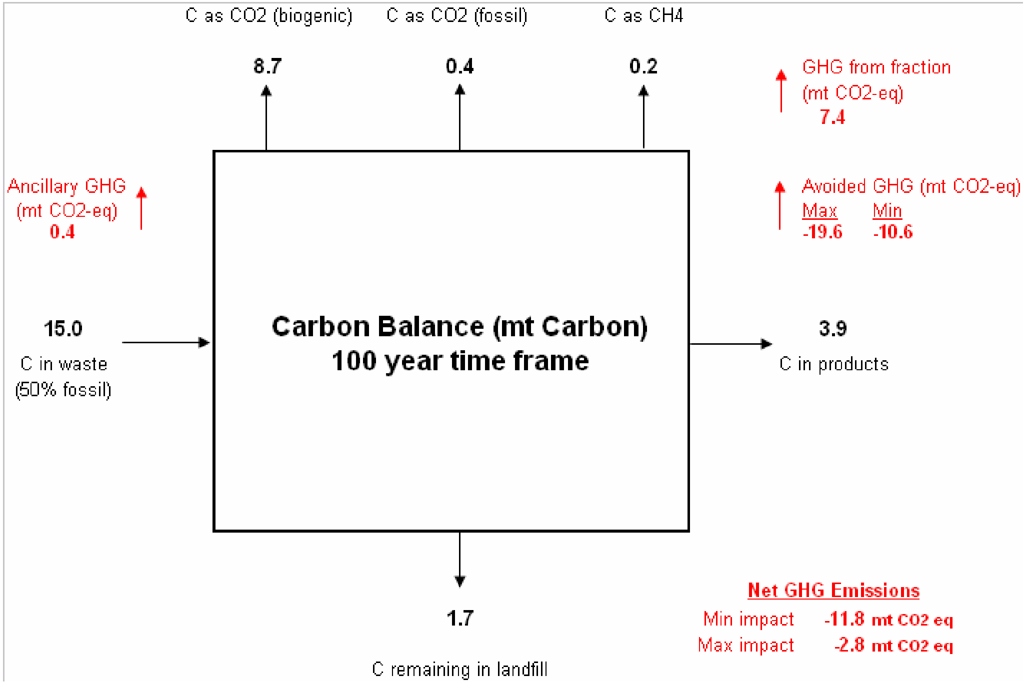
Figure 5.33 Textiles - Average Net Greenhouse Gas Emissions (Mt CO_2-equivalents)



- Baseline = business as usual. High resource = moving from 13% recycling in 2005 to 50% in 2031. High energy = moving from 11% thermal treatment in 2005 to 90% in 2031
- Estimates include committed emissions from the landfill of waste over the period 2005-2031

Figure 5.33 shows resource recovery to be favoured over energy recovery for textiles waste management scenarios. However, *Figure 5.34* shows that the overall scale of the climate change benefit potentially achievable under the resource recovery scenario varies widely with assumptions regarding the routes via which they are reprocessed and the alternative materials avoided. As with the recycling of waste plastics, there is a significant net benefit achieved through the high value reprocessing route (low intensity sorting to avoid primary cloth production), due to the high resource requirements of primary material production (polyester and cotton). The low value recycling route is to reprocess into rag/packing materials and offset low grade paper materials. Under this assumption, net greenhouse gas savings are much lower.

Figure 5.34 *Textiles - Carbon and Greenhouse Gas Balance over Period (High Resource Recovery)*



High resource recovery = moving from 13% recycling in 2005 to 50% in 2031.

5.3.6 *Metals*

As might be expected, the recycling of ferrous and non-ferrous metals conveys significant net greenhouse gas and energy benefits. These benefits increase steadily as recycling rates increase and a summary of the scale of potential benefit accumulated over the assessment period is shown in *Table 5.9* and *Table 5.10*.

However, note that a considerable quantity of metal recycling is carried out in the UK already, such that additional benefits over and above the baseline average at 8.9 Mt CO_2-equivalents (ferrous) and 44 Mt CO_2-equivalents (non-ferrous) over the period assessed.

Table 5.9 *Metals – Summary Results (Net Greenhouse Gas Emissions over Period)*

Material	**Max Net GHG Emissions over Period (Mt CO_2-eq) - Baseline**	**Min Net GHG Emissions over Period (Mt CO_2-eq) - Baseline**	**Max Net GHG Emissions over Period (Mt CO_2-eq) – High Recycling**	**Min Net GHG Emissions over Period (Mt CO_2-eq) – High Recycling**
Ferrous Metals	-33.5	-48.6	-40.7	-59.0
Non-ferrous Metals	-423.8	-451.4	-466.7	-497.2

Baseline = business as usual. High recycling = moving from 59% (ferrous)/ 74% (non-ferrous) recycling in 2005 to 95% recycling in 2031

Table 5.10 Metals – Summary Results (Net Fossil Energy Demand over Period)

Material	Max Net Energy Demand over Period (PJ-eq) - Baseline	Min Net Energy Demand over Period (PJ-eq) - Baseline	Max Net Energy Demand over Period (PJ-eq) – High Recycling	Min Net Energy Demand over Period (PJ eq) – High Recycling
Ferrous Metals	-51.2	-450.7	-63.8	-547.9
Non-ferrous Metals	-4545.3	-4924.9	-5006.1	-5424.2

Baseline = business as usual. High recycling = moving from 59% (ferrous)/ 74% (non-ferrous) recycling in 2005 to 95% recycling in 2031

The ranges presented are relatively large for ferrous metals as recycling routes (via electric arc furnace or blast oxygen furnace) have differing resource requirements and resulting net avoided burdens. However, there is less variation in the processing and production of secondary aluminium.

The scale of potential benefit presented in *Table 5.9* and *Table 5.10* has been quantified on the assumption that materials are transported a maximum of 100 km to reprocessing. As transport distances increase, the benefits potentially achieved decrease accordingly. Breakpoint is reached at approximately 5000 km for ferrous metals and closer to 100,000 km for non-ferrous metals. If materials must be transported in excess of this to be reprocessed, the greenhouse gas impacts of transport are approximately equivalent to avoided impacts through recycling (assuming an average avoided burden) and no overall benefit is seen. Clearly, these transport distances are high and so it can reasonably be considered that metals recycling offers significant potential for climate change benefit under all logistical scenarios.

5.3.7 Soil and Mineral Materials

Results for waste soil and mineral materials show relatively little difference between the baseline and high resource recovery (recycling) scenarios. Under the assumptions modelled, both the current management of soil and minerals and their increased recycling convey a net greenhouse gas and energy impact. A summary of the scale of potential impact over the assessment period is shown in *Table 5.11* and *Table 5.12*.

Table 5.11 Soil/Minerals – Summary Results (Net Greenhouse Gas Emissions over Period)

Material	Max Net GHG Emissions over Period (Mt CO_2-eq) - Baseline	Min Net GHG Emissions over Period (Mt CO_2-eq) - Baseline	Max Net GHG Emissions over Period (Mt CO_2-eq) – High Recycling	Min Net GHG Emissions over Period (Mt CO_2-eq) – High Recycling
Soil	17.5	17.4	20.6	18.2
Minerals	27.6	22.3	27.8	22.4

Baseline = business as usual. High recycling = moving from 2% (soils)/ 85% (minerals) recycling in 2005 to 95% recycling in 2031

Table 5.12 Soil/Minerals – Summary Results (Net Fossil Energy Demand over Period)

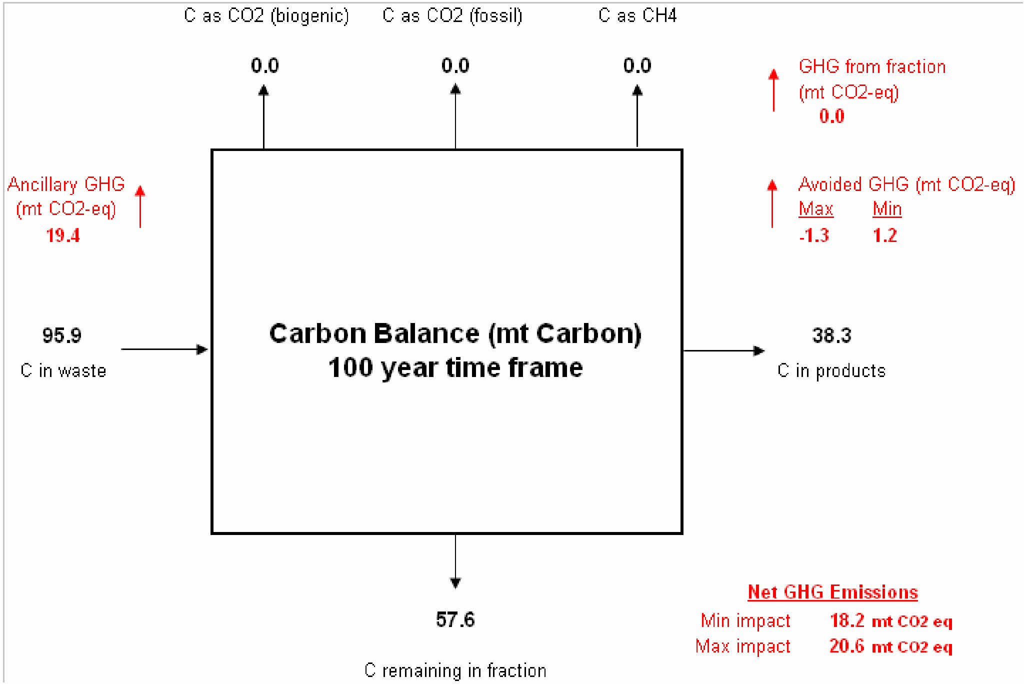
Material	Max Net Energy Demand over Period (PJ-eq) - Baseline	Min Net Energy Demand over Period (PJ-eq) - Baseline	Max Net Energy Demand over Period (PJ-eq) – High Recycling	Min Net Energy Demand over Period (PJ eq) – High Recycling
Soil	252.5	251.2	298.1	266.3
Minerals	396.5	325.7	401.7	330.1

Baseline = business as usual. High recycling = moving from 2% (soils)/ 85% (minerals) recycling in 2005 to 95% recycling in 2031

The balance of greenhouse gas impacts and benefits is somewhat different for minerals and soil in comparison with other waste materials discussed. The low embodied energy, and therefore reduced potential for avoided greenhouse gas or energy burden, but very high volume of these waste materials is such that parameters like transport, fuel and energy demands of processing are of much greater significance.

The balance diagrams presented in *Figure 5.35* and *Figure 5.36* show that the majority of net greenhouse gas impacts are incurred as a result of the ancillary burdens of sorting and transport (1). These are greater than those burdens avoided in the mining of virgin aggregate, or fill materials (assumed to be represented by gravel mining), such that an overall impact is seen.

Figure 5.35 Soil Carbon and Greenhouse Balance over Period (High Resource Recovery)



High resource recovery = moving from 2% recycling in 2005 to 95% in 2031

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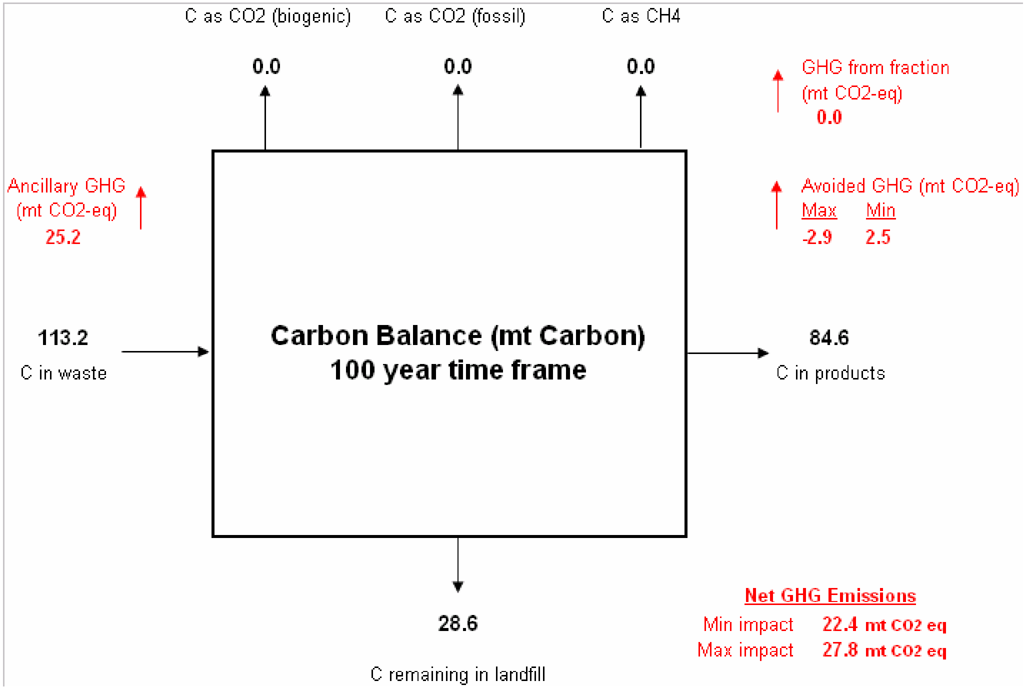
(1) We see the same trend for energy demand impacts.

Figure 5.36 Minerals Carbon and Greenhouse Balance over Period (High Resource Recovery)



High resource recovery = moving from 85% recycling in 2005 to 95% in 2031

Sensitivity analyses show transport to be the key influencing factor, and results are sensitive to the transport assumptions made during modelling. For example, if it were assumed that recovered minerals are sorted and crushed on site and transported 10km for local use (instead of the 100km to reprocessor applied as standard), ancillary impacts are reduced to 9.8 Mt CO_2-equivalents over the period (as opposed to the 25.2 Mt CO_2-eq shown in *Figure 5.36*). If, in comparison, virgin materials must be sourced and transported significant distances, it is likely that a net greenhouse gas benefit will be seen.

It is of further note that recovered soil and mineral materials were assumed to be used as relatively low grade aggregate or fill materials, and to avoid the mining and transport of gravel. Should separated high value materials, such as brick, ceramics or concrete, be recovered, used for specific applications and avoid the production of higher grade materials, it is likely that net greenhouse gas and energy demand benefits would result.

6 *WHERE DO THE GREATEST OPPORTUNITIES LIE?*

In order to determine where the greatest greenhouse gas and energy benefits lie with regard to the management of waste materials, we first looked to the scale of potential impact/benefit achievable over the period. **Maximum and minimum net greenhouse gas emissions and fossil energy demand over the assessment period** are shown in *Table 6.1* and *Table 6.2* (1).

Estimates were then **expressed in terms of net impact over the baseline scenario** (a range, showing maximum estimate for scenario minus maximum estimate for baseline; and minimum estimate for scenario minus minimum estimate for baseline), to identify areas of greatest opportunity for savings. Results of these calculations are shown in *Table 6.3* and *Table 6.4* and are colour coded to emphasise categories of potential savings, or impact.

It is evident that findings are, in part, dependent on the estimates of waste material arisings. For example, we see significant potential savings with regard to energy recovery from manure/slurry and this is unsurprising given the large quantity of materials arising. Given the unreliability of waste arisings data in the UK, it is useful also to look at results on a tonne-for-tonne basis.

Table 6.5 and *Table 6.6* show **maximum and minimum net greenhouse gas emissions and fossil energy demand per tonne of material** and by scenario. These were then expressed in terms of net impact over the baseline scenario (a range, showing maximum estimate for scenario minus maximum estimate for baseline; and minimum estimate for scenario minus minimum estimate for baseline), to identify opportunities for improvement by material and scenario on a unit basis (*Table 6.7* and *Table 6.8*).

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(1) A summary of all scenario results is also presented in *Annex C*

Table 6.1 Summary Results - Net Greenhouse Gas Emissions over Period

Material	**Total Waste Arisings over Period (Mt)**	**Net GHG Emissions over Period (Mt CO_2-eq) – Baseline**	**Net GHG Emissions over Period (Mt CO_2-eq)– Baseline**	**Net GHG Emissions over Period (Mt CO_2-eq) – High Resource**	**Net GHG Emissions over Period (Mt CO_2-eq) – High Resource**	**Net GHG Emissions over Period (Mt CO_2-eq) – High Energy**	**Net GHG Emissions over Period (Mt CO_2-eq) – High Energy**	**Net GHG Emissions over Period (Mt CO_2-eq) – Combined**	**Net GHG Emissions over Period (Mt CO_2-eq) – Combined**
		Max Impact	*Min Impact*	*Max Impact*	*Min Impact*	*Max Impact*	*Min Impact*	*Max Impact*	*Min Impact*
Paper/Card	369.9	76.1	17.2	37.6	-35.7	8.9	-98.1	30.5	-46.0
Kitchen/ Food Waste	318.4	47.0	52.0	38.4	35.6	19.7	-1.5	34.0	28.0
Green Waste	286.1	24.6	21.2	19.9	18.0	-0.5	-24.2	n/a	n/a
Agricultural Crop Waste	177.1	-0.7	-3.9	1.0	-0.9	-13.0	-40.2	n/a	n/a
Manure/ Slurry	2241.7	5.2	-8.8	15.7	3.5	-59.6	-166.3	n/a	n/a
Other Organics	107.9	1.2	-3.6	3.1	0.5	-5.9	-24.5	-2.0	-11.4
Wood	202.5	40.7	33.8	36.0	28.5	-11.1	-79.2	10.5	-26.0
Dense Plastic	74.5	13.5	1.0	23.0	-32.9	55.3	13.2	39.0	-29.1
Plastic Film	83.3	13.9	-5.4	24.9	-32.4	54.1	10.6	40.5	-28.3
Textiles	37.6	3.9	-1.4	-2.8	-11.8	9.3	-3.7	-1.3	-15.0
Ferrous Metals	111.2	-33.5	-48.6	-40.7	-59.0	n/a	n/a	n/a	n/a
Non-ferrous Metals	53.7	-423.8	-451.4	-466.7	-497.2	n/a	n/a	n/a	n/a
Silt/Soil	1369.6	17.5	17.4	20.6	18.2	n/a	n/a	n/a	n/a
Minerals/Aggregate	1617.6	27.6	22.3	27.8	22.4	n/a	n/a	n/a	n/a

Note: Estimates include committed emissions from landfill over the 100 year period

Table 6.2 Summary Results - Net Fossil Energy Demand over Period

Material	**Total Waste Arisings over Period (Mt)**	**Net Fossil Energy Demand over Period (PJ-eq) – Baseline**	**Net Fossil Energy Demand over Period (PJ-eq) – Baseline**	**Net Fossil Energy Demand over Period (PJ-eq) – High Resource**	**Net Fossil Energy Demand over Period (PJ-eq) – High Resource**	**Net Fossil Energy Demand over Period (PJ-eq) – High Energy**	**Net Fossil Energy Demand over Period (PJ-eq) – High Energy**	**Net Fossil Energy Demand over Period (PJ-eq) – Combined**	**Net Fossil Energy Demand over Period (PJ-eq) – Combined**
		Max Impact	*Min Impact*	*Max Impact*	*Min Impact*	*Max Impact*	*Min Impact*	*Max Impact*	*Min Impact*
Paper/Card	369.9	-908.0	-1795.7	-984.5	-2075.3	-1190.8	-2969.1	-998.7	-2144.6
Kitchen/ Food Waste	318.4	-256.3	-360.2	-132.3	-258.7	-367.4	-792.3	-150.9	-339.3
Green Waste	286.1	-98.7	-174.6	-16.8	-116.5	-317.3	-776.6	n/a	n/a
Agricultural Crop Waste	177.1	-13.4	-279.0	4.6	-207.8	-225.9	-852.2	n/a	n/a
Manure/ Slurry	2241.7	68.3	-2897.2	197.8	-2501.5	-1057.0	-5126.6	n/a	n/a
Other Organics	107.9	-26.9	-210.5	-2.4	-140.2	-159.7	-527.7	-53.1	-285.0
Wood	202.5	-172.7	-282.9	-131.1	-243.4	-681.7	-1848.7	-360.5	-970.0
Dense Plastic	74.5	-14.5	-291.8	207.3	-1237.5	-328.5	-1083.2	96.7	-1558.1
Plastic Film	83.3	47.7	-488.8	261.1	-1459.6	-277.7	-1127.8	157.8	-1760.2
Textiles	37.6	-83.0	-233.9	-140.8	-429.7	-134.7	-387.5	-178.7	-547.8
Ferrous Metals	111.2	-51.2	-450.7	-63.8	-547.9	n/a	n/a	n/a	n/a
Non-ferrous Metals	53.7	-4545.3	-4924.9	-5006.1	-5424.2	n/a	n/a	n/a	n/a
Silt/Soil	1369.6	252.5	251.2	298.1	266.3	n/a	n/a	n/a	n/a
Minerals/Aggregate	1617.6	396.5	325.7	401.7	330.1	n/a	n/a	n/a	n/a

Note: Estimates include energy recovery from committed landfill gas over the 100 year period

Table 6.3 Net Greenhouse Gas Emissions over Period – Net Impacts over Baseline

Material	**Total Waste Arisings over Period (Mt)**	**Net GHG Emissions over Baseline (Mt CO_2-eq)**	**Net GHG Emissions over Baseline (Mt CO_2-eq)**	**Net GHG Emissions over Baseline (Mt CO_2-eq)**
		High Resource	*High Energy*	*Combined*
Paper/Card	369.9	-38.5 to -52.9	-67.2 to -115.3	-45.6 to -63.2
Kitchen/ Food Waste	318.4	-8.6 to -16.4	-27.3 to -53.5	-13.0 to -24.0
Green Waste	286.1	-3.2 to -4.7	-25.1 to -45.4	n/a
Agricultural Crop Waste	177.1	1.7 to 3.0	-12.3 to -36.3	n/a
Manure/ Slurry	2241.7	10.5 to 12.3	-64.8 to -157.5	n/a
Other Organics	107.9	1.9 to 4.1	-7.1 to -20.9	-3.2 to -7.8
Wood	202.5	-4.7 to -5.3	-51.8 to -113.0	-30.2 to -59.8
Dense Plastic	74.5	9.5 to -33.9	12.2 to 41.8	25.5 to -30.1
Plastic Film	83.3	11.0 to -27.0	16.0 to 40.2	26.6 to -22.9
Textiles	37.6	-6.7 to -10.4	5.4 to -2.3	-5.2 to -13.6
Ferrous Metals	111.2	-7.2 to -10.4	n/a	n/a
Non-ferrous Metals	53.7	-42.9 to -45.8	n/a	n/a
Silt/Soil	1369.6	0.8 to 3.1	n/a	n/a
Minerals/Aggregate	1617.6	0.1 to 0.2	n/a	n/a

Key:

Midpoint = 0+
Midpoint = 0 to -50
Midpoint = -50 to -100
Midpoint = <-100

Table 6.4 Net Fossil Energy Demand over Period – Net Impacts over Baseline

Material	**Total Waste Arisings over Period (Mt)**	**Net Energy Demand over Baseline (PJ-eq)**	**Net Energy Demand over Baseline (PJ-eq)**	**Net Energy Demand over Baseline (PJ-eq)**
		High Resource	*High Energy*	*Combined*
Paper/Card	369.9	-76.5 to -279.6	-282.9 to -1173.4	-90.7 to -348.8
Kitchen/ Food Waste	318.4	101.5 to 124.0	-111.1 to -432.1	20.9 to 105.4
Green Waste	286.1	58.1 to 81.9	-218.6 to -602.0	n/a
Agricultural Crop Waste	177.1	18.0 to 71.2	-212.5 to -573.2	n/a
Manure/ Slurry	2241.7	129.4 to 395.7	-1125.3 to -2229.4	n/a
Other Organics	107.9	24.5 to 70.3	-132.9 to -317.2	-26.2 to -74.6
Wood	202.5	39.5 to 41.5	-509.0 to -1565.8	-187.8 to -687.1
Dense Plastic	74.5	221.8 to -945.7	-314.0 to -791.4	111.2 to -1266.3
Plastic Film	83.3	213.4 to -970.8	-325.4 to -639.0	110.0 to -1271.4
Textiles	37.6	-57.7 to -195.8	-51.7 to -153.6	-95.7 to -313.9
Ferrous Metals	111.2	-12.6 to -97.2	n/a	n/a
Non-ferrous Metals	53.7	-460.8 to -499.3	n/a	n/a
Silt/Soil	1369.6	15.1 to 45.6	n/a	n/a
Minerals/Aggregate	1617.6	4.4 to 5.2	n/a	n/a

Key:

🟧 **Midpoint = 0+**
🟨 **Midpoint = 0 to -500**
🟫 **Midpoint = -500 to -1000**
🟩 **Midpoint = <-1000**

Table 6.5 Summary Results - Net Greenhouse Gas Emissions (kg CO_2-eq) per Tonne of Waste Material

Material	**Net GHG Emissions (kg CO_2-eq/ tonne) – Baseline**	**Net GHG Emissions (kg CO_2-eq/ tonne) – Baseline**	**Net GHG Emissions (kg CO_2-eq/ tonne) – High Resource**	**Net GHG Emissions (kg CO_2-eq/ tonne) – High Resource**	**Net GHG Emissions (kg CO_2-eq/ tonne) – High Energy**	**Net GHG Emissions (kg CO_2-eq/ tonne) – High Energy**	**Net GHG Emissions (kg CO_2-eq/ tonne) – Combined**	**Net GHG Emissions (kg CO_2-eq/ tonne) – Combined**
	Max Impact	*Min Impact*	*Max Impact*	*Min Impact*	*Max Impact*	*Min Impact*	*Max Impact*	*Min Impact*
Paper/Card	205.7	46.5	101.6	-96.5	24.1	-265.2	82.5	-124.4
Kitchen/ Food Waste	147.6	163.3	120.6	111.8	61.9	-4.7	106.8	87.9
Green Waste	86.0	74.1	69.6	62.9	-1.7	-84.6	n/a	n/a
Agricultural Crop Waste	-4.0	-22.0	5.6	-5.1	-73.4	-227.0	n/a	n/a
Manure/ Slurry	2.3	-3.9	7.0	1.6	-26.6	-74.2	n/a	n/a
Other Organics	11.1	-33.4	28.7	4.6	-54.7	-227.1	-18.5	-105.7
Wood	201.0	166.9	177.8	140.7	-54.8	-391.1	51.9	-128.4
Dense Plastic	181.2	13.4	308.7	-441.6	742.3	177.2	523.5	-390.6
Plastic Film	166.9	-64.8	298.9	-389.0	649.5	127.3	486.2	-339.7
Textiles	103.7	-37.2	-74.5	-313.8	247.3	-98.4	-34.6	-398.9
Ferrous Metals	-301.3	-437.1	-366.0	-530.6	n/a	n/a	n/a	n/a
Non-ferrous Metals	-7892.0	-8406.0	-8690.9	-9258.8	n/a	n/a	n/a	n/a
Silt/Soil	12.8	12.7	15.0	13.3	n/a	n/a	n/a	n/a
Minerals/Aggregate	17.1	13.8	17.2	13.8	n/a	n/a	n/a	n/a

Table 6.6 Summary Results - Net Fossil Energy Demand (MJ-eq) per Tonne of Waste Material

Material	**Net Fossil Energy Demand (MJ-eq/ tonne) – Baseline**	**Net Fossil Energy Demand (MJ-eq/ tonne) – Baseline**	**Net Fossil Energy Demand (MJ-eq/ tonne) – High Resource**	**Net Fossil Energy Demand (MJ-eq/ tonne) – High Resource**	**Net Fossil Energy Demand (MJ-eq/ tonne) – High Energy**	**Net Fossil Energy Demand (MJ-eq/ tonne) – High Energy**	**Net Fossil Energy Demand (MJ-eq/ tonne) – Combined**	**Net Fossil Energy Demand (MJ-eq/ tonne) – Combined**
	Max Impact	*Min Impact*	*Max Impact*	*Min Impact*	*Max Impact*	*Min Impact*	*Max Impact*	*Min Impact*
Paper/Card	-2454.7	-4854.6	-2661.5	-5610.4	-3219.4	-8026.9	-2699.9	-5797.7
Kitchen/ Food Waste	-805.0	-1131.4	-415.5	-812.5	-1154.0	-2488.5	-474.1	-1065.8
Green Waste	-345.0	-610.1	-58.6	-407.1	-1109.1	-2714.4	n/a	n/a
Agricultural Crop Waste	-75.9	-1575.5	25.8	-1173.6	-1275.6	-4811.9	n/a	n/a
Manure/ Slurry	30.5	-1292.4	88.2	-1115.9	-471.5	-2286.9	n/a	n/a
Other Organics	-249.1	-1950.8	-21.8	-1299.5	-1480.5	-4890.3	-492.4	-2641.8
Wood	-852.6	-1397.0	-647.4	-1202.1	-3366.4	-9129.2	-1780.1	-4790.1
Dense Plastic	-194.7	-3916.7	2782.7	-16,610.4	-4409.8	-14,539.9	1298.3	-20,913.7
Plastic Film	573.1	-5867.7	3134.9	-17,521.9	-3333.3	-13,539.3	1894.1	-21,130.3
Textiles	-2208.5	-6219.6	-3743.7	-11,427.9	-3582.3	-10,305.7	-4753.2	-14,568.3
Ferrous Metals	-460.1	-4053.0	-573.5	-4926.7	n/a	n/a	n/a	n/a
Non-ferrous Metals	-84,641.5	-91,711.5	-93,222.8	-101,009.1	n/a	n/a	n/a	n/a
Silt/Soil	184.4	183.4	217.7	194.4	n/a	n/a	n/a	n/a
Minerals/Aggregate	245.1	201.3	248.3	204.0	n/a	n/a	n/a	n/a

Table 6.7 Net Greenhouse Gas Emissions (kg CO_2-eq) per Tonne of Waste Material – Net Impacts over Baseline

Material	**Net GHG Emissions over Baseline (kg CO_2-eq/ tonne)**	**Net GHG Emissions over Baseline (kg CO_2-eq/ tonne)**	**Net GHG Emissions over Baseline (kg CO_2-eq/ tonne)**
	High Resource	*High Energy*	*Combined*
Paper/Card	-104.1 to -143.0	-181.7 to -311.7	-123.3 to -170.9
Kitchen/ Food Waste	-27.0 to -51.5	-85.7 to -168.0	-40.8 to -75.4
Green Waste	-11.2 to -16.4	-87.7 to -158.7	n/a
Agricultural Crop Waste	9.6 to 16.9	-69.5 to -205.0	n/a
Manure/ Slurry	4.7 to 5.5	-28.9 to -70.3	n/a
Other Organics	17.6 to 38.0	-65.8 to -193.7	-29.7 to -72.3
Wood	-23.2 to -26.2	-255.8 to -558.0	-149.1 to -295.3
Dense Plastic	127.5 to -455.0	163.8 to 561.1	-404.0 to 342.3
Plastic Film	132.1 to -324.1	192.1 to 482.6	-274.9 to 319.3
Textiles	-178.2 to -276.6	-61.2 to 143.6	-138.3 to -361.7
Ferrous Metals	-64.7 to -93.5	n/a	n/a
Non-ferrous Metals	-798.9 to -852.9	n/a	n/a
Silt/Soil	0.6 to 2.3	n/a	n/a
Minerals/Aggregate	0.1 to 0.1	n/a	n/a

Key:

🟧 **Midpoint = 0+**
🟨 **Midpoint = 0 to -100**
🟫 **Midpoint = -100 to -200**
🟩 **Midpoint = <-200**

Table 6.8 Net Fossil Energy Demand (MJ-eq) per Tonne of Waste Material – Net Impacts over Baseline

Material	**Net Energy Demand over Baseline (MJ-eq/ tonne)**	**Net Energy Demand over Baseline (MJ-eq/ tonne)**	**Net Energy Demand over Baseline (MJ-eq/ tonne)**
	High Resource	*High Energy*	*Combined*
Paper/Card	-206.8 to -755.8	-764.7 to -3172.3	-245.1 to -943.1
Kitchen/ Food Waste	318.9 to 389.5	-349.0 to -1357.1	65.6 to 330.9
Green Waste	203.0 to 286.4	-764.1 to -2104.3	n/a
Agricultural Crop Waste	101.7 to 401.8	-1199.7 to -3236.5	n/a
Manure/ Slurry	57.7 to 176.5	-502.0 to -994.5	n/a
Other Organics	227.3 to 651.3	-1231.4 to -2939.5	-243.3 to -691.0
Wood	194.9 to 205.1	-2513.8 to -7732.2	-927.5 to -3393.2
Dense Plastic	2977.4 to -12,693.7	-4215.1 to -10,623.2	1493.0 to -16,997.0
Plastic Film	2561.7 to -11,654.2	-3906.4 to -7671.6	1321.0 to -15,262.6
Textiles	-1535.2 to -5208.3	-1373.7 to -4086.1	-2544.7 to -8348.6
Ferrous Metals	-113.4 to -873.7	n/a	n/a
Non-ferrous Metals	-8581.2 to -9297.6	n/a	n/a
Silt/Soil	11.0 to 33.3	n/a	n/a
Minerals/Aggregate	2.7 to 3.2	n/a	n/a

Key:

Midpoint = 0+
Midpoint = 0 to -2500
Midpoint = -2500 to -5000
Midpoint = <-5000

Table 6.3 and *Table 6.4* show significant potential greenhouse gas and fossil energy savings associated with a number of the material waste management scenarios assessed over the period 2005-2031, in particular with regard to:

- **energy recovery from agricultural manures/slurries** (via anaerobic digestion);
- **energy recovery from wood** (via thermal treatment);
- both **recovery of energy** (via thermal treatment) **and recycling of paper and card**; and
- **recycling of non-ferrous metals**.

We also see net energy demand benefits associated with energy recovery from plastics, but these are not translated into greenhouse gas savings due to associated emissions of fossil carbon dioxide.

Some management routes showed a net greenhouse gas impact over current practices:

- composting (resource recovery) of some organic fractions;
- recycling of wood; and
- recycling of soil and mineral materials.

However, it must be noted that estimates for organics composting and soil/minerals recycling are sensitive to a number of modelling assumptions. For example, analyses found that the results for soil and mineral materials are sensitive to the assumptions regarding transport. The balance between net impact and benefit for recycling these materials is likely to be dependent on the relative distances travelled by the waste materials and the virgin aggregates that they are assumed to displace.

With regard to organics, estimates are sensitive to assumptions regarding the relative benefits of stabilising, landspreading and landfilling biodegradable materials. We have relatively little information on which to base estimates of benefit, and avoided burden, for compost materials; and this is an area in which additional research would aid interpretation. Further, with regard to landfill, should reduced quantities of landfill gas be captured and used, we will see the relative balance between landfill and composting start to change.

When we look to results on a tonne-for-tonne basis (*Table 6.7*and *Table 6.8*), we see some differences to those for total benefits (*Table 6.3* and *Table 6.4*), namely that:

- energy recovery from manure/slurry shows a relatively lower benefit (on a tonne-for-tonne basis);
- the relative benefits of **energy recovery from organics** (anaerobic digestion of kitchen and green wastes, combustion of crop and other organic wastes) are increased; and
- the relative benefits of **recycling textiles and plastics** are increased.

The summary results we have discussed so far represent average estimates for each scenario over the period 2005-2031. Over this time, management practices are assumed to increase linearly from baseline levels to reach the theoretically achievable recovery rates (presented in *Table 5.1*). They will therefore vary if rates of recovery increase more/less quickly.

To provide a more absolute comparison of the principal alternative recovery routes (ie energy versus resource recovery), it is revealing to look at **estimates in the final year of assessment (2031)**, where maximum levels of recycling or energy recovery (according to *Table 5.1*) are reached. These are shown on a per tonne basis for energy and resource recovery in *Table 6.9* and *Table 6.10*.

Table 6.9 ***Net Greenhouse Gas Emissions (kg CO_2-eq) per Tonne of Waste Material at Maximum Recovery (2031)***

Material	**Min Net GHG Emissions in 2031 (kg CO_2-eq/ tonne)**	**Max Net GHG Emissions in 2031 (kg CO_2-eq/ tonne)**	**Min Net GHG Emissions in 2031 (kg CO_2-eq/ tonne)**	**Max Net GHG Emissions in 2031 (kg CO_2-eq/ tonne)**
	High Resource	*High Resource*	*High Energy*	*High Energy*
Paper/Card	-267.6	-32.2	-597.1	-131.7
Kitchen/ Food Waste	98.2	100.1	-135.5	-17.0
Green Waste	62.6	64.4	-227.2	-73.6
Agricultural Crop Waste	9.9	13.7	-480.1	-159.9
Manure/ Slurry	7.1	11.8	-144.5	-55.4
Other Organics	37.0	40.6	-459.3	-136.3
Wood	87.9	127.6	-1013.4	-302.8
Dense Plastic	-872.6	425.5	182.3	1235.6
Plastic Film	-702.5	425.5	182.5	1083.6
Textiles	-621.0	-289.7	-218.2	386.7
Ferrous Metals	-619.8	-428.2	n/a	n/a
Non-ferrous Metals	-10,064.7	-9449.1	n/a	n/a
Silt/Soil	14.0	17.4	n/a	n/a
Minerals	3.9	7.3	n/a	n/a

Table 6.10 ***Net Fossil Energy Demand (MJ-eq) per Tonne of Waste Material at Maximum Recovery (2031)***

Material	**Min Net GHG Emissions in 2031 (MJ-eq/ tonne)**	**Max Net GHG Emissions in 2031 (MJ-eq/ tonne)**	**Min Net GHG Emissions in 2031 (MJ-eq/ tonne)**	**Max Net GHG Emissions in 2031 (MJ-eq/ tonne)**
	High Resource	*High Resource*	*High Energy*	*High Energy*
Paper/Card	-6755.3	-3285.2	-12,807.5	-4805.1
Kitchen/ Food Waste	-684.7	-229.7	-4031.2	-1679.2
Green Waste	-285.6	130.9	-4904.3	-1958.7
Agricultural Crop Waste	-762.2	126.5	-8880.8	-2766.6
Manure/ Slurry	-940.0	146.2	-3282.0	-972.9
Other Organics	-668.8	174.4	-8440.9	-2922.0
Wood	-1309.2	-751.1	-19,024.5	-6805.4
Dense Plastic	-28,549.4	5616.4	-27,588.4	-9476.6
Plastic Film	-28,743.8	5616.4	-23555.1	-8061.2
Textiles	-16,616.1	-5419.1	-16,066.6	-5665.1
Ferrous Metals	-5758.2	-679.5	n/a	n/a
Non-ferrous Metals	-109,810.0	-101,345.5	n/a	n/a
Silt/Soil	207.8	252.5	n/a	n/a
Minerals	61.6	106.3	n/a	n/a

Findings illustrate that some materials and management routes show significant potential for greenhouse gas emission and fossil energy demand savings. The largest potential, over and above current recovery efforts, is with regard to:

- energy recovery via anaerobic digestion of agricultural manures/slurries;
- energy recovery via combustion of waste wood;
- recovery of both energy (through combustion) and resources (through recycling) from waste paper and card; and
- recycling of non-ferrous metals.

Discounting the influence of relative material arisings, on a tonne-for-tonne basis the recycling of textiles and plastics and energy recovery through anaerobic digestion of kitchen and green wastes and combustion of crop and other organic wastes (1) also show significant potential for benefit.

These results have been quantified on the basis of a number of modelling assumptions, and show variation accordingly. Extensive sensitivity analyses were carried out to understand where and how results are significantly influenced. This was a valuable exercise to identify…

…where findings should be treated with caution

- Average estimates show energy recovery to be favoured over recycling for waste paper and card. In fact, there is a fine balance between these alternative recovery methods. The balance is directly dependent on the assumptions regarding the efficiency of energy recovery technologies in particular. If recovery is initially of low efficiency, as it is reasonable to expect, and increases over time, it is only in later years, at higher levels of efficiency, that energy recovery is favoured over recycling. Further, if in this time period the efficiency of the fossil energy generation technologies that are offset by recovering energy from wastes also increases, it was found that energy recovery is no longer favoured over high quality recycling routes in these final years. Coupled with other uncertainties, such as the likely improvement in efficiency of paper recycling technologies, leads us to conclude that no firm inference can be drawn as to the benefit of one recovery route over the other on the basis of this analysis.

- Greenhouse gas and energy impacts associated with soil and mineral materials recycling were found to be sensitive to the transport assumptions made during modelling. If it were assumed that recovered materials are sorted and used locally, we can expect to see climate change

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(1) Predominantly sewage sludge.

and energy benefits, as opposed to the net impacts seen. This is particularly probable if the virgin materials that they displace are sourced from greater distances.

…where we have insufficient data to be able to draw accurate conclusions

- We do not know as well as we might how much waste there is, what it is comprised of and how it is currently managed. All findings were based on, or drawn from, baseline estimates of current arisings and management and so are inhibited by limitations in data quality.

- For some organic materials (crop and 'other' organic waste, such as sewage sludge) we found increased greenhouse gas and/or energy demand impacts associated with resource recovery (composting). There were a number of reasons for this, and they derive predominantly from assumptions regarding the benefits of composted materials versus direct spreading of raw organics to land. In analyses we have assumed an equal benefit for each, as very little data or information exist to enable us to explore this further. However, in practice the balance of greenhouse gas potential may swing either way.

- Results for organics, as well as for other biodegradable materials, were found to be highly sensitive to assumptions regarding landfill gas capture. This had a considerable influence on estimates, such that should only 60% of landfill gas be captured and used over the 100 year period, the overall net greenhouse gas benefits that we see for the UK currently (for example in *Figure 5.1*) become net impacts.

- The scale of avoided greenhouse gas emissions and energy demand associated with recycling of the majority of materials, but chiefly plastics, textiles and paper/card varies widely with assumptions regarding the routes via which they may be processed.

- Composting performs relatively poorly in carbon and energy terms as the use of compost products displaces alternatives which tend themselves to be organically-derived (with the exception of inorganic chemicals fertilisers) and are therefore not energy or carbon intensive to produce in the first place. The use of compost is likely to convey additional benefits, for example in terms of soil structure, fertility or the maintenance of carbon sinks, but these factors are difficult to quantify in carbon terms and it was not within the scope of this work to do so.

…and where we need to focus future research

Combining both the scale of potential impacts/benefits quantified, and known limitations of the study, we can identify a number of key areas in which further research could aid our understanding of the greenhouse gas and energy impacts of methods for managing waste materials.

- The development of a long term strategy to collect and collate data regarding the availability, sources and current management of materials. Data in particular for waste composition, and thus arisings on a material basis are lacking. Further, we have little information on how waste may change over time. If we are to take a resource management approach to waste, data such as these are essential. The Defra waste data strategy (1) provides a base for this, proposing that detailed data are collected at the waste management facility level. These will then be centrally processed to allow ongoing analysis.

- A more sophisticated approach to assessing the fertiliser, sequestration, and other benefits of composting activities, relative to landfill, landspread and other waste management activities. Compost and digestate products differ from the majority of other materials, where greenhouse gas benefit data are readily available. Assessing the benefits of substituting products, such as fertilisers and soil conditioners, is difficult, and understanding the service delivered by the products is also complex and uncertain. We have made some attempt to quantify these benefits, but further research is needed to enable a more complete understanding of the relative benefits of composting in comparison with other waste management activities.

- The development of an improved understanding of the relative importance of alternative reprocessing routes for plastics, textiles and paper and card. We found that the scale of avoided greenhouse gas emissions and energy demand associated with the recovery and recycling of these materials to vary widely with assumptions regarding the routes via which they may be reprocessed, and the alternative products that they will displace. However, we only presented two alternatives – a high value and low value route. A greater understanding of the range of alternative reprocessing opportunities will aid the identification and advancement of routes for which greater benefits can be achieved.

- The development of more sophisticated impact factors to describe the potential benefits and avoided burdens of soil/minerals recycling. Currently studies and data are lacking in this area and a greater understanding is required to understand the greenhouse gas and energy potential for recovering these materials.

- Further consideration of the potential for capture and treatment of landfill gas. A 75% capture rate over 100 years was modelled in the assessment, as this is a best estimate, based on current thinking (2). However, the resulting estimates are highly sensitive to this estimate. To enable a more accurate quantification of current, and future, climate change impacts associated with landfill, research would benefit from further work in this area.

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(1) Defra (2006). *The Defra/WAG Waste Data Strategy for Waste Streams across the UK*. Defra, London

(2) *Annex B* provides further detail on the background to this assumption. Original Source: Golder Associates (2005). *UK Landfill Methane Emissions: Evaluation of Waste Polices and Projections to 2050*. Report for Defra, London.

- The development of a method to quantify the greenhouse gas and energy benefits of reducing and re-using waste materials. The current work did not attempt to quantify the potential for reduction and re-use. There is undoubted benefit associated with these routes and future studies would benefits from their inclusion.

Annex A

Review of UK Waste Arisings and Composition

CONTENTS

A1 INTRODUCTION

The overall aim of this project was to carry out a macro-level investigation of the source and scale of energy and greenhouse gas benefits and impacts associated with the management of waste streams arising in the UK. To do this, the current waste management situation (arisings, composition and management) had first to be defined.

The starting point for the research was therefore a review of data and information pertaining to the range of UK waste streams. This report presents the results of this review, setting out:

- definitions of the specific streams comprising UK waste;
- estimated current arisings for each waste stream;
- best estimates of waste stream composition; and
- current and anticipated waste management routes.

An estimated composition has been developed for each waste stream comprising total UK waste, employing fractional components such as paper/card; food/animal waste; green waste; textiles; fines; ferrous metals; non-ferrous metals; glass; dense plastic; plastic film; and miscellaneous wastes (split by combustible/non-combustible fractions). In addition, estimated carbon content (fossil and biogenic) and calorific value of alternative waste fractions has been presented.

Some analysis and discussion has been presented regarding the potential growth of these waste streams. However, we will see that data and information are lacking and make it difficult to make reliable predictions regarding waste growth over the assessment period, however. For this reason, and to aid the clarity of results, it was decided that greenhouse gas and energy impacts would be modelled on the basis that waste growth will be static over the period of the study, and the most up to date estimates of arisings were used.

A1.1 WASTE STATISTICS

The shortage, and limitations, of the statistics on specific waste stream arisings, their growth rates, composition and management is well-documented and hampers the development of effective waste strategies and the ability to measure and monitor progress effectively. As a result, Defra has implemented a programme to ensure effective co-ordination, provision and dissemination of reliable data on different waste streams, through the development of a national three-year data strategy.

In reality, a long term vision is needed to ensure cohesive and comparable statistics on the range of waste streams and sources. Meanwhile, one must rely is on the limited number of published sources of data regarding UK waste arisings.

The waste data available derive predominantly from the various UK Government bodies which gather and/or publish waste statistics. These include:

- Defra;
- the Environment Agency for England & Wales (EA);
- the Scottish Environmental Protection Agency (SEPA);
- the Northern Ireland Environment and Heritage Service (EHS);
- the Office of the Deputy Prime Minister (ODPM);
- local waste authorities;
- Water UK; and
- the Centre for Environment, Fisheries and Aquaculture Science (CEFAS).

Each of these bodies has been consulted to collate an overall data set for waste arisings, management and composition.

A1.2 *WASTE DEFINITIONS*

The first task in this review was to clarify the waste streams to be included (ie the predominant UK waste streams) and to determine the wastes incorporated within each stream. Direction was taken from Pat Kilby and Guy Lever in Defra's Waste Statistics Division in answering these questions. *Table A1.1* shows the assumed definition of waste for this study, together with descriptions of the predominant waste streams arising in the UK. Waste stream definitions have been supplemented, where necessary, with information from relevant reporting bodies.

Table A1.1 Waste Stream Definitions

Waste Type	Background and Definition
Waste	In the EU, the Waste Framework Directive (Council Directive 75/442/EEC as amended)(WFD) sets out the legal framework of controls governing the management of waste in the EU. When the WFD was first adopted in 1975, it was left to Member States to adopt their own national definition of waste. However, in 1991 the WFD was substantially amended, including the introduction of an EU-wide definition of waste. The amended Directive, including the definition of waste, was transposed into UK national legislation in May 1994. The definition of waste in force in the UK then is the definition in Article 1(a) of the WFD which provides that "waste" is: *"…any substance or object…which the holder discards or intends or is required to discard."* Article 2 of the WFD lists a number of waste streams which are excluded from the Directive's scope. These wastes have to be defined as waste in accordance with the definition in Article 1(a) in order to be excluded from the Directive's scope.
Agricultural waste	The legal definition of agricultural waste, as drafted in the proposed Waste Management (England and Wales) Regulations 2006, states that agricultural waste is: *"waste from premises used for agriculture within the meaning of the Agriculture Act 1947."* The Agriculture Act 1947 stipulates that: *"Agriculture includes: horticulture, fruit growing, seed growing, dairy farming and livestock breeding and keeping, the use of land as grazing land, meadow land, osier land, market gardens and nursery grounds, and the use of land for woodlands where that use is ancillary to the farming of land for other agricultural purposes, and 'agriculture' shall be construed accordingly."*
Mining & Quarrying waste	For historical reasons, mineral waste from mines and quarries is largely controlled through the town and country planning system in the UK and, as a consequence, falls under the remit of the ODPM. Mine and quarry waste is now defined by reference to, and regulated in accordance with, the Mining Waste Directive. In setting out the scope of the Directive, Article 2(1) effectively defines extractive waste by providing that: *"…this Directive covers the management of waste resulting from the prospecting, extraction, treatment and storage of mineral resources and the working of quarries, hereinafter "extractive waste".* Further, recital 4 of the Mining Waste Directive effectively indicates the types of waste which are to come under the heading of 'extractive waste' *"In accordance with the objectives of Community policy on the environment, it is necessary to lay down minimum requirements in order to prevent or reduce as far as possible any adverse effects on the environment or on human health which are brought about as a result of the management of waste from the extractive industries, such as tailings (ie the waste solids or slurries that remain after the treatment of minerals by a number of techniques), waste rock and overburden (ie the material that extractive operations removed during the process of accessing an ore of mineral body, including during the pre-production development stage), and topsoil (ie the upper layer of the ground) provided that they constitute waste as defined in the Waste Framework Directive."*

Waste Type	Background and Definition
Sewage Sludge	This waste stream is formally defined by the European Commission in the Urban Wastewater Treatment Directive (UWWTD) as *Sludge from urban waste water treatment plants, whereby 'urban waste water' is understood as: "domestic waste water or the mixture of domestic waste water with industrial waste water and/or run-off rain water"* (Directive 91/271/EEC). The definition of 'domestic waste water' in Directive reads: *"waste water from residential settlements and services which originates predominantly from the human metabolism and from household activities"*.
Dredged Material	CEFAS defines dredging wastes as: *"Material generated when dredging ports, harbours, rivers and approach channels."*
Municipal waste	Article 2(b) of the Landfill Directive and provides that: *"municipal waste' means waste from households, as well as other waste which, because of its nature or composition, is similar to waste from household."*
Commercial waste	Defra defines commercial wastes as those wastes arising from any premises which are used wholly or mainly for trade, business, sport recreation or entertainment, excluding municipal and industrial waste.
Industrial waste	The definition of industrial waste is set out in section 75(6) of the Environmental Protection Act 1990 (EPA 1990) as "waste from any of the following premises: (a) any factory (within the meaning of the Factories Act 1961); (b) any premises used for the purposes of, or in connection with, the provision to the public of transport services by land, water or air; (c) any premises used for the purposes of, or in connection with, the supply to the public of gas, water or electricity or the provision of sewerage services; or (d) any premises used for the purposes of, or in connection with, the provision to the public of postal or telecommunication services." It is a further point of notes that waste from mines and quarries is excluded from the definition of commercial waste in section 75(7) (c) of EPA 1990 but not from the definition of industrial waste. The effect of the proposals in the Waste Management (England and Wales) Regulations 2006 will be to repeal this exclusion and reclassify (non-mineral) waste from mines and quarries, as well as agricultural waste, as industrial waste.
Construction & demolition waste	Construction and demolition waste (C&D waste) includes hard C&D and excavation waste materials. ODPM defines these waste materials as those that arise as a direct result of: • the total or partial demolition of buildings and/or civil engineering infrastructure; or • the construction of buildings and/or civil engineering infrastructure.

A1.3 AGRICULTURAL WASTES

Agricultural waste arisings in the UK have been estimated to amount to around 90 million tonnes per annum. The Defra e-digest statistics (Defra, 2003) suggest 87 million tonnes per annum, while the EU survey of wastes spread on land (European Communities, 2001) estimates 91 million tonnes per annum in the UK. It is reported that the overwhelming majority of the waste arisings consists of natural manure or slurry, with non-natural waste likely to be less than 1 million tonnes per annum. The European Commission judged in September 2005 that livestock effluent may fall outside of the classification of waste if it is used as a soil fertiliser as part of a lawful practice of spreading.

The Environment Agency comment that this would not be classed as waste. However, other legal controls such as the Nitrate Vulnerable Zones (NVZ) Action Programme and the Groundwater Regulations would still need to be complied with. The quantity and fate of livestock effluent is therefore included within estimates of waste arisings

In the following sections, a review is made of agricultural waste and its fate arising from both natural and non-natural waste in turn.

A1.3.1 Natural Waste

The natural waste comprising the majority of agricultural waste arisings consists of housed livestock waste, crop residues, animal tissue; and animal carcasses. The estimated quantities reported for each of these waste streams is summarised in *Table A1.2*. The DETR report summarised in the Review of Agricultural Waste Research and Development Projects (DETR, 2000) calculated a UK arisings estimate from farm unit waste estimates and information on crop areas and livestock numbers from farm census data. The 2001 Environment Agency report used a similar method. The Biffaward estimates are on a farm unit basis, the report gives no indication of the number of each type of farm unit in the UK. The annual quantities are estimated in all sources from data collected from farm surveys and census, in many cases stockpiled wastes were included suggesting that the annual tonnages have been over estimated.

Housed Livestock Waste

Housed livestock waste is handled as solid manure (mainly cattle, sheep, pig and poultry) and liquid slurry (cattle and pig). The amount of manure and slurry produced varies depending on the type of stock and the degree of dilution with either straw or water. However, the quantities produced by various classes of livestock have been predicted for England and Wales (*Table A1.3)*. It is also reported that an additional 60 million tonnes of excreta are deposited directly on fields by grazing cattle, sheep and pigs.

The majority of the housed livestock waste is applied to farmland at the site of production, slurry is stored prior to use on land in the drier months of the year, while manure is stored on bare field land and left to digest slowly. The European Commission (European Communities, 2001) states that only a small minority of farmers treat slurry before landspreading, mainly to mitigate odour problems.

Table A1.2 Estimated Annual Quantities of Natural Waste Arisings

Natural Waste Stream	**UK Total (million tonnes) (1)**	**UK Total (million tonnes) (2)**	**Dairy Unit (tonnes) (3)**	**Pig Unit (tonnes) (3)**	**Poultry Unit (tonnes) (3)**	**Sheep Unit (tonnes) (3)**	**Beef Unit (tonnes) (3)**	**Arable Unit (tonnes) (3)**
Housed Livestock Waste - Manure	28.8 to 40.46	83.0 (manure, slurry and silage effluent)	231	1700		20	643	
Housed Livestock Waste – Slurry	27.83 to 42.37 (m^3 per year)		1361	3000				
Poultry Litter					4125			
Crop Residues	4.63 to 6.56	22.0	35				16	377
Animal Tissue	0.099	0.11	0.48			0.66	1	
Animal Carcasses	0.098	0.23	0.88	5.2 (with tissue)	25 (with tissue)	1.17	1.5	
Total	**33.6 – 47.2***	**22.3**	**1628.4**	**4700.0**	**4125.0**	**21.8**	**661.5**	**377.0**

Sources:

1) Environment Agency, 2004. Review of Agricultural waste research and development projects. Produced by Atkins Environment.

2) Environment Agency, 2001. Towards Sustainable Agricultural Waste Management. Environment Agency R&D Technical Report P1-399 co-sponsored by the Environment Agency and Biffaward. Prepared by Marcus Hodges Environment, BDB Associates and the Westcountry Rivers Trust.

3) Biffaward, 2002. Agricultural Waste Mass balance: Opportunities for recycling and producing energy from waste technologies. A Biffaward Programme on Sustainable Resource Use. Prepared by C-Tech Innovations Ltd.

Notes:

* Not including housed livestock waste

Table A1.3 Estimated Quantities of Farm Yard Manure Handled Annually in England and Wales (Million Tonnes)

Animal Type	As Solid Manure (million tonnes)	As Liquid Manure (million tonnes)	Total Fresh Weight (million tonnes)
Cattle	21	32	53
Pig	4.3	4.6	8.9
Poultry	3.5	-	3.5
Sheep	1.9	-	1.9
Total	**30.7**	**36.6**	**67.3**

Source:
European Communities, 2001 European Commission-Directorate-General for Environment Survey of Wastes Spread on Land – Final Report Study Contract B4-3040/99/110194/MAR/E3. Prepared by WRc Ltd, SEDE and REI.

40% of the poultry and 15% of pig manure is transported off-site for disposal (European Communities, 2001). Some poultry waste is disposed via incineration in specially built power plants (Biffaward, 2002) and pig manure is used by neighbouring arable enterprises as a fertiliser. Silage effluent is either fed directly back to cattle or landspread without treatment.

The Biomass Task Force was launched in October 2004 to assist the Government and the biomass industry in optimising the contribution that biomass energy can make to renewable energy targets and to sustained farming and forestry and rural objectives. The Biomass Task Force (BTF) has raised the potential for certain agricultural waste to be used as a biomass resource for energy production. The Task Force report stated that dry agricultural materials, cereal straw and poultry manure can be used to generate energy through biomass-fired processes such as mass-burn steam turbines, heat-only boilers or combined heat and power (CHP) plants.

Wet materials, such as pig and cattle slurries, would not be viable inputs for the biomass-fired processes due to the high energy cost of drying the materials prior to burning or the reduced calorific values of incinerating 'wet' materials directly. However, anaerobic digestion (AD) offers a potential solution for these waste streams. It is estimated that the maximum available arisings total around 2.9 million tonnes (mt): 0.36mt from poultry manure; 2.02mt from dairy cattle slurry; and 0.54mt from pig manures (Biomass Task Force, 2005).

Small-scale on-farm incinerators (of which there are approximately 3000 in England and Wales) are used on large scale poultry and pig farms for the disposal of animal carcasses (Environment Agency, 2001).

Crop Residues

Crop residues consist of straw, vegetable waste, and cereal waste. The estimated arisings of each of these waste streams reported are presented in *Table A1.4*.

Table A1.4 Estimated Annual Quantities of Crop Residues

Crop Residue	UK Total (million tonnes per year) (1)	Per Arable Unit (tonnes per year) (2)
Straw	1.84 to 3.14	344
Vegetable Waste	0.67 to 1.30	33
Cereal Waste	2.12	
Total	**4.63 to 6.56**	**377**

Sources:
1) Environment Agency, 2004. Review of Agricultural waste research and development projects. Produced by Atkins Environment.
2) Biffaward, 2002. Agricultural Waste Mass balance: Opportunities for recycling and producing energy from waste technologies. A Biffaward Programme on Sustainable Resource Use. Prepared by C-Tech Innovations Ltd.

Some straw is recycled as animal bedding, some ploughed into the land, and some burnt. Under the proposed new Agricultural Waste Regulations (to begin in 2006) the burning of crop residues will be allowed provided a licensing exeption has been registered and any conditions applied adhered to. It is reported in the Biffaward report (Biffaward, 2002) that about 200,000 tonnes of baled straw are used as a fuel in a purpose-built power station operating at Sutton, near Ely, Cambridgeshire. Vegetable and cereal waste is mostly returned to land, with composting increasing.

A1.3.2 Non-Natural Waste

Non-natural waste comprises plastics, paper and board, machinery, chemicals, medicines, scrap metal, glass, rubber and general building waste. The estimated quantities reported for each of these waste streams is summarised in *Table A1.5*, with estimated totals ranging between 0.5 mt (Environment Agency, 2001) and 1 mt (Defra, 2003). Non-natural waste from farms that have diversified (to include, for example, tourism) is not yet well documented, but is anticipated to be growing in scale.

Table A1.5 Non-Natural Waste Estimated Annual Quantities

Non-Natural Waste Stream	**UK Total (thousand tonnes) (1)**	**UK Total (thousand tonnes) (1)**	**Agricultural Waste Estimate Model 1998 UK total (thousand tonnes) (3)**	**Dairy Unit (tonnes) (4)**	**Dairy Unit (tonnes) (4)**	**Poultry Unit (tonnes) (4)**	**Sheep Unit (tonnes) (4)**	**Beef Unit (tonnes) (4)**	**Arable Unit (tonnes) (4)**
Plastics and packaging	58.8	34 (packaging) 60 (non-packaging)	135.7	0.78	0.44	0.18	0.096	0.77	0.32
Paper and board		10.9	10.9	0.072	0.20	0.13	0.03	0.11	0.12
Machinery	73.0 to 76.0	79.5	79.2	0.36	0.32		0.36	0.36	0.32
Glass			1.95 (plus rubber)	0.0012	0.24	0.04	0.0012	0.0012	
Rubber				0.001	0.0029		0.001	0.001	
Scrap Metal				0.11	0.096		0.11	0.11	0.096
Chemicals	144.2 to 300.3 (m^3/yr)		104.5				1.62		3.2
Medicines	0.25		116.5						
General Building Waste			33.6						
Total	**276.3 to 435.4***	**90.4**	**480.5**	**1.3**	**1.3**	**0.35**	**2.2**	**1.4**	**4.0**

Sources:

1) Environment Agency, 2004. Review of Agricultural waste research and development projects. Produced by Atkins Environment.

2) Environment Agency, 2001. Towards Sustainable Agricultural Waste Management. Environment Agency R&D Technical Report P1-399 co-sponsored by the Environment Agency and Biffaward. Prepared by Marcus Hodges Environment, BDB Associates and the Westcountry Rivers Trust.

3) Environment Agency, 2003. Agricultural Waste Survey 2003: A study of the management of non-natural agricultural waste on farms. Environment Agency R&D Technical Report co-sponsored by the Environment Agency and a grant from Biffaward (the latter with contribution from DEFRA and the Crop Protection Association). Prepared by Marcus Hodges Environment, BDB Associates and the Westcountry Rivers Trust.

4) Biffaward, 2002. Agricultural Waste Mass balance: Opportunities for recycling and producing energy from waste technologies. A Biffaward Programme on Sustainable Resource Use. Prepared by C-Tech Innovations Ltd.

Notes:

* Assuming density of chemicals to be 1kg/litre

Plastics and Packaging

Plastic and packaging waste from agriculture consists of silage film, horticultural film, agrochemical containers, fertiliser and seed bags and other miscellaneous packaging. The types of plastic are principally polyethylene and polypropylene. Quantities reported in the Environment Agency's Agricultural Waste Survey 2003 are presented in *Table A1.6*.

Table A1.6 UK Estimates of Plastics and Packaging Agricultural Waste Arisings (Tonnes per Year)

Waste Type	Total UK Estimate (tonnes per year)
Plastic Packaging	
Agrochemical packaging	2400
Fertiliser bags	12,200
Seed bags	1000
Animal feed bags	11,400
Animal health packaging	750
Oil containers	669
Miscellaneous packaging	3800
Non-packaging Plastics	
Films	
Silage plastic	25,000
Silage plastic and contamination	50,000
Greenhouse and tunnel film	500
Mulch film and crop cover	4500
Mulch film and crop cover and contamination	22,500
Other Non-Packaging Plastics	
Cores for silage wrap	1506
Other horticultural plastics	6000
Bale twine and net wrap	11,100
Tree guards	11,900
Total	**165,225**

Source: Environment Agency, 2003. Agricultural Waste Survey 2003: A study of the management of non-natural agricultural waste on farms. Environment Agency R&D Technical Report

Traditionally, plastics have been burnt on-site, either in incinerators or in the open. This will not be permissible under the proposed new Agricultural Waste Regulations, when the only realistic way of disposal will be to send it off-farm for recovery or disposal. As the pressure to stop burning has grown, more stockpiling has occurred on-site.

Recycling schemes for farm films exist in certain parts of the country; with film taken to the BPI reprocessing site in Dumfries. Take-back schemes run by suppliers also exist (Biffaward, 2002). Survey responses from farmers have shown that some plastics are buried on-site, where old quarries or suitable excavations exist, and some is included in the household waste collection. This will be banned under the proposed new Agricultural Waste Regulations and will potentially lead to increased arisings.

Paper and Board

Paper is mainly in the form of secondary cardboard packaging, with some cardboard arising from silage sheet, horticultural film and net wrap cores. Quantities reported in the Agricultural Waste Survey 2003 are presented in *Table A1.7*.

Table A1.7 ***UK Estimates of Paper and Board Agricultural Waste Arisings (Tonnes per Year)***

Waste Type	**Total UK Estimate (tonnes per year)**
Agrochemical packaging	1600
Animal health packaging	250
Animal feed bags	6000
Seed bags	1800
Silage wrap boxes	335
Cores for silage sheet	929
Total	**10,914**

Source: Environment Agency, 2003. Agricultural Waste Survey 2003: A study of the management of non-natural agricultural waste on farms. Environment Agency R&D Technical Report

Paper and cardboard waste is recycled (13%), burnt for heating (8%) or burnt in the open (just over two thirds) (Environment Agency, 2004). Under the proposed new Agricultural Waste Regulations, the burning in the open of paper and cardboard will be banned, and therefore this proportion will require an alternative disposal route.

Machinery

The main wastes related to machinery are oils, tyres, batteries and scrap machinery or parts. Quantities reported in the Agricultural Waste Survey 2003 are presented in *Table A1.8*. Equipment containing chloroflurocarbons (CFCs) and halons, and electrical equipment containing polychlorinated biphenyls (PCBs) still exists on farms at unknown quantities.

Table A1.8 ***UK Estimates of Machinery Agricultural Waste Arisings (Tonnes per Year)***

Waste Type	**Total UK Estimate (tonnes per year)**
Oils	27,095
Batteries	2812
Tyres	25,974
Redundant vehicles and machinery	23,312
Total	**79,193**

Source: Environment Agency, 2003. Agricultural Waste Survey 2003: A study of the management of non-natural agricultural waste on farms. Environment Agency R&D Technical Report

Tyres are either recycled (around half of farms do this) or re-used on-farm (Environment Agency, 2004). It has been found that around 20% of farms have been stockpiling tyres, and, in addition, it has been reported that around 10% of farms burn tyres in the open. This will be banned the under proposed new Agricultural Waste Regulations. The stockpiling of other machinery and batteries is also common practice.

Batteries are re-used by around 10% farms, typically for powering electric fences. Some batteries and machinery are taken back by suppliers as part of take-back schemes. Scrap metal is mostly recycled off-farm, although around 10% has been reported to be stockpiled with no disposal plans (Environment Agency, 2004).

Chemicals

Chemical waste produced consists of agrochemicals, such as: pesticides; sheep dip chemicals; and waste oil.

The recommended practice is for pesticide washings to be applied to unsprayed areas of crop. The quantities of unused agrochemical concentrates stored on farms have declined due to improved control and take back schemes.

It is estimated that the total quantity of waste sheep dip solution is 116,000 tonnes per year (Environment Agency, 2001). The spent sheep dip is typically spread to land. This requires authorisation from the Environment Agency. Approximately 11,000 authorisations had been issued at 2000. Unused sheep-dip concentrate is typically returned to the supplier.

Generally around 30% to 50% of farms recycle oils off-farm, with a quarter reusing the oil (Environment Agency, 2004). It is also stated that one in seven farms were burning waste oil for heating, or burning oils in the open. This will be banned under the proposed new Agricultural Waste Regulations.

Medicines

It is estimated that the total quantity of waste syringes and needles is around 46 tonnes per year (Environment Agency, 2001) and includes vaccines, antibiotics and mineral supplements. Each type of farming will have a different type and quantity of health waste arising.

Veterinary needles are most often returned to the vet. However it has been reported that one in seven practices dispose of them to the dustbin (Environment Agency, 2004). It is reported that some veterinary product waste is burnt, some buried and some included in the household waste collection (Environment Agency, 2001). Under the proposed new Agricultural Waste Regulations, veterinary waste will be classified as hazardous, which will have associated cost implications.

Glass waste arises from the packaging from the supply of medicines, and is estimated to be around 750 tonnes per year (Environment Agency, 2004).

General Building Waste

The general building waste that can be produced on farms includes bricks, concrete, metal and cement-bonded asbestos. No reliable data exists on quantities, but arisings are likely to increase in the future due to diversification and building conversion. An estimate of asbestos cement roof sheeting waste arisings is made in the Agricultural Waste Survey 2003 at around 33,600 tonnes per year. This is classed as a hazardous waste and is therefore a management issue.

Survey responses from farmers have shown that some building waste is buried on-site, where old quarries or suitable excavations exist (Environment Agency, 2001). The burial of waste onsite will be banned under the proposed new Agricultural Waste Regulations, unless the tips aquire a permit under the Pollution Prevention and Control Regulations (2000). Some building waste is re-used for farm tracks, with some re-use of asbestos sheeting reported. Long term storage with no plans for disposal is also common.

A1.3.3 Summary of Treatment and Disposal Methods

As discussed in the previous sections, the treatment and disposal of agricultural wastes varies according to the type of waste handled. The treatment and disposal routes currently employed for agricultural wastes are detailed in *Table A1.9*.

Table A1.9 Best Estimates of Agricultural Waste Management (Tonnes per Year)

Management Route	Manure[1]	Slurry[1]	Crop Residues[1]	Animal Tissue[1]	Animal Carcasses[1,4]	Plastics[2,4]	Paper[2,4]	Tyres and Other Machinery[2,5]	Chemicals[2,6]	Medicines[2,6]	Building Waste[2,6]
Land Spreading	40,460,000	42,370,000	6,360,000						116,000 (sheep dip) +92,300 (pesticides)		
Incineration with energy recovery			200,000								
Incineration without energy recovery				99,000	98,000	Unknown		7919		11,650	
Anaerobic Digestion[3]		50,000				Unknown					
Recycled on Farm						Unknown			23,000		11,201
Recycled off Farm						Unknown	1420	55,435	46,000	81,550	
Burnt for heating							874		23,000		
Buried on Farm					Unknown	Unknown				11,650	11,201
Stock Piled								15,839			
Included in Household Waste						Unknown	Unknown			11,650	
Landfilled						135,725	8634				11,201
Total	**40,460,000**	**42,370,000**	**6,560,000**	**99,000**	**98,000**	**135,725**	**10,914**	**79,193**	**300,300**	**116,500**	**33,602**

Notes:

1. Natural Waste arisings taken from Environment Agency 2004
2. Non- Natural Waste arisings taken from Environment Agency 2003, except chemicals from Environment Agency 2004
3. Data from Holsworthy Anaerobic Digestion plant
4. 'Unknown' shows where quantities of arisings are unknown due to qualitative nature of the surveys
5. Machinery estimates and disposal routes mainly from information regarding tyres due to qualitative nature of the surveys
6. With exception of Sheep dip, quantities are estimated due to the qualitative nature of the surveys

A1.3.4 *Agricultural Waste Composition*

Table A1.10 presents the assumed composition and properties of agricultural wastes. The carbon content for each waste fraction has been estimated using a common set of fractional components and carbon content estimates.

Table A1.10 Estimated UK Agricultural Waste Composition (2003/2004)

Waste Fraction	Thousand Tonnes Arising	% of Sector Arisings	% Carbon (Biogenic)[1]	% Carbon (Fossil)[1]	Gross Calorific Value (MJ/kg)[1]
Paper	10.9	0.01%	32%		12.6
Manure/Slurry/Other Organics [2]	83,027	92.0%	12.4%		5.7
Crop Residues	6,560	7.3%	17.3%		13.5
Chemicals	300.3	0.3%		38.4%[3]	15.6[3]
Medicines	116.5	0.1%	3.5%[4]	3.5%[4]	2.8[4]
Building Waste	33.6	0.05%	3.5%[5]	3.5%[5]	2.8[5]
Tyres and Other Machinery[6]	79.2	0.09%		45%	19.7
Plastic (Film)	135.7	0.2%		48%	23.6
Total	**90,263**	**100%**	**14%**	**0.3%**	**5.5**

Sources:

1. Environment Agency, 2004. Review of Agricultural waste research and development projects. Produced by Atkins
2. Environment Agency, 2003. Agricultural Waste Survey 2003: A study of the management of non-natural agricultural waste on farms. Environment Agency R&D Technical Report

Notes:

1. Carbon content and gross calorific value estimated from work carried out as part of the development of the WRATE LCA tool for waste management (ERM and Environment Agency data, 2003-2005)
2. Includes animal tissue and animal carcasses (0.1%)
3. Values for the waste fraction 'paint/varnish/herbicides&pesticides" have been used (ERM and Environment Agency data, 2003-2005)
4. Values for the waste fraction 'clinical waste' have been used (ERM and Environment Agency data, 2003-2005)
5. Values for the waste fraction 'miscellaneous non-combustible' have been used (ERM and Environment Agency data, 2003-2005)
6. Waste categories described as 'Tyres and Other Machinery' assumed to comprise 50% tyres and 50% WEEE waste.

A1.3.5 *Agricultural Waste Growth*

The report, 'Towards sustainable agricultural waste management' (Environment Agency, 2001), concludes that there is potential for reduction of some waste streams through improved farming practices (1).

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(1) http //www environment-agency gov uk/commondata/acrobat/toward_sust_ag_588593 pdf

A1.3.6 Agricultural Waste Future Management (1)

There is a legal obligation to implement the Waste Framework Directive (75/442/EEC, as amended) in the agricultural sector. The implementation of this Directive will mean that, from 2006, the on-farm disposal of waste packaging, plastic films and other 'non-natural' waste, including the burning of plastic waste, will no longer be allowed and alternative management routes will be required.

Note that the Directive will not apply to manures and other non-dangerous substances used on farms for agricultural benefit. This follows a recent court decision that manures and slurries are not classified as wastes when used as a fertiliser on agricultural premises (2).

The future management of agricultural waste will need an integrated strategy, although perhaps the most likely option for most farms will be to transfer waste to a registered waste contractor for disposal or recovery at a licensed facility. It is expected that the following methods of waste management will become more important:

- waste minimisation – it is easiest to persuade farmers to minimise their waste, since this will deliver cost savings;
- recycling schemes and take-back schemes by suppliers – this is the favoured option for dealing with plastic wastes and health care wastes. Defra are looking into the introduction of a national scheme for collecting and recycling non-packaging plastic waste;
- composting – this is a growing industry in the UK, and may be suitable for some agricultural wastes;
- landspreading – will continue to be available for the disposal of natural agricultural waste but is required to be properly controlled;
- energy recovery Schemes – schemes such as the burning of straw, poultry litter etc are becoming increasingly important, along with the collection of methane from other processes such as anaerobic digestion (AD);
- AD schemes – it has been recommended by the Biomass Task Force that the UK AD capacity is increased, even though is constrained by poor financial returns since most waste is spread to land. British Biogen (now merged with the Renewable Energy Association) has proposed a programme that aims to achieve the installation of 50 AD plant, 100 on-site agri-industrial AD plant and 500 on-farm AD plant by 2010. The on-farm AD plants will only be appropriate for large farms due to the large capital outlay required; and

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(1) Biffaward, 2002, Biffaward, 2003, Biomass Taskforce, 2005, Defra, 2004

(2) This includes when they are used on other agricultural premises that did not produce the manure and slurries

- stockpiled materials - one-off schemes are recommended for the recovery of stockpiled materials, such as scrap metal, tyres and asbestos.

A1.4 MINING AND QUARRYING WASTES

Mine and quarry waste includes materials such as overburden (useless material that overlies a bed of useful material), interburden (rock inter-bedded with the mineral) and residues left over from initial processing of the extracted material into saleable products. The majority of these wastes are either tipped locally, used for infilling prior to restoration of land, or re-used.

Wastes derived from mining and quarrying activities are comprised of approximately two-thirds quarrying, china clay extraction and colliery-derived waste and one third wastes from other clay extraction, coal mining wastes and chemical residues. *Table A1.11* shows estimates of minerals waste arising since 1992 for the six major categories of minerals waste. The overall trend shows waste arisings decreasing, predominantly due to the decline in UK collieries (deep-mined coal production) over this period. The decrease in waste arisings has stabilised over the last few years, but still shows some decline across the board.

Data have been sourced from Defra waste statistics, and originate from the 2002 volume of the United Kingdom Minerals Yearbook, compiled by the British Geological Society (British Geological Survey, 2002). Annual production data are collated by the British Geological Survey and are published in the United Kingdom Minerals Yearbook. All information sources are referenced in the Yearbook, however the principal sources of annual production data are:

- the Office of National Statistics (ONS) Annual Minerals Raised Inquiry (AMRI);
- the Aggregate Minerals Survey for England and Wales;
- the Quarry Products Association; and
- the Coal Authority.

Estimates for 2004 UK mineral production are provided in the revised, 2004 volume of the Minerals Yearbook and show a slight decline in production in comparison with 2003. However, the most complete dataset available remains that for 2003.

Minerals waste estimates have been derived based on the ratios of waste to product, as defined by Defra's Waste Statistics Division. It should be noted that mineral extraction processes differ significantly with respect to waste generation and vary from site to site. The arisings presented herein are very much estimates, therefore.

Table A1.11 UK Mineral Waste Arisings (estimated as a ratio to production) (Thousand Tonnes)

	1992	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
Colliery	32,900	25,229	15,927	17,575	16,112	15,141	12,543	10,444	8,594	8,674	8,196	7,818
Coal	9,347	8,871	8,559	8,944	9,292	9,107	8,094	8,095	7,005	7,292	6,799	6,300
China Clay	22,526	22,156	22,778	23,283	20,537	26,648	21,608	20,738	21,388	19,839	19,469	18,875
Clay	15,172	13,799	15,174	16,725	14,507	13,791	14,110	13,560	13,096	12,352	12,114	12,041
Slate	6,520	9,240	8,040	5,500	8,180	6,940	9,000	7,220	9,580	11,020	14,840	18,000
Quarrying	38,525	39,464	42,115	40,769	39,039	37,541	25,602	36,530	36,223	36,897	34,190	33,849
Total	**124,990**	**118,759**	**112,593**	**112,795**	**107,666**	**109,167**	**90,957**	**96,586**	**95,886**	**96,073**	**95,608**	**96,882**

Source: Defra e-Digest of Environmental Statistics, Published August 2003, Defra

Notes:

- Colliery waste estimate is based on deep-mined coal assuming a ratio of waste to saleable product of 1:2
- Coal waste is based on opencast and other coal production and is also based on a 1:2 ratio.
- China clay waste is estimated on the ratio of waste to saleable product of 9:1
- Clay waste is estimated on the ratio of waste to saleable product of 9:1
- Slate waste is estimated on the ratio of waste to saleable product of 20:1
- Quarrying waste is estimated on the ratio of waste to saleable product of 1:9
- Figures are provisional for 2003.

A1.4.1 Mining and Quarrying Waste Composition

Mining and quarrying wastes are assumed to consist of top and sub-soils, rock and soil overburden and interburden and primary processing wastes. The majority of these materials will have a relatively low carbon content and calorific value. For example, work carried out as part of the Environment Agency's development of the WRATE tool reports non-combustible mineral materials, such as bricks, plaster and soil, to have a carbon content of 7% and a gross calorific value of 2.8 MJ/kg.

Some minerals and their wastes may contain carbon fixed in carbonates, or appreciable organic content, for example associated with coal seams or peat. In the absence of further, reliable information, however, it will be assumed that mining and quarrying wastes have similar properties to those reported for non-combustible materials and that proportions of biogenic carbon (in soils) to fossil carbon (in rock/mineral) will be 50:50.

It is a further point of note that the carbon contained within these materials will not be emitted unless the material is subjected to intentional or unintentional roasting or combustion. As such, these materials are likely to have only a minimal direct impact in terms of greenhouse gases. Of greater significance will be assumptions regarding fuel and transport requirements in their management.

A1.4.2 Mining and Quarrying Waste Management

There are no definitive statistics available regarding mineral waste management, as individual mines and quarries will manage wastes according to local conditions.

In most mineral workings, extraction wastes are deposited in tips and lagoons. In some workings, at least part of the tipped material may be returned to the void as part of the restoration landscaping scheme (with or without other wastes brought onto the site). In a few cases, notably opencast coal extraction, the amount of waste is large compared with the product and the void is refilled and restored close to original ground levels.

In practice, it is normally required that the topsoil and subsoil are stored temporarily and then used in reinstating the site. Some over and interburden and processing wastes may in some circumstances be saleable products. In other cases, they may remain in tips/lagoons or be returned to the void depending on local circumstance and requirements (1).

For the purposes of this study, it has been assumed that 1% of mineral materials are recycled, 50% of remaining minerals are used as void fill, 50% of remaining minerals are deposited in tips on site and 100% of soils are used as void fill.

A1.4.3 Mining and Quarrying Waste Growth

According to the British Geologcial Survey's 2004-2005 annual report (2), it is becoming increasingly challenging to locate areas of the UK which contain high-grade, economically-viable minerals and which can be consensually worked in line with modern principles of planning and sustainable development.

This might imply that mining operations in the UK may decrease over the long-term. However, no definitive statistics are available and, while some minerals are now significantly constrained by environmental designations, many are widespread in occurrence and sites will be identified for the foreseeable future (eg aggregates, industrial limestone, brick clays, building and roofing stone) (3).

A1.5 SEWAGE SLUDGE

Sewage sludge is an inevitable by-product of sewage treatment. It is produced at sewage works as a thick, odorous liquid containing around 4% solid matter (Water UK, 2005).

This waste stream is formally defined by the European Commission in the Urban Wastewater Treatment Directive (UWWTD) as *Sludge from urban waste water treatment plants, whereby 'urban waste water' is understood as: "domestic waste water or the mixture of domestic waste water with industrial waste water and/or run-off rain water"* (Directive 91/271/EEC).

The definition of 'domestic waste water' in the Directive reads:

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(1) Brian Marker, ODPM, pers comm

(2) [redacted]

(3) Brian Marker, ODPM, pers comm

"waste water from residential settlements and services which originates predominantly from the human metabolism and from household activities".

Water UK monitor sewage sludge arisings and management as an indicator of the extent to which the water industry takes the opportunity to reuse the main by-products of its treatment operations, water treatment sludge and sewage sludge. In 2003/04, approximately 1.3 million tonnes of sludge (dry weight) was produced as a result of treating drinking water and sewage. 77.3% of sewage sludge and 71% of drinking water sludge was recycled on agricultural land, reaching a combined recycling rate of 77% (Water UK, 2005) (1).

Historical data regarding sewage sludge arisings and disposal are presented in *Table A1.12* and *Table A1.13*. When compared against Water UK's 2004 estimate, these data show that there has been a increase, albeit not significant, in arisings for this waste stream over the last 15 years. Further, an Envrionment Agency survey carried out in 1999 (Gendebien *et al*, 1999) predicted that sludge production in the UK would reach 1.22mt (dry weight) by 2005, as a result of the implementation of the UWWTD. Water UK's current figures show that this predicted increase has been surpassed.

The Environment Agency survey further considered that the increase in sludge arisings would be accommodated by use in agriculture or by incineration. *Table A1.13* accordingly shows that agricultural and incineration disposal routes have increased significantly. The amount of sewage sludge disposed of at sea decreased by 41% between 1997/98 and 1998/99 and disposal of sewage at sea ceased altogether at the end of 1998 as a result of the UWWTD. Incineration is now the second largest disposal route.

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(1) Data on sewage sludge are complete for the UK Data on water treatment sludge are from operators that serve about 85% of the UK population Overall confidence in the data set is medium/high

Table A1.12 Estimated UK Sewage Sludge Arisings (Thousand Tonnes Dry Weight)

Administration	**1990/91**	**1991/92**	**1992/93**	**1993/94**	**1994/95**	**1995/96**	**1996/97**	**1997/98**	**1998/99**	**1999/00**	**2001**	***2002***	**2003**	**2004**
England and Wales	945	945	907	902	916	993	942	873	936	999	-	*1,191*	-	-
Scotland	80	100	80	80	90	93	105	98	97	97	-	-	-	-
N.Ireland	27	27	32	32	33	34	31	34	25	34	-	-	-	-
												-	-	
Total	**1,052**	**1,072**	**1,019**	**1,014**	**1,039**	**1,124**	**1,079**	**1,005**	**1,058**	**1,130**	**1,123**	**-**	**-**	**1,334**

Sources 1990/91-1999/00: Water UK (Water Companies; Scottish Executive; DOE (NI) Water Service), e-Digest of Environmental Statistics, Published August 2003, Defra

Notes:

- Information on sewage sludge arisings and disposal in 1990/91 was obtained on a dry weight basis in a UK-wide survey of the sewerage authorities.
- Value for 1989/90 estimated from wet sludge data assuming uniform solid content. The methodology used for this estimate was not used in subsequent years. This estimate is now looked upon as an overestimate.
- No data collected in 1991, therefore 1990 figure is used as a best estimate for 1991.
- No data collected in 1993 or 1994, therefore 1992 figure is used as a best estimate.
- Data are estimated for 1989/90.

Sources 2001-2004: Water UK, Sarah-Jane Hadlow, personal communication 2005-12-19.

Notes:

- Only data for England and Wales are included for 2002.
- No data collected for 2003.

Table A1.13 UK Disposal of Sewage Sludge (Thousand Tonnes Dry Weight)

Fate	**1991/92**	**1992/93**	**1993/94**	**1994/95**	**1995/96**	**1996/97**	**1997/98**	**1998/99**	**1999/00**	**2000**	**2001**	***2002***	**2003**	**2004**
Farmland	507	482	502	504	548	535	525	504	587	610			-	
Agriculture											690	*701*	-	818
Industrial crops											47	*46*	-	60
Landfill	123	130	104	123	115	97	75	115	192	102	62	*64*	-	15
Sea disposal	279	274	270	263	254	264	258	150	-	-			-	
Incineration	69	72	84	72	82	88	81	185	237	282	211	*269*	-	243
Compost											6	*5*	-	16
Land reclamation											106	*93*	-	150
Cement manufacture													-	12
Other	94	61	54	77	125	95	67	105	113	135		*13*	-	20
													-	
Total	**1,072**	**1,019**	**1,014**	**1,039**	**1,124**	**1,079**	**1,005**	**1,058**	**1,130**	**1,130**	**1,123**	***1,191***	**-**	**1,334**

Sources 1991/92-2000: Water UK (Water Companies; Scottish Executive; DOE (NI) Water Service), e-Digest of Environmental Statistics, Published August 2003, Defra, ENDS 2001.

Notes:

- ‘Other’ includes beneficial uses for land reclamation and forestry and soil and compost products.
- Totals may not add up due to rounding.
- Figures for 1999/00 and 2000 taken from estimated percentages based on ENDS 2001 report "Sewage sludge disposal outlets" and based on arisings estimates for 1999/00.

Sources 2001-2004: Water UK, Sarah-Jane Hadlow, personal communication 2005-12-19.

Notes:

- Only data for England and Wales are included for 2002.
- No data collected for 2003.

A1.5.1 Sewage Sludge Composition

Sewage sludge composition varies depending on catchment. Typical carbon content will also vary according to moisture content. Data collated as part of the Environment Agency's development of WRATE estimated the biogenic carbon content of dry sewage sludge to be 30.9% and gross calorific value to be 12 MJ/kg.

A1.5.2 Growth in Sewage Sludge Arisings

Legislation

Growth of sewage sludge arisings has historically been directly correlated to changes in sewage treatment standards. In the early 1990s, the EC Bathing Water Directive was transposed into national legislation through Regulations and Directions, leading to increased treatment standards for the UK. The Urban Waste Water Directive was transposed into legislation across the UK in 1995, leading to further increases in treatment standards. Historical data regarding sewage sludge arisings are presented in *Table A1.12* and *Table A1.13* and show a significant increase in arisings since the late 1990s, in accordance with tighter regulations.

The latest piece of legislation potentially having an impact on treatment standards for sewage sludge is the Water Framework Directive, which came into force in 2000. Defra note that the Water Framework Directive is the most substantial piece of EC water legislation to date. It requires all inland and coastal waters to reach "good status" by 2015 (1).

Growth estimate by the water industry

In 2004 , he water industry supplied Defra with an estimation of total sludge available for disposal in 2010, in order to help Defra collate the Regulatory Impact Assessment for the forthcoming consultation on the Sludge (Use in Agriculture) Regulations. Nine of the ten main water and sewerage companies supplied data in response. The total estimated sludge arisings in 2010 were 1,428,400 tonnes dry weight per year (2), corresponding to a 7% increase in comparison with arisings in 2004.

A1.5.3 Future Sewage Sludge Management

The dominating and increasing use of sewage sludge has historically been on farmland (see *Table A1.13*). This corresponds with information sourced from UK water companies (outlined in the following sections). Concerns are expressed, however, that future legislation and public perception may restrain the use of sewage sludge on farmland.

The use of sewage sludge in agriculture has, in some European countries, decreased due to protection of soils and health concerns. As an example, the

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(1) http //www defra gov uk/environment/water/wfd/

(2) Sarah-Jane Hadlow, Water UK E-mail 2005-12-19

use of sewage sludge in agriculture has been banned altogether in Switzerland, a favour of incineration with energy recovery as the waste management treatment option (Federal Administration, Switzerland, 2003).

The Sewage Sludge Directive 86/278/EC regulates the use of sewage sludge in agriculture. Restrictions on heavy metal content and receiving land type are given in the Directive. A proposed revision of the Directive intends to (1):

- broaden its scope to include a wider range of sludges and receiving land types;
- result in a diversion into other treatment/disposal options; and
- require the development of more advanced technologies in the long term.

The Defra Waste and Resources Research Advisory Group working paper (2004) discusses the potential implications of revisions to the Directive (2):

"(…) The UK already has a strong voluntary code of practice in place but will come under pressure from lobby groups concerned about pathogen content. Market forces from food retailers and manufacturers also discourage sludge spreading. If this becomes a high profile issue more sludge may end up being diverted to landfill or incineration. (…)"

There are ten main water and sewage operators in the UK. The following sections summarise thoughts on future sewage sludge management for three of the largest operators.

Thames Water (3)

Thames Water processed 245,584 tonnes (dry solids) of sewage sludge in 2004, corresponding to approximately one fifth of the total UK arisings.

Sewage sludge disposal is one of the sustainability indicators that Thames Water report on. The target for 2004 was to put 100% of sewage sludge to beneficial use, which was achieved through use in agriculture (57%), incineration with energy recovery (32%), industrial crops (5%), land restoration (5%), and composting (1%). The target for 2005 is again 100% put to beneficial use.

Severn Trent(4)

In 2004, Severn Trent Plc undertook a carbon management project, with the support of the Carbon Trust. The Carbon Management Report was launched in 2005, which produced a scenario projecting the group's net UK greenhouse gas emissions to 2020. The future of sludge arisings and sludge waste management is discussed in the report, and summarised below.

(1) CIWM webpage 2005-12-16
[redacted]

(2) Defra (2004) Background Info Future legislative drivers on waste and resource management
http //www defra gov uk/environment/waste/wip/research/wrrag/papers/drivers-background pdf

(3) [redacted]

(4) [redacted]

The greenhouse gas emissions associated with sludge treatment are projected to decrease from the current baseline of 8000 tonnes CO_2/year to -6000 tonnes CO_2/year in 2020. This decrease is explained by business decisions to increase the percentage of methane that is captured/utilised from landfills and sewage treatment works, and by decisions to increase the percentage of methane utilised in CHP plant to generate electricity.

Projected policy drivers are also considered to decrease the greenhouse gas emissions. According to the study, the quantity of sludge requiring treatment will increase by 20%, which in turn will increase the amount of methane from sludge digestion. This methane can be used for renewable energy generation.

Concerns are expressed in the report regarding the consequence of possible stricter legislation on the use of sewage sludge, possibly ending the use of sewage sludge on farmland.

Anglian Water (1)

Anglian Water details in their Monitoring Plan 2005-2010 commitments for service and quality improvements. For sewage sludge, use in agriculture is planned to continue. However, concerns are expressed on potential loss of agricultural disposal routes due to public attitudes to food production.

A1.6 DREDGED MATERIALS

Dredged spoils consist of the sediments left over from dredging aggregates and through maintenance and capital dredging activities. CEFAS defines this waste stream as "the material generated when dredging ports, harbours, rivers and approach channels".

A1.6.1 Dredged Material Arisings

Marine Dredging

Harbour Authorities, port and marina operators, dredging companies, developers, the marine aggregate industry and others carry out a variety of dredging operations including:

- maintenance dredging - removal of accumulated sediments from harbour channels and berths to ensure a safe depth of water for navigational purposes, to restore an adequate flow of water to mitigate risk of flooding or to protect a sensitive habitat;

- capital dredging - excavation of material to deepen or create navigational channels and berths, to provide additional harbour infrastructure or during construction works at sea; and

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(1) [redacted]

- extraction - of sands and gravels (marine aggregates) to provide material for construction works and for 'soft engineered' sea defences and beach replenishment.

Waste from marine sand extraction is difficult to quantify. However, it is returned to the sea and hence never becomes a waste issue. Sea movements (coastal drift and tide) are also likely to redistribute any discarded fine material back in to the location, and fill voids left through extraction.

The majority of material from UK capital and maintenance dredging is also disposed of at sea, at a number of licensed disposal sites. *Table A1.14* shows the amounts of dredged materials dumped at sea in the UK between 1996 and 2003 and that they are extremely variable over this time, dependent on when dredging activities occur.

Table A1.14 UK Marine Dredged Materials (Thousand Tonnes)

	1996	1997	1998	1999	2000	2001	2002	2003
Total amount dumped (wet weight)	51,251	41,241	35,724	56,821	33,053	-	-	-
Total amount dumped (dry weight)	27,235	22,333	17,359	32,828	16,567	20,768	39,758	23,114

Source 1990-2000: CEFAS, e-Digest of Environmental Statistics, Published August 2003, Defra
Source 2001-2003: CEFAS, Marie Pendle, personal communication 2005-12-19.

Inland Waterways

Dredging activities are further carried out on inland waterways as part of routine maintenance works by water authorities. In 2002/03, approximately 84,000 tonnes of material was dredged from waterways in the UK (1).

Dredging spoils from inland waterways are usually disposed of in lagoons where excess water drains, although some sands and silts can be removed for reuse as construction materials.

There are three large publicly-funded navigation authorities operating in Great Britain: British Waterways; the Environment Agency; and the Broads Authority. British Waterways manage more than 70% of Great Britain's inland dredging operations. The remaining 30% are handled by the Environment Agency, Broads Authority and around 20 other operators, including local authorities, national park authorities, drainage commissioners, port and harbour authorities and original canal companies (2)(3).

Collated information relating to all inland dredging operations is currently unavailable. However, it is assumed that data provided by British Waterways are representative for dredging operations throughout the UK, given that this authority manages a significant proportion of all dredged materials. Waste

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(1) British Waterways Facts & Figures [redacted]

(2) The Association of Inland Navigation Authorities (AINA) Philip Burgess, psonal communication 2005-12-14

[redacted]

arisings data provided by British Waterways have been scaled accordingly in order to generate a total for the UK.

Data relating to inland dredging arisings are summarised in *Table A1.15*. Discussion with British Waterways revealed that the amount of material dredged varies significantly year-by-year and is difficult to predict. A large proportion of sands and gravels are recycled as aggregate. There are four predominant disposal routes for the remaining materials:

- deposited onto banks and in bankside lagoons;
- spread on agricultural land;
- disposed in British Waterways-owned licensed facilities; and
- sent to commercial landfill sites, following pre-treatment (eg with lime, pulverised fuel ash (PFA) or cement).

Table A1.15 Inland Dredged Material Arisings (Thousand Tonnes).

	1999/00	2000/01	2001/02	2002/03	2003/04
Rivers dredged	12.8	365		149.6	194.7
Contamination removed from channels	19.1	0.22		170	50.2
Total British Waterways	**31.8**	**366**		**320**	**245**
Total UK¹	**45.5**	**523**	**-**	**457**	**350**

Source: British Waterways. Paul Beckwith, personal communication 2005-12-22.
No data available for 2001/02.
1. Scaled up from British Waterways figure. British Waterways are handling 70% of the inland dredging operations

A1.6.2 Dredged Materials Composition, Growth and Future Management

Marine Dredging (1)

Detailed information relating to the composition of materials dredged at sea are currently unavailable, with the exception of heavy metal content, which is monitored by CEFAS. Given its origin, it is reasonable to assume that the waste material consists predominantly of sand, silts and minerals, with a relatively low carbon content.

CEFAS has been tracking the quantities marine dredged materials arising for many years, but no trends are apparent in historical arisings data. This, together with the intermittent and unpredictable nature of dredging operations, makes it difficult to make any estimation of future change in arisings. However, CEFAS note a trend towards the use of larger ships, necessitating large capital dredging projects at many ports around the country.

There are a number of factors which may affect the future of sea disposal for maintenance dredging. In particular, consideration is now being given to sediment budgets and sea level rise in estuarine habitats. Soft engineering approaches to flood defence, bolstering extant mudflats, salt marshes or

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(1) CEFAS, Marie Pendle, personal communication 19/12/2005

beaches with suitable dredged material are becoming more commonplace. However, no strong predictions can be given as to the balance, or consequence, of these factors can be made.

Further detail regarding marine dredging composition and future management potential was not available within the timescale of this project. A simplistic assumption was made that 50% of marine dredgings are sand and 50% are silt. It was assumed that all marine dredgings would be disposed at sea.

Inland Dredging

As earlier noted, discussions with British Waterways revealed that the amount of material dredged from inland waterways varies significantly year-by-year and, as such, is difficult to predict. The quantities of material arising are dependent on the type and extent of dredging activities to be undertaken. British Waterways have indicated that their dredging budget will increase from £2.5 million in 2004/04 to £7 million in 2005/06 (1). This is likely to correlate with an increase in dredged material arisings. However, beyond 2005/06, a prediction of trends cannot be made.

Further detail regarding inland dredging composition and future management potential was not available within the timescale of this project. A simplistic assumption was made that 50% of inland dredgings are sand and recycled as aggregate and 50% are silt, disposed of in landfills, was made.

A1.7 MUNICIPAL SOLID WASTE (MSW)

Municipal waste includes all waste under the control of local authorities, or agents acting on their behalf. This encompasses all household waste, street litter, waste delivered to council recycling points, municipal parks and gardens wastes, council office waste, civic amenity site waste and some commercial waste from shops and smaller trading estates where local authority waste collection arrangements are in place (*Waste Strategy 2000* for England and Wales).

A1.7.1 Municipal Waste Arisings

Published data relating to municipal waste arisings in each of the UK's devolved administrations are relatively complete.

England

The 2003/04 Municipal Waste Management Survey for England and Wales was published by Defra in July 2005. The survey collates municipal waste arisings, management and composition data from waste authorities across the UK. The response rate to the survey is high, enabling relatively accurate

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(1) British Waterways, Nick Smith, personal communication 21/12/2005

national estimates to be made. For the 2003/04 survey, 96% of authorities returned a questionnaire.

Table A1.16 shows estimated arisings of household and municipal waste in England from 1996/97 to 2003/04, based on the Municipal Waste Management Survey results. Some of the key results of the survey were:

- the total amount of municipal waste has fallen slightly to an estimated 29.1 million tonnes in England in 2003/04 compared to 29.4 million tonnes in 2002/03, a decrease of 1.0%. This was the first time, in recent years, that the statistics have shown a reduction in municipal waste arisings;

- the proportion of municipal waste being disposed of at landfill has continued to fall from 75% in 2002/03 to 72% in 2003/04. The actual tonnage of waste being disposed of in this way has also decreased, from 22.1 million tonnes to 20.9 million tonnes following the previous years' fall;

- approximately 8.1 million tonnes (28%) of municipal waste had some sort of value (recycling, composting, energy recovery, RDF manufacture) recovered from it in 2003/04. This represents an increase from 7.3 million tonnes (or 24.7%) in 2002/03;

- around 87% of municipal waste comes from households, a total of 25.4 million tonnes in 2003/04 and a 1.5% reduction on the previous year. This represent 1.2 tonnes of waste per household per year;

- the household recycling rate increased to 17.7% in 2003/04, up from 14.5% in 2002/03;

- the proportion of households served by 'kerbside' collection schemes has increased to 79%. The amount of waste collected for recycling through such schemes has increased by 52% compared to the previous year, to 1.9 million tonnes in 2003/04. Almost all authorities collected some waste for recycling through kerbside schemes; and

- waste for composting remained the most commonly collected material for recycling, with 1.4 million tonnes collected (30% of the total recycling) in 2003/04. Paper and card was the next most commonly collected (28%, 1.3 million tonnes).

Table A1.16 Management of Municipal Waste in England (Thousand Tonnes)

Method of Management	**1996/97**	**1997/98**	**1998/99**	**1999/00**	**2000/01**	**2001/02**	**2002/03**	**2003/04**
Landfill	20,635	21,798	21,517	21,963	22,039	22,421	22,068	20,936
Incineration with energy recovery	1435	1573	2139	2302	2391	2438	2600	2596
Incineration without energy recovery	619	61	17	8	20	9	7	8
RDF manufacture	148	167	131	106	67	84	87	12
Recycled/composted	1751	2068	2523	3097	3446	3921	4572	5528
Other	0	45	10	4	95	32	59	26
Total	**24,588**	**25,711**	**26,337**	**27,480**	**28,057**	**28,905**	**29,394**	**29,106**

Source: Municipal Waste Management Survey, Published July 2005. Defra

Notes: 'Other' treatment and disposal processes are unspecified but exclude any processing prior to landfilling and materials sent to Materials Reclamation Facilities (MRFs).

Wales

Summary results from the Environment Agency's 2003/04 Municipal Waste Management Survey for Wales were published in October 2004. *Table A1.17* shows estimated arisings of household and municipal waste in Wales from 1996/97 to 2003/04. Some of the key results of the survey were:

- the total amount of municipal waste arising in Wales in 2003/04 was 1.83 million tonnes, up from 1.79 million tonnes in 2002/03. This represents an increase of 2%;

- waste from household sources in Wales (1.52 million tonnes) accounted for 83% of municipal waste in 2003/04;

- excluding abandoned vehicles, the proportion of municipal waste being recycled or composted increased from 12.7% in 2002/03 to 17.6% in 2003/04;

- excluding abandoned vehicles, the amount of municipal waste which was recycled or composted increased by 41% from around 226,000 tonnes in 2002/03 to 319,000 tonnes in 2003/04. In particular, the amount of municipal waste being composted increased by 56% from around 71,000 tonnes in 2002/03 to 111,000 tonnes in 2003/04; and

- excluding abandoned vehicles, the amount of municipal waste which was landfilled decreased by 3% from 1.55 million tonnes in 2002/03 to 1.50 million tonnes in 2003/04.

Table A1.17 Management of Municipal Waste in Wales (Thousand Tonnes)

Method of Management	1996/97	1997/98	1998/99	1999/00	2000/01	2001/02	2002/03	2003/04
Landfill	Not detailed		1472	1515	1537	1573	1547	1496
Incineration	Not detailed		-	-	-	-	-	-
Recycled	Not detailed		67	86	96	107	155	208
Composted	Not detailed		8	23	19	37	71	111
Total	**1391**	**1455**	**1547**	**1624**	**1652**	**1717**	**1773**	**1815**

Source: Municipal Waste Management Survey, Published October 2005. Department for Environment, Food and Rural Affairs.

Note: Municipal waste reported here refers to household waste plus waste collected from non-household sources. Abandoned vehicles are excluded.

Scotland

SEPA publishes an annual Waste Data Digest of data collected on controlled waste in Scotland. It deals with waste arisings, recovery and disposal and with waste-related operational activities. Information from Scottish local authorities on their recycling, composting and waste disposal activity is collated every three months and available in the Quarterly Recycling/ Composting Returns.

The Local Authority Waste Arisings Survey (LAWAS) is the main source of municipal waste data routinely collected by SEPA. The survey collects data on wastes collected by, or on behalf of, Scottish local authorities and is completed annually on a voluntary basis by Scotland's 32 local authorities. The survey has run successfully since April 2001.

The data presented below are based on the returns provided for the Local Authority Waste Arisings Survey (LAWAS) 2003/2004. All 32 Scottish local authorities responded to SEPA's 2003/2004 LAWAS. In 2003/2004, a total of 3.32 million tonnes of controlled wastes were collected by, or on behalf of, local authorities in Scotland.

Table A1.18 Management of Municipal Waste in Scotland, 2003/2004 (Thousand Tonnes)

Management Route	Proportion of Arisings (thousand tonnes)
Disposal: Landfill	2830
Disposal: Energy from Waste	70
Recycling and Composting	420
Total	**3320**

Source: SEPA (2005) Waste Data Digest 5.

[redacted]

Northern Ireland

In January 2002, the EHS commissioned MEL Research and Envirocentre Ltd to carry out the Waste Arisings Survey Phase III, consisting of a census of District Councils on municipal waste and a survey of industry and commerce.

Table A1.19 shows the estimated arisings resulting from the municipal survey, supplemented with data collected as part of more recent Key Performance Indicator reports from District Councils (ERM, 2005). The data show a progressive increase in household waste and household waste recycling from 1998/99 to 2003. However, over the period 2001-2003, there has been in a decline in overall municipal waste arisings, resulting from a decline in local authority commercial and industrial waste collections. It should be noted that this does not necessarily reflect a reduction in waste production *per se*, merely that the commercial and industrial waste formally catergorised as municipal waste may have entered the commercial or industrial waste streams, as described in *Section A1.8*.

Table A1.19 Municipal Waste Arisings in Northern Ireland 1998/99-2003 (Thousand Tonnes)

	1998/99 (1)	**1999/00 (1)**	**2001 (1)**	**2002(2)**	**2003 (2)**
Household waste	868	869	879	913	925
Household waste recycling and composting (%)	5.9	6.4	8.9	10	12
C&I waste	88	159	135	118	101
Total Municipal waste	**960**	**1004**	**1056**	**1031**	**1027**

Sources:

- (1) Environment and Heritage Service Waste Arisings Survey Phase III (2002). MEL Research and Envirocentre Ltd
- (2) KPI reports of the District Councils. Source publication: Assessment of the Best Practicable Environmental Option for Waste Management in Northern Ireland: Development and Analysis (ERM 2005)

Table A1.20 further shows a more detailed breakdown of municipal waste arisings and management across Northern Ireland in 2003.

Table A1.20 *Northern Ireland Waste Treatment and Disposal Methods 2003 (Tonnes)*

Waste Stream	**Landfilled**	**Recycled (via MRF)**	**Recycled (direct to reprocessor)**	**Composted**	**Total**
Household	589,850	279	0	0	590,129
Bulky household waste	18,528	0	133	0	18,661
Household clinical waste	151	0	0	0	151
Garden waste (not composted)	0	0	128	0	128
Street cleansing and litter	39,710	0	0	157	39,867
Kerbside collection of recyclables	537	3130	4738	490	23,641
Kerbside collection compostables	0	0	0	7670	7670
Civic Amenity sites	172,960	2193	3514	42,579	257,236
Other bring recycling schemes	7054	253	1965	419	14,088
Municipal parks/gardens waste	3183	0	0	217	3400
Fly-tipped waste clearance	1353	0	0	0	1353
Commercial or Industrial waste	61,295	186	351	0	63,147
Third parties / voluntary groups	3168	0	5	239	3412
Other sources (unspecified)	3728	0	68	0	3796
Total municipal waste	**901,517**	**6040**	**10,902**	**51,771**	**1,026,679**

Source: KPI reports of the District Councils. Source publication: Assessment of the Best Practicable Environmental Option for Waste Management in Northern Ireland: Development and Analysis (ERM 2005)

Total UK

Combining national datasets results in a total estimated 35.3 million tonnes of municipal waste arisings in 2003/04. A breakdown of the routes by which wastes were managed is shown in *Table A1.21*.

Table A1.21 *Total Municipal Waste Arisings UK 2003/04 (Thousand Tonnes)*

Management Route	**England**	**Wales**	**Scotland**	**Northern Ireland**	**Total**
Landfill	20,936	1496	2830	902	26,164
Recycled/composted	5528	319	420	125	6392
Incineration	2604	0	70	0	2674
Other (unspecified)	38	0	0	0	38
Total	**29,106**	**1815**	**3320**	**1027**	**35,268**

Sources:

- Municipal Waste Management Survey for England and Wales (2005). Department for Environment, Food and Rural Affairs.
- SEPA (2005) Waste Data Digest 5. [redacted]
- Assessment of the Best Practicable Environmental Option for Waste Management in Northern Ireland: Development and Analysis (ERM 2005)

A1.7.2 *MSW Composition*

Estimates of municipal waste composition vary in detail according to national datasets available. The most complete dataset relating to total MSW (household and non-household wastes) derives from the National Assembly for Wales and is presented in *Table A1.22*.

Table A1.22 Estimated MSW Composition in Wales

Waste Fraction	% of Municipal Waste	Thousand Tonnes (2003/04 Arisings in Wales)
Paper and card	21%	381
Plastic film	3%	51
Dense plastic	5%	82
Textiles	2%	33
Absorbent hygiene products	2%	42
Wood	3%	51
Other combustibles[1]	7%	127
Non-combustibles	8%	145
Glass	6%	105
Ferrous metal	5%	85
Non-ferrous metal	1%	15
Kitchen waste	18%	323
Green waste	13%	231
Fine material <10mm	5%	94
Waste Electrical and Electronic Equipment	2%	36
Specific Hazardous Household Waste Items (including all batteries)	1%	15
Total	**100%**	**1815**

Source: Adapted from: *The Composition of Municipal Waste in Wales*. National Assembly for Wales (NAW)/AEAT Technology - December 2003. Data as used in the ERM/Environment Agency update to the WISARD software tool.

Notes:

1. includes furniture

The Northern Ireland Environment and Heritage Service have also carried out municipal waste compositional analyses. *Table A1.23* shows the composition used in the assessment of best practicable options for waste management in Northern Ireland. It includes a compositional estimates for household, civic amenity and municipally-derived trade waste.

Table A1.23 Estimated MSW Composition in Northern Ireland

Waste Fraction	**% of Municipal Waste**	**Thousand Tonnes (2003/04 Arisings in Northern Ireland)**
Paper and card	18.2%	187
Kitchen waste[1]	19.8%	204
Green waste[1]	14.2%	145
Textiles	1.8%	19
Fines	5.4%	56
Absorbent hygiene products[2]	2.3%	24
Wood[2]	2.8%	29
Other combustibles[2]	7.1%	73
Non-combustibles	6.0%	62
Ferrous metal	3.7%	38
Non-ferrous metal	0.9%	9
Glass	6.6%	68
Plastic dense	5.3%	54
Plastic film	3.0%	31
Waste Electrical and Electronic Equipment[3]	2.0%	21
Specific Hazardous Household Waste Items (including all batteries) [3]	0.8%	8
Total	**100%**	**1027**

Sources:

- Towards Resource Management (EHSNI, 2005), Annex 2 "Waste stream summaries"
- Assessment of the Best Practicable Environmental Option for Waste Management in Northern Ireland: Development and Analysis (ERM 2005)

Notes:

1. Proportional split between organic kitchen and green waste unknown. Assumed to be equivalent to that estimated for Wales in '*The Composition of Municipal Waste in Wales*. National Assembly for Wales (NAW)/AEAT Technology - December 2003'.

2. Proportional split between combustible materials (wood, absorbent hygiene products and 'other' (including furniture) unknown. Assumed to be equivalent to that estimated for Wales in '*The Composition of Municipal Waste in Wales*. National Assembly for Wales (NAW)/AEAT Technology - December 2003'.

3. Quantity of WEEE and hazardous material unknown. Assumed to be equivalent to that estimated for Wales in '*The Composition of Municipal Waste in Wales*. National Assembly for Wales (NAW)/AEAT Technology - December 2003' and proportion of miscellaneous non-combustibles was adjusted accordingly.

Data relating to municipal waste composition are more limited for England and Scotland. Estimates relating to collected household waste composition are available, but data are limited regarding the composition of other household wastes (litter, street sweepings, bulky wastes) and non-household elements of the municipal waste stream. In the absence of this information, and in order to derive a representative picture of waste composition across the UK, a number of assumptions were made regarding the composition of these sub-streams. On the majority of occasions, assumptions were based on estimates derived from the National Assembly for Wales study, as this provides detail on the range of municipal waste sub-streams. Resulting estimates, together with all assumptions made are shown in *Table A1.24* and *Table A1.25*.

Table A1.24 Estimated MSW Composition in England

Waste Fraction	**% of Household Collected Waste[a]**	**% of Other Household Sources[b]**	**% of CA Site Waste (Residual) [c]**	**% of Non-household Sources (residual)[d]**	**% of Total Recycling[e] (Household and Non-household)**	**Total MSW (Thousand Tonnes, 2003/04 Arisings)**	**% of Total MSW**
Paper and card	19.8%	12.5%	3.3%	7.4%	28.7%	5234	18.0%
Plastic film	4.4%	3.0%	0.4%	0.9%	0.0%	780	2.7%
Dense plastic	5.2%	5.9%	1.1%	1.6%	0.3%	1012	3.5%
Textiles	3.3%	0.7%	2.3%	0.2%	1.3%	703	2.4%
Absorbent hygiene products	3.3%	0.4%	2.9%	0.4%		650	2.2%
Wood	3.0%	2.5%	11.2%	0.1%		918	3.2%
Other combustibles[1]	0.3%	17.9%	4.2%	0.5%		433	1.5%
Non-combustibles	1.6%	1.5%	17.5%	55.3%	22.0%[4]	3574	12.3%
Glass	7.0%	3.0%	1.0%	0.6%	12.8%	1934	6.6%
Ferrous metal	2.2%[2]	3.3%	0.001%[2]	0.9%	0.8%	469	1.6%
Non-ferrous metal	0.6%	1.4%	0.041%	0.2%	0.2%	125	0.4%
Kitchen waste	25.6%[3]	12.8%	14.8%	7.1%	0.3%	5016	17.2%
Green waste	16.0%	7.7%	32.1%	14.5%	25.2%	5601	19.2%
Fine material <10mm	4.1%	16.9%	1.2%	10.0%		1176	4.0%
Waste Electrical and Electronic Equipment	3.0%	10.2%	6.2%	0.2%	8.4%	1305	4.5%
Hazardous Household Waste Items (inc. batteries)	0.7%[5]	0.2%	1.7%[5]	0.1%		180	0.6%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**29,109**	**100%**
Arisings ('000 Tonnes)	**16,071**	**1293**	**3574**	**2647**	**5524**	**29,109**	**29,106**

Sources:

a. Parfitt, J. (2002). Analysis of household waste composition and factors driving waste increases. WRAP, Banbury. http://www.number-10.gov.uk/su/waste/report/downloads/composition.pdf. Household collection composition

b. Average of composition datasets for litter, street sweepings and bulky waste. Adapted from *The Composition of Municipal Waste in Wales*. National Assembly for Wales (NAW)/AEAT Technology - December 2003.

c. Parfitt, J. (2002). Analysis of household waste composition and factors driving waste increases. WRAP, Banbury. http://www.number-10.gov.uk/su/waste/report/downloads/composition.pdf. Residual CA composition.

d. *The Composition of Municipal Waste in Wales*. National Assembly for Wales (NAW)/AEAT Technology - December 2003. Non-household sources composition.

e. Defra Waste Statistics group (personal communications). Total municipal recycling. Co-mingled recycling (8%) assumed to have the same composition as segregated materials

Notes:

1. Includes furniture
2. 80% of metal cans assumed to be ferrous, 20% non-ferrous
3. Includes 'other' organic material
4. Includes rubble and 'other' category
5. Quantity of hazardous material unknown. Assumed to be equivalent to that estimated for household collected waste/CA site waste in Wales in '*The Composition of Municipal Waste in Wales*. National Assembly for Wales (NAW)/AEAT Technology - December 2003' and proportion of miscellaneous non-combustibles was adjusted accordingly.

Table A1.25 Estimated MSW Composition in Scotland

Material	**% of Household Waste (kerbside collected / residual)**[a]	**% of CA Site Waste**[b]	**% of Non-household Sources (residual)**[c]	**% of Non-household Recycling**[d]	**Total MSW (Thousand Tonnes, 2003/04 Arisings)**	**% of Total MSW**
Paper and card	25.0%	9.3%	7.4%	1.4%	660	20%
Plastic film	4.2%	0.7%	0.9%		107	3%
Dense plastic	6.3%	2.8%	1.6%		166	5%
Textiles	4.8%	2.2%	0.2%		121	4%
Absorbent hygiene products	3.8%[2]	0.3%	0.4%		92	3%
Wood	1.2%[2]	12.6%	0.1%		73	2%
Other combustibles[1]	3.7%[2]	13.7%	0.5%		138	4%
Non-combustibles	2.3%	18.5%	55.3%	90.2%	481	15%
Glass	7.2%	2.8%	0.6%	1.1%	184	6%
Ferrous metal	4.3%	5.8%	0.9%		127	4%
Non-ferrous metal	1.4%	0.9%	0.2%		38	1%
Kitchen waste	21.4%[3]	3.2%	7.1%		552	17%
Green waste	6.7%[3]	18.0%	14.5%	7.4%	305	9%
Fine material <10mm	0.5%	0.8%	10.0%		69	2%
Waste Electrical and Electronic Equipment	0.3%	6.7%	0.2%		32	1%
Hazardous Household Waste Items (inc. batteries)	7.0%	1.7%	0.1%		171	5%
Total	**100%**	**100%**	**100%**	**100%**	**3317**	**100%**
Arisings 2003/04 (Thousand Tonnes)	**2346**	**360**	**544**	**66**	**3317**	**3317**

Sources:

a. SEPA (2005) Waste Data Digest 5. [redacted]

b. *The Composition of Municipal Waste in Wales*. National Assembly for Wales (NAW)/AEAT Technology - December 2003. CA composition.

c. *The Composition of Municipal Waste in Wales*. National Assembly for Wales (NAW)/AEAT Technology - December 2003. Non-household sources composition.

d. Adapted from J. Parfitt , J. (2002). Analysis of household waste composition and factors driving waste increases. WRAP, Banbury. (assumed estimates of non-household waste recycling in England)

Notes:

1. Includes furniture
2. Proportional split between combustible materials (wood, absorbent hygiene products and 'other' (including furniture) unknown. Assumed to be equivalent to that estimated for Wales in 'The Composition of Municipal Waste in Wales. National Assembly for Wales (NAW)/AEAT Technology - December 2003'.
3. Proportional split between organic kitchen and green waste unknown. Assumed to be equivalent to that estimated for Wales in 'The Composition of Municipal Waste in Wales. National Assembly for Wales (NAW)/AEAT Technology - December 2003'.

Combining national datasets and estimates results in an estimated municipal waste composition as shown in *Table A1.26*.

It should be noted that there is still some uncertainty surrounding these estimates, particularly with regard to relative proportions of biodegradable materials.

Table A1.26 Estimated UK MSW Composition

Waste Fraction	England ('000 Tonnes, 2003/04 Arisings)	Wales ('000 Tonnes, 2003/04 Arisings)	Scotland ('000 Tonnes, 2003/04 Arisings)	Northern Ireland ('000 Tonnes, 2003/04 Arisings)	Total	% of Total	% Carbon (Biogenic)[2]	% Carbon (Fossil)[2]	Gross Calorific Value (MJ/kg)[2]
Paper and card	5234	381	660	187	6462	18%	32%		12.6
Plastic film	780	51	107	31	969	3%		48%	23.6
Dense plastic	1012	82	166	54	1313	4%		55%	26.7
Textiles	703	33	121	19	876	2%	20%	20%	16.0
Absorbent hygiene products	650	42	92	24	807	2%	15%	4%	8.0
Wood	918	51	73	29	1070	3%	44%		18.3
Other combustibles[1]	433	127	138	73	771	2%	19%	19%	15.6
Non-combustibles	3574	145	481	62	4262	12%	3.5%	3.5%	2.8
Glass	1934	105	184	68	2291	6%	0.3%		1.5
Ferrous metal	469	85	127	38	719	2%			
Non-ferrous metal	125	15	38	9	186	1%			
Kitchen waste	5016	323	552	204	6095	17%	14%		5.3
Green waste	5601	231	305	145	6282	18%	17%		6.5
Fine material <10mm	1176	94	69	56	1395	4%	7%	7%	4.8
Waste Electrical and Electronic Equipment	1305	36	32	21	1394	4%		16%	7.6
Hazardous Household Waste Items (inc. batteries)	180	15	171	8	374	1%		30%[3]	12.4[3]
Total	**29,109**	**1815**	**3317**	**1027**	**35,268**	**100%**	**14%**	**6%**	**8.4**

Sources:

- The Composition of Municipal Waste in Wales. National Assembly for Wales (NAW)/AEAT Technology - December 2003.
- Parfitt, J. (2002). Analysis of household waste composition and factors driving waste increases. WRAP, Banbury. http://www.number-10.gov.uk/su/waste/report/downloads/composition.pdf
- SEPA (2005) Waste Data Digest 5. [redacted]
- Assessment of the Best Practicable Environmental Option for Waste Management in Northern Ireland: Development and Analysis (ERM 2005)
- Towards Resource Management (EHSNI, 2005), Annex 2 "Waste stream summaries"

Notes:

1. Includes furniture
2. Source: National Household Waste Analysis Programme NHWAP (1992/3). UK Department of Environment
3. Average values for the category used.

A1.7.3 MSW Growth

Growth in MSW production is generally believed to be a function of two factors: increase in the numbers of households in a specific area; and growth in mean waste production per household, as a result of changing patterns of consumption. However, since time series data regarding waste arisings are generally poor, the relationship between these two factors is not clearly defined, and can not be predicted reliably.

The average rate of UK municipal waste growth over the past six years was 2.5% and over the past three years was 1.3% (1). In comparison, the best estimate of historical growth in household waste only is 1.5% (2).

A1.7.4 Future MSW Management

With the introduction of targets for the diversion of biodegradable municipal waste (BMW) from landfill under the Landfill Directive, the future management of MSW is expected to change considerably over the next 15 years.

Although considerable emphasis is currently placed on prevention and recycling initiatives, there are limits to the quantities of waste that can be diverted via these routes. If local authorities are to meet their assigned landfill allowances, it is recognised that significant additional treatment through recovery processes will be required. Authorities may employ a number of options to achieve diversion targets, including:

- recovery of materials from source segregated collection systems;
- recovery through production of compost from source-segregated green/kitchen wastes;
- potential stabilisation of residual mixed wastes using biological treatment processes such as mechanical biological treatment (MBT), or anaerobic digestion; and
- recovery of energy from waste using conventional mass-burn (EfW), or advanced thermal treatment technologies (eg gasification, pyrolysis).

A1.8 COMMERCIAL AND INDUSTRIAL (C&I) WASTE

The term 'commercial waste' relates to wastes arising from wholesalers, catering establishments, shops and offices. 'Industrial waste', in comparison, relates to wastes arising from factories and industrial plants. Both streams have discreet composition and growth implications and so will be addressed separately in the research. However, the majority of data regarding arisings and management of commercial and industrial wastes are reported in a combined fashion, and are based on combined survey work. As a result, these streams will be discussed in parallel with regard to waste arisings.

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(1) Defra waste Statistics Division, personal communication

(2) Represents household waste growth in England Growth estimate used for Defra LAWRRD model

A1.8.1 Commercial and Industrial Waste Arisings

Published data relating to commercial and industrial waste arisings in the UK derive from a number of sources, dependent on devolved administration.

England and Wales

In 1998, the Environment Agency carried out a survey of some 20,000 industrial and commercial businesses. The survey was carried out across England and Wales and collected data regarding the type, quantity of waste arising from businesses/industry and the waste disposal or recovery method. A summary of the results of this survey is presented in *Table A1.27* and *Table A1.28*.

The survey showed that, in 1998/99, industrial and commercial waste totalled around 75 million tonnes. Of this, approximately 50 million tonnes was attributable to industry and 25 million to commerce. The individual sector that produced the most waste was the basic metals sector (over 9 million tonnes of waste). This was followed by the food, drink and tobacco industry at more than 7 million tonnes and the coke, oil, gas, electricity and water industries at just under 7 million tonnes.

Table A1.28 summarises the waste management options adopted for the types of waste streams within industry and within commerce. Almost all (90%) of the separated paper and card and the metals and scrap equipment waste streams were recycled irrespective of whether they were generated in an industrial or a commercial organisation. However, it should be appreciated when using this data, that the 'paper and card' waste stream refers only to that collected separately. It does not include the paper and card component in the general waste streams.

Landfill disposal was the main waste management option employed for almost half the wastes arising in 1998/99. 30% of the waste arising in this period was recycled and a further 7% was re-used. The survey further found that industrial companies are more inclined to recycle or re-use their waste (44%) than are commercial companies (24%).

Data Updates

The Environment Agency recently carried out a second survey of industrial and commercial waste arising in England (England, Commercial and Industrial Waste Survey, 2002/03). The results of this survey were under analysis at the time of writing, but initial findings are shown in *Table A1.29* and *Table A1.30*.

Table A1.27 Industrial and Commercial Waste Arisings in England and Wales (1998/99) (Thousand Tonnes)

Sector/Type	Inert	Construction demolition & asbestos	Paper & card	Food	General commercial	General industrial	Other general & biodegradable	Metals & scrap equipment	Contaminated general	Healthcare risk	Mineral wastes & residues	Chemical & other	Total
Industrial													
Food, drink and tobacco	292	143	233	1939	12	1065	2118	67	417	280	8	629	7203
Textiles	0	1	60	1	1	321	97	5	49	0	2	11	548
Wearing apparel	0		11	1	0	171	16	1	6	0		0	207
Leather, luggage, handbags and footwear	8		5		0	69	99	1	56	0		18	255
Wood and wood products	28	1	22	0	0	230	763	6	5	0	0	9	1064
Pulp, paper and paper products	0	5	409	3	4	465	1165	12	15	0	34	155	2265
Publishing, printing and recording	0	2	1056	2	84	615	78	28	22	0	1	46	1935
Chemicals and chemical products	27	187	21	3	2	233	605	376	698	44	134	1541	3870
Cleaning products, man-made fibres etc.	5	5	44	2	5	142	90	24	72	0	6	159	555
Rubber and plastic products	69	0	91	2	1	571	446	55	33	0	3	69	1339
Other non-metallic mineral products	744	214	37	1	2	400	68	36	174	0	443	98	2217
Basic metals	102	72	26	1	1	267	77	1066	720	0	6218	559	9108
Fabricated metal products	9	7	25	0	7	624	57	835	78	1	11	119	1774
Machinery and equipment	20	4	36	3	2	464	71	571	123	0	13	158	1467
Office machinery, computers and electrical	11	0	46	2	0	262	32	270	14	0	11	22	670
Radio, television and communication	7	1	21	1	0	113	55	13	3	0	0	30	244
Medical and optical instruments and clocks	1	0	10	2	0	165	6	17	11	0	0	6	219
Motor vehicles	6	3	31	2	10	313	81	512	43	0	1	281	1283
Other transport equipment	0	1	10	1	1	167	36	126	432	0		50	825
Furniture and other manufacturing	4	0	56	1		442	446	47	207	0	22	27	1252
Coke, oil, gas, electricity, water	55	76	23	3	2	296	44	50	17	0	5821	198	6585
Transport, storage, communications	8	3	349	208	18	1655	310	119	71	0	0	525	3266
Miscellaneous	3	51	123	9	2	1045	112	18	11	337	56	175	1942
Industrial total	*1399*	*777*	*2744*	*2185*	*155*	*10093*	*6873*	*4254*	*3278*	*663*	*12,785*	*4886*	*50090*

Commercial													
Wholesale	4	3	539	54	2098		306	149	26	0	1	113	3293
Retail - motor vehicles, parts and fuel	0	6	62	0	654		171	125	12	0	0	67	1097
Retail – others	7	3	951	253	3515		329	49	511	27	1	8	5654
Hotels, catering	30	17	126	10	3083		199	51	63	1	1	15	3596
Finance	0	8	173	4	653		7	10	6	0	0	5	865
Education	11	21	78	41	1681		370	24	13	9	0	2	2251
Travel agents, other business and others	23	48	305	19	3977		333	64	71	10	7	29	4887
Real estate and computer	1	1	63	2	877		40	14	9	1	0	5	1013
Social work and public administration	2	18	206	20	1566		156	51	23	31	9	65	2146
Commercial total	*78*	*125*	*2502*	*404*	*18,105*	*0*	*1911*	*537*	*734*	*79*	*19*	*309*	*24802*
Total Commercial and Industrial	**1477**	**902**	**5245**	**2589**	**18,260**	**10,093**	**8784**	**4790**	**4012**	**741**	**12,804**	**5195**	**74892**

Source: EA National Waste Production Survey 1998

Source publication: e-Digest of Environmental Statistics, Published August 2003, Department for Environment, Food and Rural Affairs, http://www.defra.gov.uk/environment/statistics/index.htm.

Table A1.28 Industrial and Commercial Waste Management in England and Wales (1998/99) (Thousand Tonnes)

Type/Management	**Land disposal**	**Land recovery**	**Re-used**	**Recycled**	**Thermal**	**Transfer**	**Treatment**	**Unrecorded**	**No local data**	**Total**
Industrial										
Inert	699	15	34	568	0	40	42	1	1	1399
Construction, demolition & asbestos	635		35	65	0	26	11	2	3	777
Paper and card	144	2	13	2487	23	17	44	13		2744
Food	500	154	885	493	12	12	120	1	7	2185
General commercial	123	0	0	8	4	3	1	17		155
General industrial	8822	46	45	335	217	387	106	135		10,093
Other general & biodegradable	1454	969	839	2320	309	156	785	40		6873
Metals & scrap equipment	241		67	3880	0	20	37	8		4254
Contaminated general	1951	17	93	905	3	21	272	2	12	3278
Healthcare risk	15	7	20	11	203	2	403		2	663
Mineral wastes & residues	4793	3	2840	5087	0	21	14	2	24	12,785
Chemical & other	1721	65	263	802	131	88	1810	0	6	4886
Industrial total	*21,099*	*1278*	*5135*	*16,961*	*902*	*793*	*3645*	*221*	*55*	*50,090*
Commercial										
Inert	37	1	1	35	0	3	1	0	0	78
Construction, demolition & asbestos	108		3	8	0	4	1	0	0	125
Paper and card	130	1	11	2270	24	17	33	15		2502
Food	130	19	121	96	4	3	29	0	2	404
General commercial	12,175	1	7	1507	469	461	94	3391		18,105
Other general & biodegradable	429	162	228	758	97	35	183	20		1911
Metals & scrap equipment	30		16	482	0	4	4	2		537
Contaminated general	352	5	13	282	1	6	71	1	3	734
Healthcare risk	2	1	1	1	31	0	41		0	79
Mineral wastes & residues	8	0	1	8	0	0	2	0	1	19
Chemical & other	84	3	13	62	8	7	132	0	1	309
Commercial total	*13,484*	*193*	*416*	*5508*	*633*	*540*	*591*	*3429*	*7*	*24,802*
Total Commercial and Industrial	**34,583**	**1471**	**5552**	**22469**	**1535**	**1334**	**4236**	**3650**	**62**	**74,892**

Source: EA National Waste Production Survey 1998

Source publication: e-Digest of Environmental Statistics, Published August 2003, Department for Environment, Food and Rural Affairs, http://www.defra.gov.uk/environment/statistics/index.htm.

Table A1.29 Commercial and Industrial Waste Arisings in England (2002/03) by Sector (Thousand Tonnes)

Commercial/Industrial Sector	**Arisings (thousand tonnes)**
Commercial	
Education	1939
Hotels/Catering	3352
Miscellaneous	1554
Retail	12,753
Social work and public administration	1390
Transport, storage, communications	2182
Travel agents, other business, finance, real estate and computer related activities	7150
Total Commercial	*30,320*
Industrial	
Food, drink and tobacco	7230
Furniture and other manufacturing	675
Manufacture of basic metals	4815
Manufacture of chemicals and chemical products; cleaning products, man-made fibres etc; rubber and plastic products	5257
Manufacture of fabricated metal products	1525
Manufacture of machinery and equipment	939
Manufacture of motor vehicles and other transport equipment	1475
Manufacture of office machinery, computers, electrical, radio, television and communication equipment; medical and optical instruments and clocks	515
Manufacture of pulp, paper and paper products	1822
Manufacture of textiles, wearing apparel, leather, luggage, handbags and footwear	1234
Other non-metallic mineral products	2272
Production of coke, oil, gas, electricity, water	6182
Publishing, printing and recording	2174
Wood and wood products	1471
Total Industrial	*37,587*
Total	**67,907**

Source: EA England, Commercial and Industrial Waste Survey 2002/03

Table A1.30 Commercial and Industrial Waste Arisings in England (2002/03) by Waste Type (Thousand Tonnes)

Waste Type	Industrial Arisings (thousand tonnes)	Commercial Arisings (thousand tonnes)
Oils & solvents	583	546
Paints, varnishes, etc.	221	16
Industrial sludges	1621	36
Other chemical wastes	3267	1343
Metallic Wastes	2727	604
Paper and card	2656	5976
Other non-metallic, non-mineral wastes	2526	2675
Discarded equipment	88	262
Food	4121	2067
Other animal and	22	84
Sorting residues	665	0
Other mixed general waste	5392	15,569
Common Sludges	761	154
Combustion wastes	9598	92
C&D	859	772
Other mineral wastes	2482	123
Total	**37,587**	**30,320**

Source: EA England, Commercial and Industrial Waste Survey 2002/03

Table A1.31 Commercial and Industrial Waste Management in England (2002/03)

Management Route	% of Total Commercial and Industrial Arisings
Land disposal	47%
Land recovery	3%
Recycled	38%
Thermal	4%
Transfer	2%
Treatment	5%

Source: EA England, Commercial and Industrial Waste Survey 2002/03

Scotland

Gathering data on non-municipal waste arisings in Scotland is difficult. There is currently no requirement for organisations to report non-municipal waste arisings to SEPA. To address this data gap, and to meet EU requirements for waste data reporting, SEPA commissioned a pilot national survey of commercial and industrial waste producers in 2004. The survey was completed in May 2005. However, results are still in the process of being analysed and so are, as yet, unavailable.

Data relating to commercial and industrial waste arisings, according to European Waste Catalogue codings were provided by SEPA and collated as part of their review of licensed site returns.

Table A1.32 Commercial and Industrial Waste Arisings in Scotland 2004/05 (Tonnes)

European Waste Catalogue (2002) Code	Tonnes to Landfill	Tonnes to Recycling
02 - Wastes from agriculture, horticulture, aquaculture, forestry, hunting and fishing, food preparation and processing	94,153	54,412
03 - Wastes from wood processing (including paper and card production)	85,371	55,196
04 - Wastes from the leather, fur and textiles industries	37,743	3791
05 - Wastes from Petroleum refining, natural gas purification and pyrolytic treatment of coal	636	108
06 - Wastes from inorganic chemical processes	11,558	-
07 - Wastes from organic chemical processes	12,540	1143
08 - Waste from the manufacture and use of coatings, adhesives, sealants and printing inks	960	5
09 - Wastes from the photographic industry	113	0.0
10 - Wastes from thermal processes	1,255,384	1209
11 - Wastes from chemical surface treatment and coating of metals and other materials	52	-
12 - Wastes from shaping and physical and mechanical surface treatment of metals and plastics	960	93,803
13- Oil wastes and wastes of liquid fuels	538	1861
15 - Waste packaging, absorbents, wipings cloths, filter materials and protective clothing not otherwsie specified	90,291	62,818
16 - Waste not otherwise specified	46,163	703,795
18 - Wastes from human or animal health care and/or related research	15340	-
19 - Waste from waste management facilties, off-site waste water treatment plants and water treatment plants	922,527	77,879
20 - Municipal waste (household waste and similar commercial and industrial waste)	3,237,472	416,634
Uncoded/alternative classification system used	152,800	242
Total	**5,964,602**	**1,472,896**

Source: SEPA Waste Statistics Regulations Review of Licensed Site Returns Database (Jan 2004 – 31 March 2005).

Notes:

- Estimates are based on data from licensed waste management site returns. 95% of licensed sites in Scotland provided information on waste throughputs
- Data regarding tonnages sent directly to landfill or reprocessing sites are compiled in the database and these amounted to some 8.5 million tonnes in 2004/05 (including mining and quarrying, construction and demolition and municipal wastes collected by local authorities). Total waste arisings at licensed sites were estimated to be approximately 13.7 million tonnes, however, with the remaining 5 million tonnes passing through transfer and civic amenity sites. Data regarding the classification of wastes passing through these sites, or their final destination, are not currently available. It was assumed that the composition/management of these arisings is proportional to those sent directly to treatment facilities.
- Data regarding exempt sites are not available, but relate predominantly to construction and demolition wastes (estimated to be in the region of 1.3-2 million tonnes/year)

- EWC code 01 – *Mining and quarrying wastes* and 17 – *Construction and demolition wastes* have been discounted from the total in order to prevent double counting with the mining and quarrying and C&D waste streams
- EWC code 02 - *Wastes from agriculture, horticulture, aquaculture, forestry, hunting and fishing, food preparation and processing* has been included in the total as it was considered that this waste code encompasses wider wastes than those included within the agriculture waste stream. However, it is noted that there is a risk of double counting between these two streams of arisings.
- Municipal wastes known to be collected by local authorities have been discounted from EWC code 20 – *Municipal waste*. Thus this code is considered only to include similar commercial and industrial wastes

Northern Ireland

In January 2002, the EHS commissioned MEL Research and Envirocentre Ltd to carry out the Waste Arisings Survey Phase III, consisting of a census of District Councils on municipal waste and a survey of industry and commerce.

Table A1.33 shows the estimated arisings resulting from the industrial and commercial waste survey. Further, work carried out by ERM as part of a Best Practicable Environmental Option (BPEO) assessment for waste management in Northern Ireland collated information on the fate of commercial and industrial wastes. These data are shown in *Table A1.34*.

Estimates show that, in 2001, the commercial and industrial waste stream totalled approximately 635,000 tonnes. Over 500,000 tonnes was from the commercial sector, the most significant fraction of which was paper/card. *Table A1.33* further shows that recovery rates were high, with only 40% of the total waste stream being landfilled. The most significant route for recovery was through reuse/recycling.

Table A1.33 Commercial and Industrial Waste Arisings in Northern Ireland (2001)

Waste Fraction	Commercial Waste (tonnes)	Industrial Waste (tonnes)
Paper/card	225,804	66,149
Putrescible	32,990	9814
Misc non-combustible	40,891	7832
Ferrous metal	30,149	5308
Non-ferrous metal	10,050	1769
Glass	82,060	0
Plastic dense	74,436	17,127
Plastic film	24,812	5709
Total	**521,192**	**113,708**

Source: Environment and Heritage Service Waste Arisings Survey Phase III (2002). MEL Research and Envirocentre Ltd

Table A1.34 *Fate of Commercial and Industrial Waste in Northern Ireland (2001)*

Management Route	**% of Arisings**
Landfill	39.6%
Recycled	32.7%
Incinerated	18.9%
Land Application	2.3%
Other Treatment (unspecified)	6.4%

Source: Assessment of the Best Practicable Environmental Option for Waste Management in Northern Ireland: Development and Analysis (ERM 2005)

Total UK

Combining national datasets results in a total best current estimate of 82.1 million tonnes of commercial and industrial waste across the UK. Final estimates of total UK commercial and industrial waste arisings and management are summarised in *Table A1.35* to *Table A1.37*.

Table A1.35 *Total Commercial and Industrial Waste Arisings in the UK (latest estimate) (Thousand Tonnes)*

Management Route	**England**	**Wales**	**Scotland**	**Northern Ireland**	**Total**
Landfill	32075	2,896	5965	251	41186
Recycled	26111	2,357	1473	208	30148
Incinerated/Burned	2954	267		120	3341
Land Application/ Recovery	2021	182		15	2218
Other Treatment (unspecified)	4747	429		41	5216
Total	**67,907**	**6130**	**7437**	**634**	**82,109**

Sources:

- EA National Waste Production Survey 1998.
- EA England, Commercial and Industrial Waste Survey 2002/03.
- SEPA Waste Statistics Regulations Review of Licensed Site Returns Database (Jan 2004 – 31 March 2005).
- Assessment of the Best Practicable Environmental Option for Waste Management in Northern Ireland: Development and Analysis (ERM 2005).
- Environment and Heritage Service Waste Arisings Survey Phase III (2002). MEL Research and Envirocentre Ltd

Notes:

- Estimates for England based on 2002/03 survey data
- Estimates for Wales based on 1998 survey data
- Estimates for Scotland based on SEPA licensed site returns database 2004/05
- Estimates for Northern Ireland based on 2001 survey data

Table A1.36 Total Commercial Waste Arisings in the UK (latest estimate) (Thousand Tonnes)

Management Route	England	Wales	Scotland	Northern Ireland	Total
Landfill	15,240	574	3314	206	19,258
Recycled/reused	9147	344	417	170	10,078
Incinerated/Burned	1170	44		99	1313
Land Application/ Recovery	15	1		12	28
Other Treatment (unspecified)	4747	179		33	4959
Total	**30,320**	**1141**	**3731**	**521**	**35,636**

Sources:

- EA National Waste Production Survey 1998.
- EA England, Commercial and Industrial Waste Survey 2002/03.
- SEPA Waste Statistics Regulations Review of Licensed Site Returns Database (Jan 2004 – 31 March 2005).
- Assessment of the Best Practicable Environmental Option for Waste Management in Northern Ireland: Development and Analysis (ERM 2005).
- Environment and Heritage Service Waste Arisings Survey Phase III (2002). MEL Research and Envirocentre Ltd

Notes:

- Estimates for England based on 2002/03 survey data
- Estimates for Wales based on 1998 survey data
- Estimates for Scotland based on SEPA licensed site returns database 2004/05, assuming that commercial waste comprises EWC code 20 and 50% of uncoded wastes
- Estimates for Northern Ireland based on 2001 survey data

Table A1.37 Total Industrial Waste Arisings in the UK (latest estimate) (Thousand Tonnes)

Management Route	England	Wales	Scotland	Northern Ireland	Total
Landfill	13,148	1745	2651	45	17,666
Recycled	18,256	2423	1056	37	21,772
Incinerated/Burned	1014	135		21	1170
Land Application/ Recovery	2230	296		3	2529
Other Treatment (unspecified)	2939	390		7	3337
Total	**37,587**	**4989**	**3707**	**114**	**46,474**

Sources:

- EA National Waste Production Survey 1998.
- EA England, Commercial and Industrial Waste Survey 2002/03.
- SEPA Waste Statistics Regulations Review of Licensed Site Returns Database (Jan 2004 – 31 March 2005).
- Assessment of the Best Practicable Environmental Option for Waste Management in Northern Ireland: Development and Analysis (ERM 2005).
- Environment and Heritage Service Waste Arisings Survey Phase III (2002). MEL Research and Envirocentre Ltd

Notes:

- Estimates for England based on 2002/03 survey data
- Estimates for Wales based on 1998 survey data
- Estimates for Scotland based on SEPA licensed site returns database 2004/05, assuming that industrial waste comprises EWC codes 02, 03, 04, 05, 06, 07, 08, 09, 10, 11, 12, 13, 14, 15, 16, 18, 19 and 50% of uncoded wastes
- Estimates for Northern Ireland based on 2001 survey data

A1.8.2 Commercial Waste Composition

Estimates of commercial waste composition vary in detail according to national datasets available. The most complete and recent data relating to commercial wastes derive from the Environment Agency's second survey of C&I waste arising in England (England, Commercial and Industrial Waste Survey 2002/03). These data are disaggregated by commercial sector and provide the most interesting and indicative picture of the composition of wastes that derive from commercial premises.

Estimates are shown in *Table A1.38* to *Table A1.45*. The data clearly show the difference in waste composition between commercial sectors and it is important that these are taken into account when forecasting the growth of alternative material fractions (1).

The Environment Agency is currently carrying out further analyses of the composition of 'mixed' waste categories, potentially providing more detail and less aggregation into 'miscellaneous' categories. This work will be incorporated into the modelling of waste stream impacts as far as is possible within the timescales of the research.

Further, it must be noted that there is some debate regarding the tonnage of paper assumed to be present in the pooled municipal, commercial and industrial waste streams. The British Paper Federation estimates paper consumption (production and imports less exports) in Great Britain to be in the region of 13 million tonnes per annum. However, the estimates below show paper and card arisings in the commercial and industrial waste streams alone, and in England only, to be in excess of 10 million tonnes. Coupled with the estimated 6 million tonnes of paper and card arising through municipal sources, it is clear that the proportion of this waste fraction in one, or more, waste streams may have been overestimated.

This overestimation may have occurred, in part, due to inconsistencies in volume to weight conversion estimates during data collection. Inconsistencies such as this highlight the need for care when interpreting results driven by the currently available data. The figures presented represent only estimates of the breakdown of materials present in commercial and industrial wastes, and should be treated as such. Further, ERM have made a number of assumptions in assigning waste categories from the original data.

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(1) *Section A1.8.3*

Table A1.38 Commercial Waste Composition (England, 2002/03): Education Sector

Waste Fraction[1-6]	**Tonnes Arising 2002/03**	**% of Sector Arisings**
Paper & Card	411696	21.2%
Organic/Food Waste	369809	19.1%
Green Waste	238704	12.3%
Wood	44746	2.3%
Textiles	33862	1.7%
Fines	51314	2.6%
Glass	100274	5.2%
Plastic (dense)	51271	2.6%
Plastic (film)	49987	2.6%
Ferrous Metal	54587	2.8%
Non-Ferrous Metal	13918	0.7%
WEEE	45842	2.4%
End of Life Vehicles	205	0.01%
Tyres	2644	0.1%
Batteries	4103	0.2%
Oils/fuels	215	0.01%
Paints/Inks/Varnishes	172	0.01%
Organic Chemicals	19	0.001%
Inorganic Chemicals		
Unknown Chemicals	12184	0.6%
Aqueous Chemical Effluents	148	0.01%
Organic Sludges	11413	0.6%
Inorganic Sludges		
Unknown/Mixed Sludges		
Combustion Residues		
Miscellaneous – Combustible[7]	209363	10.8%
Miscellaneous - Non-Combustible[8]	232564	12.0%
Total	**1939041**	**100%**

Source: EA England, Commercial and Industrial Waste Survey 2002/03. Data provided by the Strategic Waste and Resource Management group of the Environment Agency

Notes: 1. Waste category 'mixed municipal waste' (EWC code 20 03 01) has been included in the statistics and has been assumed to have the same composition as that assumed for municipal waste. This may potentially have resulted in a double-count of municipal wastes.

2. Composition of waste category 'bulky waste' assumed on the basis of Welsh bulky waste composition, taken from *The Composition of Municipal Waste in Wales*. National Assembly for Wales (NAW)/AEAT Technology - December 2003.

3. Waste category 'construction & demolition' assumed to comprise 99% non-combustible waste and 1% combustibles

4. Waste category 'mixed packaging' assumed to comprise 20% paper & card, 20% glass, 20% metals, 20% wood and 20% plastics

5. Waste categories described as 'plastics' assumed to comprise 50% dense and 50% film

6. Waste categories described as 'metals' assumed to comprise 50% ferrous and 50% non-ferrous

7. Includes all miscellaneous wastes not otherwise specified

8. Includes inert wastes only

Table A1.39 Commercial Waste Composition (England, 2002/03): Hotels and Catering Sector

Waste Fraction[1-6]	**Tonnes Arising 2002/03**	**% of Sector Arisings**
Paper & Card	571424	17.0%
Organic/Food Waste	554400	16.5%
Green Waste	370719	11.1%
Wood	71245	2.1%
Textiles	54595	1.6%
Fines	82867	2.5%
Glass	847408	25.3%
Plastic (dense)	83463	2.5%
Plastic (film)	79196	2.4%
Ferrous Metal	81862	2.4%
Non-Ferrous Metal	16190	0.5%
WEEE	63984	1.9%
End of Life Vehicles		
Tyres		
Batteries	6563	0.2%
Oils/fuels	54	0.002%
Paints/Inks/Varnishes	36	0.001%
Organic Chemicals		
Inorganic Chemicals		
Unknown Chemicals	19636	0.6%
Aqueous Chemical Effluents		
Organic Sludges		
Inorganic Sludges		
Unknown/Mixed Sludges		
Combustion Residues		
Miscellaneous – Combustible[7]	169422	5.1%
Miscellaneous - Non-Combustible[8]	278567	8.3%
Total	**3351629**	**100%**

Source: EA England, Commercial and Industrial Waste Survey 2002/03. Data provided by the Strategic Waste and Resource Management group of the Environment Agency

Notes: 1. Waste category 'mixed municipal waste' (EWC code 20 03 01) has been included in the statistics and has been assumed to have the same composition as that assumed for municipal waste. This may potentially have resulted in a double-count of municipal wastes.

2. Composition of waste category 'bulky waste' assumed on the basis of Welsh bulky waste composition, taken from *The Composition of Municipal Waste in Wales*. National Assembly for Wales (NAW)/AEAT Technology - December 2003.

3. Waste category 'construction & demolition' assumed to comprise 99% non-combustible waste and 1% combustibles

4. Waste category 'mixed packaging' assumed to comprise 20% paper & card, 20% glass, 20% metals, 20% wood and 20% plastics

5. Waste categories described as 'plastics' assumed to comprise 50% dense and 50% film

6. Waste categories described as 'metals' assumed to comprise 50% ferrous and 50% non-ferrous

7. Includes all miscellaneous wastes not otherwise specified

8. Includes inert wastes only

Table A1.40 Commercial Waste Composition (England, 2002/03): Miscellaneous Sector

Waste Fraction[1-6]	Tonnes Arising 2002/03	% of Sector Arisings
Paper & Card	338532	21.8%
Organic/Food Waste	220006	14.2%
Green Waste	124936	8.0%
Wood	27473	1.8%
Textiles	18519	1.2%
Fines	27927	1.8%
Glass	53062	3.4%
Plastic (dense)	29169	1.9%
Plastic (film)	22537	1.5%
Ferrous Metal	54218	3.5%
Non-Ferrous Metal	14269	0.9%
WEEE	30641	2.0%
End of Life Vehicles	4	0.0003%
Tyres	1353	0.1%
Batteries	2779	0.2%
Oils/fuels	7842	0.5%
Paints/Inks/Varnishes	1076	0.1%
Organic Chemicals	26696	1.7%
Inorganic Chemicals	130	0.01%
Unknown Chemicals	15706	1.0%
Aqueous Chemical Effluents	11126	0.7%
Organic Sludges	2746	0.2%
Inorganic Sludges		
Unknown/Mixed Sludges	232	0.0%
Combustion Residues	6820	0.4%
Miscellaneous – Combustible[7]	370259	23.8%
Miscellaneous - Non-Combustible[8]	145515	9.4%
Total	**1553572**	**100%**

Source: EA England, Commercial and Industrial Waste Survey 2002/03. Data provided by the Strategic Waste and Resource Management group of the Environment Agency

Notes: 1. Waste category 'mixed municipal waste' (EWC code 20 03 01) has been included in the statistics and has been assumed to have the same composition as that assumed for municipal waste. This may potentially have resulted in a double-count of municipal wastes.

2. Composition of waste category 'bulky waste' assumed on the basis of Welsh bulky waste composition, taken from *The Composition of Municipal Waste in Wales*. National Assembly for Wales (NAW)/AEAT Technology - December 2003.

3. Waste category 'construction & demolition' assumed to comprise 99% non-combustible waste and 1% combustibles

4. Waste category 'mixed packaging' assumed to comprise 20% paper & card, 20% glass, 20% metals, 20% wood and 20% plastics

5. Waste categories described as 'plastics' assumed to comprise 50% dense and 50% film

6. Waste categories described as 'metals' assumed to comprise 50% ferrous and 50% non-ferrous

7. Includes all miscellaneous wastes not otherwise specified

8. Includes inert wastes only

Table A1.41 *Commercial Waste Composition (England, 2002/03): Retail Sector*

Waste Fraction[1-6]	Tonnes Arising 2002/03	% of Sector Arisings
Paper & Card	4522145	35.5%
Organic/Food Waste	1079420	8.5%
Green Waste	798308	6.3%
Wood	494414	3.9%
Textiles	127546	1.0%
Fines	169211	1.3%
Glass	376153	2.9%
Plastic (dense)	279877	2.2%
Plastic (film)	1025223	8.0%
Ferrous Metal	412265	3.2%
Non-Ferrous Metal	211047	1.7%
WEEE	181062	1.4%
End of Life Vehicles	33584	0.3%
Tyres	146966	1.2%
Batteries	40037	0.3%
Oils/fuels	181180	1.4%
Paints/Inks/Varnishes	5127	0.04%
Organic Chemicals	29997	0.2%
Inorganic Chemicals	15	0.0001%
Unknown Chemicals	42485	0.3%
Aqueous Chemical Effluents	15250	0.1%
Organic Sludges	10969	0.1%
Inorganic Sludges		
Unknown/Mixed Sludges	92728	0.7%
Combustion Residues	722	0.006%
Miscellaneous – Combustible[7]	1826560	14.3%
Miscellaneous - Non-Combustible[8]	650545	5.1%
Total	**12752835**	**100%**

Source: EA England, Commercial and Industrial Waste Survey 2002/03. Data provided by the Strategic Waste and Resource Management group of the Environment Agency

Notes: 1. Waste category 'mixed municipal waste' (EWC code 20 03 01) has been included in the statistics and has been assumed to have the same composition as that assumed for municipal waste. This may potentially have resulted in a double-count of municipal wastes.

2. Composition of waste category 'bulky waste' assumed on the basis of Welsh bulky waste composition, taken from *The Composition of Municipal Waste in Wales*. National Assembly for Wales (NAW)/AEAT Technology - December 2003.

3. Waste category 'construction & demolition' assumed to comprise 99% non-combustible waste and 1% combustibles

4. Waste category 'mixed packaging' assumed to comprise 20% paper & card, 20% glass, 20% metals, 20% wood and 20% plastics

5. Waste categories described as 'plastics' assumed to comprise 50% dense and 50% film

6. Waste categories described as 'metals' assumed to comprise 50% ferrous and 50% non-ferrous

7. Includes all miscellaneous wastes not otherwise specified

8. Includes inert wastes only

Table A1.42 Commercial Waste Composition (England, 2002/03): Social Work and Public Administration Sector

Waste Fraction[1-6]	**Tonnes Arising 2002/03**	**% of Sector Arisings**
Paper & Card	431052	31.0%
Organic/Food Waste	167592	12.1%
Green Waste	129699	9.3%
Wood	25002	1.8%
Textiles	19119	1.4%
Fines	28991	2.1%
Glass	51703	3.7%
Plastic (dense)	28577	2.1%
Plastic (film)	22696	1.6%
Ferrous Metal	31518	2.3%
Non-Ferrous Metal	7908	0.6%
WEEE	32984	2.4%
End of Life Vehicles		
Tyres	28	0.002%
Batteries	2321	0.2%
Oils/fuels	2428	0.2%
Paints/Inks/Varnishes	28	0.002%
Organic Chemicals	9	0.001%
Inorganic Chemicals	2	0.0001%
Unknown Chemicals	8976	0.6%
Aqueous Chemical Effluents		
Organic Sludges		
Inorganic Sludges		
Unknown/Mixed Sludges		
Combustion Residues	1070	0.1%
Miscellaneous – Combustible[7]	252534	18.2%
Miscellaneous - Non-Combustible[8]	146228	10.5%
Total	**1390465**	**100%**

Source: EA England, Commercial and Industrial Waste Survey 2002/03. Data provided by the Strategic Waste and Resource Management group of the Environment Agency

Notes: 1. Waste category 'mixed municipal waste' (EWC code 20 03 01) has been included in the statistics and has been assumed to have the same composition as that assumed for municipal waste. This may potentially have resulted in a double-count of municipal wastes.

2. Composition of waste category 'bulky waste' assumed on the basis of Welsh bulky waste composition, taken from *The Composition of Municipal Waste in Wales*. National Assembly for Wales (NAW)/AEAT Technology - December 2003.

3. Waste category 'construction & demolition' assumed to comprise 99% non-combustible waste and 1% combustibles

4. Waste category 'mixed packaging' assumed to comprise 20% paper & card, 20% glass, 20% metals, 20% wood and 20% plastics

5. Waste categories described as 'plastics' assumed to comprise 50% dense and 50% film

6. Waste categories described as 'metals' assumed to comprise 50% ferrous and 50% non-ferrous

7. Includes all miscellaneous wastes not otherwise specified

8. Includes inert wastes only

Table A1.43 Commercial Waste Composition (England, 2002/03): Transport, Storage and Communications Sector

Waste Fraction[1-6]	**Tonnes Arising 2002/03**	**% of Sector Arisings**
Paper & Card	517368	23.7%
Organic/Food Waste	276451	12.7%
Green Waste	168230	7.7%
Wood	136407	6.3%
Textiles	30393	1.4%
Fines	38203	1.8%
Glass	106437	4.9%
Plastic (dense)	41192	1.9%
Plastic (film)	37781	1.7%
Ferrous Metal	93106	4.3%
Non-Ferrous Metal	53018	2.4%
WEEE	38940	1.8%
End of Life Vehicles	8342	0.4%
Tyres	9000	0.4%
Batteries	11292	0.5%
Oils/fuels	184062	8.4%
Paints/Inks/Varnishes	8778	0.4%
Organic Chemicals	6328	0.3%
Inorganic Chemicals		
Unknown Chemicals	8928	0.4%
Aqueous Chemical Effluents	32316	1.5%
Organic Sludges	40064	1.8%
Inorganic Sludges		
Unknown/Mixed Sludges	8439	0.4%
Combustion Residues		
Miscellaneous – Combustible[7]	166082	7.6%
Miscellaneous - Non-Combustible[8]	160852	7.4%
Total	**2182010**	**100%**

Source: EA England, Commercial and Industrial Waste Survey 2002/03. Data provided by the Strategic Waste and Resource Management group of the Environment Agency

Notes: 1. Waste category 'mixed municipal waste' (EWC code 20 03 01) has been included in the statistics and has been assumed to have the same composition as that assumed for municipal waste. This may potentially have resulted in a double-count of municipal wastes.

2. Composition of waste category 'bulky waste' assumed on the basis of Welsh bulky waste composition, taken from *The Composition of Municipal Waste in Wales*. National Assembly for Wales (NAW)/AEAT Technology - December 2003.

3. Waste category 'construction & demolition' assumed to comprise 99% non-combustible waste and 1% combustibles

4. Waste category 'mixed packaging' assumed to comprise 20% paper & card, 20% glass, 20% metals, 20% wood and 20% plastics

5. Waste categories described as 'plastics' assumed to comprise 50% dense and 50% film

6. Waste categories described as 'metals' assumed to comprise 50% ferrous and 50% non-ferrous

7. Includes all miscellaneous wastes not otherwise specified

8. Includes inert wastes only

Table A1.44 Commercial Waste Composition (England, 2002/03): Travel Agents, Other Business, Finance, Real Estate and Computer-related Activities Sector

Waste Fraction[1-6]	Tonnes Arising 2002/03	% of Sector Arisings
Paper & Card	1984889	27.8%
Organic/Food Waste	921577	12.9%
Green Waste	725330	10.1%
Wood	185115	2.6%
Textiles	117211	1.6%
Fines	162133	2.3%
Glass	471766	6.6%
Plastic (dense)	185128	2.6%
Plastic (film)	178327	2.5%
Ferrous Metal	199816	2.8%
Non-Ferrous Metal	69067	1.0%
WEEE	145448	2.0%
End of Life Vehicles	735	0.01%
Tyres	1320	0.02%
Batteries	49819	0.7%
Oils/fuels	6280	0.1%
Paints/Inks/Varnishes	604	0.0%
Organic Chemicals	29558	0.4%
Inorganic Chemicals	0	0.0%
Unknown Chemicals	354192	5.0%
Aqueous Chemical Effluents	3412	0.05%
Organic Sludges	25437	0.4%
Inorganic Sludges	0	0.0%
Unknown/Mixed Sludges	0	0.0%
Combustion Residues	49854	0.7%
Miscellaneous – Combustible[7]	280893	3.9%
Miscellaneous - Non-Combustible[8]	1002320	14.0%
Total	**7150230**	**100%**

Source: EA England, Commercial and Industrial Waste Survey 2002/03. Data provided by the Strategic Waste and Resource Management group of the Environment Agency

Notes: 1. Waste category 'mixed municipal waste' (EWC code 20 03 01) has been included in the statistics and has been assumed to have the same composition as that assumed for municipal waste. This may potentially have resulted in a double-count of municipal wastes.

2. Composition of waste category 'bulky waste' assumed on the basis of Welsh bulky waste composition, taken from *The Composition of Municipal Waste in Wales*. National Assembly for Wales (NAW)/AEAT Technology - December 2003.

3. Waste category 'construction & demolition' assumed to comprise 99% non-combustible waste and 1% combustibles

4. Waste category 'mixed packaging' assumed to comprise 20% paper & card, 20% glass, 20% metals, 20% wood and 20% plastics

5. Waste categories described as 'plastics' assumed to comprise 50% dense and 50% film

6. Waste categories described as 'metals' assumed to comprise 50% ferrous and 50% non-ferrous

7. Includes all miscellaneous wastes not otherwise specified

8. Includes inert wastes only

Table A1.45 Commercial Waste Composition (England, 2002/03): All Sectors Combined

Waste Fraction[1-6]	**Tonnes Arising 2002/03**	**% of Sector Arisings**	**% Carbon (Biogenic)[9]**	**% Carbon (Fossil)[9]**	**Gross Calorific Value (MJ/kg)[9]**
Paper & Card	8732896	28.8%	31.9%		12.6
Other Organics	448894	1.5%	13.5%		5.3
Food Waste	2983120	9.8%	17.2%		6.5
Green Waste	2704280	8.9%	13.5%		5.3
Wood	999597	3.3%	43.8%		18.3
Textiles	327554	1.1%	19.9%[10]	19.9%[10]	15.9
Fines	590162	1.9%	6.9%[10]	6.9%[10]	4.8
Glass	1962875	6.5%	0.3%		1.5
Plastic (dense)	882145	2.9%		54.8%	26.7
Plastic (film)	1306030	4.3%		47.8%	23.6
Ferrous Metal	706152	2.3%			
Non-Ferrous Metal	458965	1.5%			
WEEE	730494	2.4%		15.8%	7.6
End of Life Vehicles	42870	0.1%		15.8%[11]	7.6[11]
Tyres	161310	0.5%		74.0%	31.7
Batteries	102176	0.3%			
Oils/fuels	382061	1.3%		80.4%	37.7[12]
Paints/Inks/Varnishes	15821	0.1%		38.4%	15.6
Organic Chemicals	92606	0.3%		38.4%[13]	15.6[13]
Inorganic Chemicals	149	0.0005%		38.4%[13]	15.6[13]
Unknown Chemicals	447369	1.5%		38.4%[13]	15.6[13]
Aqueous Chemical Effluents	62818	0.2%		38.4%[13]	15.6[13]
Organic Sludges	11119	0.0%	30.9%[14]		12.0[14]
Inorganic Sludges	0	0.0%		30.9%[14]	12.0[14]
Unknown/Mixed Sludges	101540	0.3%	15.5%[14]	15.5%[14]	12.0[14]
Combustion Residues	58466	0.2%		7.0%[15]	2.8[15]
Miscellaneous – Combustible[7]	3161665	10.4%	19.2%[10]	19.2%[10]	15.6
Soils/silts	528092	1.7%	7.0%		2.8
Mineral/aggregate waste	360549	1.2%		7.0%	2.8
Other Non-Combustible[8]	1958005	6.5%	3.5%	3.5%	2.8
Total	**30319781**	**100%**	**17%**	**9%**	**10.7**

Source: EA England, Commercial and Industrial Waste Survey 2002/03. Data provided by the Strategic Waste and Resource Management group of the Environment Agency

Notes: 1. Waste category 'mixed municipal waste' (EWC code 20 03 01) has been included in the statistics and has been assumed to have the same composition as that assumed for municipal waste. This may potentially have resulted in a double-count of municipal wastes.

2. Composition of waste category 'bulky waste' assumed on the basis of Welsh bulky waste composition, taken from *The Composition of Municipal Waste in Wales*. National Assembly for Wales (NAW)/AEAT Technology - December 2003.

3. Waste category 'construction & demolition' assumed to comprise 99% non-combustible waste and 1% combustibles

4. Waste category 'mixed packaging' assumed to comprise 20% paper & card, 20% glass, 20% metals, 20% wood and 20% plastics

5. Waste categories described as 'plastics' assumed to comprise 50% dense and 50% film

6. Waste categories described as 'metals' assumed to comprise 50% ferrous and 50% non-ferrous

7. Includes all miscellaneous wastes not otherwise specified

8. Includes minerals, bricks, blocks, plaster, ceramics etc.

9. Source: ERM and Environment Agency Data (2003-2005)

10. Assumed 50% biogenic carbon content and 50% fossil carbon content

11. Assumed to be the same as the waste fraction, WEEE

12. Net Calorific Value

13. Generic value assumed for chemicals

14. Assumed to be the same as the waste fraction, sewage sludge and apportioned accordingly

15. Assumed to be the same as the waste fraction, non-combustibles

Composition data disaggregated at the sector-level have not been compiled for commercial waste arisings in Scotland, Wales and Northern Ireland. However, an estimate of total commercial waste composition has been published for Northern Ireland, and this is presented in *Table A1.46*. No estimates are currently available regarding commercial waste composition in Scotland and Wales.

Table A1.46 ***Commercial Waste Composition in Northern Ireland (2001)***

Waste Fraction	**% of Arisings**	**Tonnes Arising**	**% Carbon (Biogenic)**[1]	**% Carbon (Fossil)** [1]
Paper/card	43%	225,804	32%	
Putrescible	6%	32,990	14%	
Misc non-combustible	8%	40,891	3.5%[2]	3.5%[2]
Ferrous metal	6%	30,149		
Non-ferrous metal	2%	10,050		
Glass	16%	82,060	0.28%	
Plastic dense	14%	74,436		55%
Plastic film	5%	24,812		48%
Total	**100%**	**521,192**	**15%**	**10%**

Source: Assessment of the Best Practicable Environmental Option for Waste Management in Northern Ireland: Development and Analysis (ERM 2005)

Notes:

1. ERM and Environment Agency Data (2003-2005)
2. Assumed 50% biogenic carbon content and 50% fossil carbon content

A1.8.3 Commercial Waste Growth

There is a common opinion that commercial waste production is linked, to some degree, with economic growth. However, the relationship cannot be confirmed by the available statistics, due to a lack of consistent time series data, making forecasting of commercial waste arisings difficult.

A workshop on commercial and industrial waste arisings and management was held early in the research period. This highlighted the need to forecast growth in arisings on a sector-by-sector basis. Representatives from waste-producing industries confirmed the opinion that waste growth in the commercial sector as a whole is on the rise and that some sub-sectors, such as travel and hotels and catering, are likely to grow faster than others.

A1.8.4 Industrial Waste Composition

Estimates of industrial waste composition vary in detail according to national datasets available. The most complete and recent data relating to industrial wastes derive from the Environment Agency's second survey of C&I waste arising in England (England, Commercial and Industrial Waste Survey 2002/03). These data are disaggregated by industrial sector and provide the most interesting and indicative picture of the composition of wastes that derive from alternative industry sectors.

Estimates are shown in *Table A1.47* to *Table A1.61*. The data clearly show the difference between waste composition between industry sectors (1).

As discussed in *Section A1.8.2*, there is a need for care to be taken when interpreting results driven by currently available data. The figures presented represent only estimates of the breakdown of materials present in commercial and industrial wastes, and should be treated as such. Further, ERM have made a number of assumptions in assigning waste categories from the original data.

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(1) *Section A1.8.5*

Table A1.47 Industrial Waste Composition (England, 2002/03): Food, Drink and Tobacco Sector

Waste Fraction[1-6]	**Tonnes Arising 2002/03**	**% of Sector Arisings**
Paper & Card	388483	5.4%
Organic/Food Waste	1161241	16.1%
Green Waste	144843	2.0%
Wood	117611	1.6%
Textiles	16618	0.2%
Fines	25874	0.4%
Glass	79083	1.1%
Plastic (dense)	30405	0.4%
Plastic (film)	76928	1.1%
Ferrous Metal	52476	0.7%
Non-Ferrous Metal	31447	0.4%
WEEE	18267	0.3%
End of Life Vehicles	37	0.001%
Tyres	174	0.002%
Batteries	2027	0.03%
Oils/fuels	4331	0.1%
Paints/Inks/Varnishes	38	0.001%
Organic Chemicals	3162	0.04%
Inorganic Chemicals	93553	1.3%
Unknown Chemicals	11628	0.2%
Aqueous Chemical Effluents	159564	2.2%
Organic Sludges	444702	6.2%
Inorganic Sludges		
Unknown/Mixed Sludges	890580	12.3%
Combustion Residues	14785	0.2%
Miscellaneous – Combustible[7]	2787764	38.6%
Miscellaneous - Non-Combustible[8]	674618	9.3%
Total	**7230238**	**100%**

Source: EA England, Commercial and Industrial Waste Survey 2002/03. Data provided by the Strategic Waste and Resource Management group of the Environment Agency

Notes: 1. Waste category 'mixed municipal waste' (EWC code 20 03 01) has been included in the statistics and has been assumed to have the same composition as that assumed for municipal waste. This may potentially have resulted in a double-count of municipal wastes.

2. Composition of waste category 'bulky waste' assumed on the basis of Welsh bulky waste composition, taken from *The Composition of Municipal Waste in Wales*. National Assembly for Wales (NAW)/AEAT Technology - December 2003.

3. Waste category 'construction & demolition' assumed to comprise 99% non-combustible waste and 1% combustibles

4. Waste category 'mixed packaging' assumed to comprise 20% paper & card, 20% glass, 20% metals, 20% wood and 20% plastics

5. Waste categories described as 'plastics' assumed to comprise 50% dense and 50% film

6. Waste categories described as 'metals' assumed to comprise 50% ferrous and 50% non-ferrous

7. Includes all miscellaneous wastes not otherwise specified

8. Includes inert wastes only

Table A1.48 Industrial Waste Composition (England, 2002/03): Furniture and Other Manufacturing Sector

Waste Fraction[1-6]	**Tonnes Arising 2002/03**	**% of Sector Arisings**
Paper & Card	104289	15.5%
Organic/Food Waste	69568	10.3%
Green Waste	61629	9.1%
Wood	193489	28.7%
Textiles	9065	1.3%
Fines	13776	2.0%
Glass	26528	3.9%
Plastic (dense)	13853	2.1%
Plastic (film)	12267	1.8%
Ferrous Metal	79030	11.7%
Non-Ferrous Metal	4926	0.7%
WEEE	12615	1.9%
End of Life Vehicles	5	0.001%
Tyres	68	0.01%
Batteries	1126	0.2%
Oils/fuels	282	0.04%
Paints/Inks/Varnishes	2583	0.4%
Organic Chemicals	574	0.1%
Inorganic Chemicals	2	0.0003%
Unknown Chemicals	3263	0.5%
Aqueous Chemical Effluents	204	0.03%
Organic Sludges		
Inorganic Sludges		
Unknown/Mixed Sludges	454	0.1%
Combustion Residues	1020	0.2%
Miscellaneous – Combustible[7]	18217	2.7%
Miscellaneous - Non-Combustible[8]	45795	6.8%
Total	**674628**	**100%**

Source: EA England, Commercial and Industrial Waste Survey 2002/03. Data provided by the Strategic Waste and Resource Management group of the Environment Agency

Notes: 1. Waste category 'mixed municipal waste' (EWC code 20 03 01) has been included in the statistics and has been assumed to have the same composition as that assumed for municipal waste. This may potentially have resulted in a double-count of municipal wastes.

2. Composition of waste category 'bulky waste' assumed on the basis of Welsh bulky waste composition, taken from *The Composition of Municipal Waste in Wales*. National Assembly for Wales (NAW)/AEAT Technology - December 2003.

3. Waste category 'construction & demolition' assumed to comprise 99% non-combustible waste and 1% combustibles

4. Waste category 'mixed packaging' assumed to comprise 20% paper & card, 20% glass, 20% metals, 20% wood and 20% plastics

5. Waste categories described as 'plastics' assumed to comprise 50% dense and 50% film

6. Waste categories described as 'metals' assumed to comprise 50% ferrous and 50% non-ferrous

7. Includes all miscellaneous wastes not otherwise specified

8. Includes inert wastes only

Table A1.49 Industrial Waste Composition (England, 2002/03): Manufacture of Basic Metals

Waste Fraction[1-6]	**Tonnes Arising 2002/03**	**% of Sector Arisings**
Paper & Card	38367	0.8%
Organic/Food Waste	30205	0.6%
Green Waste	25272	0.5%
Wood	12999	0.3%
Textiles	3721	0.1%
Fines	5670	0.1%
Glass	9824	0.2%
Plastic (dense)	6036	0.1%
Plastic (film)	5190	0.1%
Ferrous Metal	192147	4.0%
Non-Ferrous Metal	114341	2.4%
WEEE	4774	0.1%
End of Life Vehicles		
Tyres	5	0.0001%
Batteries	479	0.01%
Oils/fuels	9645	0.2%
Paints/Inks/Varnishes	566	0.01%
Organic Chemicals	4772	0.1%
Inorganic Chemicals	33077	0.7%
Unknown Chemicals	4940	0.1%
Aqueous Chemical Effluents	11087	0.2%
Organic Sludges	37745	0.8%
Inorganic Sludges	28262	0.6%
Unknown/Mixed Sludges	53632	1.1%
Combustion Residues	435217	9.0%
Miscellaneous – Combustible[7]	3443035	71.5%
Miscellaneous - Non-Combustible[8]	304141	6.3%
Total	**4815147**	**100%**

Source: EA England, Commercial and Industrial Waste Survey 2002/03. Data provided by the Strategic Waste and Resource Management group of the Environment Agency

Notes: 1. Waste category 'mixed municipal waste' (EWC code 20 03 01) has been included in the statistics and has been assumed to have the same composition as that assumed for municipal waste. This may potentially have resulted in a double-count of municipal wastes.

2. Composition of waste category 'bulky waste' assumed on the basis of Welsh bulky waste composition, taken from *The Composition of Municipal Waste in Wales*. National Assembly for Wales (NAW)/AEAT Technology - December 2003.

3. Waste category 'construction & demolition' assumed to comprise 99% non-combustible waste and 1% combustibles

4. Waste category 'mixed packaging' assumed to comprise 20% paper & card, 20% glass, 20% metals, 20% wood and 20% plastics

5. Waste categories described as 'plastics' assumed to comprise 50% dense and 50% film

6. Waste categories described as 'metals' assumed to comprise 50% ferrous and 50% non-ferrous

7. Includes all miscellaneous wastes not otherwise specified

8. Includes inert wastes only

Table A1.50 Industrial Waste Composition (England, 2002/03): Manufacture of Chemicals and Chemical Products

Waste Fraction[1-6]	**Tonnes Arising 2002/03**	**% of Sector Arisings**
Paper & Card	292845	5.6%
Organic/Food Waste	148789	2.8%
Green Waste	118645	2.3%
Wood	90885	1.7%
Textiles	28681	0.5%
Fines	26448	0.5%
Glass	59256	1.1%
Plastic (dense)	71356	1.4%
Plastic (film)	111562	2.1%
Ferrous Metal	68736	1.3%
Non-Ferrous Metal	54670	1.0%
WEEE	23595	0.4%
End of Life Vehicles	6	0.0001%
Tyres	1033	0.02%
Batteries	3284	0.1%
Oils/fuels	9160	0.2%
Paints/Inks/Varnishes	26358	0.5%
Organic Chemicals	357666	6.8%
Inorganic Chemicals	318656	6.1%
Unknown Chemicals	78388	1.5%
Aqueous Chemical Effluents	147580	2.8%
Organic Sludges	17071	0.3%
Inorganic Sludges	41	0.001%
Unknown/Mixed Sludges	539652	10.3%
Combustion Residues	18445	0.4%
Miscellaneous – Combustible[7]	2408569	45.8%
Miscellaneous - Non-Combustible[8]	236104	4.5%
Total	**5257480**	**100%**

Source: EA England, Commercial and Industrial Waste Survey 2002/03. Data provided by the Strategic Waste and Resource Management group of the Environment Agency

Notes: 1. Waste category ‘mixed municipal waste’ (EWC code 20 03 01) has been included in the statistics and has been assumed to have the same composition as that assumed for municipal waste. This may potentially have resulted in a double-count of municipal wastes.

2. Composition of waste category ‘bulky waste’ assumed on the basis of Welsh bulky waste composition, taken from *The Composition of Municipal Waste in Wales*. National Assembly for Wales (NAW)/AEAT Technology - December 2003.

3. Waste category ‘construction & demolition’ assumed to comprise 99% non-combustible waste and 1% combustibles

4. Waste category ‘mixed packaging’ assumed to comprise 20% paper & card, 20% glass, 20% metals, 20% wood and 20% plastics

5. Waste categories described as ‘plastics’ assumed to comprise 50% dense and 50% film

6. Waste categories described as ‘metals’ assumed to comprise 50% ferrous and 50% non-ferrous

7. Includes all miscellaneous wastes not otherwise specified

8. Includes inert wastes only

Table A1.51 Industrial Waste Composition (England, 2002/03): Manufacture of Fabricated Metal Products

Waste Fraction[1-6]	Tonnes Arising 2002/03	% of Sector Arisings
Paper & Card	89549	5.9%
Organic/Food Waste	58278	3.8%
Green Waste	45037	3.0%
Wood	32709	2.1%
Textiles	6676	0.4%
Fines	10067	0.7%
Glass	20810	1.4%
Plastic (dense)	13084	0.9%
Plastic (film)	10771	0.7%
Ferrous Metal	396399	26.0%
Non-Ferrous Metal	298177	19.6%
WEEE	35340	2.3%
End of Life Vehicles	93	0.01%
Tyres		
Batteries	864	0.1%
Oils/fuels	8313	0.5%
Paints/Inks/Varnishes	1783	0.1%
Organic Chemicals	1863	0.1%
Inorganic Chemicals	113837	7.5%
Unknown Chemicals	4512	0.3%
Aqueous Chemical Effluents	28180	1.8%
Organic Sludges	8666	0.6%
Inorganic Sludges	448	0.03%
Unknown/Mixed Sludges	60466	4.0%
Combustion Residues	25615	1.7%
Miscellaneous – Combustible[7]	217789	14.3%
Miscellaneous - Non-Combustible[8]	35360	2.3%
Total	1524684	100%

Source: EA England, Commercial and Industrial Waste Survey 2002/03. Data provided by the Strategic Waste and Resource Management group of the Environment Agency

Notes: 1. Waste category 'mixed municipal waste' (EWC code 20 03 01) has been included in the statistics and has been assumed to have the same composition as that assumed for municipal waste. This may potentially have resulted in a double-count of municipal wastes.

2. Composition of waste category 'bulky waste' assumed on the basis of Welsh bulky waste composition, taken from *The Composition of Municipal Waste in Wales*. National Assembly for Wales (NAW)/AEAT Technology - December 2003.

3. Waste category 'construction & demolition' assumed to comprise 99% non-combustible waste and 1% combustibles

4. Waste category 'mixed packaging' assumed to comprise 20% paper & card, 20% glass, 20% metals, 20% wood and 20% plastics

5. Waste categories described as 'plastics' assumed to comprise 50% dense and 50% film

6. Waste categories described as 'metals' assumed to comprise 50% ferrous and 50% non-ferrous

7. Includes all miscellaneous wastes not otherwise specified

8. Includes inert wastes only

Table A1.52 Industrial Waste Composition (England, 2002/03): Manufacture of Machinery and Equipment

Waste Fraction[1-6]	**Tonnes Arising 2002/03**	**% of Sector Arisings**
Paper & Card	95228	10.1%
Organic/Food Waste	43723	4.7%
Green Waste	34185	3.6%
Wood	40968	4.4%
Textiles	5027	0.5%
Fines	7649	0.8%
Glass	20475	2.2%
Plastic (dense)	84237	9.0%
Plastic (film)	15911	1.7%
Ferrous Metal	196687	20.9%
Non-Ferrous Metal	65244	6.9%
WEEE	7921	0.8%
End of Life Vehicles		
Tyres		
Batteries	1272	0.1%
Oils/fuels	10819	1.2%
Paints/Inks/Varnishes	1910	0.2%
Organic Chemicals	5443	0.6%
Inorganic Chemicals	285	0.03%
Unknown Chemicals	1871	0.2%
Aqueous Chemical Effluents	5532	0.6%
Organic Sludges	1364	0.1%
Inorganic Sludges	40	0.004%
Unknown/Mixed Sludges	6681	0.7%
Combustion Residues		
Miscellaneous – Combustible[7]	35729	3.8%
Miscellaneous - Non-Combustible[8]	251128	26.7%
Total	939331	100%

Source: EA England, Commercial and Industrial Waste Survey 2002/03. Data provided by the Strategic Waste and Resource Management group of the Environment Agency

Notes: 1. Waste category 'mixed municipal waste' (EWC code 20 03 01) has been included in the statistics and has been assumed to have the same composition as that assumed for municipal waste. This may potentially have resulted in a double-count of municipal wastes.

2. Composition of waste category 'bulky waste' assumed on the basis of Welsh bulky waste composition, taken from *The Composition of Municipal Waste in Wales*. National Assembly for Wales (NAW)/AEAT Technology - December 2003.

3. Waste category 'construction & demolition' assumed to comprise 99% non-combustible waste and 1% combustibles

4. Waste category 'mixed packaging' assumed to comprise 20% paper & card, 20% glass, 20% metals, 20% wood and 20% plastics

5. Waste categories described as 'plastics' assumed to comprise 50% dense and 50% film

6. Waste categories described as 'metals' assumed to comprise 50% ferrous and 50% non-ferrous

7. Includes all miscellaneous wastes not otherwise specified

8. Includes inert wastes only

Table A1.53 *Industrial Waste Composition (England, 2002/03): Manufacture of Motor Vehicles and Other Transport Equipment*

Waste Fraction[1-6]	**Tonnes Arising 2002/03**	**% of Sector Arisings**
Paper & Card	103604	7.0%
Organic/Food Waste	59356	4.0%
Green Waste	49622	3.4%
Wood	94309	6.4%
Textiles	7727	0.5%
Fines	11959	0.8%
Glass	21221	1.4%
Plastic (dense)	13753	0.9%
Plastic (film)	16903	1.1%
Ferrous Metal	531519	36.0%
Non-Ferrous Metal	235928	16.0%
WEEE	13887	0.9%
End of Life Vehicles	443	0.03%
Tyres	301	0.02%
Batteries	14373	1.0%
Oils/fuels	13332	0.9%
Paints/Inks/Varnishes	7231	0.5%
Organic Chemicals	6431	0.4%
Inorganic Chemicals	9779	0.7%
Unknown Chemicals	2920	0.2%
Aqueous Chemical Effluents	13051	0.9%
Organic Sludges	6458	0.4%
Inorganic Sludges	2546	0.2%
Unknown/Mixed Sludges	15007	1.0%
Combustion Residues	87450	5.9%
Miscellaneous – Combustible[7]	88259	6.0%
Miscellaneous - Non-Combustible[8]	47851	3.2%
Total	**1475221**	**100%**

Source: EA England, Commercial and Industrial Waste Survey 2002/03. Data provided by the Strategic Waste and Resource Management group of the Environment Agency

Notes: 1. Waste category 'mixed municipal waste' (EWC code 20 03 01) has been included in the statistics and has been assumed to have the same composition as that assumed for municipal waste. This may potentially have resulted in a double-count of municipal wastes.

2. Composition of waste category 'bulky waste' assumed on the basis of Welsh bulky waste composition, taken from *The Composition of Municipal Waste in Wales*. National Assembly for Wales (NAW)/AEAT Technology - December 2003.

3. Waste category 'construction & demolition' assumed to comprise 99% non-combustible waste and 1% combustibles

4. Waste category 'mixed packaging' assumed to comprise 20% paper & card, 20% glass, 20% metals, 20% wood and 20% plastics

5. Waste categories described as 'plastics' assumed to comprise 50% dense and 50% film

6. Waste categories described as 'metals' assumed to comprise 50% ferrous and 50% non-ferrous

7. Includes all miscellaneous wastes not otherwise specified

8. Includes inert wastes only

Table A1.54 Industrial Waste Composition (England, 2002/03): Manufacture of Office Machinery, Media and Medical Equipment

Waste Fraction[1-6]	Tonnes Arising 2002/03	% of Sector Arisings
Paper & Card	120831	23.4%
Organic/Food Waste	36734	7.1%
Green Waste	32433	6.3%
Wood	19982	3.9%
Textiles	5102	1.0%
Fines	7250	1.4%
Glass	15840	3.1%
Plastic (dense)	10115	2.0%
Plastic (film)	20918	4.1%
Ferrous Metal	57599	11.2%
Non-Ferrous Metal	32465	6.3%
WEEE	15636	3.0%
End of Life Vehicles		
Tyres		
Batteries	2252	0.4%
Oils/fuels	1008	0.2%
Paints/Inks/Varnishes	1690	0.3%
Organic Chemicals	52801	10.2%
Inorganic Chemicals	4072	0.8%
Unknown Chemicals	9750	1.9%
Aqueous Chemical Effluents	2346	0.5%
Organic Sludges	21	0.004%
Inorganic Sludges		
Unknown/Mixed Sludges	8719	1.7%
Combustion Residues	61	0.01%
Miscellaneous – Combustible[7]	20230	3.9%
Miscellaneous - Non-Combustible[8]	37445	7.3%
Total	**515300**	**100%**

Source: EA England, Commercial and Industrial Waste Survey 2002/03. Data provided by the Strategic Waste and Resource Management group of the Environment Agency

Notes: 1. Waste category 'mixed municipal waste' (EWC code 20 03 01) has been included in the statistics and has been assumed to have the same composition as that assumed for municipal waste. This may potentially have resulted in a double-count of municipal wastes.

2. Composition of waste category 'bulky waste' assumed on the basis of Welsh bulky waste composition, taken from *The Composition of Municipal Waste in Wales*. National Assembly for Wales (NAW)/AEAT Technology - December 2003.

3. Waste category 'construction & demolition' assumed to comprise 99% non-combustible waste and 1% combustibles

4. Waste category 'mixed packaging' assumed to comprise 20% paper & card, 20% glass, 20% metals, 20% wood and 20% plastics

5. Waste categories described as 'plastics' assumed to comprise 50% dense and 50% film

6. Waste categories described as 'metals' assumed to comprise 50% ferrous and 50% non-ferrous

7. Includes all miscellaneous wastes not otherwise specified

8. Includes inert wastes only

Table A1.55 *Industrial Waste Composition (England, 2002/03): Manufacture of Pulp, Paper and Paper Products*

Waste Fraction[1-6]	**Tonnes Arising 2002/03**	**% of Sector Arisings**
Paper & Card	418712	23.0%
Organic/Food Waste	35081	1.9%
Green Waste	28134	1.5%
Wood	33653	1.8%
Textiles	4391	0.2%
Fines	6289	0.3%
Glass	11136	0.6%
Plastic (dense)	6210	0.3%
Plastic (film)	17093	0.9%
Ferrous Metal	11104	0.6%
Non-Ferrous Metal	5596	0.3%
WEEE	4536	0.2%
End of Life Vehicles		
Tyres		
Batteries	504	0.03%
Oils/fuels	774	0.04%
Paints/Inks/Varnishes	1544	0.1%
Organic Chemicals	10432	0.6%
Inorganic Chemicals	15	0.001%
Unknown Chemicals	1611	0.1%
Aqueous Chemical Effluents	23360	1.3%
Organic Sludges	63471	3.5%
Inorganic Sludges	168385	9.2%
Unknown/Mixed Sludges	164245	9.0%
Combustion Residues	64558	3.5%
Miscellaneous – Combustible[7]	720933	39.6%
Miscellaneous - Non-Combustible[8]	20260	1.1%
Total	**1822025**	**100%**

Source: EA England, Commercial and Industrial Waste Survey 2002/03. Data provided by the Strategic Waste and Resource Management group of the Environment Agency

Notes: 1. Waste category 'mixed municipal waste' (EWC code 20 03 01) has been included in the statistics and has been assumed to have the same composition as that assumed for municipal waste. This may potentially have resulted in a double-count of municipal wastes.

2. Composition of waste category 'bulky waste' assumed on the basis of Welsh bulky waste composition, taken from *The Composition of Municipal Waste in Wales*. National Assembly for Wales (NAW)/AEAT Technology - December 2003.

3. Waste category 'construction & demolition' assumed to comprise 99% non-combustible waste and 1% combustibles

4. Waste category 'mixed packaging' assumed to comprise 20% paper & card, 20% glass, 20% metals, 20% wood and 20% plastics

5. Waste categories described as 'plastics' assumed to comprise 50% dense and 50% film

6. Waste categories described as 'metals' assumed to comprise 50% ferrous and 50% non-ferrous

7. Includes all miscellaneous wastes not otherwise specified

8. Includes inert wastes only

Table A1.56 *Industrial Waste Composition (England, 2002/03): Manufacture of Textiles and Other Apparel*

Waste Fraction[1-6]	Tonnes Arising 2002/03	% of Sector Arisings
Paper & Card	73248	5.9%
Organic/Food Waste	71559	5.8%
Green Waste	49097	4.0%
Wood	18593	1.5%
Textiles	22838	1.9%
Fines	10975	0.9%
Glass	19091	1.5%
Plastic (dense)	12127	1.0%
Plastic (film)	40898	3.3%
Ferrous Metal	17734	1.4%
Non-Ferrous Metal	8775	0.7%
WEEE	7897	0.6%
End of Life Vehicles		
Tyres		
Batteries	878	0.1%
Oils/fuels	261	0.02%
Paints/Inks/Varnishes	1	0.0001%
Organic Chemicals	137	0.01%
Inorganic Chemicals	4	0.0003%
Unknown Chemicals	37543	3.0%
Aqueous Chemical Effluents	2643	0.2%
Organic Sludges	350	0.03%
Inorganic Sludges		
Unknown/Mixed Sludges	497537	40.3%
Combustion Residues		
Miscellaneous – Combustible[7]	305056	24.7%
Miscellaneous - Non-Combustible[8]	37188	3.0%
Total	**1234430**	**100%**

Source: EA England, Commercial and Industrial Waste Survey 2002/03. Data provided by the Strategic Waste and Resource Management group of the Environment Agency

Notes: 1. Waste category 'mixed municipal waste' (EWC code 20 03 01) has been included in the statistics and has been assumed to have the same composition as that assumed for municipal waste. This may potentially have resulted in a double-count of municipal wastes.

2. Composition of waste category 'bulky waste' assumed on the basis of Welsh bulky waste composition, taken from *The Composition of Municipal Waste in Wales*. National Assembly for Wales (NAW)/AEAT Technology - December 2003.

3. Waste category 'construction & demolition' assumed to comprise 99% non-combustible waste and 1% combustibles

4. Waste category 'mixed packaging' assumed to comprise 20% paper & card, 20% glass, 20% metals, 20% wood and 20% plastics

5. Waste categories described as 'plastics' assumed to comprise 50% dense and 50% film

6. Waste categories described as 'metals' assumed to comprise 50% ferrous and 50% non-ferrous

7. Includes all miscellaneous wastes not otherwise specified

8. Includes inert wastes only

Table A1.57 Industrial Waste Composition (England, 2002/03): Manufacture of Non-Metallic Mineral Products

Waste Fraction[1-6]	**Tonnes Arising 2002/03**	**% of Sector Arisings**
Paper & Card	62383	2.7%
Organic/Food Waste	33227	1.5%
Green Waste	29774	1.3%
Wood	31711	1.4%
Textiles	4379	0.2%
Fines	6655	0.3%
Glass	70709	3.1%
Plastic (dense)	13578	0.6%
Plastic (film)	13281	0.6%
Ferrous Metal	78536	3.5%
Non-Ferrous Metal	69221	3.0%
WEEE	8269	0.4%
End of Life Vehicles	1	0.00002%
Tyres	484	0.02%
Batteries	580	0.03%
Oils/fuels	2464	0.1%
Paints/Inks/Varnishes	3211	0.1%
Organic Chemicals	699	0.03%
Inorganic Chemicals	46	0.002%
Unknown Chemicals	1725	0.1%
Aqueous Chemical Effluents	664	0.03%
Organic Sludges	5166	0.2%
Inorganic Sludges	103686	4.6%
Unknown/Mixed Sludges	25690	1.1%
Combustion Residues	151064	6.6%
Miscellaneous – Combustible[7]	992898	43.7%
Miscellaneous - Non-Combustible[8]	562342	24.7%
Total	**2272442**	**100%**

Source: EA England, Commercial and Industrial Waste Survey 2002/03. Data provided by the Strategic Waste and Resource Management group of the Environment Agency

Notes: 1. Waste category 'mixed municipal waste' (EWC code 20 03 01) has been included in the statistics and has been assumed to have the same composition as that assumed for municipal waste. This may potentially have resulted in a double-count of municipal wastes.

2. Composition of waste category 'bulky waste' assumed on the basis of Welsh bulky waste composition, taken from *The Composition of Municipal Waste in Wales*. National Assembly for Wales (NAW)/AEAT Technology - December 2003.

3. Waste category 'construction & demolition' assumed to comprise 99% non-combustible waste and 1% combustibles

4. Waste category 'mixed packaging' assumed to comprise 20% paper & card, 20% glass, 20% metals, 20% wood and 20% plastics

5. Waste categories described as 'plastics' assumed to comprise 50% dense and 50% film

6. Waste categories described as 'metals' assumed to comprise 50% ferrous and 50% non-ferrous

7. Includes all miscellaneous wastes not otherwise specified

8. Includes inert wastes only

Table A1.58 Industrial Waste Composition (England, 2002/03): Production of Coke, Oil, Gas, Electricity and Water

Waste Fraction[1-6]	**Tonnes Arising 2002/03**	**% of Sector Arisings**
Paper & Card	32608	0.5%
Organic/Food Waste	21170	0.3%
Green Waste	18500	0.3%
Wood	8601	0.1%
Textiles	2730	0.04%
Fines	4135	0.1%
Glass	8239	0.1%
Plastic (dense)	6842	0.1%
Plastic (film)	6063	0.1%
Ferrous Metal	27348	0.4%
Non-Ferrous Metal	17412	0.3%
WEEE	10109	0.2%
End of Life Vehicles	2	0.00003%
Tyres	15	0.0002%
Batteries	1295	0.02%
Oils/fuels	13298	0.2%
Paints/Inks/Varnishes	4	0.0001%
Organic Chemicals	11781	0.2%
Inorganic Chemicals	2401	0.04%
Unknown Chemicals	1156	0.02%
Aqueous Chemical Effluents	2193	0.04%
Organic Sludges	6516	0.1%
Inorganic Sludges	1183	0.02%
Unknown/Mixed Sludges	172577	2.8%
Combustion Residues	5585760	90.4%
Miscellaneous – Combustible[7]	176105	2.8%
Miscellaneous - Non-Combustible[8]	43696	0.7%
Total	**6181738**	**100%**

Source: EA England, Commercial and Industrial Waste Survey 2002/03. Data provided by the Strategic Waste and Resource Management group of the Environment Agency

Notes: 1. Waste category 'mixed municipal waste' (EWC code 20 03 01) has been included in the statistics and has been assumed to have the same composition as that assumed for municipal waste. This may potentially have resulted in a double-count of municipal wastes.

2. Composition of waste category 'bulky waste' assumed on the basis of Welsh bulky waste composition, taken from *The Composition of Municipal Waste in Wales*. National Assembly for Wales (NAW)/AEAT Technology - December 2003.

3. Waste category 'construction & demolition' assumed to comprise 99% non-combustible waste and 1% combustibles

4. Waste category 'mixed packaging' assumed to comprise 20% paper & card, 20% glass, 20% metals, 20% wood and 20% plastics

5. Waste categories described as 'plastics' assumed to comprise 50% dense and 50% film

6. Waste categories described as 'metals' assumed to comprise 50% ferrous and 50% non-ferrous

7. Includes all miscellaneous wastes not otherwise specified

8. Includes inert wastes only

Table A1.59 Industrial Waste Composition (England, 2002/03): Publishing, Printing and Recording Sector

Waste Fraction[1-6]	**Tonnes Arising 2002/03**	**% of Sector Arisings**
Paper & Card	1431317	65.8%
Organic/Food Waste	99235	4.6%
Green Waste	90590	4.2%
Wood	30266	1.4%
Textiles	13322	0.6%
Fines	20250	0.9%
Glass	36323	1.7%
Plastic (dense)	21380	1.0%
Plastic (film)	22025	1.0%
Ferrous Metal	25657	1.2%
Non-Ferrous Metal	67584	3.1%
WEEE	16184	0.7%
End of Life Vehicles		
Tyres		
Batteries	1599	0.1%
Oils/fuels	777	0.04%
Paints/Inks/Varnishes	5173	0.2%
Organic Chemicals	60189	2.8%
Inorganic Chemicals	408	0.02%
Unknown Chemicals	11483	0.5%
Aqueous Chemical Effluents	14210	0.7%
Organic Sludges	2430	0.1%
Inorganic Sludges		
Unknown/Mixed Sludges	232	0.01%
Combustion Residues	308	0.01%
Miscellaneous – Combustible[7]	130713	6.0%
Miscellaneous - Non-Combustible[8]	72189	3.3%
Total	**2173844**	**100%**

Source: EA England, Commercial and Industrial Waste Survey 2002/03. Data provided by the Strategic Waste and Resource Management group of the Environment Agency

Notes: 1. Waste category 'mixed municipal waste' (EWC code 20 03 01) has been included in the statistics and has been assumed to have the same composition as that assumed for municipal waste. This may potentially have resulted in a double-count of municipal wastes.

2. Composition of waste category 'bulky waste' assumed on the basis of Welsh bulky waste composition, taken from *The Composition of Municipal Waste in Wales*. National Assembly for Wales (NAW)/AEAT Technology - December 2003.

3. Waste category 'construction & demolition' assumed to comprise 99% non-combustible waste and 1% combustibles

4. Waste category 'mixed packaging' assumed to comprise 20% paper & card, 20% glass, 20% metals, 20% wood and 20% plastics

5. Waste categories described as 'plastics' assumed to comprise 50% dense and 50% film

6. Waste categories described as 'metals' assumed to comprise 50% ferrous and 50% non-ferrous

7. Includes all miscellaneous wastes not otherwise specified

8. Includes inert wastes only

Table A1.60 Industrial Waste Composition (England, 2002/03): Wood and Wood Products Sector

Waste Fraction[1-6]	**Tonnes Arising 2002/03**	**% of Sector Arisings**
Paper & Card	55450	3.8%
Organic/Food Waste	45596	3.1%
Green Waste	41663	2.8%
Wood	1152698	78.4%
Textiles	6127	0.4%
Fines	9313	0.6%
Glass	17940	1.2%
Plastic (dense)	10641	0.7%
Plastic (film)	9123	0.6%
Ferrous Metal	14937	1.0%
Non-Ferrous Metal	7906	0.5%
WEEE	8567	0.6%
End of Life Vehicles		
Tyres	2	0.0001%
Batteries	735	0.05%
Oils/fuels	172	0.01%
Paints/Inks/Varnishes	1142	0.1%
Organic Chemicals	878	0.1%
Inorganic Chemicals		
Unknown Chemicals	2206	0.1%
Aqueous Chemical Effluents	620	0.04%
Organic Sludges	526	0.04%
Inorganic Sludges		
Unknown/Mixed Sludges	18	0.001%
Combustion Residues	1983	0.1%
Miscellaneous – Combustible[7]	29420	2.0%
Miscellaneous - Non-Combustible[8]	53290	3.6%
Total	**1470953**	**100%**

Source: EA England, Commercial and Industrial Waste Survey 2002/03. Data provided by the Strategic Waste and Resource Management group of the Environment Agency

Notes: 1. Waste category 'mixed municipal waste' (EWC code 20 03 01) has been included in the statistics and has been assumed to have the same composition as that assumed for municipal waste. This may potentially have resulted in a double-count of municipal wastes.

2. Composition of waste category 'bulky waste' assumed on the basis of Welsh bulky waste composition, taken from *The Composition of Municipal Waste in Wales*. National Assembly for Wales (NAW)/AEAT Technology - December 2003.

3. Waste category 'construction & demolition' assumed to comprise 99% non-combustible waste and 1% combustibles

4. Waste category 'mixed packaging' assumed to comprise 20% paper & card, 20% glass, 20% metals, 20% wood and 20% plastics

5. Waste categories described as 'plastics' assumed to comprise 50% dense and 50% film

6. Waste categories described as 'metals' assumed to comprise 50% ferrous and 50% non-ferrous

7. Includes all miscellaneous wastes not otherwise specified

8. Includes inert wastes only

Table A1.61 Industrial Waste Composition (England, 2002/03): All Sectors Combined

Waste Fraction[1-6]	Tonnes Arising 2002/03	% of Sector Arisings	% Carbon (Biogenic)[9]	% Carbon (Fossil)[9]	Gross Calorific Value (MJ/kg)[9]
Paper & Card	3293968	8.8%	31.9%		12.6
Other Organics	1727712	4.6%	13.5%		5.3
Food Waste	1771351	4.7%	17.2%		6.5
Green Waste	814361	2.2%	13.5%		5.3
Wood	1882842	5.0%	43.8%		18.3
Textiles	114830	0.3%	19.9%[10]	19.9%[10]	15.9
Fines	174940	0.5%	6.9%[10]	6.9%[10]	4.8
Glass	403563	1.1%	0.3%		1.5
Plastic (dense)	353831	0.9%		54.8%	26.7
Plastic (film)	360300	1.0%		47.8%	23.6
Ferrous Metal	1673341	4.5%			
Non-Ferrous Metal	1023419	2.7%			
WEEE	243689	0.6%		15.8%	7.6
End of Life Vehicles	586	0.002%		15.8%[11]	7.6[11]
Tyres	2081	0.01%		74.0%	31.7
Batteries	26952	0.1%			
Oils/fuels	74636	0.2%		80.4%	37.7[12]
Paints/Inks/Varnishes	53233	0.1%		38.4%	15.6
Organic Chemicals	516827	1.4%		38.4%[13]	15.6[13]
Inorganic Chemicals	576134	1.5%		38.4%[13]	15.6[13]
Unknown Chemicals	171336	0.5%		38.4%[13]	15.6[13]
Aqueous Chemical Effluents	434039	1.2%		38.4%[13]	15.6[13]
Organic Sludges	143066	0.4%	30.9%[14]		12.0[14]
Inorganic Sludges	304592	0.8%		30.9%[14]	12.0[14]
Unknown/Mixed Sludges	1880621	5.0%	15.5%[14]	15.5%[14]	12.0[14]
Combustion Residues	9590609	25.5%		7.0%[15]	2.8[15]
Miscellaneous – Combustible[7]	6659626	17.7%	19.2%[10]	19.2%[10]	15.6
Soils/silts	708297	1.9%	7.0%		2.8
Mineral/aggregate waste	752295	2.0%		7.0%	2.8
Other Non-Combustible[8]	1854382	4.9%	3.5%	3.5%	2.8
Total	**37587459**	**100%**	**11.3%**	**9.6%**	**8.5**

Source: EA England, Commercial and Industrial Waste Survey 2002/03. Data provided by the Strategic Waste and Resource Management group of the Environment Agency

Notes: 1. Waste category 'mixed municipal waste' (EWC code 20 03 01) has been included in the statistics and has been assumed to have the same composition as that assumed for municipal waste. This may potentially have resulted in a double-count of municipal wastes.

2. Composition of waste category 'bulky waste' assumed on the basis of Welsh bulky waste composition, taken from *The Composition of Municipal Waste in Wales*. National Assembly for Wales (NAW)/AEAT Technology - December 2003.

3. Waste category 'construction & demolition' assumed to comprise 99% non-combustible waste and 1% combustibles

4. Waste category 'mixed packaging' assumed to comprise 20% paper & card, 20% glass, 20% metals, 20% wood and 20% plastics

5. Waste categories described as 'plastics' assumed to comprise 50% dense and 50% film

6. Waste categories described as 'metals' assumed to comprise 50% ferrous and 50% non-ferrous

7. Includes all miscellaneous wastes not otherwise specified

8. Includes minerals, bricks, blocks, plaster, ceramics etc.

9. ERM and Environment Agency Data

10. Assumed 50% biogenic carbon content and 50% fossil carbon content

11. Assumed to be the same as the waste fraction, WEEE

12. Net Calorific Value

13. Generic value assumed for chemicals

14. Assumed to be the same as the waste fraction, sewage sludge and apportioned accordingly

15. Assumed to be the same as the waste fraction, non-combustibles

Composition data disaggregated at the sector level have not been compiled for industrial wastes arising in Scotland, Wales and Northern Ireland. However, an estimate of total industrial waste composition has been published for Northern Ireland, and this is presented in *Table A1.62*. No estimates are currently available regarding industrial waste composition in Scotland and Wales.

Table A1.62 Industrial Waste Composition in Northern Ireland (2001)

Waste Fraction	% of Arisings	Tonnes Arising	% Carbon (Biogenic)[1]	% Carbon (Fossil)[1]
Paper/card	58%	66,149	32%	
Putrescible	9%	9814	14%	
Misc non-combustible	7%	7832	3.5%[2]	3.5%[2]
Ferrous metal	5%	5308		
Non-ferrous metal	2%	1769		
Glass	0%	0	0.28%	
Plastic dense	15%	17,127		55%
Plastic film	5%	5709		48%
Total	**100%**	**113,708**	**20%**	**11%**

Source: Assessment of the Best Practicable Environmental Option for Waste Management in Northern Ireland: Development and Analysis (ERM 2005)

Notes:

1. ERM and Environment Agency Data (2003-2005)
2. Assumed 50% biogenic carbon content and 50% fossil carbon content

A1.8.5 Industrial Waste Growth

In a similar way to commercial wastes, forecasting of industrial waste arisings is difficult due to a lack of historical data and incomplete understanding of future technological developments.

Opinions raised at the workshop on commercial and industrial waste arisings and management suggested that this relatively high economic growth would not translate into an equivalent rate of waste growth. Instead, it was generally felt that technological advances are such that waste growth is likely to be lower than economic growth and that this, together with a decline in heavy industry, would lead to static industrial waste growth overall.

A1.8.6 Future Management of Commercial and Industrial Waste

The workshop on commercial and industrial waste arisings raised the question of the future management of these waste streams. A number of issues were highlighted that have influence on the way that future scenarios for the management of these waste streams may be developed. Some key points that were raised are listed below.

- It should be less important where it comes from (waste stream) – more, what it is and how much is extractable and recyclable.

- Waste management policy should be by material and not source and it is for government and the waste management sector to facilitate the development of infrastructure and cheaper alternatives to landfill. Businesses do not want to build or operate waste management facilities. They are happy to segregate wastes but they need financial incentives to do so. The biggest incentive will be when a waste service provider offers a cheaper alternative to landfill.

- Industry feels that there is scope to increase segregation of wastes for recycling/biological treatment but this would be limited by physical space and cost. For example, glass in commercial sector wastes is a likely target in light of packaging targets for glass recycling. However, segregation by small businesses is likely to be difficult. Organisations such as WRAP have been involved in schemes to increase collection of segregated glass in the service sector.

- Recycling is limited by markets and is dependent on economics. There will always be a demand for energy and so thermal processing is likely to increase for this reason. Recycling and composting only so much, especially with shift from industry to commerce.

- Recycling output will never match manufacturing demand (theoretical maximum for recycling = 60-70% for municipal waste). However, there is still a need to look at case specific industries eg glass – increased use as aggregates, plastics – future increase eg with car/electronics industries increasing recycling effort.

- One size fits all is not the solution. For example, anaerobic digestion leading to recovery on land should become of increased importance for biological commercial wastes.

- Waste itself generates residues (eg ash, APC residues) – this will be the bottom line, landfill will never disappear.

- It is unlikely that commercial waste will be required to be picked up by local authorities in the future, but the waste management industry is looking for more integration and commercial waste may bolt on to PFI schemes – merchant facility on back of PFI capital investment (but can't use for excessive capacity).

- Obstacles for waste management industry include waste producers themselves – eg on-site treatment of sludges (dependant on size of industry (not likely with small and medium enterprises (SMEs) – need to consider how much of waste stream is from SMEs.)).

A1.9 CONSTRUCTION AND DEMOLITION (C&D) WASTE

The construction and demolition waste stream relates to those wastes arises from the construction, repair, maintenance and demolition of buildings and structures. It mostly includes brick, concrete, hardcore, subsoil and topsoil, but it can also include quantities of timber, metal, plastics and small quantities of hazardous waste materials (*Waste Strategy 2000* for England and Wales).

A1.9.1 *C&D Waste Arisings*

Published data relating to construction and demolition waste arisings in the UK derive from a number of sources, dependent on devolved administration.

England & Wales

In 2001, ODPM carried out a survey into the arisings and use of construction and demolition wastes (ODPM, 2001). This followed an initial survey in conjunction with the Environment Agency in 1999/2000 and was commissioned in November 2001 by the Minerals and Waste Planning Division of the Department for Transport, Local Government and the Regions (DTLR) with the support of the Welsh Assembly. *Table A1.63* summarises the results of the 2001 survey.

There are plans to repeat this survey at regular, two yearly intervals so that a time series can be formed. As a result, a subsequent survey was carried out in 2003. At the time of writing, data from this survey had yet to be fully analysed and published. However, summary data comparing construction and demolition arisings and management between 1999 and 2003 are shown in *Table A1.64.* Note that these data relate to arisings in England only.

Data show that total construction and demolition waste arisings in England were estimated at 90.9 million tonnes in 2003. This represents an increase of 2 million tonnes from 2001. Approximately 50% of the total waste stream was recycled as aggregate or soil. A further 18% was used spread on land at registered sites and the remaining 32% was either disposed at landfill sites, or used for layering or topping.

The estimates suggest that the production of recycled aggregate and soil increased significantly (19 million tonnes) between 1999 and 2001, but relatively less from 2001 to 2003 (2 million tonnes). However, further detail regarding the 2003 survey results is required to investigate changes in other management categories.

Table A1.63 *Management of Construction and Demolition Waste in England and Wales, 2001 (Million Tonnes)*

Management Route	England	Wales	Total England & Wales
Used as recycled aggregate	36.5	1.6	38.0
Used as recycled soil	6.8	0.24	7.1
Used for landfill engineering /restoration	8.8	0.66	9.4
Used to backfill quarry voids	10.6	0.94	11.5
Spread on registered exempt sites	22.4	1.3	23.7
Disposed of at landfills	3.9	0.35	4.2
Total arisings	**88.9**	**5.0**	**93.9**

Source: ODPM (2001) Survey of Arisings and use of Construction and Demolition Waste
Source publication: e-Digest of Environmental Statistics, Published August 2003, Department for Environment, Food and Rural Affairs, http://www.defra.gov.uk/environment/statistics/index.htm.

Table A1.64 *Management of Construction and Demolition Waste in England, 1999-2003 (Million Tonnes)*

Management Route	1999	2001	2003
Recycled by crushers/screeners (as aggregate or soil)	24.4	43.3	45.5
Used or disposed in Landfill	25.8	23.2	29.1
Spread on exempt sites	19.0	22.4	16.4
Total	**69.2**	**88.9**	**90.9**

Source: ODPM 2003 survey of construction and demolition waste

Scotland

Data for arisings and management of C&D waste have been provided by SEPA (1). The amount of waste sent to landfill has decreased significantly between the mid-1990 and 2004. This is likely to be explained by both increased recycling and increased quantities of wastes sent to exempt sites. Data are currently limited, however, as SEPA posses only information relating to waste recycled at fixed sites. These data exclude materials recycling through mobile reprocessing plant and therefore underestimate both total arisings and quantities of material recycled.

Since April 2003, exempt sites in Scotland have been registered to handle 6.5 million tonnes of C&D waste. SEPA estimate the total amount of C&D waste handled at exempt sites to be in the region of 2-3 million tonnes in 2004.

The arisings presented in *Table A1.65* are considered to be a low estimates of the quantity of C&D waste generated in Scotland. However, it is currently not possible to quantify the total amount of C&D waste arisings in Scotland, due to lack of available data. SEPA is investing effort in trying to improve datasets, but the results were not available within the timescales of the current research.

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(1) Bill Proctor, Environmental Data Unit Manager, SEPA Personal communication December 2005

Table A1.65 Estimated Arisings and Management of Construction and Demolition Waste in Scotland (Million Tonnes)

Management Route	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Landfill	5.22	4.85	6.71	7.72	-	-	7.01	5.10	4.28	3.95	2.17	1.91	2.60	2.77
Exempt sites	-	-	-	-	-	-	-	-	-	-	-	-	-	2.50[1]
Recycling	-	-	-	-	-	-	-	-	-	-	-	-	-	0.855[2]
Total Arisings	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**6.13**

Source: SEPA. Bill Proctor, personal communication 2005-12-22. Data based on a based on a review of licensed site returns performed by SEPA for the period 1 April 2004 to 31 March 2005.

Notes:

1. Total amount handled by exempt sites is estimated to be in the region of 2-3 million tonnes.
2. Generated from SEPA's review of licensed site returns. Scaled to match total input to sites. Only recycling at fixed sites is included in the estimate.

Northern Ireland

In 2005, an assessment of the Best Practicable Environmental Option (BPEO) for Waste Management in Northern Ireland was carried out by ERM (ERM, 2005). Arisings for this assessment were estimated to be in the region of 2.5 to 3.75 million tonnes. The upper of these values is considered to be an appropriate, conservative estimate of C&D waste arisings in Northern Ireland. Of this, it was estimated that approximately 35% was reused or recycled and 65% sent to landfill.

Total UK

Combining national datasets results in a total best current estimate of 105.7 million tonnes of construction and demolition waste arising across the UK. Final estimates of C&D waste arisings and management in the UK are summarised in *Table A1.66*.

Table A1.66 Estimated Arisings and Management of Construction and Demolition Waste in the UK (Million Tonnes)

	England	**Wales**	**Scotland**	**Northern Ireland**	**Total**
Landfill	9.19	0.35	2.77	2.44	14.7
Land application/recovery	6.45	0.66			7.11
Exempt sites	16.4	1.28	2.50		20.2
Recycled	45.4	1.79	0.86	1.31	49.4
Void filling	13.4	0.94			14.3
Total	**90.86**	**5.02**	**6.13**	**3.75**	**105.7**

Sources:

- ODPM (2001/2003) Survey of Arisings and use of Construction and Demolition Waste.
- SEPA, personal communication
- SEPA licensed site returns 2004 - 2005
- Assessment of the Best Practicable Environmental Option for Waste Management in Northern Ireland: Development and Analysis (ERM 2005)

A1.9.2 C&D Waste Composition

England and Wales

The 2003 ODPM survey of C&D waste in England reports three categories of C&D waste:

- hard C&D waste, which includes both segregated and mixed unprocessed/uncrushed materials. Waste defined by sections 17.01, 17.03 and 17.05 of the European Waste Catalogue is assigned to this stream, which includes wastes such as bricks, concrete, tiles, ceramics, bituminous mixtures and coal and tarred products;

- excavation waste, which includes both clean and contaminated waste soil, stone and rocks arising from land levelling, civil works and/or general foundations. Such materials are defined in two categories of the European Waste Catalogue: 17.05.03 (soil and stones containing dangerous substances) and 17.05.04 (soil and stones other than those mentioned in 17.05.03); and

- mixed hard C&D and excavation waste, which relates to any mixture of the two previous categories.

Arisings of each of these categories of waste in England in 2003 is shown in *Table A1.67*. Further detail regarding composition is unavailable, and so in order to estimate carbon content it has been assumed that these wastes comprise predominantly non-combustible mineral or soil wastes, with an associated carbon content of 7% (1) (assumed to be proportionally split between inorganic and organic fractions). Compositional data from Scotland and Northern Ireland (*Table A1.68*) shows this to be a not unreasonable assumption.

With a lack of further information, it is assumed that the composition of C&D waste in Wales is similarly comprised predominantly soil and mineral materials.

Table A1.67 Estimated Composition of Construction and Demolition Waste in England (2003)

	Million Tonnes Arising
Hard C&D waste	44.4
Excavation waste	34.9
Mixed hard C&D and excavation waste	11.6
Total	**90.9**

Source: ODPM 2003 survey of construction and demolition waste

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(1) Estimated from work carried out as part of the development of the WRATE tool (ERM and Environment Agency Data, 2003-2005)

Scotland

The composition of C&D waste sent to landfill in Scotland between April 2004 and March 2005 has been collated by means of SEPA's review of licensed site returns. In the absence of any further data, it is assumed that all C&D waste arising has the same composition as that sent to landfill. Resulting estimates of Scottish C&D waste composition are presented in *Table A1.68*.

Table A1.68 Estimated Composition of Construction and Demolition Waste in Scotland (2004/05)

Waste Fraction	Million Tonnes Arising	% of Sector Arisings	% Carbon (Biogenic)[1]	% Carbon (Fossil)[1]	Gross Calorific Value (MJ/kg)[1]
Soil and stones	4.5	73.4%	3.5%[2]	3.5%[2]	2.8
Bricks, blocks, plaster	0.01	0.2%		7.0%	2.8
Other non-combustible materials (concrete, tiles, ceramics, insulation materials)[3]	1.6	26.1%	3.5%[2]	3.5%[2]	2.8
Wood	0.005	0.1%	44%		18.3
Other combustible materials (other wood, bitumous material, coal and tarred products)	0.0081	0.1%	19%[2]	19%[2]	15.6
Ferrous Metals[4]	0.00008	0.001%			
Non-ferrous Metals[4]	0.00006	0.001%			
Glass	0.003	0.05%	0.28%		1.5
Plastic (Dense)	0.0007	0.01%		55%	26.7
Total	**6.13**	**100%**	**3.6%**	**3.5%**	**2.8**

Source: SEPA, Review of licensed site returns (2004/05).

1. Carbon content and gross calorific value estimated from work carried out for the Environment Agency WRATE tool (ERM and Environment Agency Data, 2003-2005)
2. Assumed 50% biogenic and 50% fossil carbon sources.
3. Includes, mixed construction waste and wastes not otherwise specified
4. Includes 50%of 'mixed metal' categories

Northern Ireland

Estimated C&D waste composition data for Northern Ireland are shown in *Table A1.69*. Data are based on the Northern Ireland Environment and Heritage Service's most recent waste survey (2002).

Table A1.69 Estimated Composition of Construction and Demolition Waste in Northern Ireland (2002)

Waste Fraction	Million Tonnes Arising	% of Sector Arisings	% Carbon (Biogenic)[1]	% Carbon (Fossil)[1]	Gross Calorific Value (MJ/kg)[1]
Combustible materials [2]	0.075	2.0%	19%[4]	19%[4]	15.6
Non-combustible materials [3]	3.66	98%	3.5%[4]	3.5%[4]	2.8
Non-ferrous Metals	0.015	0.40%			
Total	**3.75**	**100%**	**3.8%**	**3.8%**	**3.0**

Sources:

- *Construction and Demolition Waste Survey*, completed by Enviros Consulting Ltd for EHS, 2002
- Assessment of the Best Practicable Environmental Option for Waste Management in Northern Ireland: Development and Analysis (ERM 2005). http://www.ehsni.gov.uk/pubs/publications/BPEO_Technical_Report_1_81mb.pdf

Notes:

1. Carbon content and gross calorific value estimated from work carried out for the Environment Agency WRATE tool (ERM and Environment Agency Data, 2003-2005)
2. Includes the category "Wood, glass and plastic".
3. Includes concrete, bricks, tiles and ceramics, soils, stones and dredging spoil, insulation materials and asbestos containing construction materials and 'other construction and demolition wastes'.
4. Assumed 50% biogenic and 50% fossil carbon sources.

UK Composition

Given the lack of data relating to C&D waste composition, it is not possible to derive a representative picture of the breakdown of C&D waste in the UK. Discussions with WRAP confirm that the scale of arisings estimates presented are consistent with those commonly reported for waste soil and mineral-based materials.

Data relating to arisings of other materials in this waste stream, such as wood, plastics, glass and metals are severely lacking, as the majority of studies focus on minerals and aggregates. This is a limitation of the data available and could not be reconciled within the timescale of the research. As such, the research used approximations of materials arising through the C&D waste stream on estimates of mineral/aggregate materials and soils only.

A1.9.3 C&D Waste Growth and Future Management

An evaluation of 13 waste strategies for Northern Ireland, England and Wales, carried out as part of the BPEO assessment for Northern Ireland (ERM, 2005) anticipated that quantities of C&D waste produced would increase with economic growth. The rate at which this occurs should be balanced against other influencing factors, such as landfill tax, the Landfill Directive and the Aggregates Levy, which are likely to counteract the trend of increasing C&D waste growth with economic development.

The Aggregates Levy was introduced in 2002, with the aim of increasing the use of secondary aggregates through increasing the cost of primary aggregates. As a result, the majority of easily recyclable material in the C&D waste stream (clean hard C&D waste) is currently recycled (ODPM, 2003). Furthermore, there is evidence that the economics of recycling are now encouraging recyclers to employ techniques which increase recovery rates from the 'mixed hard C&D and excavation waste' stream.

A1.10 SUMMARY: COMBINED ESTIMATES OF UK WASTE ARISINGS AND COMPOSITION

Table A1.70 shows combined estimates of UK waste arisings by waste stream and material composition, as determined through literature and data review.

The differentiation in degree to which waste streams are be broken down into discreet material fractions highlights the inherent difficulties of compiling a UK waste dataset in this way. Levels of disaggregation differ according to source as there is no consistent data collection methodology currently in existence. As such, a number of fractions may in reality be more significant in quantity than is apparent on the basis of currently available data. For example, tonnages for these fractions may be included within the 'miscellaneous' categories (combustibles and non-combustibles). More work is required to further describe the waste categories we have presented, but it not within the scope of this research to do so.

One method available to us to 'sense check' the estimates, was to consult with WRAP as to UK estimates for individual waste materials. This exercise was carried out in a series of meetings with material managers and resulted in an update of estimates of both arisings and management for a number of materials (paper and card, wood and glass). Further, additional information was sought to reconcile estimates for end of life vehicles (ELVs) and tyres, as they appeared low. Resulting estimates are presented in *Table A1.71* and represent the final material estimates used in the research.

Table A1.70 Compiled Estimates of UK Waste Arisings by Material Composition (Million Tonnes) – Results of Literature and Data Review

Waste Fraction	**Agricultural Waste[1]**	**Mining & Quarrying[2]**	**Sewage Sludge[3]**	**Dredged Materials[4]**	**Municipal Waste[5]**	**Commercial Waste[6]**	**Industrial Waste[6]**	**C&D Waste[7]**	**Total**
Paper & Card	0.01				6.3	10.3	4.1		20.6
Kitchen/food waste					6.1	3.5	2.2		11.8
Garden/Plant Waste	6.6				6.4	3.2	1.0		17.2
Other organic waste	83.0		1.3			0.5	2.1		87.0
Wood					1.1	1.2	2.3		4.6
Textiles					0.9	0.4	0.1		1.4
Fines					1.4	0.7	0.2		2.3
Glass					2.2	2.3	0.5		5.0
Plastic (dense)					1.3	1.0	0.4		2.8
Plastic (film)	0.1				1.0	1.5	0.4		3.1
Ferrous Metal					1.2	0.8	2.1		4.1
Non-Ferrous Metal					0.2	0.5	1.3		2.0
WEEE	0.03				0.9	0.9	0.3		2.1
ELVs	0.03					0.05	0.001		0.1
Tyres						0.2	0.003		0.2
Batteries						0.1	0.03		0.2
Oils/fuels						0.4	0.1		0.5
Organic Chemicals						0.1	0.7		0.8
Inorganic Chemicals	0.3						0.7		1.0
Unknown Chemicals	0.1				0.4	0.5	0.2		1.2
Aqueous Chemical Effluents						0.07	0.5		0.6
Organic Sludges						0.0	0.2		0.2
Inorganic Sludges							0.4		0.4
Unknown/Mixed Sludges						0.1	2.3		2.4
Absorbent Hygiene Products					0.8				0.8
Combustion Residues						0.07	11.9		11.9
Silt/soil		48.4		11.73		0.6	0.9	49.1	110.7
Aggregate/mineral materials		48.4		11.73	2.2	0.4	0.9	56.2	119.9
Other non-combustible materials	0.03				2.2	2.3	2.3		6.8
Miscellaneous combustibles					0.8	3.7	8.2		12.7
Total	**90.3**	**96.9**	**1.3**	**23.46**	**35.3**	**35.6**	**46.5**	**105.7**	**434.5**

Notes: 1-7. Refer to *Sections A1.3 to A1.9* for further detail and data sources and age of data

6. Quantities based on commercial and industrial waste composition estimates for England

7. Quantities based on estimates of mineral/aggregate materials and soils only

Table A1.71 *Final Estimates of UK Waste Arisings by Composition (Million Tonnes) – Sense Check*

Waste Fraction	Total
Paper & Card	**13.7**[1]
Kitchen/food waste	**11.8**
Garden/Plant Waste	**17.2**
Other organic waste	**87.0**
Wood	**7.5**[2]
Textiles	**1.4**
Fines	**2.3**
Glass	**3.5**[3]
Plastic (dense)	**2.8**
Plastic (film)	**3.1**
Ferrous Metal	**4.1**
Non-Ferrous Metal	**2.0**
WEEE	**2.1**
ELVs	**2.0**[4]
Tyres	**0.5**[5]
Batteries	**0.2**
Oils/fuels	**0.5**
Organic Chemicals	**0.8**
Inorganic Chemicals	**1.0**
Unknown Chemicals	**1.2**
Aqueous Chemical Effluents	**0.6**
Organic Sludges	**0.2**
Inorganic Sludges	**0.4**
Unknown/Mixed Sludges	**2.4**
Absorbent Hygiene Products	**0.8**
Combustion Residues	**11.9**
Silt/soil	**110.7**
Aggregate/mineral materials	**119.9**
Other non-combustible materials	**6.8**
Miscellaneous combustibles	**12.7**
Total	**431.3**

Notes:
1. WRAP, personal communication. Based on CEPI statistics.
2. WRAP (2005). *Review of Wood Waste Arisings and Management in the UK.* M.E.L Research Ltd.
3. WRAP, personal communication.
4. ERM (2006). Review of 2015 Targets for the ELV Directive. Draft Report for the DTI
5. Environment Agency 2004. *Life Cycle Assessment of the Management Options for Waste Tyres.* Environment Agency, R&D Report Ref. No. P1 437/TR, ISBN: I844 32289 0.

A1.11 COMMENTARY ON THE QUALITY OF ALTERNATIVE DATASETS

The poor quality, completeness and consistency of data regarding waste arisings, composition and management have been noted as limitations to the material arisings estimates presented. Some further comments on the relative quality of different datasets used to generate final estimates, is presented below.

Agricultural Waste

The majority of the estimates of non-natural agricultural waste presented in *Section A1.3* were based on data derived from the Agricultural Waste Survey 2003, as this is the most up to date and complete survey of UK agricultural waste. This survey gathered data from 380 holdings detailed in the June Agricultural Census, using interviews and observations collected during visits to the holdings. The estimates produced in the survey are likely to be a close representation of stockpiled waste quantities, but are likely to overestimate annual quantities of waste arisings. While the survey identified the various waste disposal routes used by farms, the quantities disposed to each were rarely provided, with qualitative descriptions produced instead.

To aid future data collection, a mass balance tool for farms has been developed by Biffaward, in conjunction with Forum for the Future (Biffaward, 2005). This tool comprises an Excel workbook that can estimate waste amounts likely to be produced and their respective waste disposal costs from various farm enterprises. The tool utilises detailed waste flow data, collected from five farms and waste audits from farms participating in the Forum Farm Network, in order to calculate waste streams, such as plastic packaging, paper, glass, wood and mixed waste. The tool could be used in future surveys of agricultural waste. However the quality of resulting estimates requires further consideration.

Mining and Quarrying

Time series data for mining and quarrying activities present only estimates of arisings, and virtually no reliable information on management is available. Minerals waste estimates have been derived based on the ratios of waste to product, as defined by Defra's Waste Statistics Division. Mineral extraction processes differ significantly with respect to waste generation and vary from site to site, and so the arisings presented are very much estimates.

Data on composition of materials are lacking and ERM was required to make a number of assumptions. These data thus cannot be considered reliable, and should be regarded as incomplete and of poor quality.

Sewage Sludge

Data relating to sewage sludge arisings and management derive from, and are monitored by, Water UK (water companies must report sludge generation and management as a sustainability indicator). As such, we can consider these data reliable.

Data regarding the chemical composition of sewage sludge composition are less reliable, as composition varies depending on catchment and typical carbon content will also vary according to moisture content. Data were collated as part of the Environment Agency's ongoing development of WRATE and are considered a reasonable representation. However, the uncertainty with respect to this parameter is noted.

Dredged Materials

Very few data are available regarding arisings and management of waste dredged materials, with inland dredgings lacking in particular. Discussion with British Waterways revealed that the amount of material dredged varies significantly year-by-year and is difficult to predict. Waste from marine sand extraction and capital and maintenance dredgings is also difficult to quantify.

The majority of data that we have collated for these sources have a high degree of variability over time and so in any one year cannot be taken as reliable estimates. However, this waste stream is of relatively low importance within the context of the research, as the majority it is returned to the sea and hence never becomes a waste issue. That which is retained on land is of a relatively low tonnage.

Municipal Solid Waste

Published data relating to MSW arisings in each of the UK's devolved administrations are relatively complete, derive predominantly from the local authorities responsible for collecting and managing wastes, and, as such, are considered to be of good quality.

Much greater uncertainty exists with regard to MSW composition. The composition data used for this study derive from the most complete sources available. However, gaps exist in a number of national datasets, requiring a number of assumptions to be made, the suitability of which are uncertain (as compositions are likely to vary across, and within, nations). Furthermore, we can expect MSW composition to vary widely over time and, within this context, the data sources available are relatively old (ranging from 2002 to 2005). As such, whilst being the best available, the quality of composition data compiled is considered to be poor.

Commercial and Industrial Waste

Published data relating to commercial and industrial waste arisings, management and composition derive from a number of sources and vary in quality and age.

The most complete and recent survey was carried out by the Environment Agency in 2002/03, and was based on a sample of approximately 4500 sites (data collection was limited to controlled waste and relate to England only). The resulting data have a degree of uncertainty and, whilst being the most complete estimates available (in particular with respect to composition) they are limited to some extent. For example, changes in method between this and pervious surveys are such that a direct, time-series comparison cannot be made, and some queries remain over estimates for specific waste materials, such as paper and card. Further, a considerable proportion of waste materials are aggregated into 'miscellaneous' categories and there is ongoing work to disaggregate these further.

Whilst some uncertainty exists, these remain the best and most complete estimates of the composition of commercial and industrial wastes and have been used as a substitute for all commercial and industrial wastes across the

UK. The suitability of making this assumption is, again, uncertain, but remains the best option available to us.

We conclude that estimates regarding commercial and industrial waste arisings are likely to be reliable, but data relating to waste composition across the UK are less so. ERM have had to make a number of assumptions in assigning waste categories from the original data, and, as such, resulting materials stream estimates should be treated with caution.

Construction and Demolition Waste

Data relating to waste arising from construction and demolition activities are of variable quality. The majority of studies and published datasets concentrate on quantifying the arisings and management of minerals and soil-based materials, and very little information is available to quantify arisings of other materials, such as wood, plastics and metals. As such, data for the former are considered relatively reliable and have been used to represent C&D waste arisings. However, it was difficult to reconcile estimates presented in alternative national datasets for alternative materials, and these represent a data gap.

A further breakdown of the specific material fractions comprising the broad categories of 'hard C&D waste', 'excavation waste', 'mixed C&D waste' and 'non-combustibles' was not available in a consistent form to enable a representative picture of the composition of UK C&D waste to be determined. As a result, it is considered that the quality of the material estimates presented is poor.

A1.12 REFERENCES

Refer to *Annex F* for all references and data sources.

Annex B

Scenario Development and Modelling Assumptions

B1 SCENARIO DEVELOPMENT AND MODELLING ASSUMPTIONS

B1.1 CURRENT WASTE ARISINGS AND MANAGEMENT ROUTES – BASELINE SCENARIO

Best estimates of current waste arisings and management were compiled as a first stage of the research and are presented in *Annex A*. Final estimates of baseline arisings and management for the materials under assessment were developed from these sources and are shown in *Table B1.1.*

Table B1.1 Baseline Arisings and Management (Million Tonnes)

Waste Fraction	**Recycling & reuse[9]**	**Windrow Comp[1]**	**IVC[2]**	**AD[10]**	**MBT**	**Combustion[3]**	**Landfill**	**Landspread/ recovery/ reclamation**	**Disposal at sea**	**Total**
Paper & card [4]	6.4				0.04	0.9	6.4			**13.7**
Kitchen/food waste	0.2		0.6	0.05	0.07	1.6	9.2	0.1		**11.8**
Green waste (excl agric)	0.03	1.7			0.05	0.9	7.9	minimal		**10.6**
Agricultural crop waste						0.2		6.4		**6.6**
Other organic (excl agric)	0.2		0.0.2			0.6	0.3	2.8		**4.0**
Agricultural manure/slurry				0.05		0.2		82.8		**83.0**
Wood [5]	1.2				0.01	0.3	6.0			**7.5**
Textiles	0.2				0.01	0.1	1.1	minimal		**1.4**
Plastic (dense)	0.1				0.01	0.2	2.4			**2.8**
Plastic (film)	0.3				0.01	0.2	2.6			**3.1**
Ferrous [6]	2.4				0.01	0.2	1.5	minimal		**4.1**
Non-ferrous metal [6]	1.5				0.002	0.03	0.5	minimal		**2.0**
Silt/soil (excl. min& quarry and marine dredgings) [7]	1.0						13.6	36.2		**50.7**
Mining and quarrying and marine dredged silt/soil [7]								48.4	11.6	**60.0**
Aggregate materials (excl. min& quarry and marine dredgings) [7]	50.6				0.01	0.1	3.4	5.8		**59.9**
Mining and quarrying and marine dredged aggregate [7]	0.5							48.0	11.6	**60.0**
Misc. combustibles	4.2				0.01	2.0	5.6	1.0		**12.7**
Total	**68.9**	**1.7**	**0.6**	**0.1**	**0.2**	**7.4**	**60.5**	**231.4**	**23.1**	**393.9**

1. This currently represents 85% of the reported 2Mt of UK composting (European Composting Network). Most statistics suggest that the majority of green waste is currently windrow composted. It is unknown how much green waste passes to in-vessel composters and so this is assumed to be zero currently. During scenario modelling,. it is assumed that green waste passing to in-vessel composting facilities increases linearly to 50%, to reflect the need for green waste input in addition to food waste at these facilities.
2. All food waste assumed to be composted via in-vessel composting (IVC)
3. Includes combustion with and without energy recovery. It is assumed that 67% of this total is combusted with energy recovery (all MSW combustion and 50% of commercial/industrial wastes to thermal treatment)
4. WRAP, personal communication. Based on CEPI statistics.
5. WRAP (2005). *Review of Wood Waste Arisings and Management in the UK.* M.E.L Research Ltd.
6. Dahlstrom *et al* (2004). *Iron, Steel and Aluminium in the UK: Material Flows and their Economic Dimensions.* Biffaward Programme on Sustainable Resource Use.
8. Aggregate and soil from C&D waste based on ODPM survey data and SEPA/NIEHS estimates. Assumed 50% of inland dredgings are sand and recycled as aggregate, with the remainder silt to landfill. Assumed all marine dredging returned to sea. Assumed 1% of mining and quarrying aggregate is recycled.
9. Estimates of 're-use' derive predominantly from commercial and industrial waste statistics (Environment Agency Commercial and Industrial Waste Survey, 2002/03) and refer to wastes that are transported off-site for re-use. For the purposes of modelling, these were treated as recycled wastes.
10. Current estimates from Holsworthy Anaerobic Digestion plant.

B1.2 *ALTERNATIVE SCENARIOS*

Of interest for the development of alternative scenarios was the maximum performance theoretically achievable in the absence of current policy or infrastructural barriers.

Recovery/recycling rates were considered 'theoretically achievable' only where a similar level of performance has been demonstrated elsewhere in Europe. For example, the ban on the landfill of combustible waste in Denmark has led to a significant increase in energy recovery and recycling, such that only 8% of total wastes were sent to landfill in 2004 (1). Denmark therefore serves as a maximum for the majority of recovery rates. The Netherlands, Sweden, Austria, Belgium and Luxembourg are also high performers, currently diverting more than 70% of wastes from landfill (2).

Based on performance and experience across Europe, a set of maximum recycling and recovery limits were developed. These are shown in *Table B1.2* and form the basis of the alternative scenarios for modelling.

Table B1.2 Recycling and Recovery Upper Limits

Material Fraction	**Recovery Upper Limit**	**Reference**	**Recycling Upper Limit**	**Reference**
Paper & card	90%	>90% recovery of total waste (not inc agric) currently achieved across Denmark (Danish Waste Statistics, 2004) [1]	85%	80-90% paper and cardboard recycling achieved in Austria, Belgium and Germany (CRN, 2002) [2]
Organic/food waste (non-agric)	90%	>90% recovery of total waste (not inc agric) currently achieved across Denmark (Danish Waste Statistics, 2004) [1]	75%	>75% source separation of organic MSW achieved in Austria and Germany (CRN, 2002) [2]
Other organic waste (predominantly sewage sludge)	90%	>90% recovery of total waste (not inc agric) currently achieved across Denmark (Danish Waste Statistics, 2004) [1]	55%	55% recycling of sewage sludge currently achieved in Denmark (Danish Waste Statistics, 2004) [1]
Garden/ plant waste (non-agric)	90%	>90% garden waste composting achieved in Denmark (Danish Waste Statistics, 2004) [1]	90%	>90% garden waste composting achieved in Denmark (Danish Waste Statistics, 2004) [1]
Organic (agric)	50%	EC report estimates 50% maximum collection of agricultural wastes [3]	50%	EC report estimates 50% maximum collection of agricultural wastes [3]
Biomass (agric)	50%	EC report estimates 50% maximum collection of agricultural wastes [3]	50%	EC report estimates 50% maximum collection of agricultural wastes [3]

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(1) Statistics do not include agricultural wastes. Danish Waste Statistics, 2004

(2) http://news.bbc.co.uk/2/hi/europe/4620041.stm

Material Fraction	Recovery Upper Limit	Reference	Recycling Upper Limit	Reference
Wood	90%	>90% recovery of total waste (not inc agric) currently achieved across Denmark (Danish Waste Statistics, 2004) [1]	50%	>50% recycling of wood packaging in UK and Italy (EEA, 2005) [4]
Textiles	90%	>90% recovery of total waste (not inc agric) currently achieved across Denmark (Danish Waste Statistics, 2004) [1]	50%	50% household textiles currently recycled in Switzerland [5]
Plastic (dense)	90%	>90% recovery of total waste (not inc agric) currently achieved across Denmark (Danish Waste Statistics, 2004) [1]	60%	>60% recycling of plastics packaging achieved in Germany (CRN, 2002) [2]
Plastic (film)	90%	>90% recovery of total waste (not inc agric) currently achieved across Denmark (Danish Waste Statistics, 2004) [1]	60%	>60% recycling of plastics packaging achieved in Germany (CRN, 2002) [2]
Non-ferrous metal	95%	EAA – 95% recycling achieved in building and automotive sectors across Europe	95%	EAA – 95% recycling achieved in building and automotive sectors across Europe
Ferrous metal	95%	Assumed equivalent to non-ferrous metals	95%	Assumed equivalent to non-ferrous metals
Aggregate materials	95%	94% recycling of building and construction waste achieved in Denmark (comprises approx 50% aggregate, 50% soil) (Danish Waste Statistics, 2004) [1] Netherlands - reuse and recycling rate of approx 95% achieved for C&D waste due to ban on the landfill of recoverable C&D waste (EC, 2005) [6]	95%	94% recycling of building and construction waste achieved in Denmark (comprises approx 50% aggregate, 50% soil) (Danish Waste Statistics, 2004) 1 Netherlands - reuse and recycling rate of approx 95% achieved for C&D waste due to ban on the landfill of recoverable C&D waste (EC, 2005) 6
Silt/soil	95%	94% recycling of building and construction waste achieved in Denmark (comprises approx 50% aggregate, 50% soil) (Danish Waste Statistics, 2004) [1]	95%	94% recycling of building and construction waste achieved in Denmark (comprises approx 50% aggregate, 50% soil) (Danish Waste Statistics, 2004) [1]
Misc combustibles (predominantly from industrial sources)	90%	>90% recovery of industrial waste currently achieved in the Netherlands (EC, 2005) [6]	80%	Approx 80% recycling of industrial waste currently achieved in the Netherlands (EC, 2005) [6]

Reference Sources:

1. Danish Ministry of the Environment, Environmental Protection Agency (2006). *Waste Statistics 2004.* Environmental Review No.1
2. CRN (2002). *Maximising Recycling Rates: Tackling Residuals.* Resource Publishing Ltd.
3. [redacted]
4. [redacted]

[redacted]

6. European Communities (2005). *Waste Generated and Treated in Europe – Data 1995-2003.* 2005 Edition. ISBN 92-894-9996-6

Based on the current levels of arisings and management shown in *Table B1.1* and the upper limit values in *Table B1.2*, four core modelling scenarios were developed:

1. **baseline scenario** – reflecting best current estimates of waste material arisings and management;
2. **high resource recovery scenario** – upper limit recycling rates are achieved via materials recycling & composting;
3. **high energy recovery** – upper limit recovery rates are achieved via thermal processing technologies (with energy recovery) or anaerobic digestion, where applicable; and
4. **combined recovery** – upper limit recovery rates are achieved through recycling & composting (to maximum recycling rate) and additional thermal processing/anaerobic digestion, where applicable.

A breakdown of the four scenarios by material and management route is shown in *Table B1.3*. It was assumed that recovery and recycling will increase in a linearly fashion over the study period, to meet these upper limits in 2031. Similarly, current treatment capacities were phased out in a linearly fashion over this period, wherever applicable.

For some materials, such as aggregates, soil and metals, it is not appropriate to use energy recovery methods and so the high energy scenario does not apply. Furthermore, for some materials, such as garden waste, upper recovery and recycling limits are the same. For these materials, the high resource recovery and combined scenarios will be the same and so the latter was not assessed.

At Defra's request, a further scenario reflecting the effect of current policies on recycling, composting and energy recovery rates was modelled. This scenario is termed the baseline policy scenario.

With no reliable data or evidence on which to base future growth scenarios, it was decided that waste arisings should remain static over the assessment period (2005 – 2031) for the four core scenarios and the Defra policy scenario. An additional scenario was developed to investigate the implication of this assumption. Defra estimates for growth in MSW arisings and differential growth in wastes from alterative commercial and industrial waste sectors were obtained. These were applied to the baseline policy scenario recycling/composting/recovery rates. This scenario is termed the policy growth scenario.

Table B1.3 Alternative Scenario Management Routes (% by Material)

Waste Fraction/ Scenario	Recycling and Reuse	Composting[1]	Energy Recovery[2]	Landspread/ Recovery[3]	Landfill	Disposal at Sea	Total
Paper & card - Baseline	47%		7%		47%		100%
High Resource Recovery	85%				15%		100%
High Energy Recovery (combustion)			90%		10%		100%
Combined Recovery	85%		5%		10%		100%
Kitchen/food waste - Baseline	2%	5%	14%	1%	78%		100%
High Resource Recovery	*2%*	*73%*			*25%*		100%
High Energy Recovery (anaerobic digestion)	*2%*		*88%*		*10%*		100%
Combined Recovery	*2%*	*73%*	*15%*		*10%*		100%
Green/plant waste (non-agriculture) - Baseline	<1%	16%	9%	<1%	74%		100%
High Resource Recovery	*0.3%*	*90%*			*10%*		100%
High Energy Recovery (anaerobic digestion)	*0.3%*		*90%*		*10%*		100%
Agricultural crop waste - Baseline			*3%*	*97%*			100%
High Resource Recovery		*50%*		*50%*			100%
High Energy Recovery (combustion)			*50%*	*50%*			100%
Other organic - Baseline	6%	0.4%	14%	71%	8%		100%
High Resource Recovery	*6%*	*49%*		*37%*	*8%*		100%
High Energy Recovery (combustion)	*6%*		*84%*	*2%*	*8%*		100%
Combined Recovery	*6%*	*49%*	*35%*	*2%*	*8%*		100%
Agricultural manure/slurry - Baseline			*0.3%*	*99.7%*			100%
High Resource Recovery		*50%*		*50%*			100%
High Energy Recovery (anaerobic digestion)			*50%*	*50%*			100%
Wood - Baseline	16%		4%		80%		100%
High Resource Recovery	50%				50%		100%
High Energy Recovery (combustion)			90%		10%		100%
Combined Recovery	50%	40%		10%			100%
Textiles - Baseline	13%		11%	<1%	76%		100%
High Resource Recovery	*50%*				*50%*		100%
High Energy Recovery (combustion)			*90%*		*10%*		100%
Combined Recovery	*50%*		*40%*		*10%*		100%

Waste Fraction/ Scenario	Recycling and Reuse	Composting [1]	Energy Recovery [2]	Landspread/ Recovery [3]	Landfill	Disposal at Sea	Total
Plastic (dense) – Baseline	4%		9%		87%		100%
High Resource Recovery	*60%*				*40%*		100%
High Energy Recovery (combustion)			*90%*		*10%*		100%
Combined Recovery	*60%*		*30%*		*10%*		100%
Plastic (film) – Baseline	9%		7%		84%		100%
High Resource Recovery	*60%*				*40%*		100%
High Energy Recovery (combustion)			*90%*		*10%*		100%
Combined Recovery	*60%*		*30%*		*10%*		100%
Ferrous metal – Baseline	59%		5%	<1%	36%		100%
High Resource Recovery	*95%*				*5%*		100%
Non-ferrous metal – Baseline	74%		2%	<1%	24%		100%
High Resource Recovery	*95%*				*5%*		100%
Silt/soil - Baseline	2%			71%	27%		100%
High Resource Recovery	*95%*				*5%*		100%
Mine/quarry/ marine dredged silt/soil – Baseline *				*81%*		*19%*	*100%*
Aggregate materials - Baseline	85%		<1%	10%	6%		100%
High Resource Recovery	*95%*				*5%*		100%
Mine/quarry/ marine dredged aggregate–Baseline *	*1%*			*80%*		*19%*	*100%*
Misc combustibles - Baseline	33%		15%	8%	44%		100%
High Resource Recovery	*80%*				*20%*		100%
High Energy Recovery (combustion)			*90%*		*10%*		100%
Combined Recovery	*80%*		*10%*		*10%*		100%

* No alternative proposed

1. Includes windrow and in-vessel

2. Includes energy recovery through anaerobic digestion, or thermal treatment

3. Includes landscaping, land restoration, land engineering, back- and void fill activities

B1.3 *KEY MODELLING ASSUMPTIONS*

A number of assumptions were required in order to model waste throughputs and to determine carbon, greenhouse gas and energy balances. Key assumptions are presented in the following sections.

B1.4 *MASS BALANCES*

To enable the modelling of carbon and energy flows through the waste management system, it was necessary to draw up mass balances describing the fate of each material passing through each treatment route.

Assumed balances for alternative treatment routes are shown in *Table B1.4* to *Table B1.6*.

Recycling and Composting

When developing mass balance assumptions for recycling and composting processes, consideration was given to how increased collection rates may influence the rate of reject materials, for example through increased co-mingled materials collections. To this end, residues rate were assumed to increase linearly over the assessment period (where recycling or composting rates also increased), from a relatively low rate of 5%, to a more significant 10%.

There has been very little research carried out to investigate how increasing recycling/composting rate might bring about a change such as this. What little that has been done suggests that a switch to bulk collection systems does bring about an increase in rejects (1). Results were examined for their sensitivity to these assumptions.

A standard 10% processing residue rate has been assumed for materials recycling. This was developed following assessment of a number of datasets for material processing in the Ecoinvent Life Cycle Inventory Database (2), and is considered to be a reasonable estimate across the range of materials.

Processing residues for composting processes were sourced from primary plant data, collected as part of the development of WRATE. Data for the Sita Lounts open windrow composting plant were used to represent windrow composting of green waste. Plant data document an input of 19,743 tonnes of feedstock waste, with an output of 5809 tonnes of compost. We have taken this to represent a product output of approximately 30% (and assumed that this would decrease to 25% with increasing collection rates and potential contamination). An output of 5490 tonnes of residue to landfill or landfill cover is also documented, and we have taken this to represent a residue rate of approximately 20% residue rate.

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(1) For example, Garuda Resource Group (1995) [redacted]

(2) [redacted]

Data for the Vital Earth batch mobile composting process for source segregated kitchen and green waste were used to represent in-vessel composting. Data for this plant document a 50% output of compost per tonne of waste input, with negligible process waste. 5% primary sorting residues were (initially) assumed, and the remaining 45% mass lost in process.

Table B1.4 Recycling/Composting Mass Balance

Waste Fraction	**Primary sorting residues (2005) ***	**Primary sorting residues (2031) ***	**Processing residues**	**Lost in Process (degraded)**	**Total product (2005) ***	**Total product (2031) ***
Paper & Card	5%	10%	10%		85.5%	81%
Wood	5%	10%	10%		85.5%	81%
Textiles	5%	10%	10%		85.5%	81%
Plastic (dense)	5%	10%	10%		85.5%	81%
Plastic (film)	5%	10%	10%		85.5%	81%
Ferrous metal	5%	10%	10%		85.5%	81%
Non-ferrous metal	5%	10%	10%		85.5%	81%
Silt/soil	5%	10%	10%		85.5%	81%
Aggregate materials	5%	10%	10%		85.5%	81%
Misc combustibles	5%	10%	10%		85.5%	81%
Organic wastes to windrow composting	5%	10%	20%	45%	30%	25%
Organic wastes to in-vessel composting	5%	10%		45%	50%	45%

Source: ERM and Environment Agency development of WRATE and ERM assumptions

Thermal Treatment

Available technologies and processes for thermally treating waste materials are many and varied and will result in different products according to technology and waste fraction. In order to represent a generic thermal treatment process, we took the approach that ash residues from treatment would be related directly to the ash content of the waste fraction. It was also further assumed that 90% of ash residues constitute bottom ash, of which 50% is recycled.

The proportions of these may differ from technology to technology, but within the context of the relative greenhouse gas and energy impacts/benefits of energy consumption and recovery associated with thermal treatment, these assumptions are likely to be of minor significance.

Table B1.5 Thermal Treatment Mass Balance

Waste Fraction	Ash Content[1]	Bottom ash	Fly ash (to haz landfill)	Bottom ash recycling	Metals recycling	Total residues to Landfill
Paper & card	8.8%	8%	1%	4.0%		4.8%
Kitchen/food waste	9.3%	8%	1%	4.2%		5.1%
Garden/plant waste	9.2%	8%	1%	4.1%		5.1%
Agricultural crop waste	9.2%	8%	1%	4%		5.1%
Other organic	26.6%	24%	3%	12%		14.6%
Wood	1.8%	2%	0.2%	0.8%		1.0%
Textiles	4.6%	4%	0.5%	2%		2.5%
Plastic (dense)	8.5%	8%	1%	4%		4.7%
Plastic (film)	10.4%	9%	1%	5%		5.7%
Ferrous metal					90%[2]	10%
Non-ferrous metal					60%[2]	40%
Silt/soil	82%	74%	8%	37%		45%
Aggregate materials	82%	74%	8%	37%		45%
Misc combustibles	13%	12%	1%	6%		7%

Notes:
1) ERM and Environment Agency data (2003-2005)
2) ERM assumption (based on WRATE *Mass Burn – Moving Grate EFW plant*)

Anaerobic Digestion

Data relating to the balance of relative inputs and outputs for anaerobic digestion were sourced from Greenfinch. The production of digestate output per mass of waste input was calculated on a dry mass basis, as it is not within the scope of the research to consider changes in moisture content. Furthermore, the mass balance is based on a food waste input, as best available data were for this feedstock. Other organic material feedstocks are likely to produce different quantities of digestate, and in all likelihood plant will handle a blend of materials, rather than, for example, green waste alone.

In order to investigate the importance of these uncertainties, the influence of assuming greater, or lower, digestate outputs was considered when developing these mass balance assumptions. It was found that this assumption had very little influence on results. Of significantly greater importance is the quantity of energy (electricity and/or heat) that can potentially be recovered from the process. This is dependent on waste degradation, assumed carbon/methane release and will also differ according to organic fraction, but data are limited (see *Section B1.5*). Sensitivity analyses were used to determine the influence of these assumptions on results.

Table B1.6 Anaerobic Digestion Mass Balance

Waste Fraction	Lost in Process	Digestate to landspread
Kitchen/food waste	74%	26%
Green waste	74%	26%
Other organic waste	74%	26%
Manure/slurry	74%	26%

Source: Greenfinch Limited – cited in C-Tech Innovation Ltd (2004). United Kingdom Food and Drink Processing Mass Balance. Biffaward Programme on Sustainable Resource Use.

B1.5 *CARBON BALANCES*

To enable the modelling of carbon flows through alternative systems, and to develop carbon balances, it was necessary to make a number of assumptions regarding their concentration in input materials and subsequent fate. Fate assumptions are detailed below and assumed waste fraction properties are presented in *Table B1.7*.

- **Recycling** – the carbon content of the input waste fraction was assumed either to be maintained in recovered products (carbon in products), or passed to landfill in residues.
- **Windrow Composting** – due to a lack of data with regard to carbon loss associated with composting processes, we have assumed a 50% percent carbon loss from input waste materials. This has been based on data collected as part of the development of the Environment Agency WRATE tool. All other carbon either passes to landfill in primary rejects or process resides, or remains in compost.
- **In-vessel Composting** – due to a lack of data with regard to carbon loss associated with composting processes, we have assumed a 50% percent carbon loss from input waste materials. This has been based on data collected as part of the development of the Environment Agency WRATE tool. All other carbon either passes to landfill in primary rejects or process resides, or remains in compost.
- **Anaerobic Digestion** – carbon losses in processing are equivalent to those assumed for composting. Carbon was assumed to be released as biogenic CO_2 on combustion of biogas.
- **Thermal Treatment** – with the exception of carbon remaining in ash residues (assumed 7% carbon content), all carbon was assumed to be released as CO_2 on combustion.
- **Landspread** – 98% of carbon in landspread wastes was assumed to be mineralised to biogenic CO_2 over a 100 year period (1). This has been modelled as an instantaneous release in the year of application.

(1) Smith et al (2001). Waste Management Option and Climate Change, Final Report to DGENV. AEA Technology.

Table B1.7 *Input Waste Fraction Properties*

Waste Fraction	**Biogenic Carbon Content (%)**	**Fossil Carbon Content (%)**	**Net Calorific Value (MJ/kg)**
Paper & card	31.9	-	11.0
Kitchen/food waste	13.5	-	3.5
Garden/plant waste	17.2	-	4.2
Agricultural crop waste	12.4	-	13.5
Agricultural manure/slurry	17.3	-	5.7
Other organics (eg sewage sludge)	26.5	-	9.1
Wood	43.8	-	16.8
Textiles *	19.9	19.9	14.3
Plastic (dense)	-	54.8	24.9
Plastic (film)	-	47.8	21.3
Ferrous metal	-	-	-
Non-ferrous metal	-	-	-
Silt/soil	7.0		2.6
Aggregate materials		7.0	2.6
Miscellaneous combustibles *	19.2	19.2	14.1

Source: ERM & Environment Agency Data (2003-2005), developed as part of the ongoing development of WRATE.

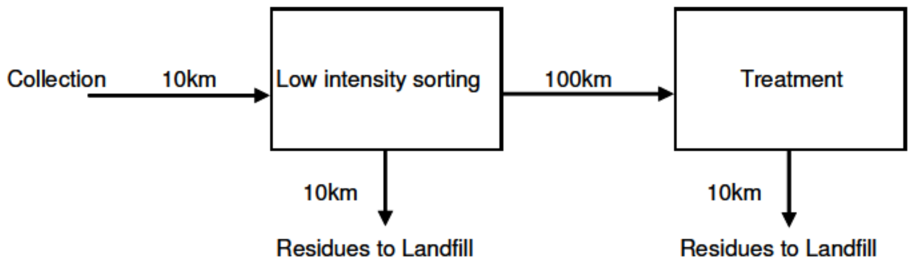
* Assumed to comprise 50% biogenic carbon content and 50% fossil carbon content

B1.6 TRANSPORT ASSUMPTIONS

Modelling required a number of assumptions to be made regarding the structure of the waste collection system and transport distances travelled. It was decided that a common approach should be taken across all material streams, and a standard model was applied. An outline of this model is shown in *Figure B1.1*.

It is not possible to determine the degree to which this model is representative of actual waste movements. It represents a 'best guess' of the distances that we might expect materials to be transported. In the assessment, it also serves as a starting point, to be re-visited where results appear sensitive. This is likely in the case of recovered materials with low intrinsic value, such as compost or aggregate materials, for which offset greenhouse gas benefits and energy benefits are relatively low, and so the balance between impacts and benefits of greater importance.

Figure B1.1 *Transport Assumptions*



Note – zero transport impacts have been assumed for on-site landspread or composting of agricultural wastes, or on-site management of mining and quarrying wastes

It has been assumed in the transport of waste that all waste fractions cause equivalent emissions per km travelled (through vehicle use), such that the only variable is the mass of the waste transported.

B1.7 GREENHOUSE GAS EMISSION AND ENERGY FACTORS

Greenhouse gas and energy factors have been used to quantify the potential climate change impacts of alternative scenarios and management of materials.

Greenhouse gas emission factors have been developed using IPCC characterisation factors for the direct global warming potential of specified air emissions (100 year timeframe) (1). Both biogenic CO_2 uptake and subsequent release (on combustion or degradation) were considered to have a carbon-neutral impact and therefore incurred neither burden nor benefit.

Cumulative fossil energy demand factors have been used as a proxy for energy impacts. These were developed based on the Ecoinvent method for cumulative energy demand.

Overall greenhouse gas and energy demand impacts were calculated using a series of steps:

1. ***Ancillary impact factors*** (greenhouse gas emissions/energy demand per tonne of diesel produced and combusted, per kWh of electricity generated, per tonne-kilometre of waste transported) were sourced from published life cycle inventory databases. These impact factors are presented in *Section B1.7.1*.
2. The ***ancillary inputs*** (tonnes of diesel, kWh of electricity, tonne-kilometres of residues transported, etc) and ***direct emissions*** associated with the management of one tonne of waste were determined for each treatment process, using data developed as part on the ongoing update of the Environment Agency life cycle tool, WRATE. These inputs and emissions are presented in *Section B1.7.2* and *B1.7.3*.
3. ***Avoided burdens*** (tonnes of material separated for recycling, kWh electricity recovered, etc) were calculated using both the mass balance assumptions presented in *Section B1.4* and further calculations, described in *Section B1.7.4*.
4. Ancillary impacts, direct process emissions and avoided burdens were combined and multiplied by process throughputs to give a total greenhouse gas/energy demand.

Impact factors form a key part of the analyses carried out. The main sources of data for used for developing impact factors were the Environment Agency work on the WRATE life cycle tool and life cycle inventories for material production and energy generation systems produced by Ecoinvent (2).

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(1) Climate Change 2001. IPCC Third Assessment Report. The Scientific Basis.

(2) http://ecoinvent.ch/

Ecoinvent is a state-of-the art, peer-reviewed database, containing life cycle inventory data for over 2500 processes in the energy, transport, building materials, chemicals, paper/board, agriculture and waste management sectors. Data relate predominantly to Western European process technologies and, as such, will confer differences from equivalent UK systems. Assuming that technologies will not differ, the most significant difference in terms of potential greenhouse gas/energy impacts is with respect to energy mix. We have addressed this by manipulating all datasets used to represent UK electricity mix (average over 25 year period).

It was considered that another key difference may lie in transport networks. This was investigated for a number of key datasets and it was found that altering assumed transport distances did not have a significant influence on resulting impact factors. Thus it is not considered that this will have a significant affect on resulting estimates.

The following sources were also drawn upon for guidance and data in support of the work:

- ERM (2006). *Impact of Energy from Waste and Recycling Policy on UK Greenhouse Gas Emisisons*. Report for Defra;
- WRAP (2006). *Environmental Benefits of Recycling. An International Review of Life Cycle Comparisons for Key Materials in the UK Recycling Sector.* WRAP, Banbury;
- Biomass Task Force Report to Government, October 2005;
- C-Tech Innovation Ltd (2003). *Thermal Methods of Municipal Waste Treatment.* Biffaward Programme on Sustainable Resource Use;
- McDougal *et al* (2001). *Integrated Solid Waste Management: A Life Cycle Inventory.* Blackwell Science;
- Hischier (2004). Life Cycle Inventories of Packaging and Graphical Papers. Ecoinvent Report No. 11;
- Enviros (2006). *Resource Efficiency and Greenhouse Gas Emissions*. Report for Yorkshire Forward; and
- other relevant work on greenhouse gas emissions including the energy projections developed by the Department of Trade and Industry (DTI) and the UK Greenhouse Gas Inventory (produced annually under contract to Defra by AEAT to meet legal reporting requirements to the EU and the United Nations Framework Convention on Climate Change).

B1.7.1 Ancillary Impact Factors – Energy Production and Use, Transport

Impact factors for the production of diesel and electricity and for the transport of wastes have been taken from published sources. Those for electricity production and distribution change over time, taking into account predicted changes in UK grid electricity mix (1), and are based upon the DTI's latest energy projection data (2005). Projections are made for electricity mixes from

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(1) Taken from the updates to the Environment Agency's WISARD tool (ERM, (2005). WRATE Electricity Database Manual. Environmental Resources Management. Unpublished.)

2005 to 2020. With no further data available, it was assumed that UK grid electricity would remain of the same mix from 2020 onwards (1).

Ancillary impact factors are shown in *Table B1.8*. Note that factors for the production of diesel, electricity generation and transport each take account of all impacts associated with the upstream extraction, processing and distribution of raw materials.

Table B1.8 Ancillary Impact Factors - Energy Production and Use, Transport

Process	**Impact Factor**	**2005**	**2010**	**2015**	**2020 onwards**	**Source**
Diesel production and use (kg)	GHG emissions (kg CO_2-eq/ kg)	3.66	3.66	3.66	3.66	- Ecoinvent v1.2 – *Diesel production, low-sulphur (average EU)* - UK GHG Inventory, Appendix 2, Table 1
	Cumulative Fossil Energy Demand (MJ-eq/kg)	53.8	53.8	53.8	53.8	
Electricity production and distribution (kWh)	GHG emissions (kg CO_2-eq/kWh)	0.57	0.49	0.47	0.47	Ecoinvent v1.2 electricity generating systems and ERM, (2005). WRATE Electricity Database Manual. Unpublished.
	Cumulative Fossil Energy Demand (MJ-eq/kWh)	7.13	6.56	6.54	6.63	
Road transport (tkm)	GHG emissions (kg CO_2-eq/ tkm)	0.12	0.12	0.12	0.12	Ecoinvent, version 1.2 - *40-tonne truck, (average EU. Adapted to reflect EU Class 1V emissions*).
	Cumulative Fossil Energy Demand (MJ-eq/tkm)	1.71	1.71	1.71	1.71	
Sea transport (tkm)	GHG emissions (kg CO_2-eq/ tkm)	0.035	0.035	0.035	0.035	Ecoinvent, version 1.2 - *Barge Transport(average EU*)
	Cumulative Fossil Energy Demand (MJ-eq/tkm)	0.5	0.5	0.5	0.5	

B1.7.2 *Ancillary Requirements of Treatment*

Section 5 of the main report notes the difficulty of collating data that are representative of a generic management process, or route, given the variation within each. The assumption that we have made with regard to the resource requirements of each treatment process are shown in *Table B1.9*. These are likely to vary within each process category, but are not likely to have significant influence on results. Through previous research in this area (2), we have found factors such as ancillary inputs to be of lesser importance, in comparison with assumptions regarding material and energy recovery.

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(1) 16% coal/thermal other/waste, 0.2% oil, 3.8% gas (non-CCGT), 55% gas (CCGT), 8.6% nuclear, 2.2% renewables thermal, 12% wind and 1.6% hydro/renewable other.

(2) ERM (2006). Impact of Energy from Waste and Recycling Policy on UK Greenhouse Gas Emissions; ERM (2004) Impact of EU Landfill Directive and National Strategies on UK Greenhouse Gas Emissions.

Requirements for reprocessing operations differ according to material and reprocessing route and so assumptions made in this respect are discussed in *Section B1.7.4*. Assumptions regarding transport requirements are presented in *Section B1.6*.

Table B1.9 Treatment Process Ancillary Inputs (per Tonne of Material Throughput)

Process	**Elec (kWh)**	**Fuel (kg diesel)**	**Data Source and Comments**
Bulking/Aggregation Point (all waste)	1.9	0.3	ERM and Environmental Agency Data collected for the development of WRATE- *Transfer Station (road) – with compaction*
Recycling	Fraction and process dependent		Refer to *Table B1.12* for assumptions
Windrow Composting	0.51	3.1	ERM and Environmental Agency Data collected for the development of WRATE- *Open Air Windrow Composting* (Sita Lounts plant). This is a relatively low intensive process in terms of electricity and relies more heavily on fuel consumed in machinery.
In-Vessel Composting	9.0	3.0	ERM and Environmental Agency Data collected for the development of WRATE- *In-Vessel Batch Mobile with Enclosed Windrow Composting* (Vital Earth plant). This process has relatively higher electricity burdens as it is an enclosed process, with a degree of automation.
Anaerobic Digestion	20.6	1.3	ERM and Environmental Agency Data collected for the development of WRATE- *Anaerobic Digestion - High Solids System* (Cambi AS Thermal Hydrolysis AD Technology). This process has higher electricity burdens due to increased levels of automation/process intensity.
Thermal Treatment (with/without energy recovery)	3.9	1.2	ERM and Environmental Agency Data collected for the development of WRATE- *Mass Burn – Moving Grate*. These process data were used as a substitute for all thermal treatment processes. In reality the ancillary requirements of each will differ, but within the context of the research the more important parameter relates to the energy conversion efficiency of the process (see *Section B1.7.4*)
Land recovery/spread	-	0.05	Ecoinvent v1.2 – estimated diesel fuel consumption for agricultural machinery
Disposal at sea	-	-	Transport impact only.

B1.7.3 *Direct Emissions from Treatment*

Assumed emissions from waste passing through alternative treatment processes are shown in *Table B1.10*. Note that all CO_2 emissions are directly related to the properties of input wastes. For further information on carbon balance assumptions refer to *Section B1.5*.

As with ancillary requirements, specific emissions are likely to vary within each process category, but are not considered to have significant influence on results. Through previous research in this area (1), we have found factors such as this to be of lesser importance, in comparison with assumptions regarding material and energy recovery.

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(1) ERM (2006). Impact of Energy from Waste and Recycling Policy on UK Greenhouse Gas Emissions; ERM (2004) Impact of EU Landfill Directive and National Strategies on UK Greenhouse Gas Emissions.

Table B1.10 Treatment Process Outputs (per Tonne of Material Throughput)

Process	**CH_4 (kg)**	**N_2O (kg)**	**Biogenic CO_2 (kg)**	**Fossil CO_2 (kg)**	**Data Source and Comments**
Bulking/Aggregation Point (all waste)	-	-	-	-	
Windrow Composting	0.030	0.017	Proportional to the biogenic C content of input waste (assumed 50% loss of carbon on degradation)	-	ERM and Environmental Agency Data collected for the development of WRATE- *Open Air Windrow Composting* (Sita Lounts plant). Process emissions of methane and N_2O are relatively higher than in-vessel composting as the process is less automated and resultantly less well aerated.
In-Vessel Composting	0.018	0.0099	Proportional to the biogenic carbon content of input waste (assumed 50% loss of carbon on degradation)	-	ERM and Environmental Agency Data collected for the development of WRATE- *In-Vessel Batch Mobile with Enclosed Windrow Composting* (Vital Earth plant). Process emissions are low as the process is aerated, thereby reducing the potential for anaerobic biological activity and associated by-products, such as methane.
Anaerobic Digestion	0.021	0.012	Proportional to the biogenic carbon content of input waste (assumed 50% loss of carbon on degradation)		ERM and Environmental Agency Data collected for the development of WRATE- *Anaerobic Digestion - High Solids System* (Cambi AS Thermal Hydrolysis AD Technology). Process emissions are intermediate. The process is entirely anaerobic and the majority of gases are captured and utilised as biogas. However there is some escape of greenhouse gases.
Thermal Treatment (with/without energy recovery)	-	0.0057	Proportional to the biogenic carbon content of input waste (all carbon is released with the exception of that contained in ash residues)	Proportional to the fossil carbon content of input waste (all carbon is released with the exception of that contained in ash residues)	ERM and Environmental Agency Data collected for the development of WRATE- *Mass Burn – Moving Grate* . These emissions were used as a substitute for all thermal treatment processes. In reality they will differ for alternative technologies, but within the context of the research the more important parameter relates to the energy conversion efficiency of the process (see *Section B1.7.4*)
Land recovery/spread	*	*	Proportional to the biogenic carbon content of input waste (assumed 98% loss of carbon over 100 year period)	-	Assumed negligible (ERM assumption)
Disposal at sea	-	-	-	-	

B1.7.4 *Avoided Burdens*

Energy

The combustion of waste in thermal treatment processes, such as EfW and gasification, is widely used to recover energy from wastes with an appropriate calorific value. Energy is recovered as heat, and either used directly, or for generating electricity.

Anaerobic digestion can also be used as an energy recovery process for biowastes with high moisture content and low calorific value, such as food, green waste and animal manures and slurries. A methane-containing 'biogas' is generated during the process, which can be combusted on site to recover heat. Again, this can be used either directly, or for generating electricity.

For energy recovery processes, the key influencing factors with regard to quantifying greenhouse gas and energy impacts and benefits relate to the efficiency at which the calorific/carbon content of waste can be converted into usable electrical energy or heat. Given the wide variation in efficiency that can be realised from energy recovery processes, a potential maximum and minimum was modelled.

The quantity of energy recovered from wastes sent to **thermal treatment** was calculated on the basis of their inherent calorific value and assumed process efficiency. Maximum and minimum conversion efficiencies are based on findings in literature of approximately 20-27%(1) for conventional incineration with steam cycle electricity generation, 40-45%(2) for gasification with combined cycle gas turbine and up to 50-70% for combined heat and electricity recovery (CHP) (3):

- *Maximum*: combined power - 40% (electricity), 30% (heat). Total = 70%
- *Minimum*: electricity only – 20%

The quantity of energy recovered from wastes sent to **anaerobic digestion** was calculated on the basis of their biodegradable carbon content, assumed conversion of carbon into methane (50% of carbon in waste converted to biogas (ERM assumption), of which approximately 66% assumed to be methane (4)) and the assumed efficiency of converting methane to heat/electricity. Maximum and minimum conversion efficiencies are based on those quoted in the Biomass Task Force to Government (2005):

- *Maximum*: combined power - 40% (electricity), 45% (heat). Total = 85%
- *Minimum*: electricity only – 30%

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(1) C-Tech Innovation Ltd (2003). Thermal Methods of Municipal Waste Treatment. Biffaward

(2) C-Tech Innovation Ltd (2003). Thermal Methods of Municipal Waste Treatment. Biffaward

(3) http://www.environment-agency.gov.uk/wtd/981058/981100/?version=1&lang=_e

(4) C-Tech Innovation Ltd (2004). United Kingdom Food and Drink Processing Mass Balance. Biffaward Programme on Sustainable Resource Use.

A conservative assumption, that marginal (offset) electricity is comprised 100% gas (CCGT) across the study period, was made and impact factors for marginal electricity were calculated accordingly. Impact factors for marginal heat production were based on heat production in an industrial furnace (average EU data, manipulated to reflect UK natural gas supply and UK electricity mix for furnace operational demands).

Table B1.11 Impact Factors for Avoided Energy Production

Process	Impact Factor	Value (average over period)
Marginal (offset) electricity production (kWh)	GHG emissions (kg CO_2-eq/ kWh)	0.46
	Cumulative Fossil Energy Demand (MJ-eq/kWh)	7.85
Marginal (offset) heat production (MJ)	GHG emissions (kg CO_2-eq/ MJ)	0.071
	Cumulative Fossil Energy Demand (MJ-eq/MJ)	1.24

Values for offset electricity production are based on an assumed conversion efficiency of 46.7% for CCGT plant. This reflects the current UK average and, on the basis of Defra/DTI fuel data, results in a greenhouse gas emission of 0.4 kg CO_2-eq/ kWh. Taking account of the contribution of upstream transport, processing, flaring, leakage and transmission losses results in an overall emission of 0.46 kg CO_2-eq/ kWh, as calculated using the Ecoinvent database (1).

Whilst average efficiency is currently at 46.7%, new CCGT plant are likely to deliver greater efficiencies (up to 60% has been proposed, although it not yet proven). To account for the consideration that energy generation via thermal treatment or anaerobic digestion technologies may displace electricity that has been produced at increased efficiencies, a sensitivity analysis was carried out. This investigated the impact of alternatively assuming that all recovered electricity displaces CCGT at 53.2% conversion efficiency – representative of UK F Class CCGT plant. This equates to a greenhouse gas emission of 0.4 kg CO_2-eq/ kWh.

Recycling

The separation of materials for recycling results in greenhouse gas benefits through offsetting the requirement for virgin materials. The substitution of recovered materials for virgin material often confers considerable energy savings, but can vary widely, dependent on reprocessing requirements and assumptions regarding the materials displaced. Given this variation, and a

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(1) The Ecoinvent database contains two datasets describing electricity generation via natural gas combustion. The first is based on average GB installed plant and assumes an efficiency of 43.4%, the second is based on a German reference plant operating at 57.5% efficiency. The value for offset electricity production was calculated based on the former, and the dataset was manipulated to reflect and efficiency of 46.7%. Further information on the Ecoinvent database can be found in: Dones *et al* (2004). *Life Cycle Inventories of Energy Systems: Results for Switzerland and other UCTE Countries*. Ecoinvent Report Number 5. Swiss Centre for Life Cycle Inventories, Dubendorf.

considerable unknown regarding current and future reprocessing routes and recyclate fates, a potential maximum and minimum greenhouse gas emission and energy saving was modelled.

Maxima and minima are based on the range of potential fates for recovered materials, for example recovery of plastics and reprocessing into granulate to replace virgin material versus recovery of plastics and reprocessing into plastic lumber for use in street furniture and replacement of wood inputs. As a general rule, the potential savings are higher where recovered materials are of higher quality, material integrity can be maintained and virgin material production is avoided (closed loop). However, the relationship is not a straightforward one for all materials, and so maxima and minima have been developed on a fraction-by-fraction basis.

Resulting impact factors for the assumed avoided burdens of recycling are shown in *Table B1.12*.

Taking a maximum/minimum avoided burdens approach is intended to present the range of potential savings associated with recycling alternative materials. Sensitivity analyses were carried out to investigate the influence on results should increased recycling rates influence the quality of materials recovered, and hence the application to which they can be put.

Table B1.12 Impact Factors for Recycling (Avoided Burdens per kg of Material Recycled)

Material Fraction	**Greenhouse Gas Emissions (kg CO_2 eq avoided/ kg)**	**Cumulative Fossil Energy Demand (MJ-eq avoided/ kg)**	**Source/Description**
Paper and card (Max)	0.62	8.48	Waste paper processing varies according to the type of waste paper that is used as the process feedstock. Higher quality grades, which need little cleaning, are used to make printing and writing paper and tissues. Lower quality grades and mixed recovery papers require de-inking and are predominantly used in the production of newspaper and hygiene papers (McDougal et al, 2001). This impact factor represents the production of recycled paper from clean recovered paper with no requirement for deinking. Graphical paper production (woodfree, non-integrated) is avoided on a mass basis and assuming 10% loss in production (1kg recovered material offsets 0.9kg virgin). Data for these processes are sourced from the Ecoinvent database. Consideration is given to the limited number of times that paper can be recycled whilst maintaining sufficient quality (approximately 4, Hischier, 2004) by allowing for an input of 75% recycled paper and 25% virgin fibre.
Paper and card (Min)	0.28	3.44	Waste paper processing varies according to the type of waste paper that is used as the process feedstock. Higher quality grades, which need little cleaning, are used to make printing and writing paper and tissues. Lower quality grades and mixed recovery papers require de-inking and are predominantly used in the production of newspaper and hygiene papers (McDougal et al, 2001). This impact factor represents the production of newsprint from mixed, recovered paper. It accounts for the difference in burdens between the production of newsprint from virgin materials and the production of newsprint from 75% recovered paper input. Data for these processes are sourced from the Ecoinvent database.
Wood (Max)	0.097	1.38	This impact factor represents the recycling of high quality recovered wood into firewood or timber products. Account is taken of the energy requirements of sorting (data from WRATE) and the production of air dried, sawn timber is offset on a mass basis and assuming 10% loss in production (1kg recovered material offsets 0.9kg virgin). Data for this process are sourced from the Ecoinvent database.
Wood (Min)	-0.0012	0.0020	This impact factor represents the recycling of low quality recovered wood for use in particle board manufacture. Data were sourced from Ecoinvent and it was assumed that waste wood substituted the requirement for wood chips from alternative sources. The energy requirements of wood chipping were also taken into account (data from Ecoinvent).

Material Fraction	Greenhouse Gas Emissions (kg CO_2 eq avoided/ kg)	Cumulative Fossil Energy Demand (MJ-eq avoided/ kg)	Source/Description
Textiles (Max)	1.75	39.95	This impact factor represents the recovery of good quality textiles and avoided production of cotton cloth (50%) and PET (50%) (on a mass basis and assuming 10% loss in production). Data for these processes were sourced from the Ecoinvent database. Data for the energy requirements of sorting were sourced from WRATE development work.
Textiles (Min)	0.93	12.30	This impact factor represents the shredding of low quality recovered textiles to produce rags or filling materials. Account is taken of the energy requirements of shredding (data from WRATE) and the production of kraft paper is offset on a mass basis and assuming 10% loss in production (1kg recovered material offsets 0.9kg virgin). Data for this process are sourced from the Ecoinvent database.
Ferrous metals (Max)	0.83	7.78	This impact factor represents the recovery of ferrous metal scrap for use in the blast oxygen furnace reprocessing route. It was assumed that the input of iron scrap offsets requirements for pig iron and that 1kg of recovered scrap offsets 0.9kg of pig iron (accounting for an average 10% process loss). Data for pig iron production are sourced from the Ecoinvent database.
Ferrous metals (Min)	0.58	1.18	This impact factor represents the recovery of ferrous metal scrap for use in the electric arc furnace reprocessing route. It relates to the difference in burdens accumulated for the production of secondary steel via electric arc furnace and the production of primary steel via blast furnace. Data for average European process requirements were sourced from the Ecoinvent database. The data already take account of an approximate 10% process loss and so no adjustment was made.
Non-ferrous metals (Max)	13.10	143.00	This impact factor represents the recycling of aluminium from high quality scrap, requiring no cleaning or pre-treatment. It relates to the difference in burdens accumulated for the production of secondary aluminium and the production of primary aluminium. Data for these processes are sourced from the Ecoinvent database. To account for an approximate 10% processing loss that has been applied across the board, it was assumed that 1kg of secondary material offsets 0.9kg of primary material.

Material Fraction	Greenhouse Gas Emissions (kg CO_2 eq avoided/ kg)	Cumulative Fossil Energy Demand (MJ-eq avoided/ kg)	Source/Description
Non-ferrous metals (Min)	12.30	132.00	This impact factor represents the recycling of aluminium from scrap that requires pre-treatment (sorting, cleaning) prior to processing. It relates to the difference in burdens accumulated for the production of secondary aluminium and the production of primary aluminium. Data for these processes are sourced from the Ecoinvent database. To account for an approximate 10% processing loss that has been applied across the board, it was assumed that 1kg of secondary material offsets 0.9kg of primary material.
Plastic, dense (Max)	1.82	59.10	This impact factor represents the closed loop recycling of plastics and the avoidance of virgin material production. Account is taken of the energy requirements of pre-treatment (washing, drying, sorting, granulation etc.) and the production of virgin PET granulate is offset, on a mass basis and assuming 10% loss in production (1kg recovered material offsets 0.9kg virgin). Data for these processes are sourced from the Ecoinvent database and US Idemat life cycle database.
Plastic, dense (Min)	-0.85	-11.20	This impact factor represents the recycling of mixed low grade plastics into plastic lumber. Account is taken of the energy requirements of washing, sorting, granulating and thermoforming the recovered plastics into lumber product. The production of air dried, sawn timber is offset on a volumetric basis, as it was considered that such products would be used as, for example, street furniture, and as such would replace wood on a volumetric basis. Data for these processes are sourced from the Ecoinvent database and US Idemat life cycle database. Avoided burdens appear negative as the processing requirements of cleaning and reforming are greater than the offset burdens of wood production.
Plastic, film (Max)	1.47	59.5	This impact factor represents the closed loop recycling of plastics and the avoidance of virgin material production. Account is taken of the energy requirements of pre-treatment (washing, drying, sorting, granulation etc.) and the production of virgin LDPE granulate is offset, on a mass basis and assuming 10% loss in production (1kg recovered material offsets 0.9kg virgin). Data for these processes are sourced from the Ecoinvent database and US Idemat life cycle database.

Material Fraction	Greenhouse Gas Emissions (kg CO_2 eq avoided/ kg)	Cumulative Fossil Energy Demand (MJ-eq avoided/ kg)	Source/Description
Plastic, film (Min)	-0.85	-11.20	This impact factor represents the recycling of mixed low grade plastics into plastic lumber. Account is taken of the energy requirements of washing, sorting, granulating and thermoforming the recovered plastics into lumber product. The production of air dried, sawn timber is offset on a volumetric basis, as it was considered that such products would be used as, for example, street furniture, and as such would replace wood on a volumetric basis. Data for these processes are sourced from the Ecoinvent database and US Idemat life cycle database. Avoided burdens appear negative as the processing requirements of cleaning and reforming are greater than the offset burdens of wood production.
Soil (Max)	0.0023	0.027	This impact factor represents the recycling of soil for use as an aggregate or fill material. Account is taken of the energy requirements of low intensity sorting (data from WRATE) and the mining of gravel is offset, on a mass basis and assuming 10% loss in processing (1kg recovered material offsets 0.9kg gravel). Data for these processes are sourced from the Ecoinvent database.
Soil (Min)	-0.0021	-0.031	This impact factor represents the sorting of recovered materials (data from WRATE), but assumes that no product of value is displaced.
Minerals (Max)	0.0023	0.027	This impact factor represents the recycling of mineral materials for use as an aggregate or fill material. Account is taken of the energy requirements of low intensity sorting (data from WRATE) and the mining of gravel is offset, on a mass basis and assuming 10% loss in processing (1kg recovered material offsets 0.9kg gravel). Data for these processes are sourced from the Ecoinvent database.
Minerals (Min)	-0.0021	-0.031	This impact factor represents the sorting of recovered materials (data from WRATE), but assumed that no product of value is displaced.
Misc Combustibles (Max)	0.0023	0.027	This impact factor represents the recycling of miscellaneous materials for use as an aggregate or fill material. Account is taken of the energy requirements of low intensity sorting (data from WRATE) and the mining of gravel is offset, on a mass basis and assuming 10% loss in processing (1kg recovered material offsets 0.9kg gravel). Data for these processes are sourced from the Ecoinvent database.

Material Fraction	Greenhouse Gas Emissions (kg CO_2 eq avoided/ kg)	Cumulative Fossil Energy Demand (MJ-eq avoided/ kg)	Source/Description
Misc Combustibles (Min)	-0.0021	-0.031	This impact factor represents the sorting of recovered materials (data from WRATE), but assumed that no product of value is displaced.
Compost (Max)	0.0067	1.33	This impact factor represents the production of high grade compost (according to APEX standards) and its use and offset alternatives according to standard practice. Avoided burdens were developed as part of work carried out for the development of WRATE. Data for offset processes (wood chips, peat etc.) were sourced from the Ecoinvent database.
Compost (Min)	0.0011	0.015	This impact factor represents the production of low grade compost, offsetting the production of low quality topsoil. Avoided burdens were developed as part of work carried out for the development of WRATE. Data for offset processes (transport of topsoil from alternative sources) were sourced from the Ecoinvent database.

B1.8 *LANDFILL ASSUMPTIONS*

Scenarios have been evaluated by taking individual material fractions and assessing each of these in isolation. In this way, the time dependent releases of carbon to the environment can be considered for each component of waste.

The GasSim model has been used to perform the bulk of the assessment work, but because GasSim only consider the mass balance of the degradable carbon entering the landfill, another spreadsheet model was also designed to calculate the mass balance of the non-degradable carbon which remains sequestrated in the landfill.

GasSim defaults for the fraction of degradable and non degradable cellulosic material in each component of each waste stream were used. Default average degradation rates were also used, but these rates are one of the most significant factors in terms of the sensitivity analysis, and so additional evaluation of the base case with wet decay rates were used to show the relative impact of this model parameter. Time dependent release of landfill gas and the greenhouse gas equivalent (as tonnes CO_2) are calculated within GasSim.

Landfill Gas Capture

The collection efficiency of landfill gas was assumed to be 75% over a 100 year period (1). Collection efficiency will vary at a site level, depending on where in an individual landfill site's life the gas is being generated, but the 75% value has been agreed from previous Defra research to be representative of the amount of gas recoverable from a single landfill over this timescale (2), and so this is therefore a suitable assumption for the population of UK, PPC-permitted landfills at a given moment in time.

The efficiency of collection of landfill gas emissions is dependent on many site specific factors. A landfill with a high rate of gas generation may have a higher potential gas collection efficiency (as a percentage), but at the same time, more gas (in tonnes) is likely to be lost to atmosphere than a landfill with a lower rate of gas generation, where the collection efficiency may be not as good in percentage terms.

Factors which move the value of collection efficiency up (or down) are:

1. whether the landfill has no cap, a temporary cap, or a permanent cap;
2. whether the landfill has no gas collection, sacrificial/temporary gas collection, or a permanent gas collection infrastructure;
3. how much degradable waste is in the landfill;
4. the rate of filling of that degradable waste; and
5. how far in time, along the gas production curve is the site.

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(1) This is assumed to be for current, PPC-permitted landfills.

(2) Golder Associates (2005). UK Landfill Methane Emissions: Evaluation of Waste Polices and Projections to 2050. Report for Defra, London.

GasSim models a range of collection efficiencies for gas utilisation resource assessment purposes, ranging from 30% for temporary gas collection systems with no temporary or permanent cap present, up to 95% for a fully engineered and capped utilisation system. The Environment Agency expects a permitted landfill to perform to at least 85% collection efficiency during the active gas management phase (1) (this value corresponds to the GasSim value for a utilisation scheme comprising permanent gas infrastructure and a temporary cap). When a landfill cell is first filling, there will be no gas collection, and so all the methane will be emitted. Similarly, when the gas generation rate drops to below the practicable level of collection, all the methane will be emitted.

The 75% value determined in previous work for Defra's Global Atmosphere Division acknowledges that, over a population of landfills, not all will be managed at the 95%, or even the 85%, collection efficiency level, as some will be accepting fresh waste with no gas collection system, while others will be beyond the practicable gas collection stage (approximately 50m^3 LFG/Ha).

Annex E explores the use of 75% as a 100-year gas collection value and it assesses the effect that the gas generation tail (post 100 years) if considered would have on the results. This modelling shows that a 100-year gas collection value of 75% could result in a lower lifetime (150 year) collection efficiency of approximately 59%. It should be realised that the nature of gas generation and emissions in the late stages of a landfill's life will be very site specific, and are not well understood or known.

Electricity Production

With regard to electricity generation from landfill gas, a nominal assumption was made that 570-600m^3 of landfill gas at 50% methane is required to generate 1MW of power. This value varies according to gas quality and engine efficiency, but is sufficiently accurate for the calculations performed.

Fuel Consumption

The generic landfill site fuel consumption (1.4 kg diesel /tonne waste) is taken from the Environment Agency's WRATE model. There is a small amount of electricity consumption as well as production from a landfill, and this has been conservatively estimated at 1% of the production level.

Carbon Remaining in Landfill

The fraction of carbon remaining within the landfill is also time dependent. In any given year, this will comprise two forms of carbon: (1) the degradable carbon that has not yet degraded from the waste deposited in current and previous years (this amount will increase as the site is filling and will then decrease exponentially towards zero as the amount of degradable carbon is degraded); plus (2) the carbon that has been landfilled in previous years plus the current year that is not available for degradation, and so remains

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(1) Environment Agency (2004) Guidance on the Management of Landfill gas. Environment Agency, Bristol.

sequestrated within the landfill. This carbon rises year on year to a peak which then remains constant.

Greenhouse Gas Emissions to Atmosphere (Emission Factors)

As one of its key inputs, GasSim will accept a detailed description of the composition of waste, in terms of tonnages and sources of the waste (for example MSW, commercial, civic amenity, industrial, etc). Within the model, these waste streams are defined by the different amounts of degradable cellulosic materials they contain, the water content of each fraction, the amount of cellulose and hemicellulose, and the degradability of that cellulose. The alternative properties each have influence on material degradation. For example, both paper and food waste have high cellulose contents and degradabilities, but food waste contains a significantly higher percentage of water and so, on a per tonne basis (as deposited to landfill), there will be a greater yield of methane from the paper waste stream than from the food waste stream.

The following graphs present the quantities of greenhouse gas emissions released to atmosphere over a period of 100 years following the deposit of one tonne of each waste fraction in landfill and thereby serve as greenhouse gas emission factors for the landfill of alternative materials. Note that they are not net emissions, in that they *do not* take account of the avoided burdens of electricity generation.

A red line —— has been marked on each graph at approximately 0.002 tonnes CO_2-eq. This has been drawn to highlight the relative scale of emissions for alternative fractions.

Figure B1.2 Landfill of One Tonne of Paper/Card - Greenhouse Gas Emissions over Time

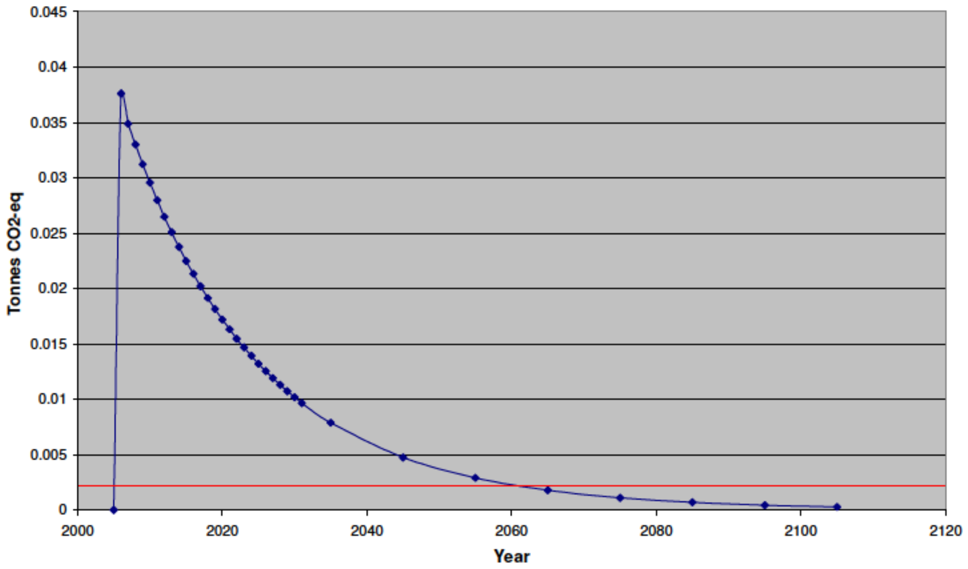


Figure B1.3 Landfill of One Tonne of Kitchen Waste - Greenhouse Gas Emissions over Time

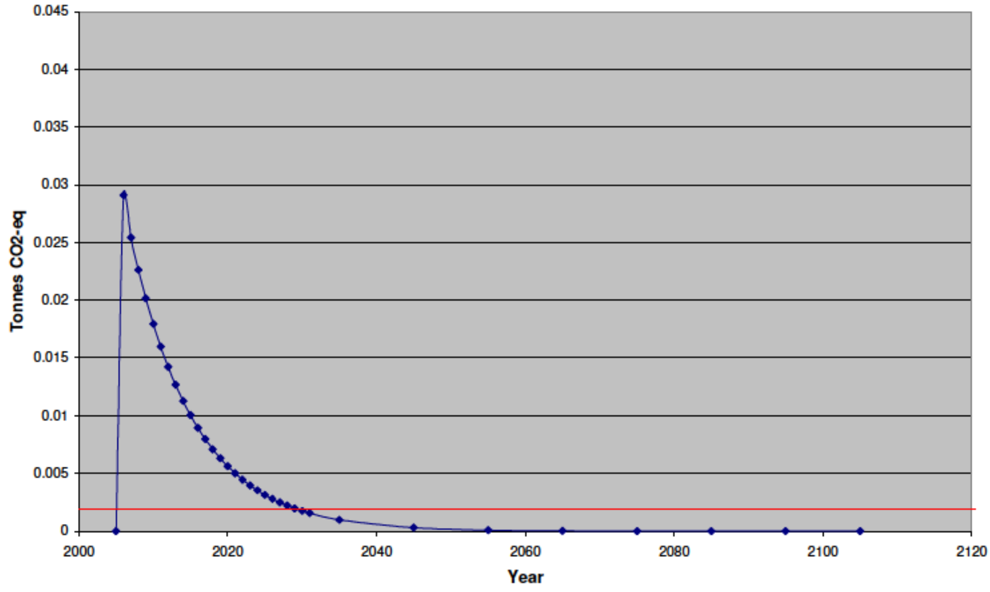


Figure B1.4 Landfill of One Tonne of Green Waste - Greenhouse Gas Emissions over Time

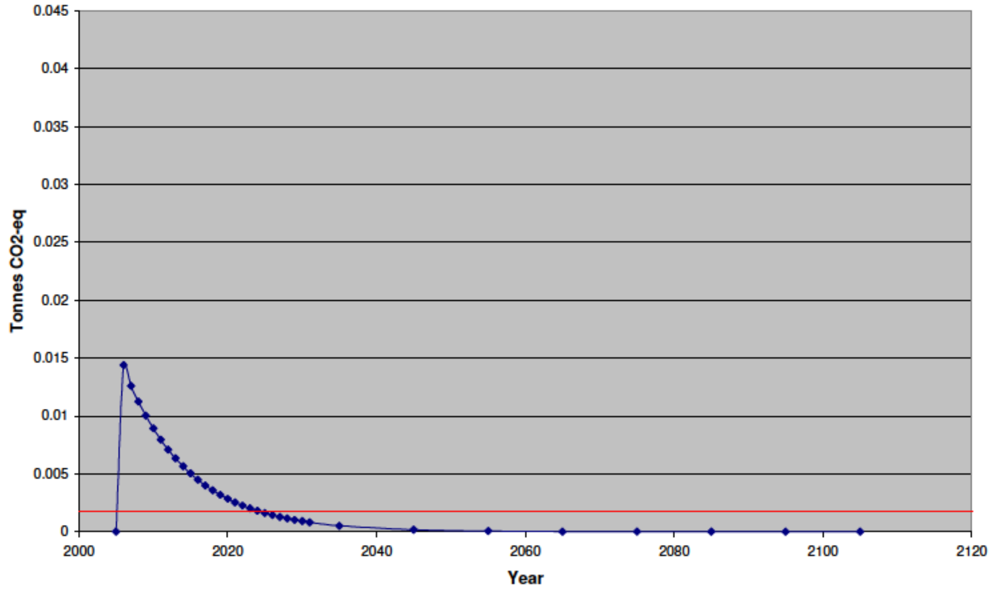


Figure B1.5 *Landfill of One Tonne of 'Other' Organic Waste - Greenhouse Gas Emissions over Time*

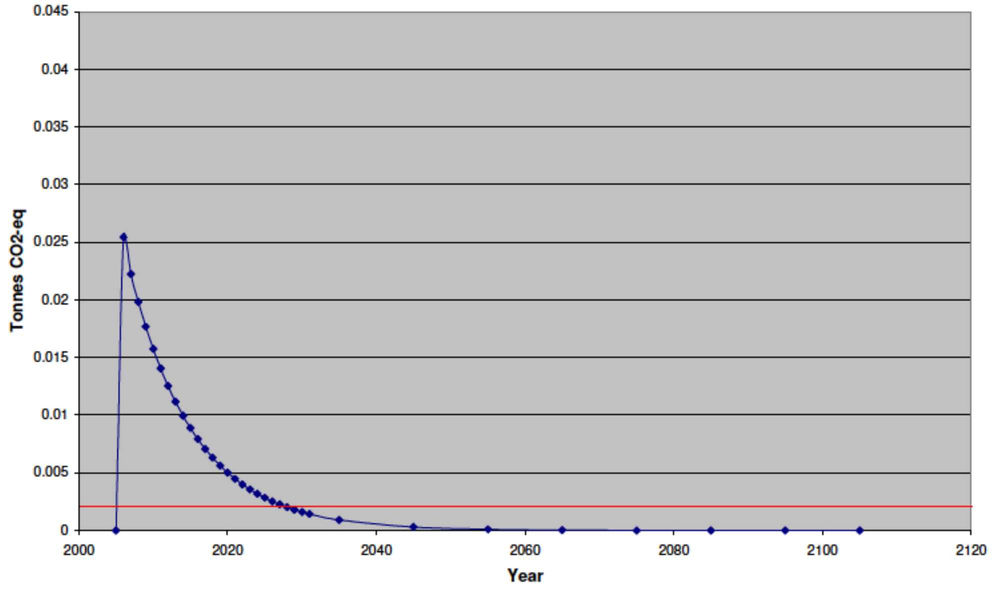


Figure B1.6 *Landfill of One Tonne of Wood - Greenhouse Gas Emissions over Time*

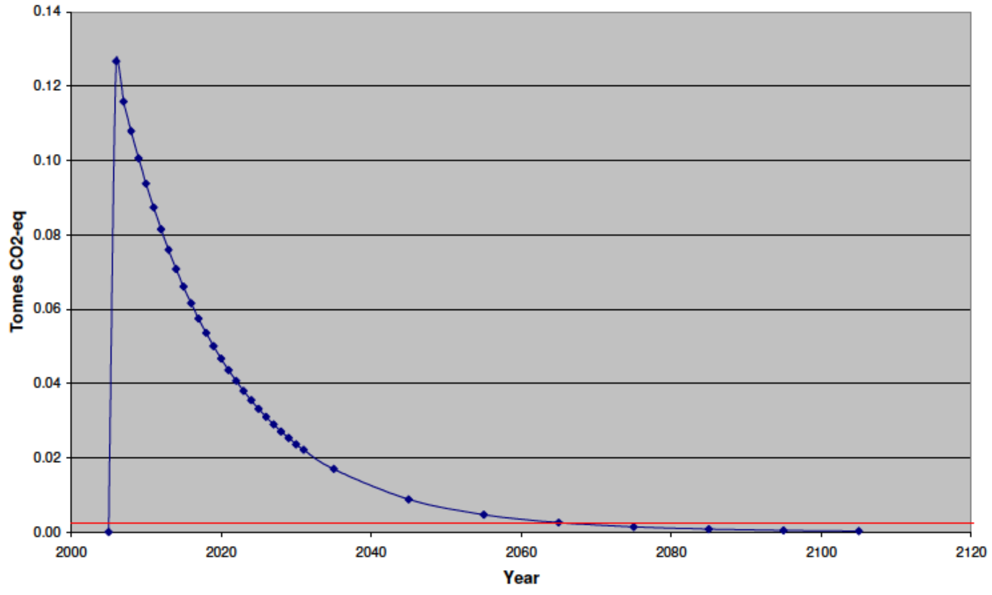


Figure B1.7 *Landfill of One Tonne of Textiles - Greenhouse Gas Emissions over Time*

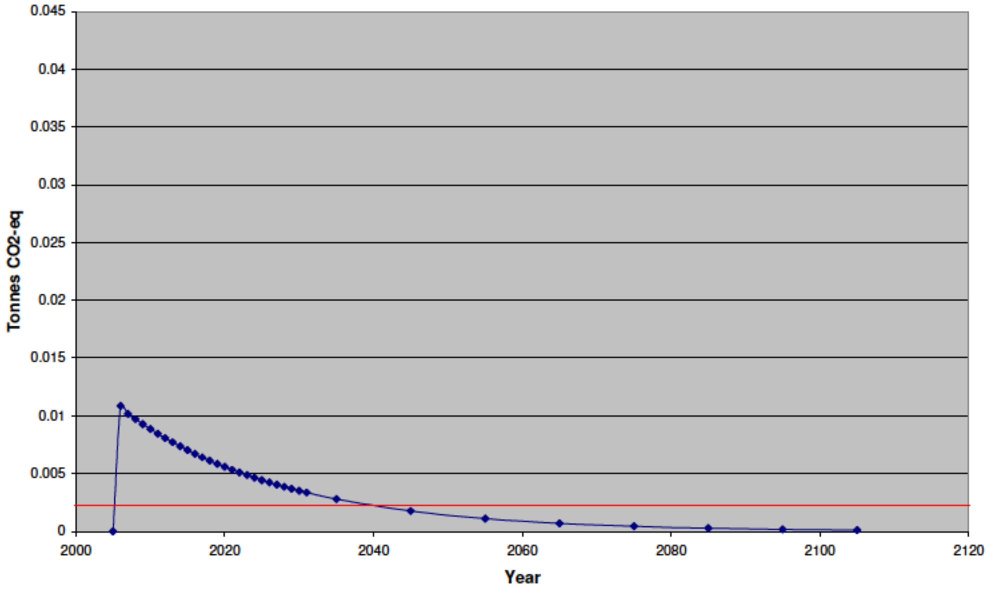
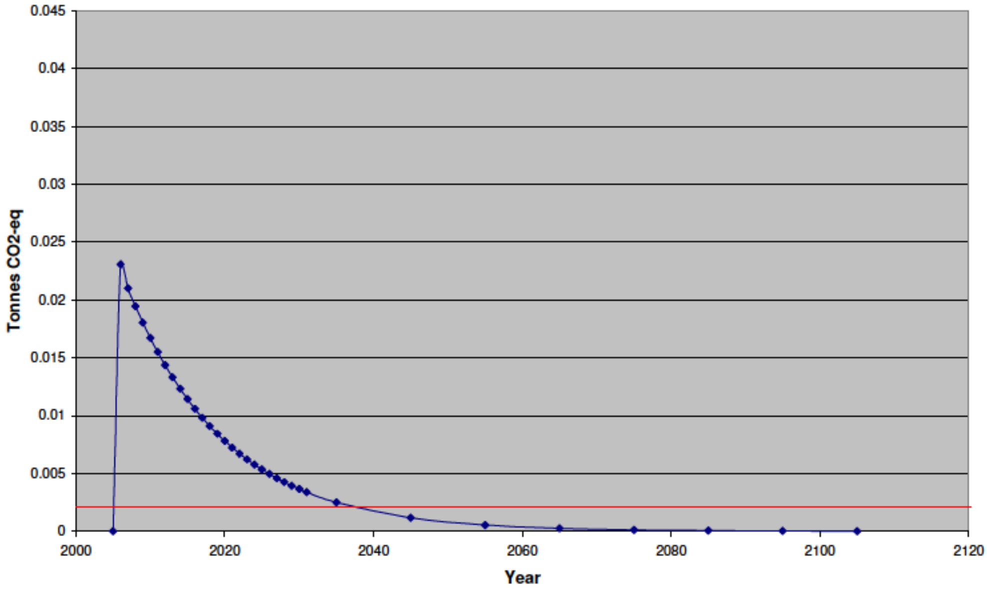


Figure B1.8 *Landfill of One Tonne of Miscellaneous Combustibles/Stabilised Waste - Greenhouse Gas Emissions over Time*



Annex C

Carbon and Greenhouse Gas Balances

C1 CARBON AND GREENHOUSE GAS BALANCES

Carbon and greenhouse gas balances for each waste material and scenario are shown in the following diagrams. Each details:

- the carbon that remains within the material fraction following treatment or disposal (both carbon in inert fractions that have been deposited in land, as well as organic carbon that has not degraded but is sequestered in landfill or other soil carbon sink);
- carbon that is contained in products, such as recyclate or composts; and
- carbon that is released to atmosphere, as carbon dioxide (fossil/biogenically derived) or methane.

A greenhouse gas balance is shown in red, detailing:

- 'ancillary' greenhouse gas emissions predominantly associated with fuel, energy and transport;
- greenhouse gas releases directly associated with the degradation of waste materials (eg on biological processing or landfill of biogenic wastes, or combustion of fossil-derived materials); and
- avoided greenhouse gases through resource and energy recovery.

The information contained in these diagrams is summarised in *Table C1.1*.

Table C1.1 100-Year Carbon (Million Tonnes) and Greenhouse Gas (GHG – Million Tonnes CO_2-equivalents) Balance Summary

Material/Scenario	Carbon in Waste	Carbon Released as CO_2 (Biogenic)	Carbon Released as CO_2 (Fossil)	Carbon Released as CH_4	Carbon in Products	Carbon Remaining in Landfill/ Soil	Ancillary GHG Emissions	GHG Released from Fraction	Avoided GHG (Max)	Avoided GHG (Min)	Net GHG (Max)	Net GHG (Min)
Paper/Card Baseline	118.0	57.7	0.0	4.6	47.2	8.5	4.6	140.0	-127.3	-68.4	17.2	76.1
Paper/Card High Resource	118.0	42.1	0.0	3.6	64.5	7.8	5.0	110.1	-150.8	-77.5	-35.7	37.6
Paper/Card High Energy	118.0	85.3	0.0	2.7	24.1	5.9	6.1	83.6	-187.9	-80.8	-98.1	8.9
Paper/Card Combined	118.0	42.7	0.0	3.4	64.6	7.3	5.2	103.7	-115.0	-78.5	-46.0	30.5
Kitchen/Food Baseline	43.0	33.0	0.0	2.2	1.9	5.9	3.2	66.5	-22.7	-17.8	47.0	52.0
Kitchen/Food High Resource	43.0	29.2	0.0	1.5	8.2	4.1	5.5	45.3	-15.2	-12.4	35.6	38.4
Kitchen/Food High Energy	43.0	27.7	0.0	1.2	10.7	3.3	8.6	38.3	-48.4	-27.1	-1.5	19.7
Kitchen/Food Combined	43.0	28.1	0.0	1.3	10.1	3.6	8.7	39.3	-20.0	-14.0	28.0	34.0
Green Baseline	49.2	34.5	0.0	1.0	3.2	5.1	3.2	29.9	-11.9	-8.5	21.2	24.6
Green High Resource	49.2	34.5	0.0	0.6	10.6	3.4	5.5	20.1	-7.6	-5.7	18.0	19.9
Green High Energy	49.2	33.1	0.0	0.5	12.7	2.9	6.1	17.42	-47.6	-24.0	-24.2	-0.5
Manure/Slurry Baseline	388.6	379.1	0.0	0.0	0.2	9.4	8.3	0.0	-17.2	-3.2	-8.8	5.2
Manure/Slurry High Resource	388.6	333.2	0.0	0.0	48.4	7.0	16.3	1.9	-14.7	-2.5	3.5	15.7
Manure/Slurry High Energy	388.6	333.0	0.0	0.0	48.6	7.0	22.7	2.2	-191.3	-84.6	-166.3	-59.6
Crop Waste Baseline	22.0	21.5	0.0	0.0	0.0	0.5	0.8	0.0	-4.7	-1.4	-3.9	-0.7
Crop Waste High Resource	22.0	19.0	0.0	0.01	2.5	0.5	1.3	0.6	-2.8	-0.8	-0.9	1.0
Crop Waste High Energy	22.0	21.5	0.0	0.0	0.1	0.4	1.5	0.1	-41.8	-14.6	-40.2	-13.0
Other Organics Baseline	28.6	26.1	0.0	0.1	1.7	0.7	1.7	2.6	-7.9	-3.0	-3.6	1.2
Other Organics High Resource	28.6	23.1	0.0	0.1	4.8	0.7	2.0	3.0	-4.5	-1.9	0.5	3.1
Other Organics High Energy	28.6	26.5	0.0	0.1	1.5	0.5	2.0	2.8	-29.3	-10.7	-24.5	-5.9
Other Organics Combined	28.6	23.0	0.0	0.1	5.0	0.5	0.0	3.0	-14.4	-5.0	-11.4	-2.0
Wood Baseline	88.7	70.3	0.0	1.6	12.0	4.7	1.7	50.6	-18.4	-11.5	338.	40.7
Wood High Resource	88.7	59.2	0.0	1.4	24.2	3.9	2.0	43.4	-16.8	-9.3	28.5	36.0
Wood High Energy	88.7	79.1	0.0	0.9	6.1	2.6	2.9	28.5	-110.6	-42.5	-79.2	-11.1
Wood Combined	88.7	60.8	0.0	1.0	24.2	2.7	2.6	31.2	-59.8	-23.4	-26.0	10.5
Textiles Baseline	15.0	10.3	0.8	0.2	1.7	1.9	0.3	9.7	-11.4	-6.1	-1.4	3.9
Textiles Resource	15.0	8.7	0.4	0.2	3.9	1.7	0.4	7.4	-19.6	-10.6	-11.8	-2.8
Textiles High Energy	15.0	9.1	3.7	0.1	0.9	1.1	0.6	17.6	-21.8	-8.8	-3.7	9.3

Material/Scenario	Carbon in Waste	Carbon Released as CO_2 (Biogenic)	Carbon Released as CO_2 (Fossil)	Carbon Released as CH_4	Carbon in Products	Carbon Remaining in Landfill/ Soil	Ancillary GHG Emissions	GHG Released from Fraction	Avoided GHG (Max)	Avoided GHG (Min)	Net GHG (Max)	Net GHG (Min)
Textiles Combined	15.0	7.8	1.9	0.1	4.0	1.2	0.5	11.1	-26.6	-13.0	-15.0	-1.3
Dense Plastic Baseline	41.2	0.0	3.7	0.0	1.4	36.0	0.6	13.8	-13.3	-0.8	1.0	13.5
Dense Plastic High Resource	41.2	0.0	1.9	0.0	10.9	28.4	0.7	6.88	-40.5	15.4	-32.9	23.0
Dense Plastic High Energy	41.2	0.00	20.2	0.0	0.8	20.2	1.1	74.2	-62.0	-20.0	13.5	55.3
Dense Plastic Combined	41.2	0.0	8.0	0.0	10.9	22.3	0.9	29.3	-59.3	8.7	-29.1	39.0
Plastic Film Baseline	39.8	0.0	2.7	0.0	3.2	34.0	0.6	9.7	-15.7	3.5	-5.4	13.9
Plastic Film High Resource	39.8	0.0	1.3	0.0	11.4	27.1	0.8	4.87	-38.1	19.3	-32.4	24.9
Plastic Film High Energy	38.8	0.00	19.0	0.0	1.7	19.1	1.2	69.62	-60.2	-16.7	10.6	54.1
Plastic Film Combined	39.8	0.0	7.2	0.0	11.5	21.1	1.0	26.5	-55.8	13.0	-28.3	40.5
Ferrous Metals Baseline	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0	-50.0	-34.9	-48.6	-33.5
Ferrous Metals High Resource	0.0	0.00	0.0	0.0	0.0	0.0	1.6	0.0	-60.6	-42.3	-59.0	-40.7
Non-Ferrous Baseline	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	-452.1	-424.5	-451.4	-423.8
Non-Ferrous High Resource	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	-497.9	-467.5	-497.2	-466.7
Soils Baseline	95.9	0.00	0.0	0.0	1.6	94.3	17.5	0.0	-0.1	0.0	17.4	17.5
Soils High Resource	95.9	0.0	0.0	0.0	38.3	57.6	19.4	0.0	-1.3	1.2	18.2	20.6
Soils (mining, quarrying, dredging) Baseline	113.4	0.0	0.0	0.0	0.0	113.4	4.8	0.0	0.0	0.0	4.8	4.8
Minerals Baseline	113.2	0.0	0.0	0.0	81.9	31.3	25.1	0.1	-2.9	2.4	22.3	27.6
Minerals High Resource	113.2	0.0	0.0	0.0	84.6	28.6	25.2	0.0	-2.9	2.5	22.4	27.8
Minerals (mining, quarrying, dredging) Baseline	113.4	0.0	0.0	0.0	0.8	112.6	4.9	0.0	0.0	0.0	4.9	5.0
Misc. Combustibles Baseline	131.9	62.8	9.9	1.7	37.3	20.1	4.5	89.5	-47.0	-22.9	47.0	71.2

C1.1 PAPER AND CARD

Figure C1.1 Baseline Scenario

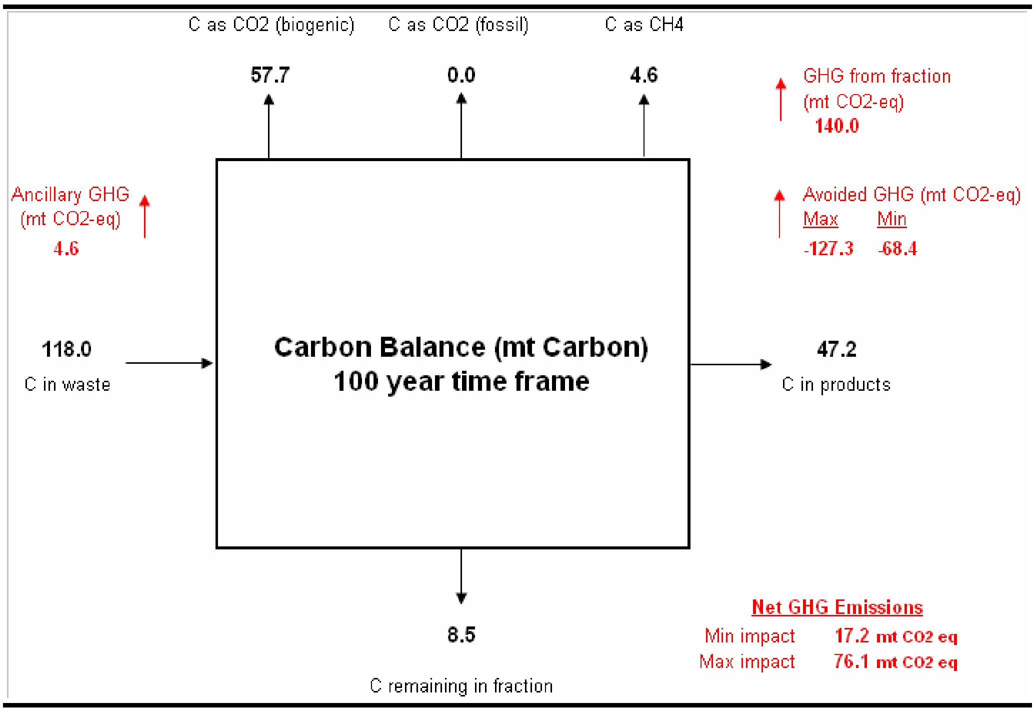


Figure C1.2 High Resource Recovery Scenario

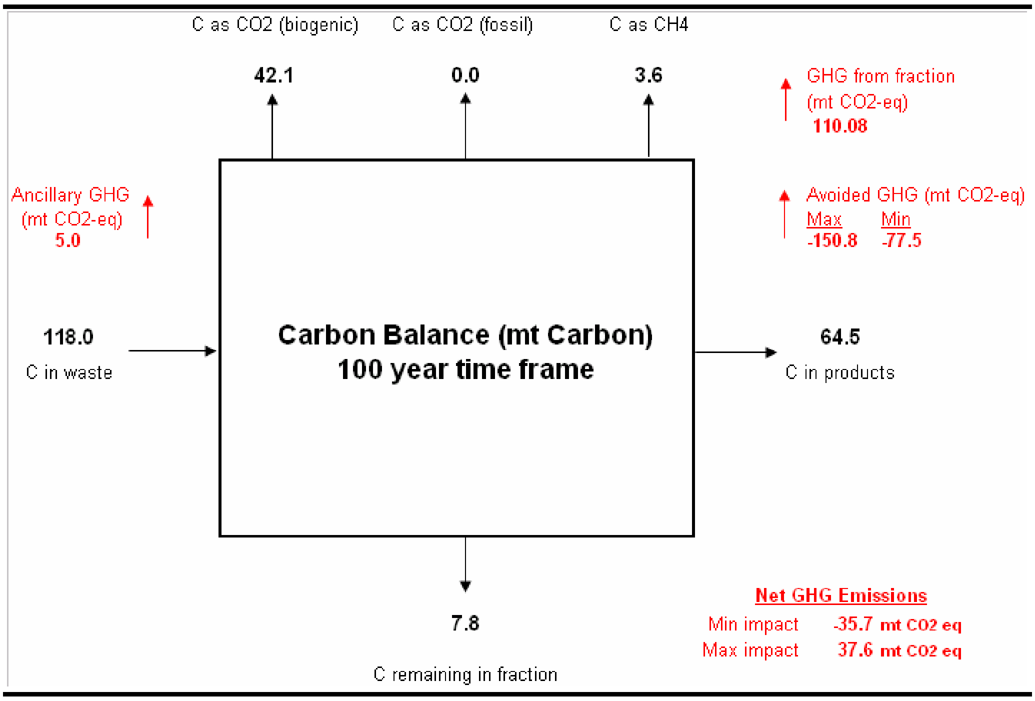


Figure C1.3 High Energy Recovery Scenario

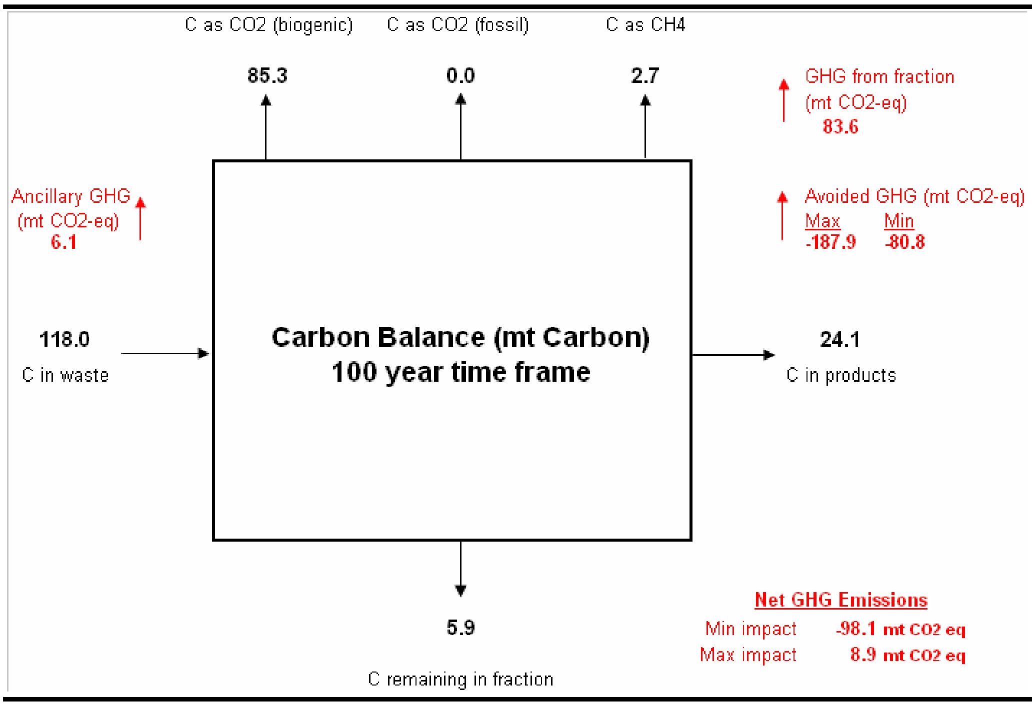
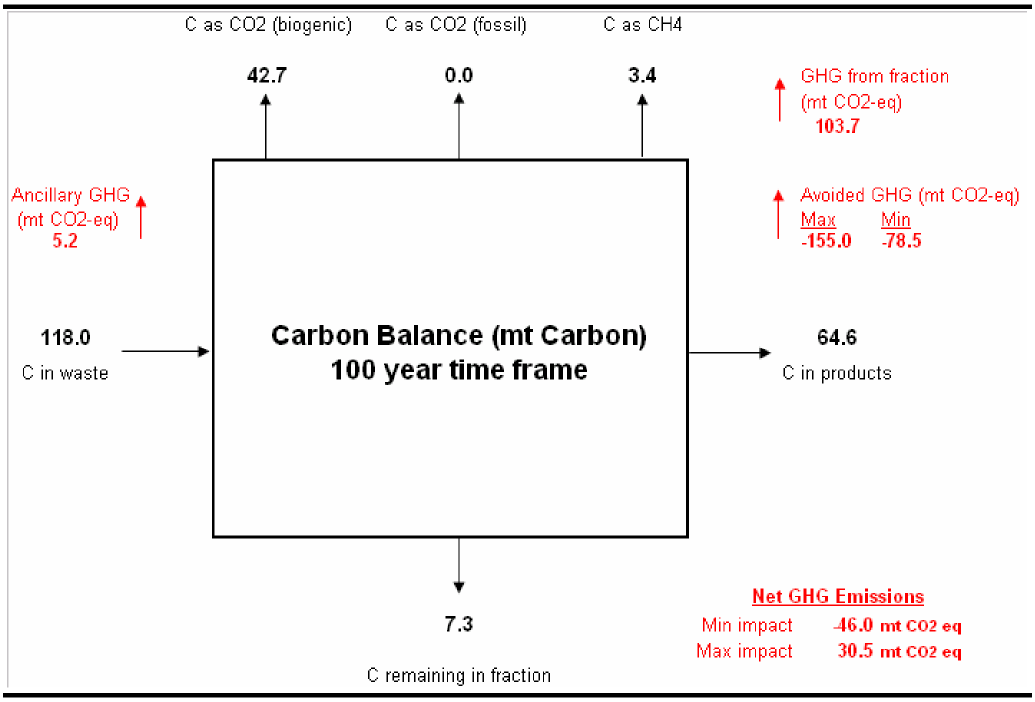


Figure C1.4 Combined Scenario



C1.2 KITCHEN/FOOD WASTE

Figure C1.5 Baseline Scenario

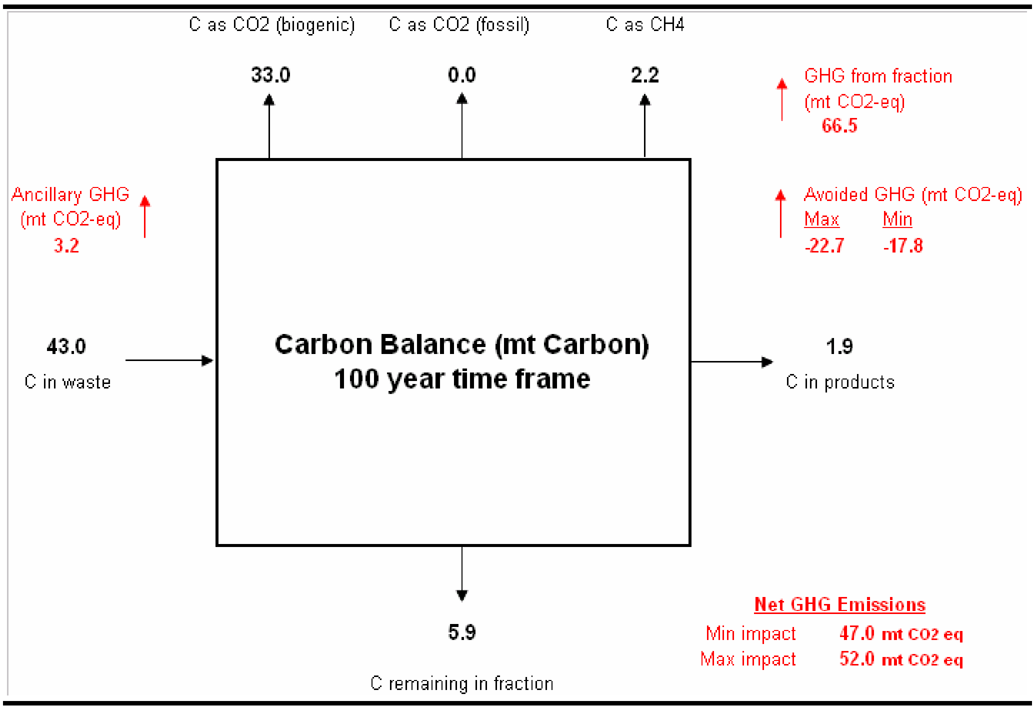


Figure C1.6 High Resource Recovery Scenario

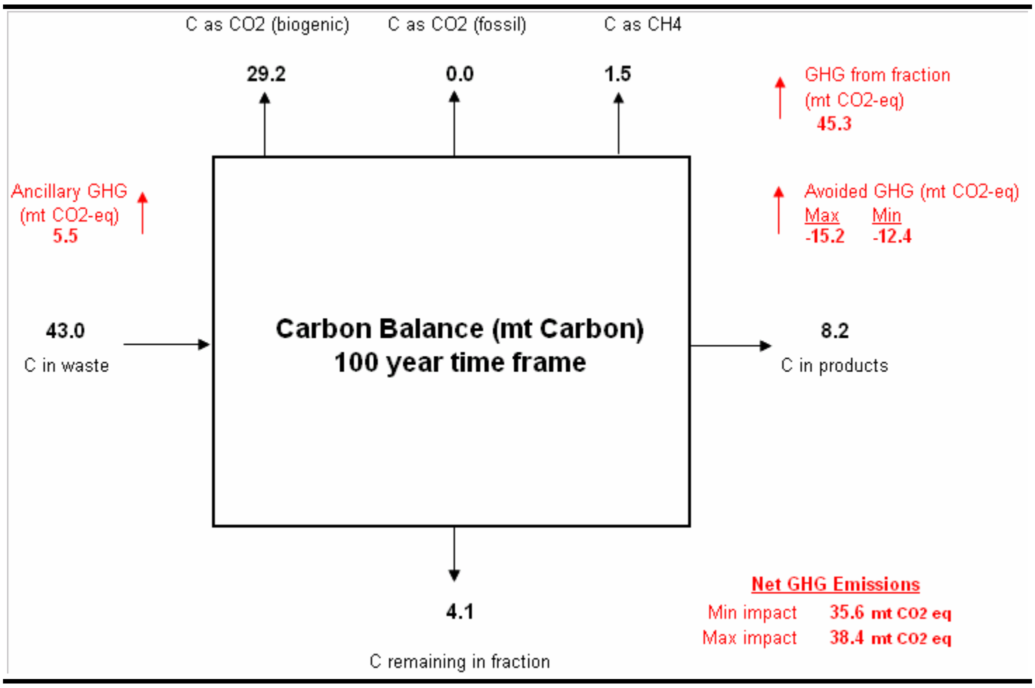


Figure C1.7 High Energy Recovery Scenario

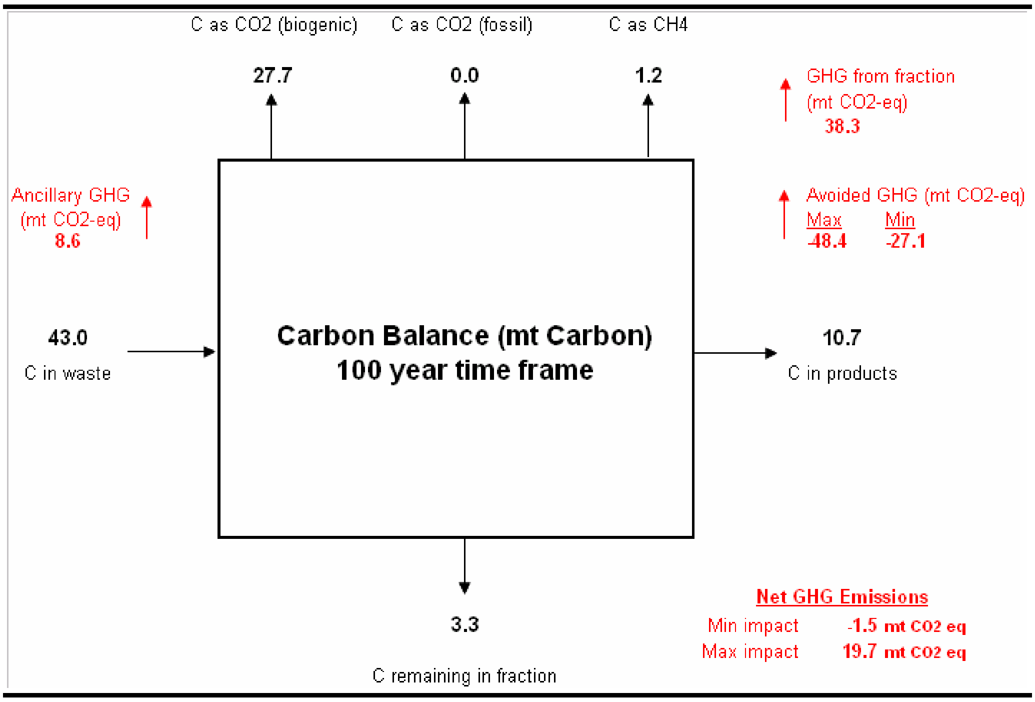
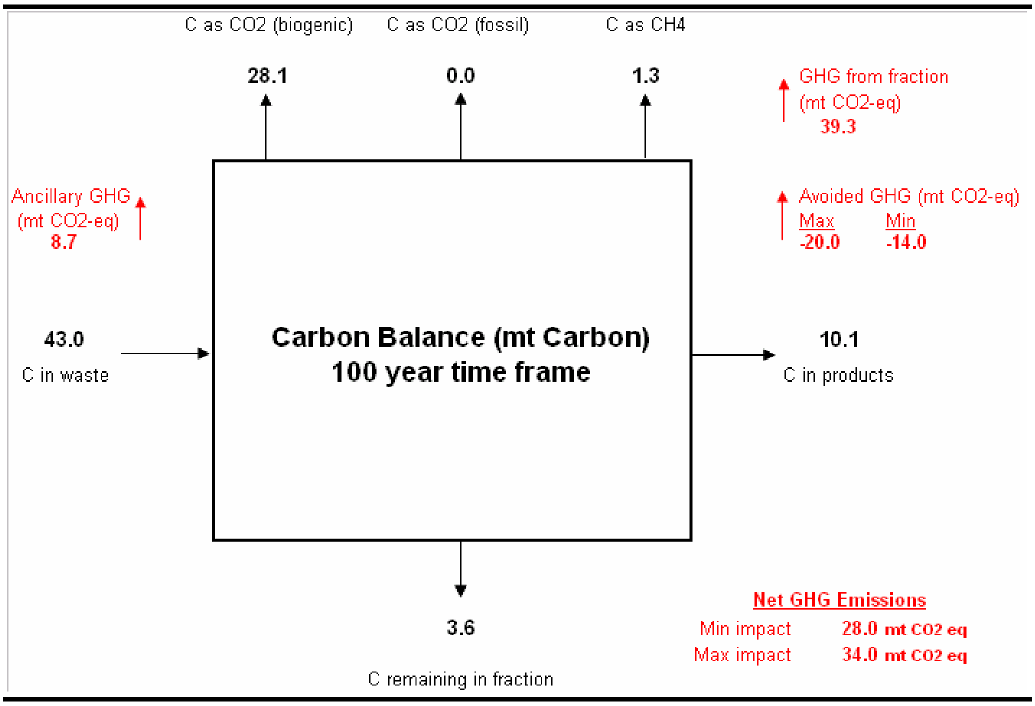


Figure C1.8 Combined Scenario



C1.3 GREEN WASTE

Figure C1.9 Baseline Scenario

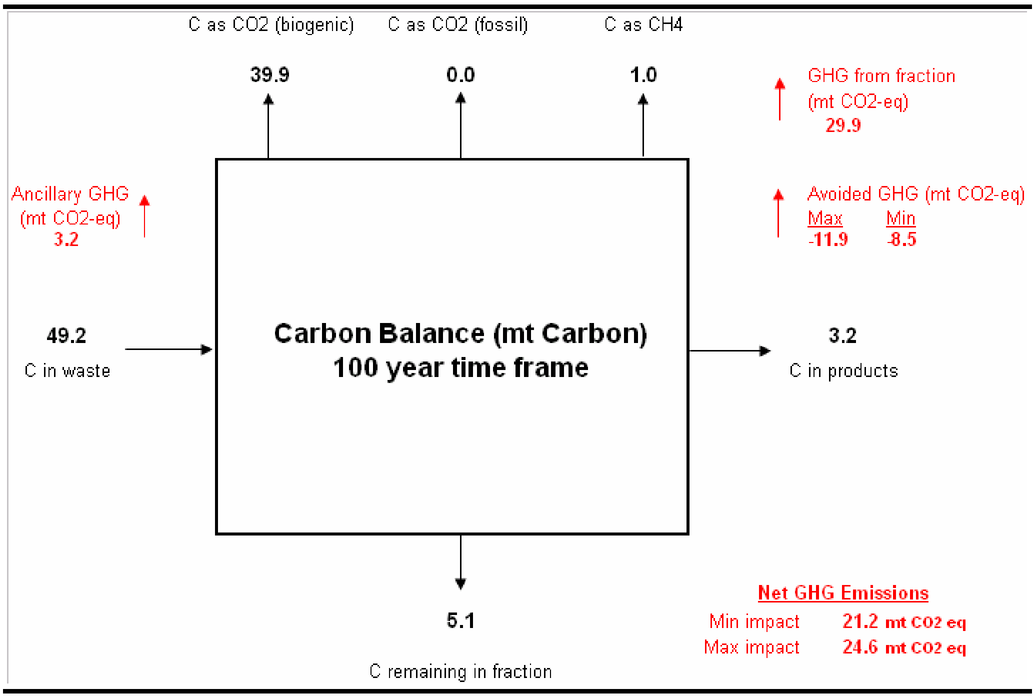


Figure C1.10 High Resource Recovery Scenario

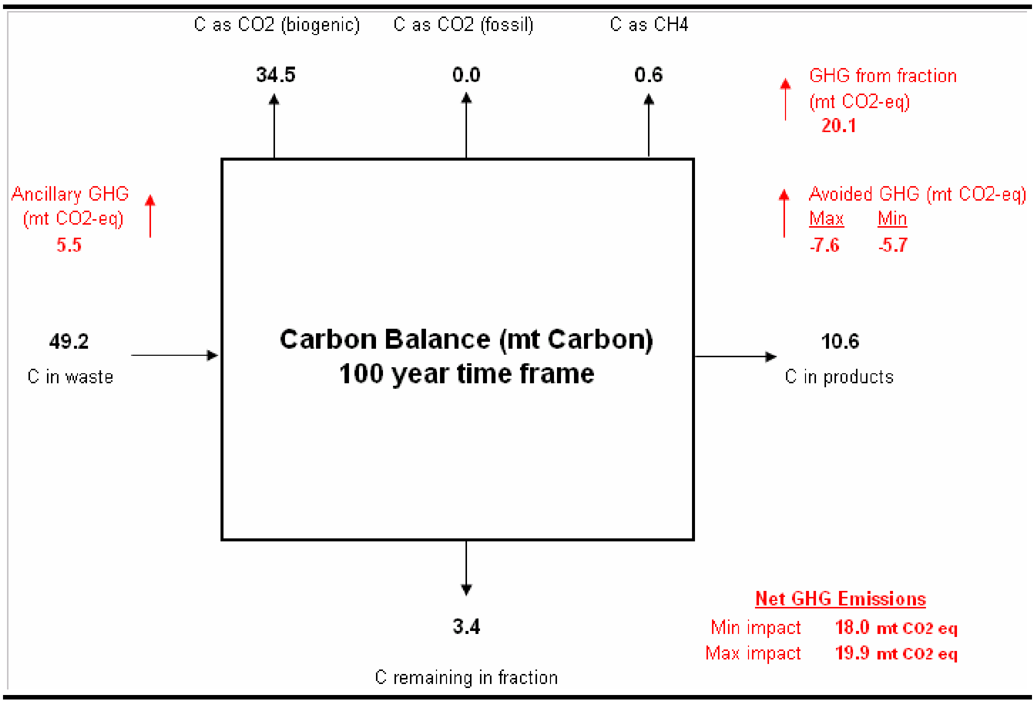
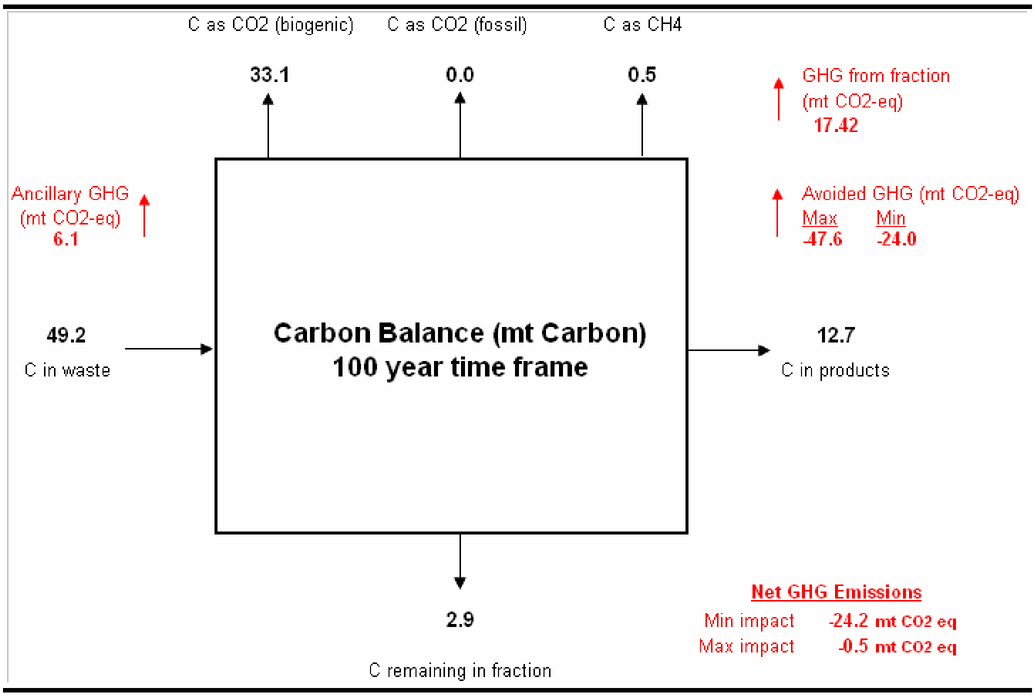


Figure C1.11 High Energy Recovery Scenario



C1.4 AGRICULTURAL CROP WASTE

Figure C1.12 Baseline Scenario

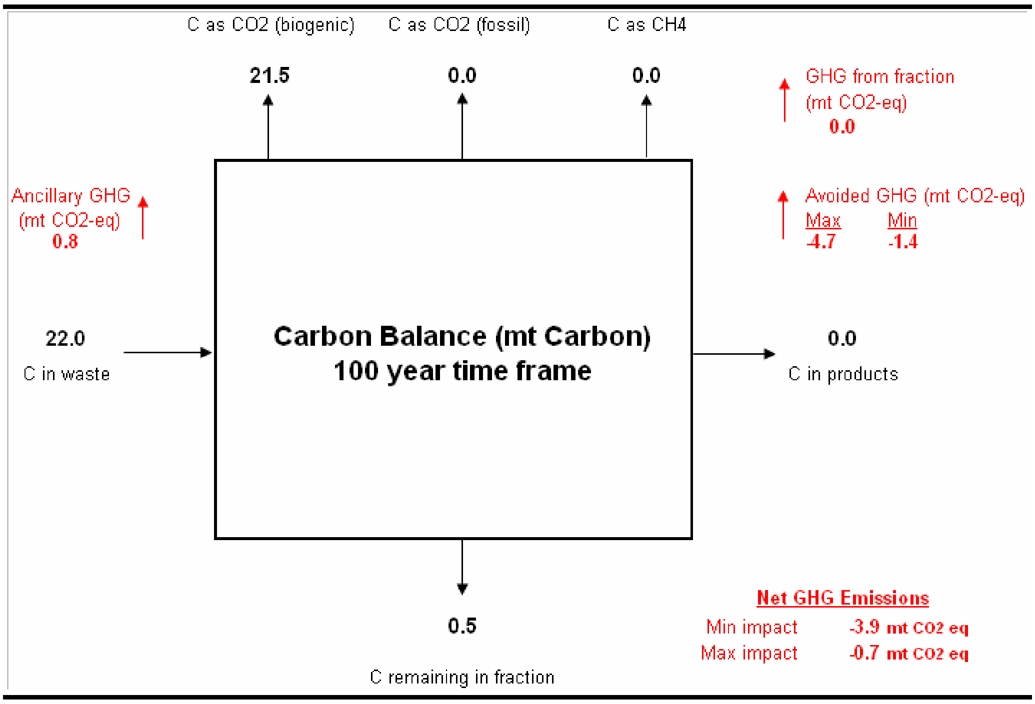


Figure C1.13 High Resource Recovery Scenario

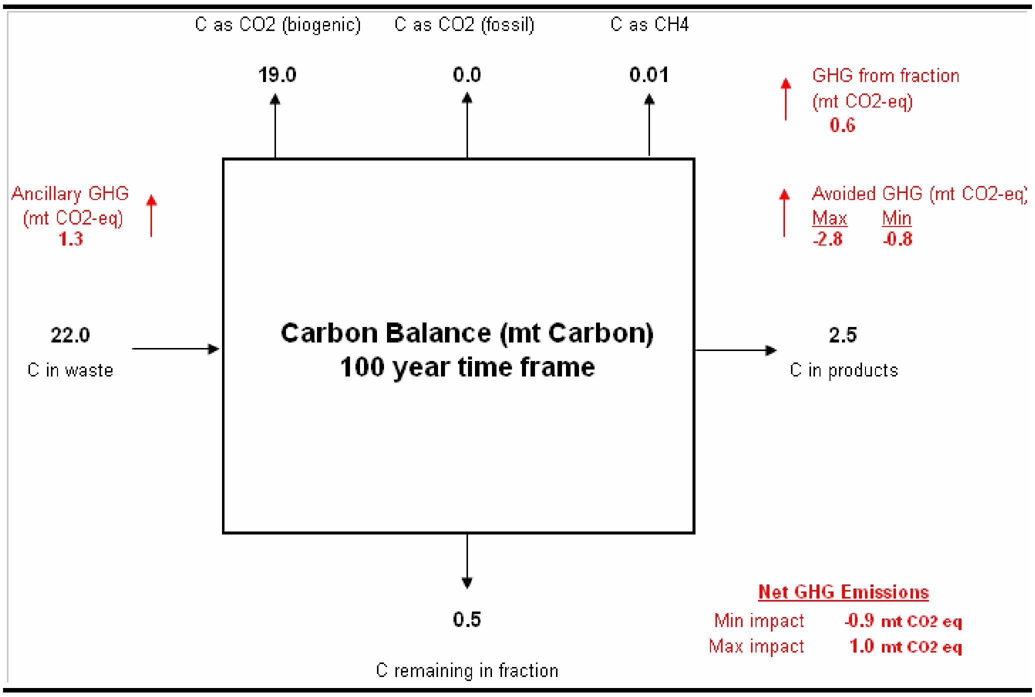
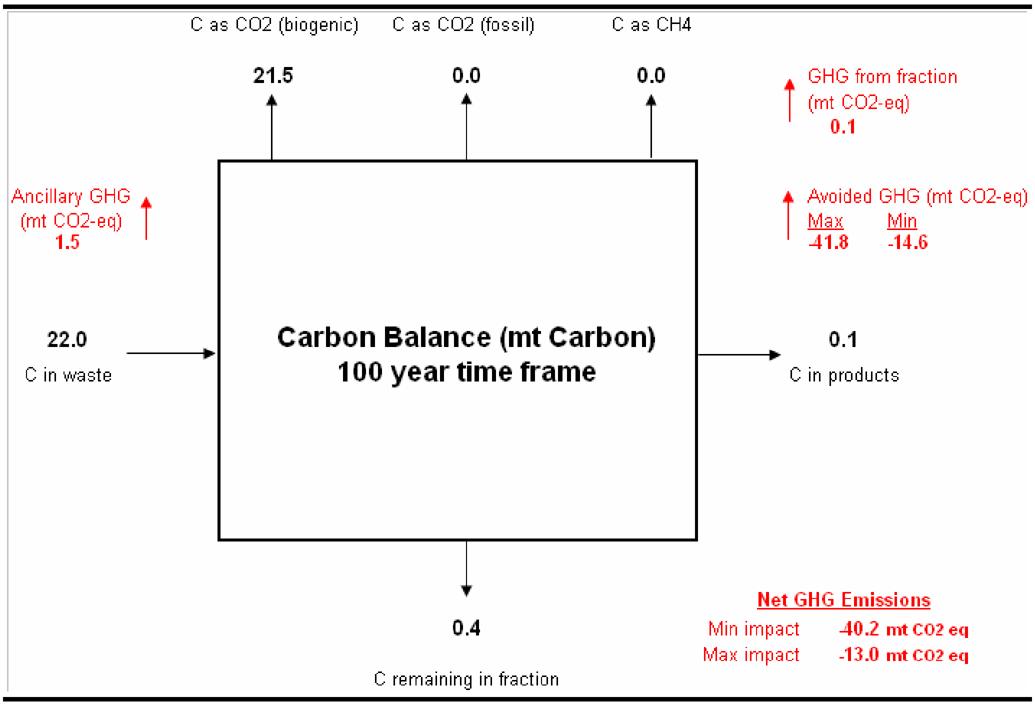


Figure C1.14 High Energy Recovery Scenario



C1.5 AGRICULTURAL MANURE/SLURRY

Figure C1.15 Baseline Scenario

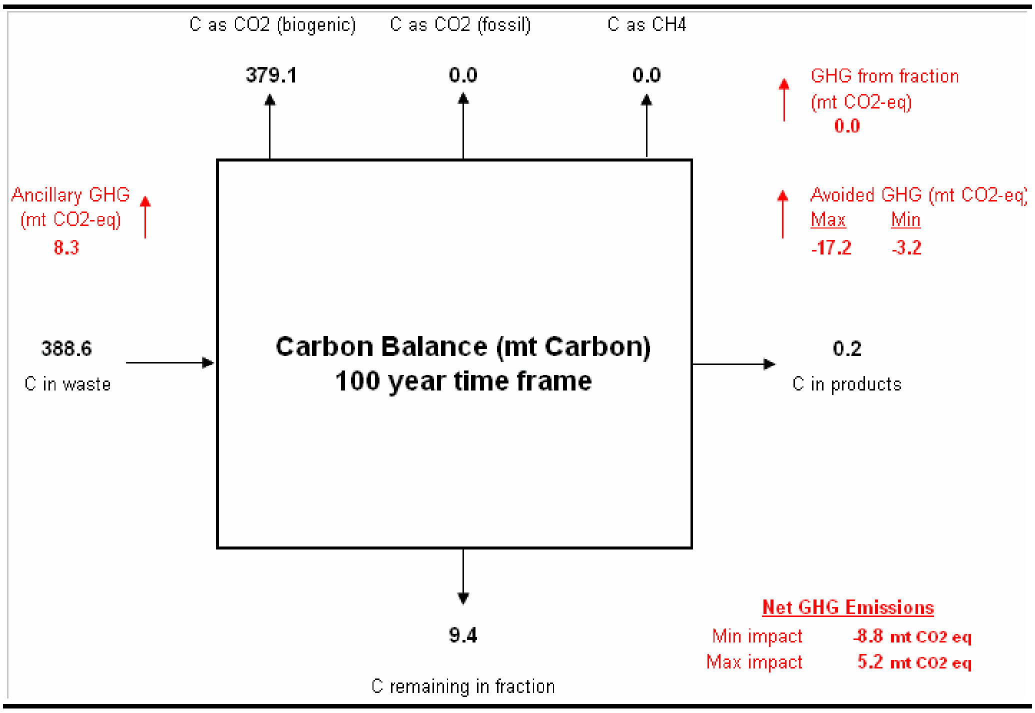


Figure C1.16 High Resource Recovery Scenario

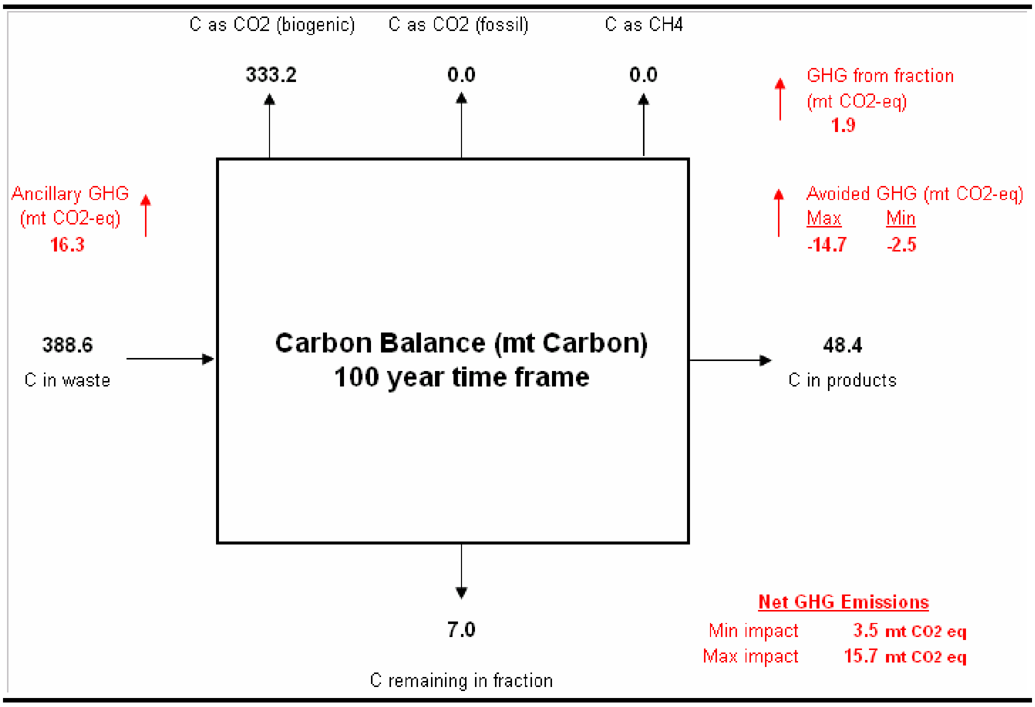
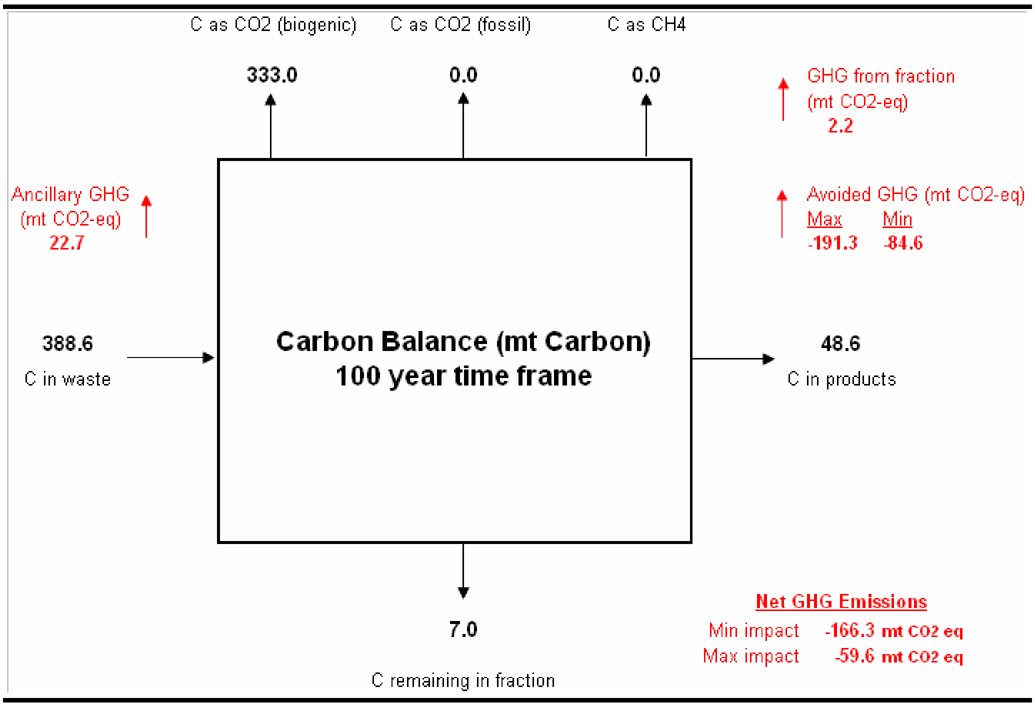


Figure C1.17 High Energy Recovery Scenario



C1.6 'OTHER ORGANICS'

Figure C1.18 Baseline Scenario

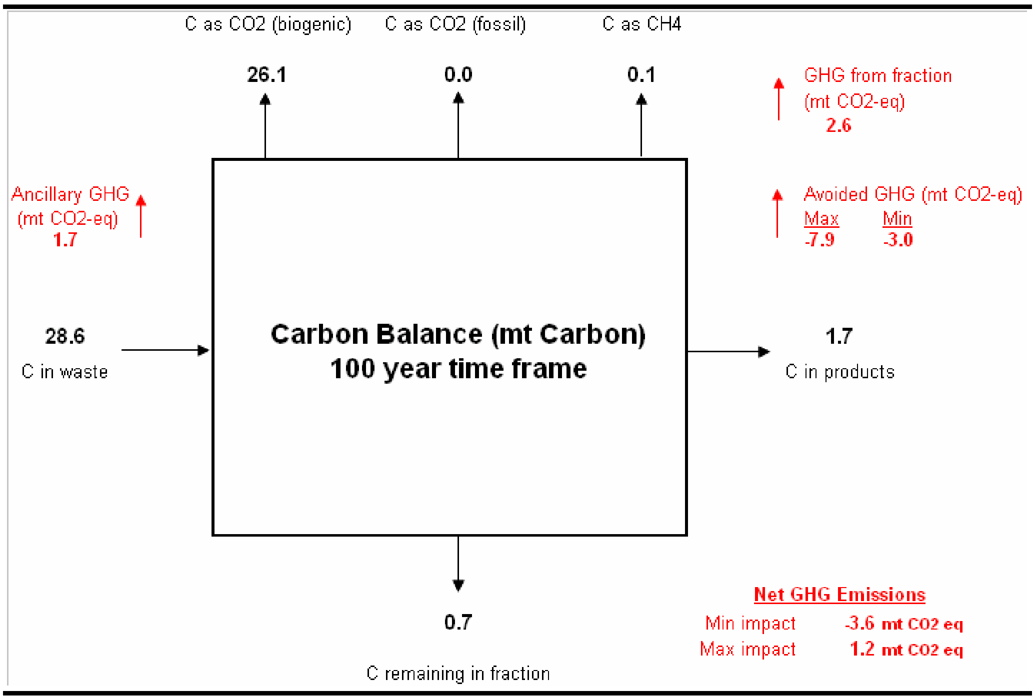


Figure C1.19 High Resource Recovery Scenario

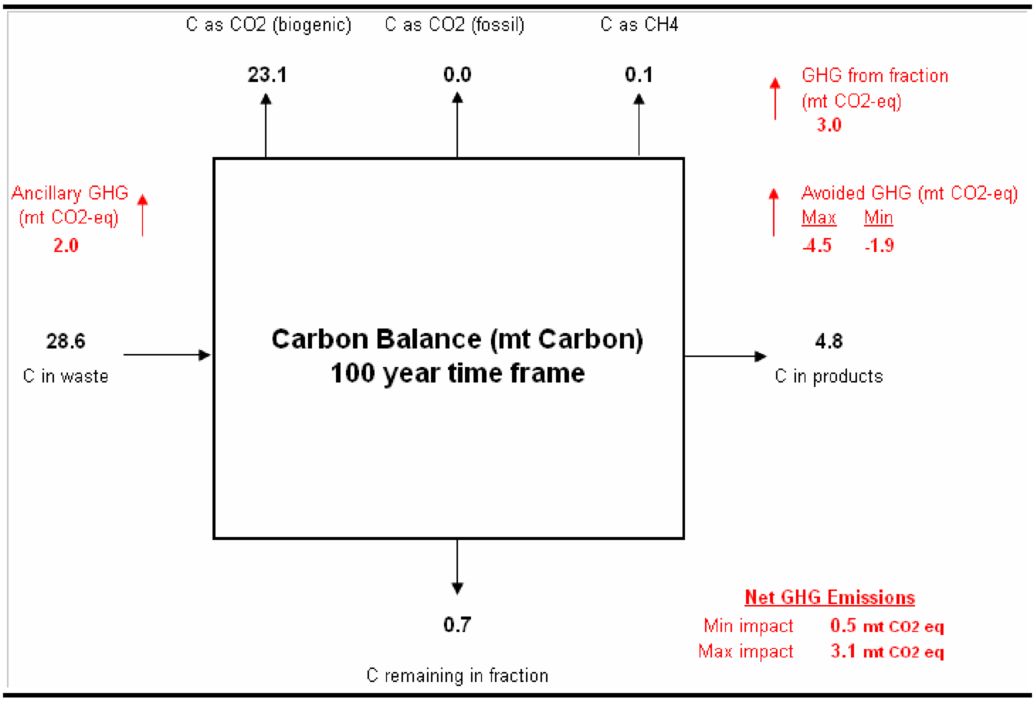


Figure C1.20 High Energy Recovery Scenario

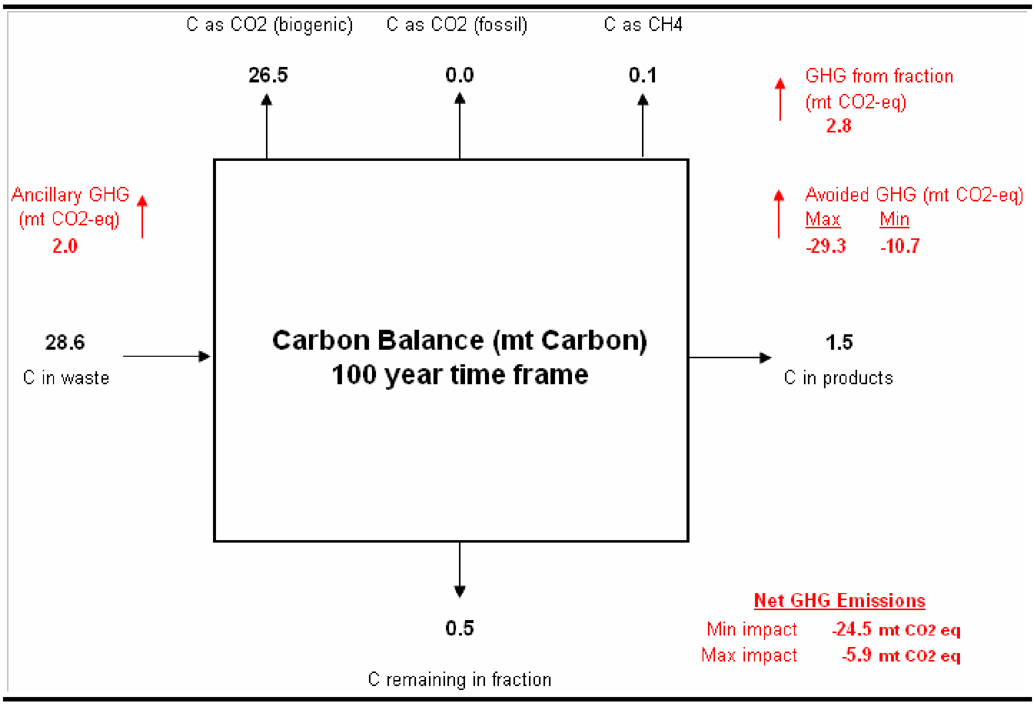
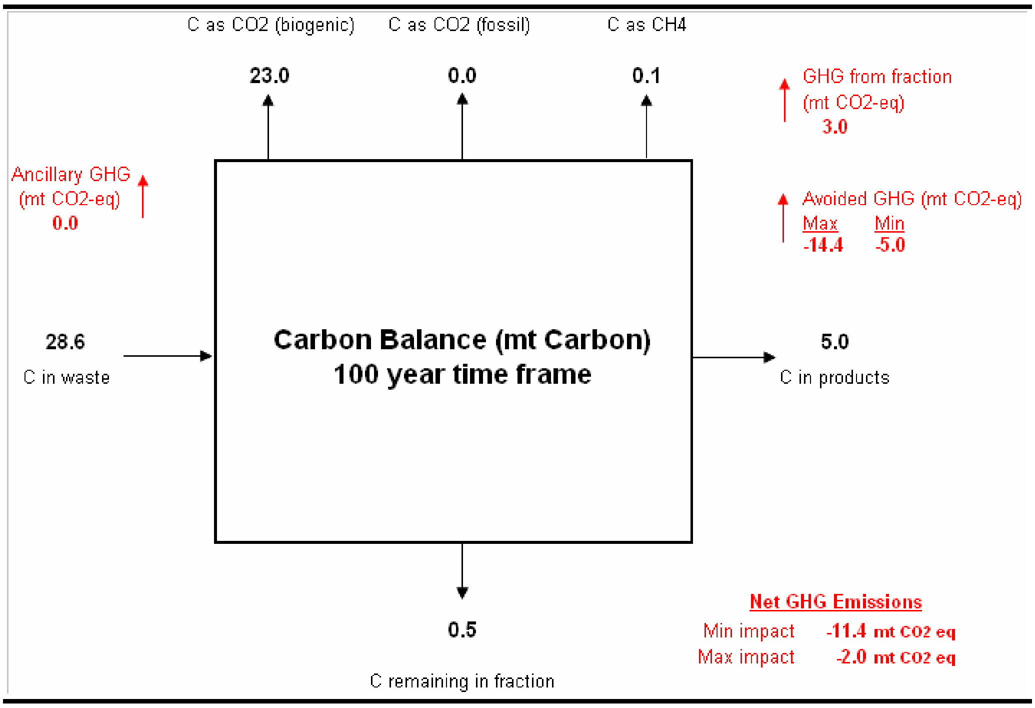


Figure C1.21 Combined Scenario



C1.7 WOOD

Figure C1.22 Baseline Scenario

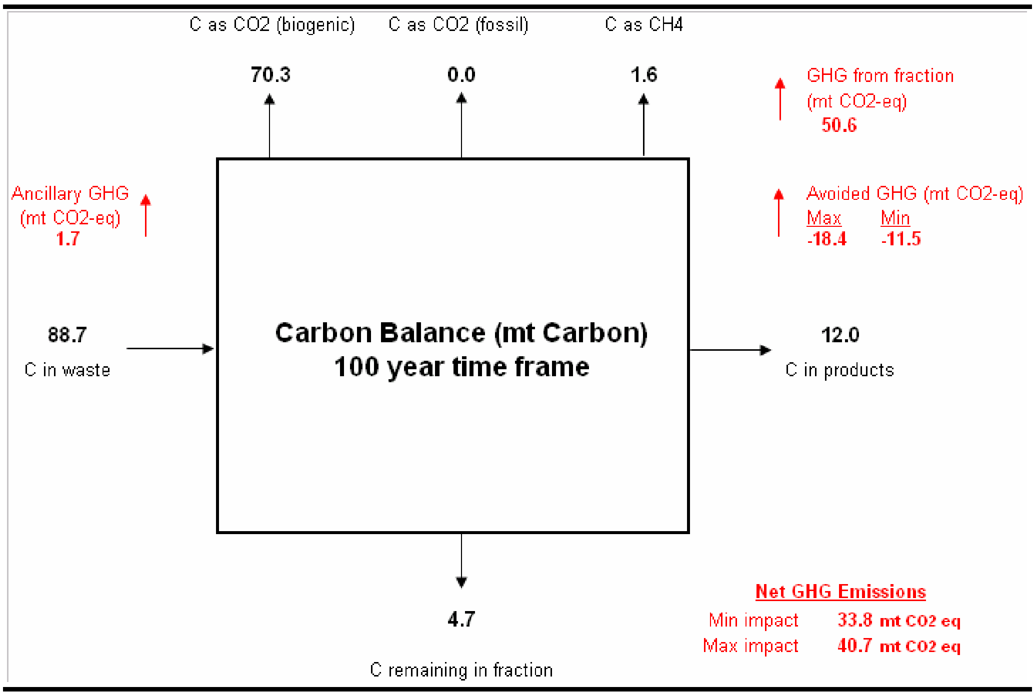


Figure C1.23 High Resource Recovery Scenario

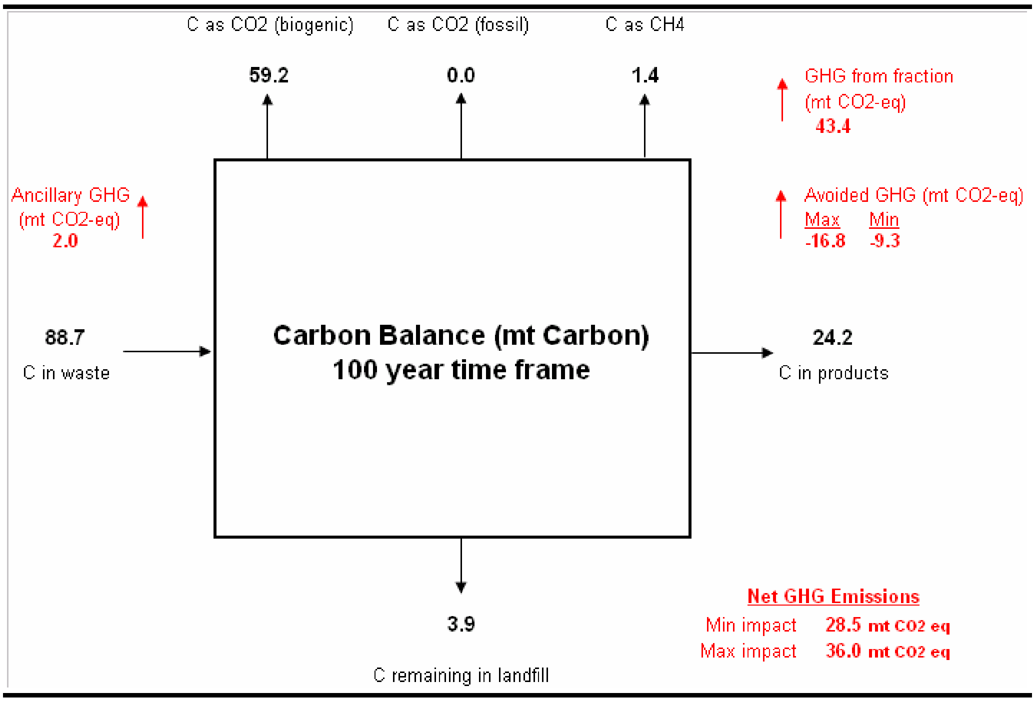


Figure C1.24 High Energy Recovery Scenario

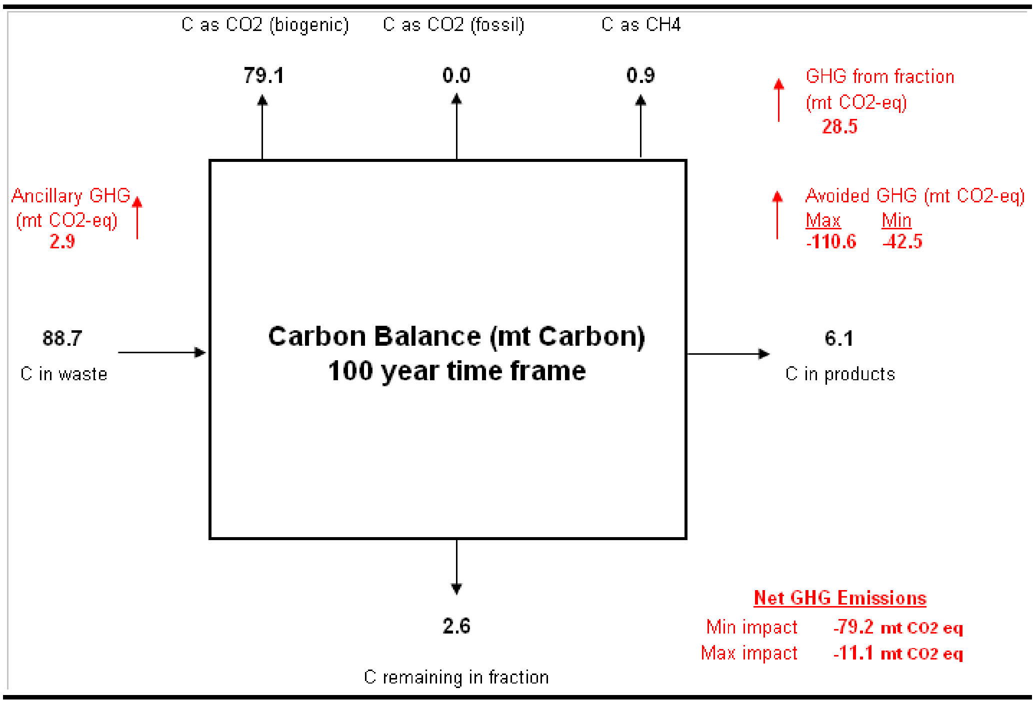
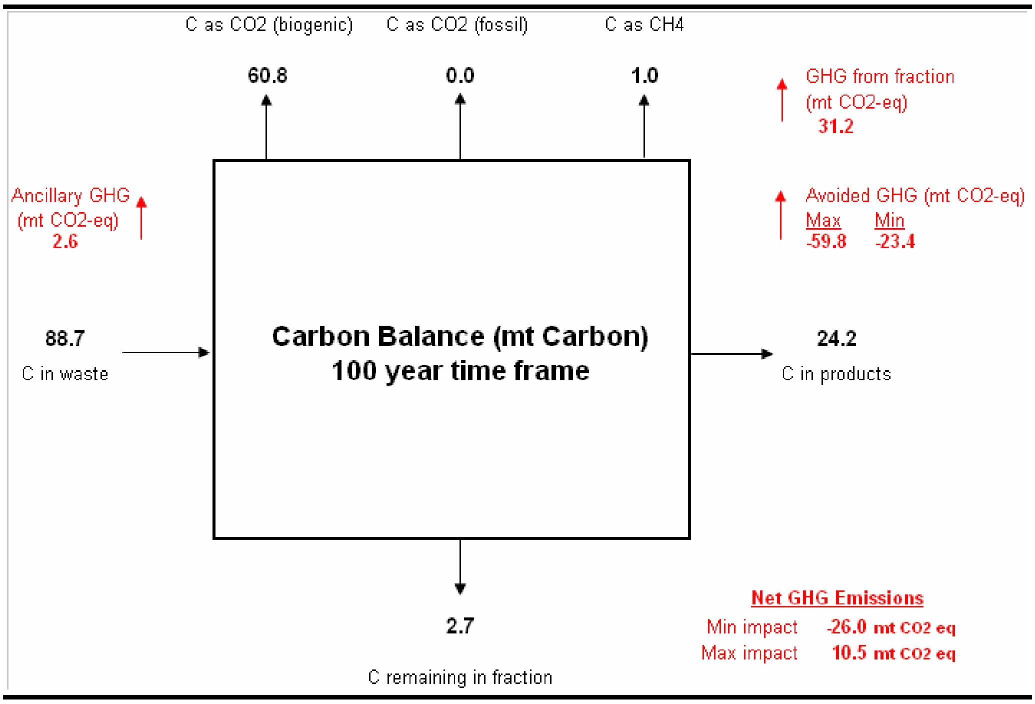


Figure C1.25 Combined Scenario



C1.8 TEXTILES

Figure C1.26 Baseline Scenario

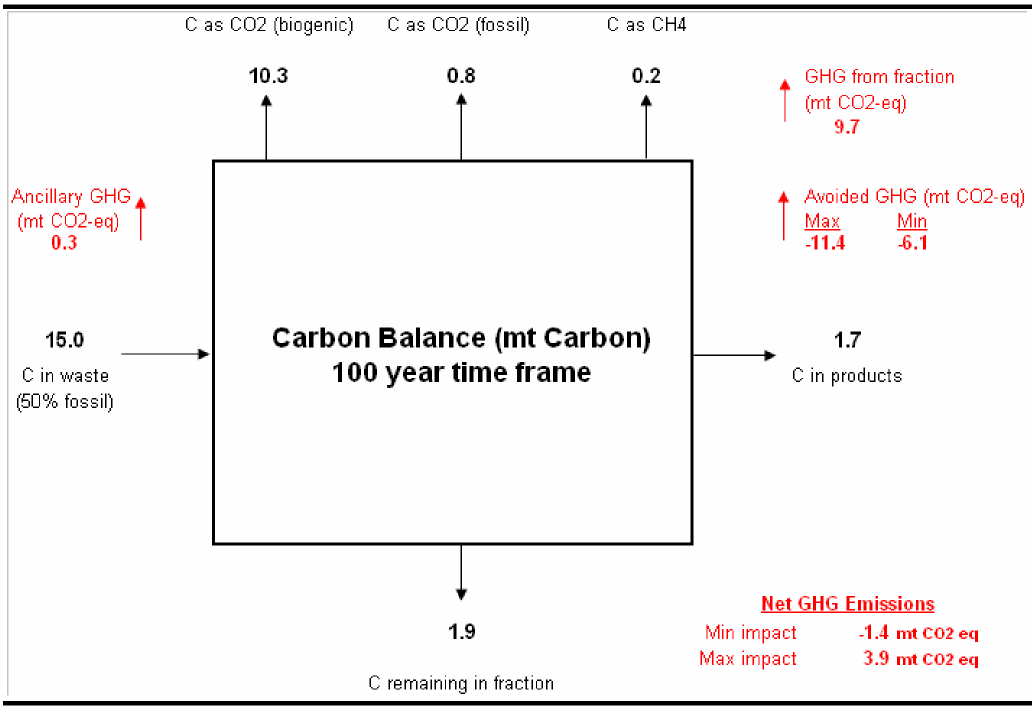


Figure C1.27 High Resource Recovery Scenario

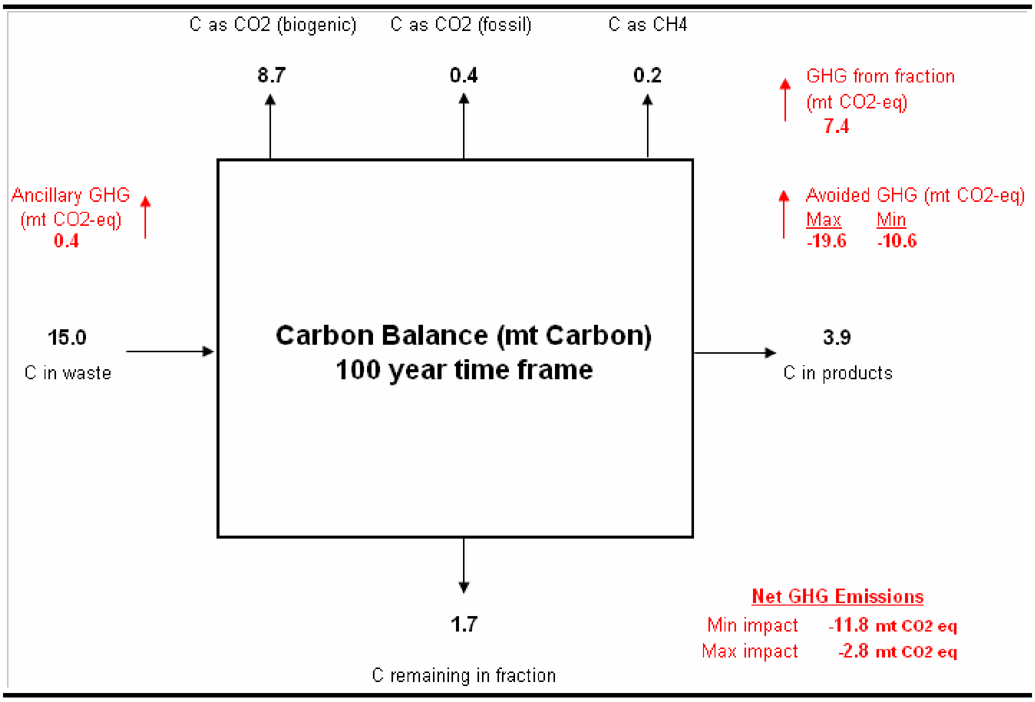


Figure C1.28 High Energy Recovery Scenario

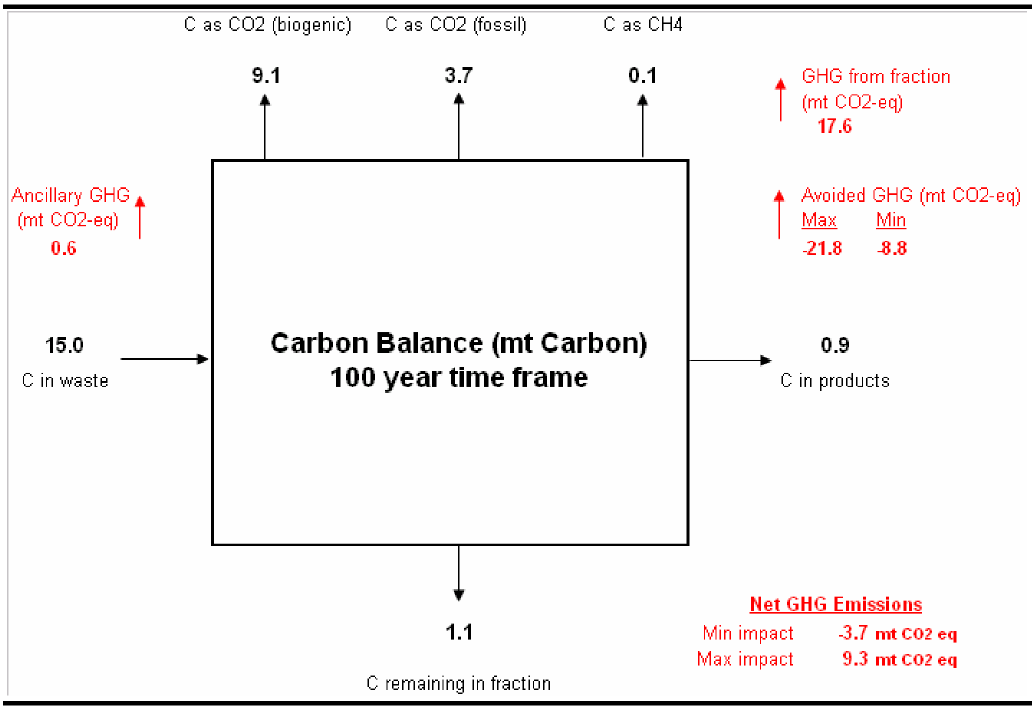
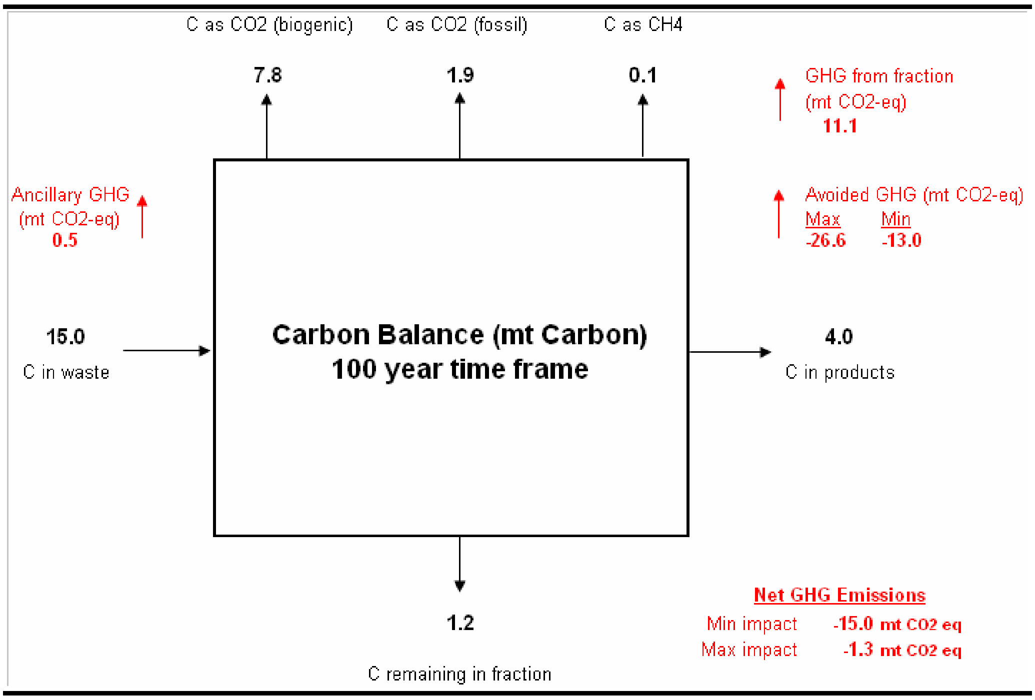


Figure C1.29 Combined Scenario



C1.9 PLASTIC (DENSE)

Figure C1.30 Baseline Scenario

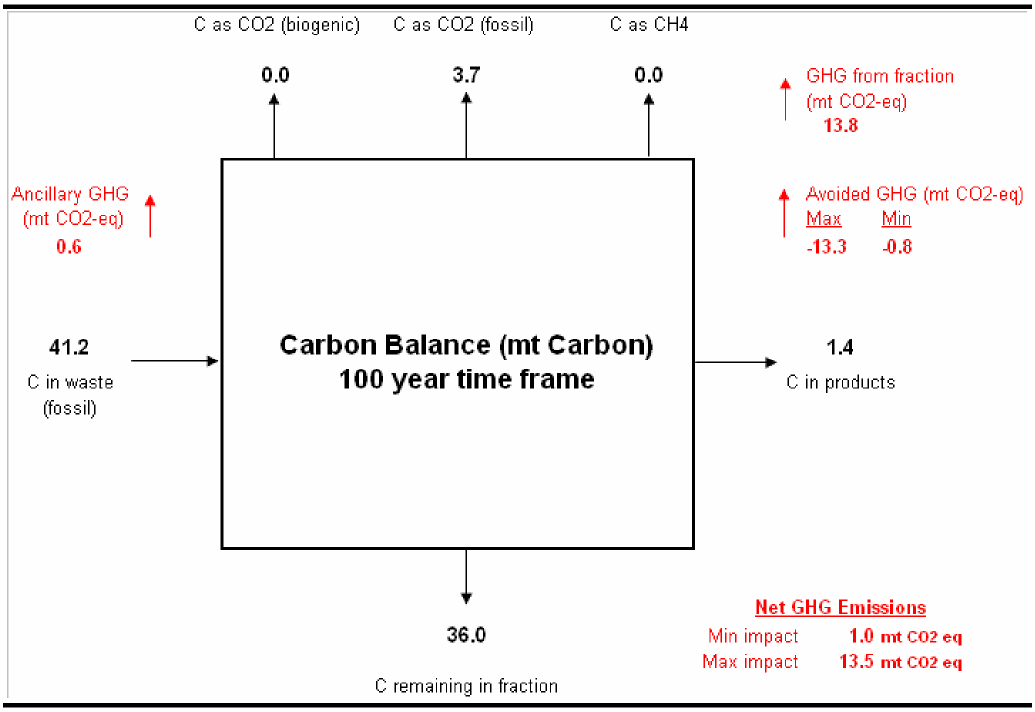


Figure C1.31 High Resource Recovery Scenario

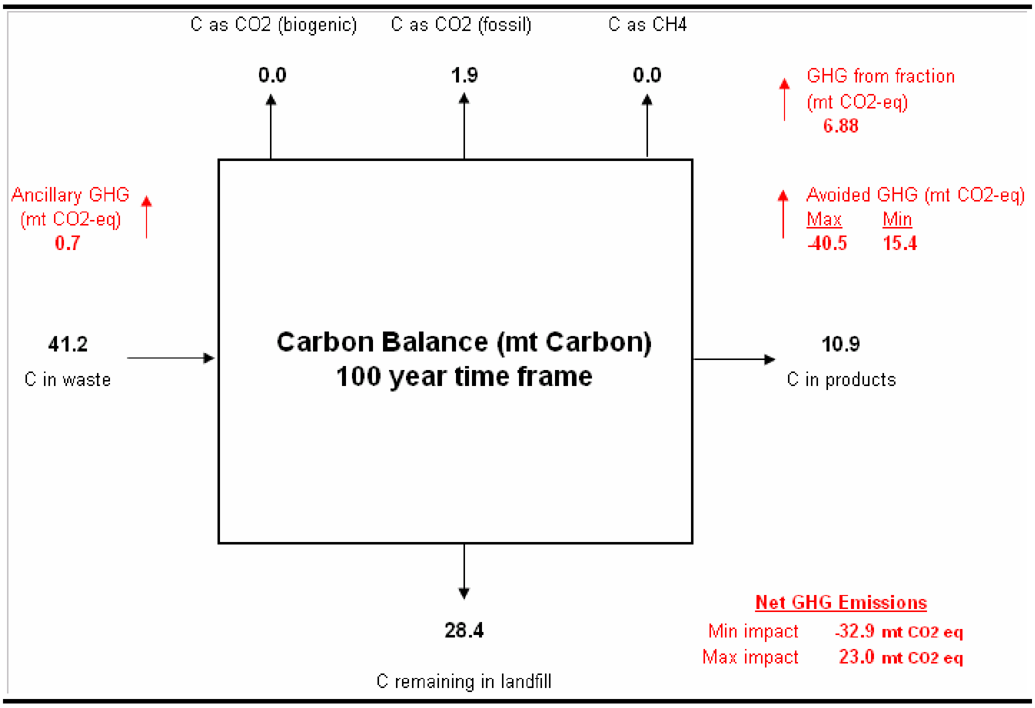


Figure C1.32 High Energy Recovery Scenario

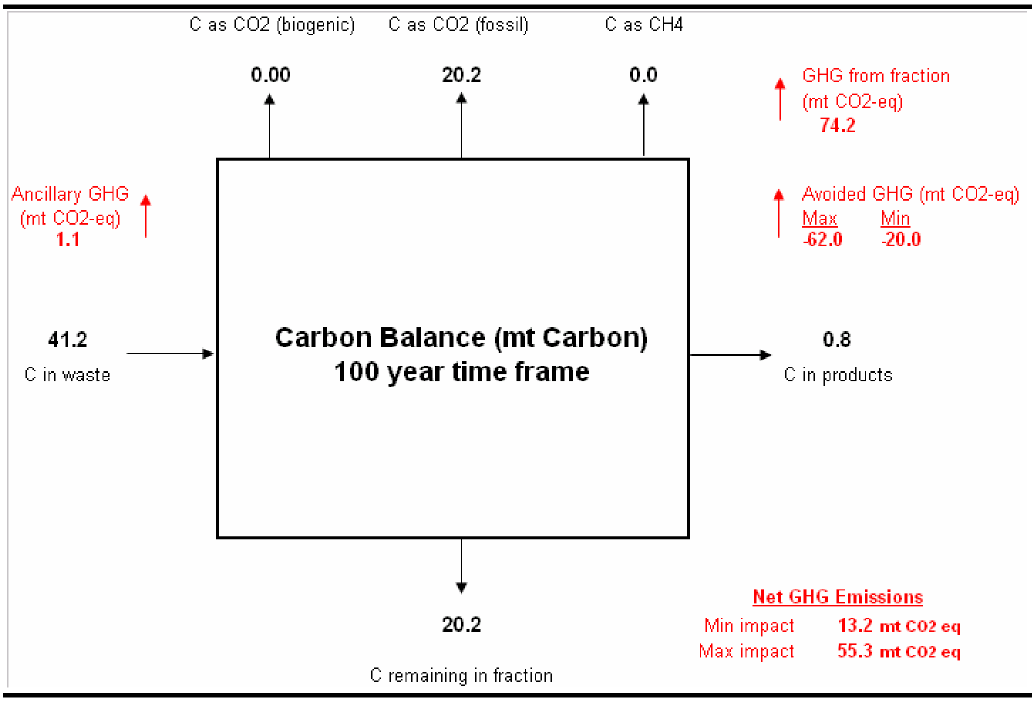
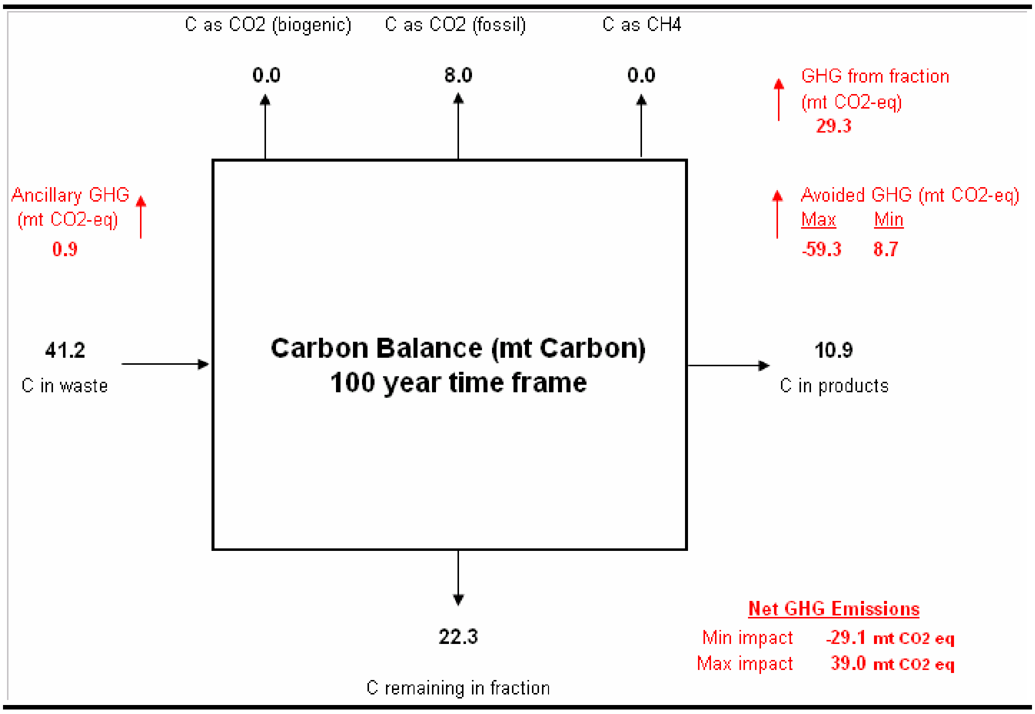


Figure C1.33 Combined Scenario



C1.10 PLASTIC (FILM)

Figure C1.34 Baseline Scenario

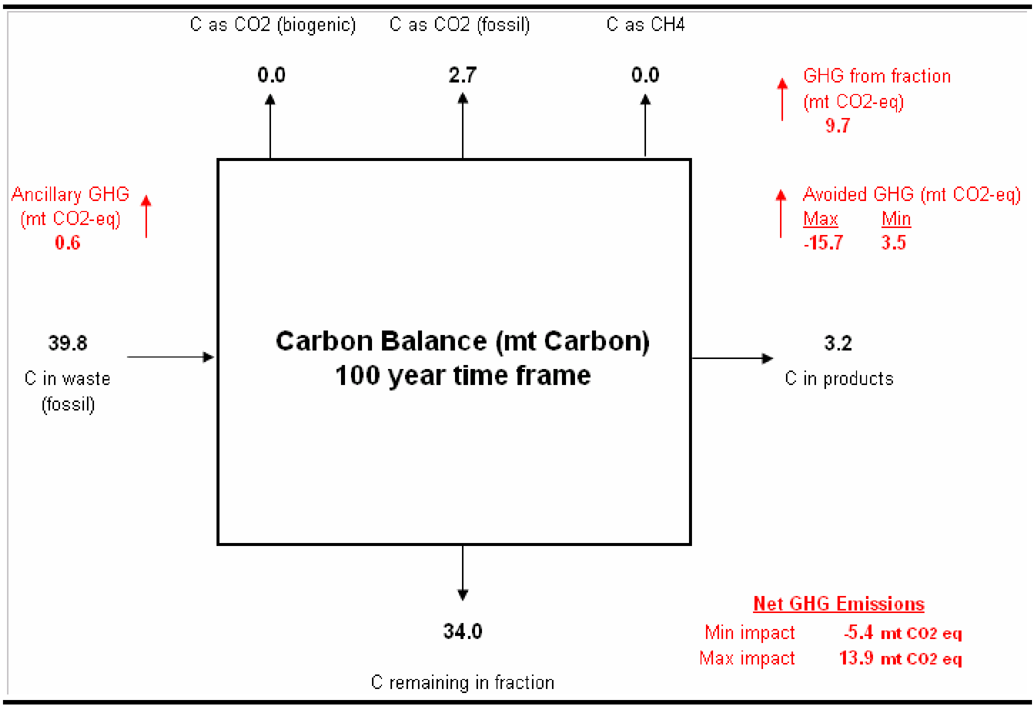


Figure C1.35 High Resource Recovery Scenario

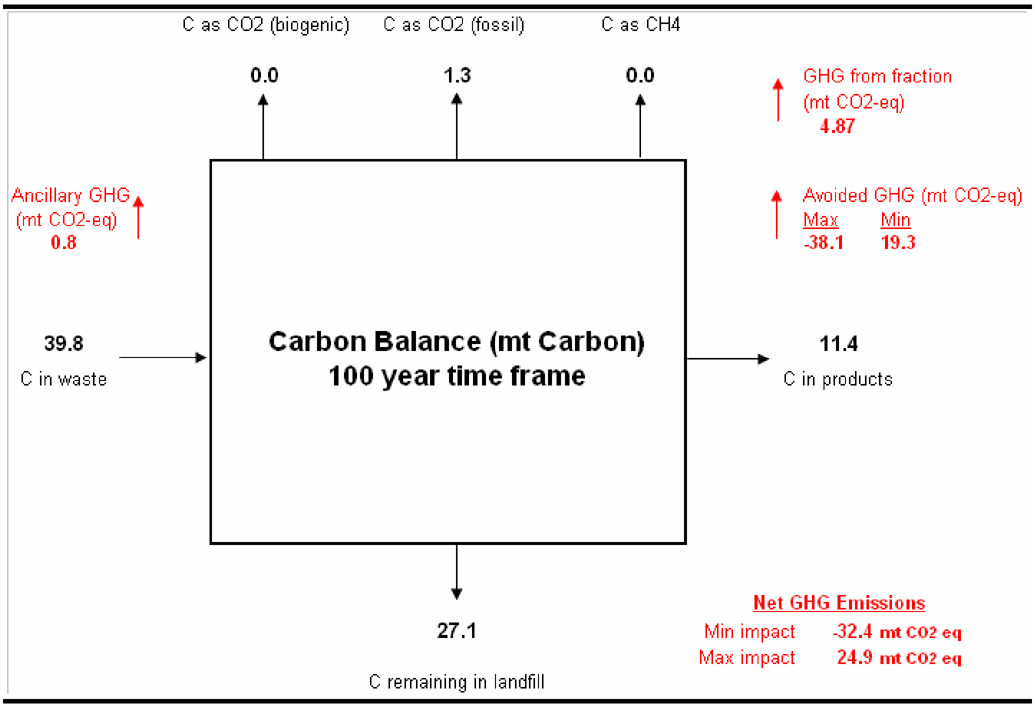


Figure C1.36 High Energy Recovery Scenario

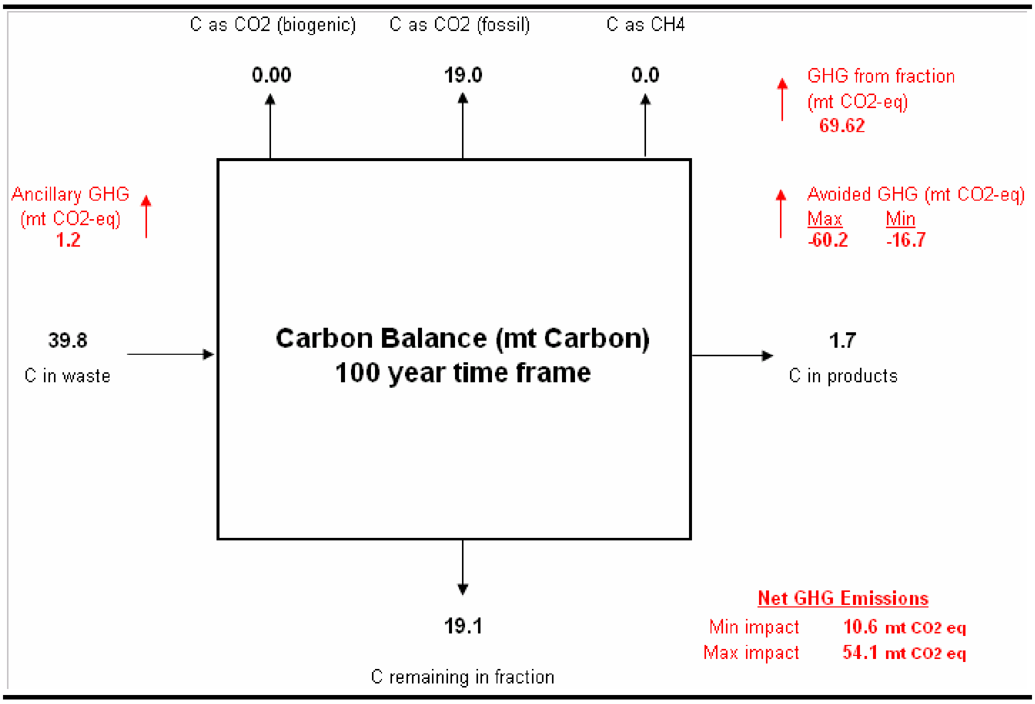
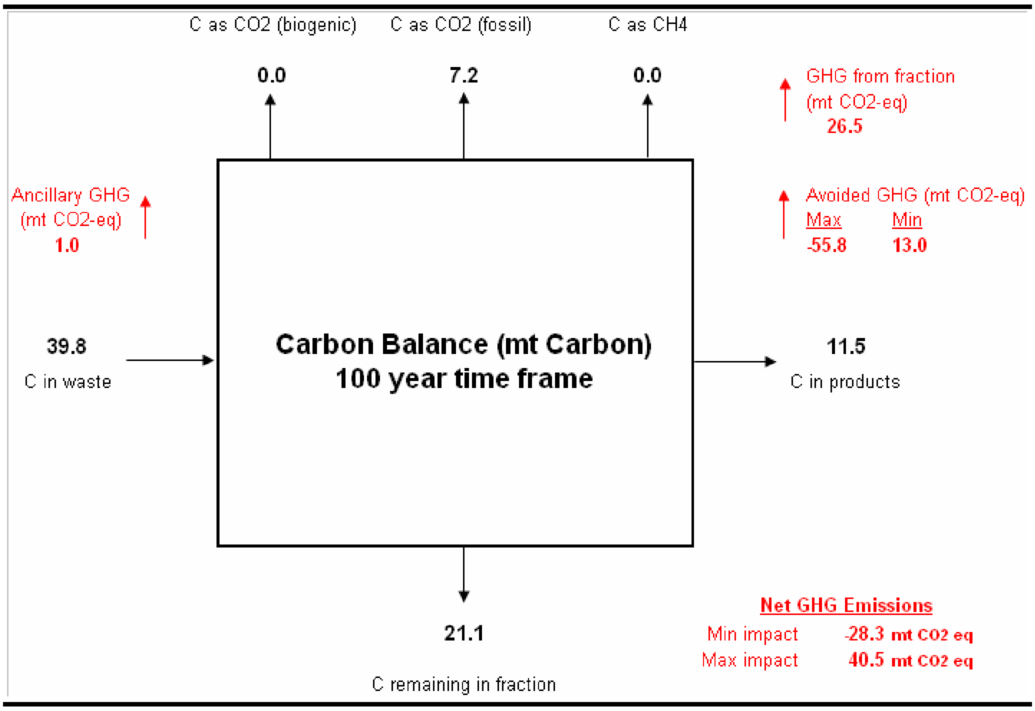


Figure C1.37 Combined Scenario



C1.11 FERROUS METALS

Figure C1.38 Baseline Scenario

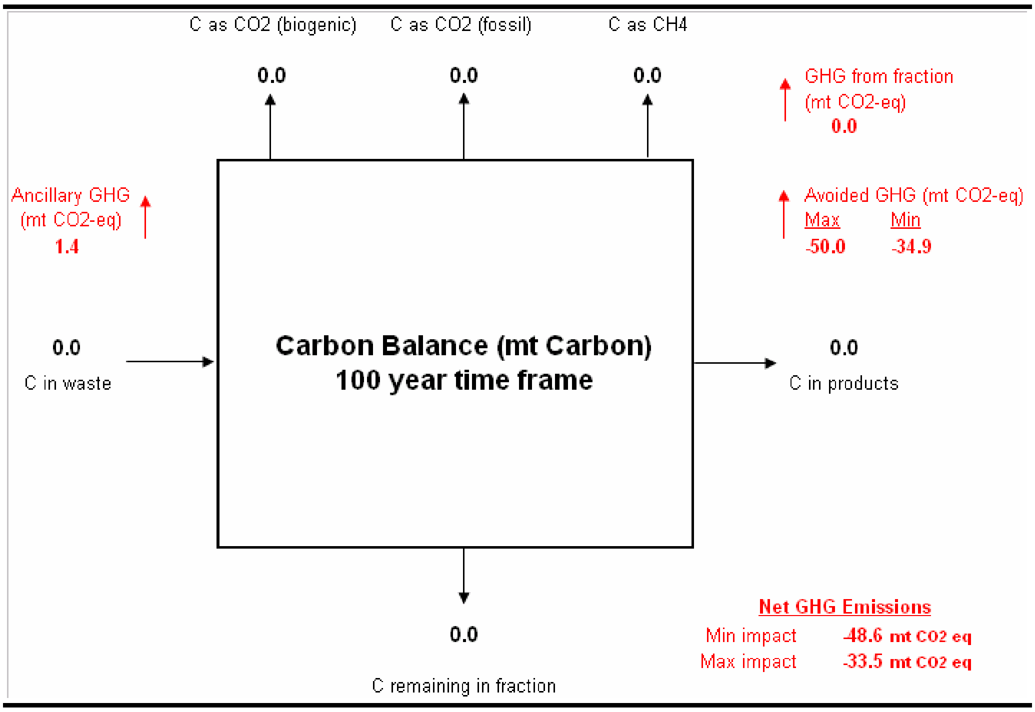
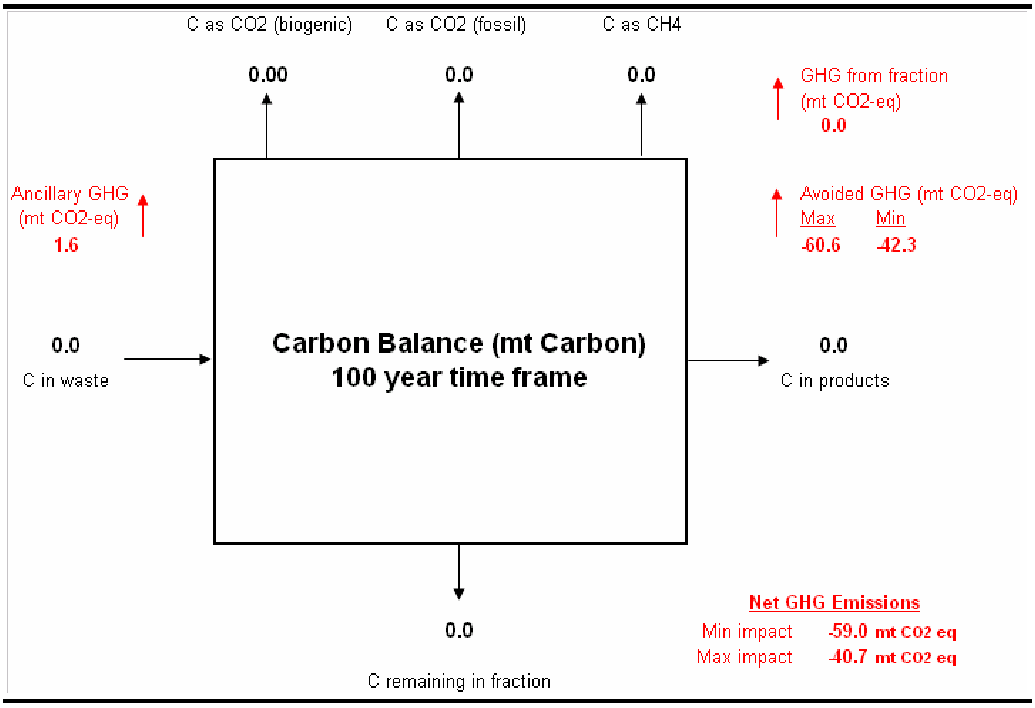


Figure C1.39 High Resource Recovery Scenario



C1.12 *NON-FERROUS METALS*

Figure C1.40 Baseline Scenario

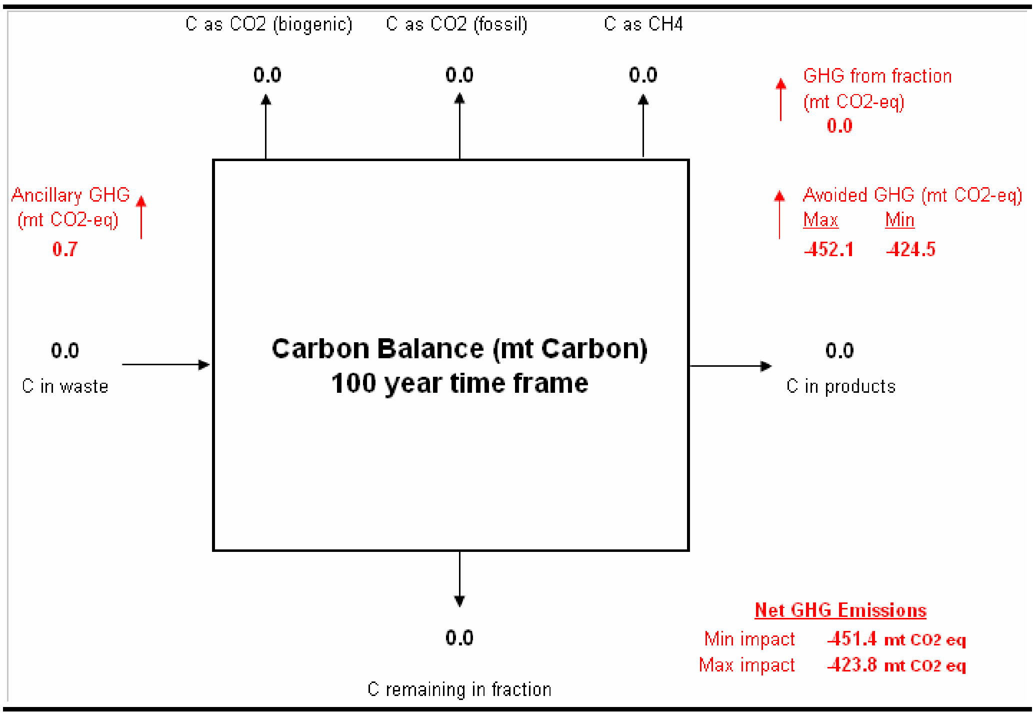
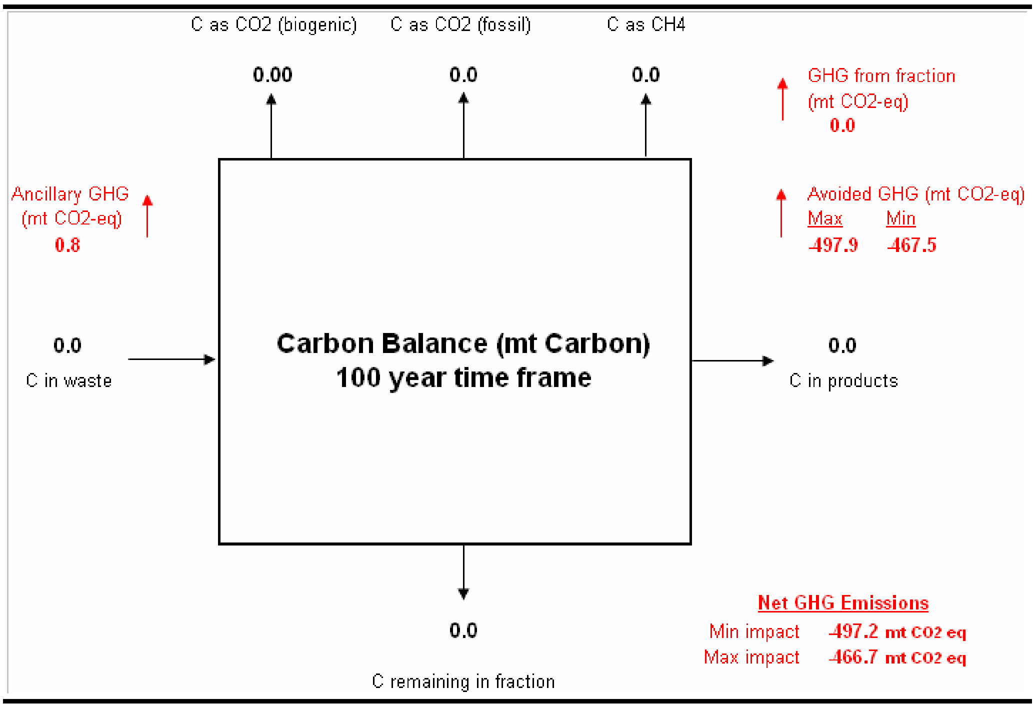


Figure C1.41 High Resource Recovery Scenario



C1.13 SOILS

Figure C1.42 Baseline Scenario

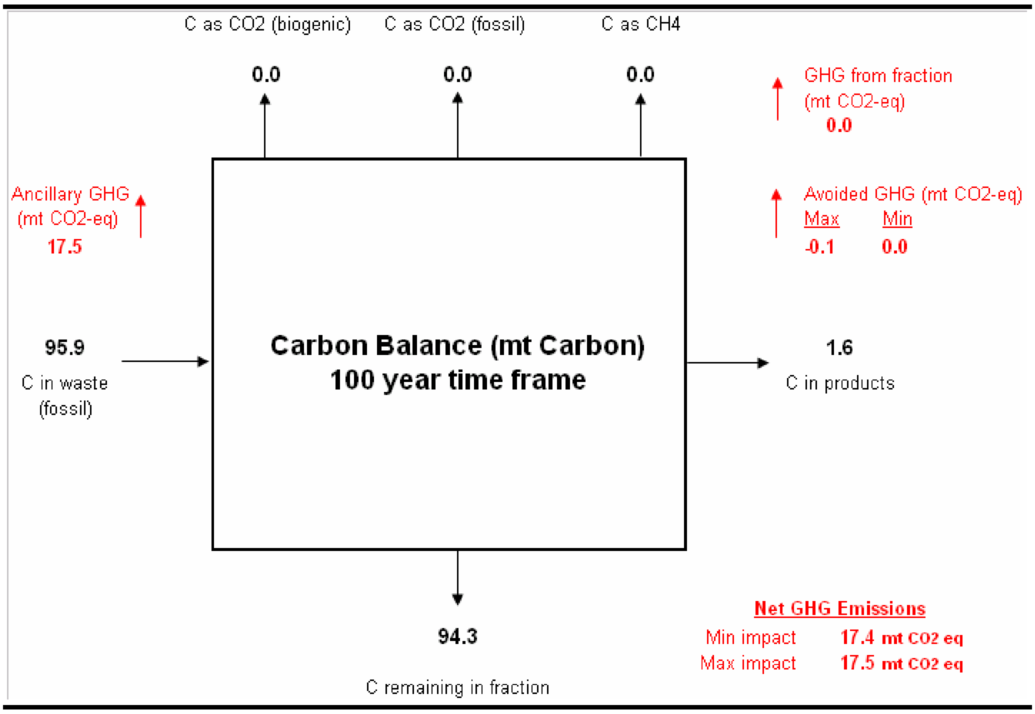
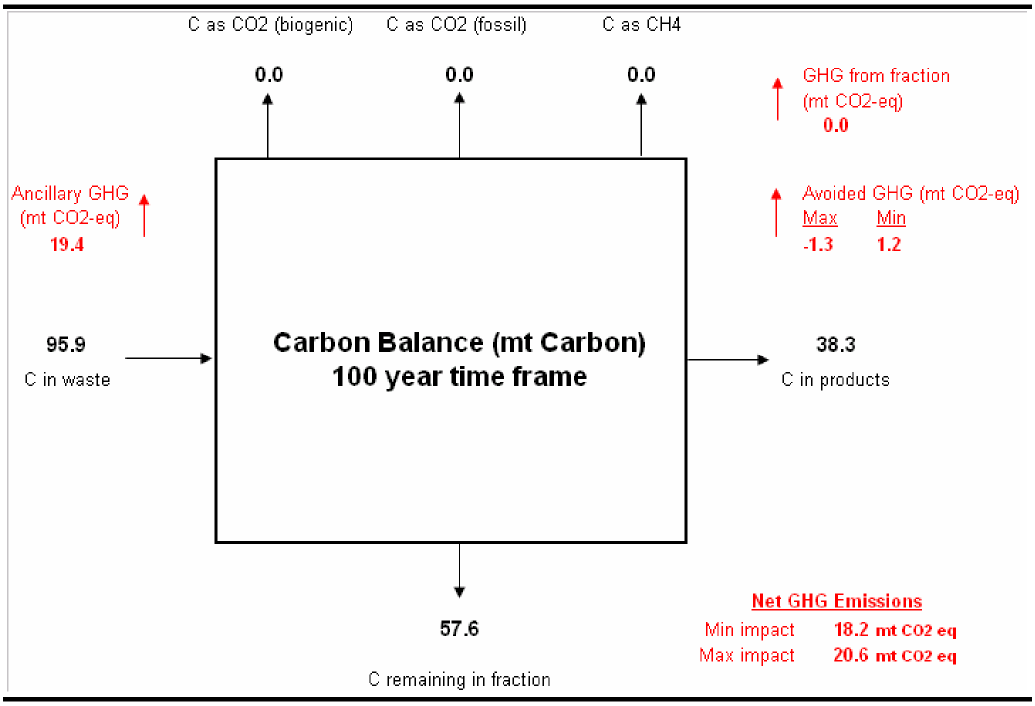
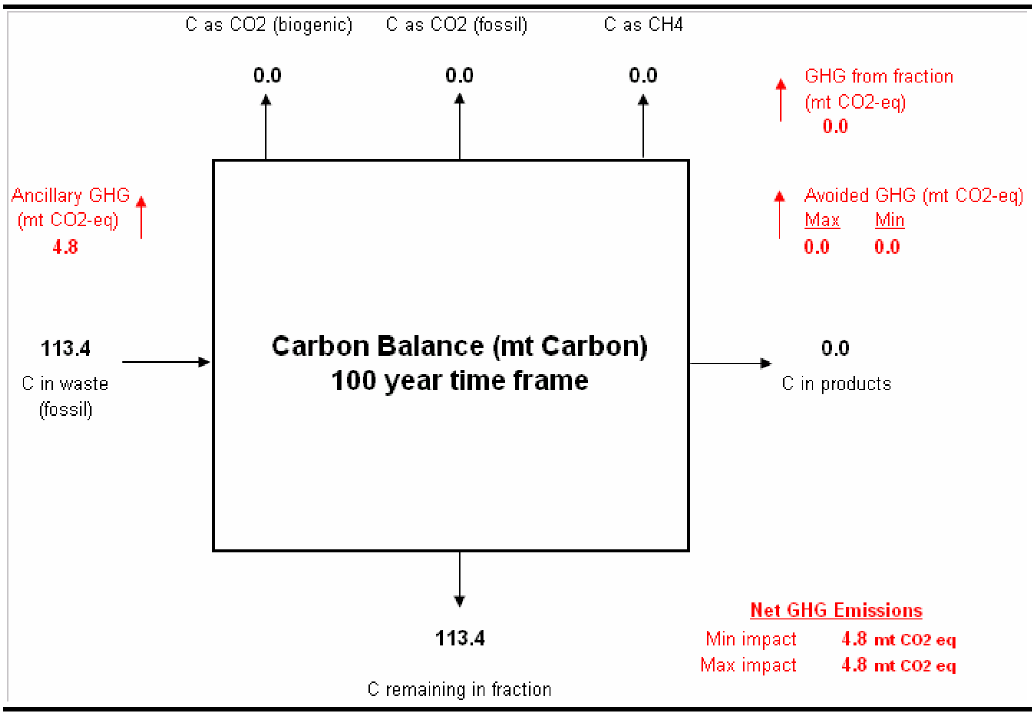


Figure C1.43 High Resource Recovery Scenario



C1.14 SOILS (MINING, QUARRYING, MARINE DERIVED)

Figure C1.44 Baseline Scenario



C1.15 *AGGREGATE/MINERALS*

Figure C1.45 Baseline Scenario

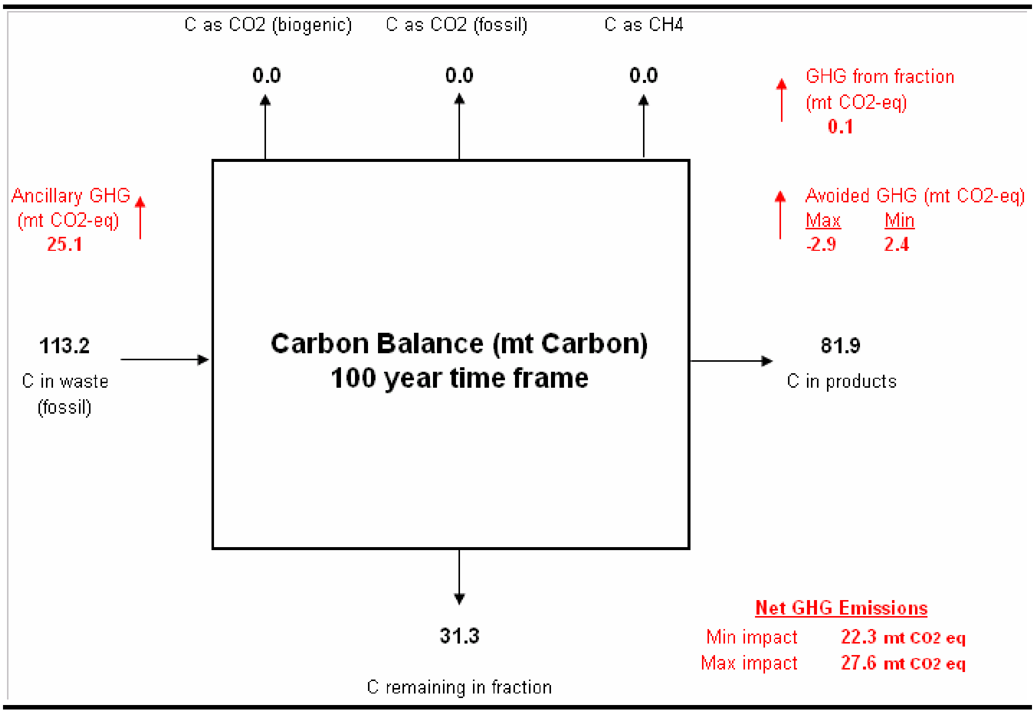
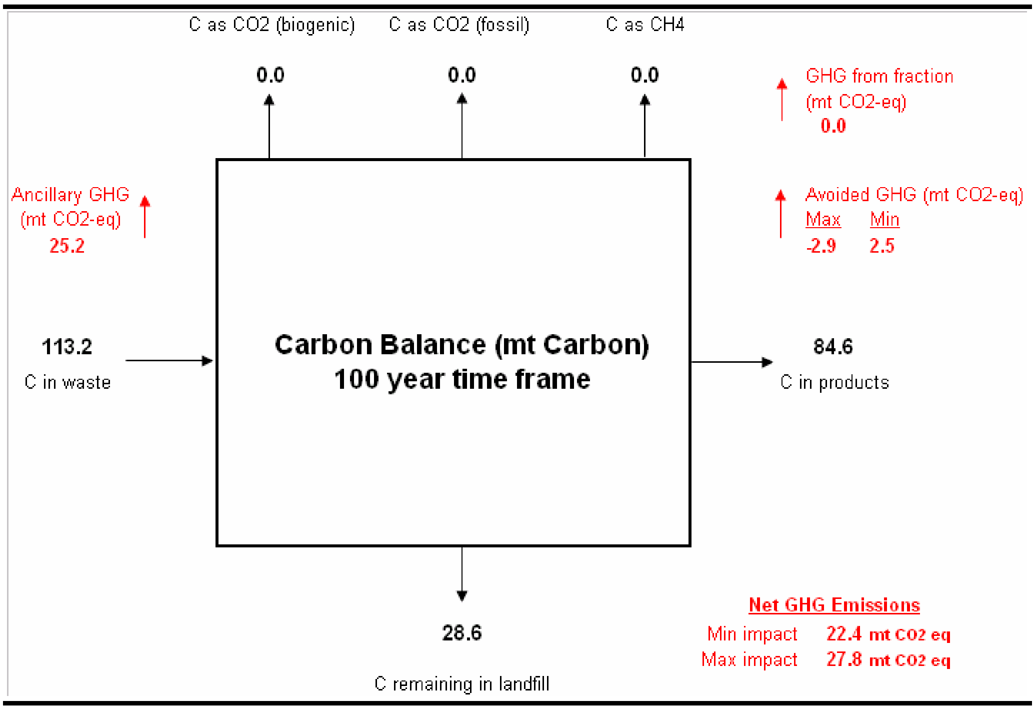
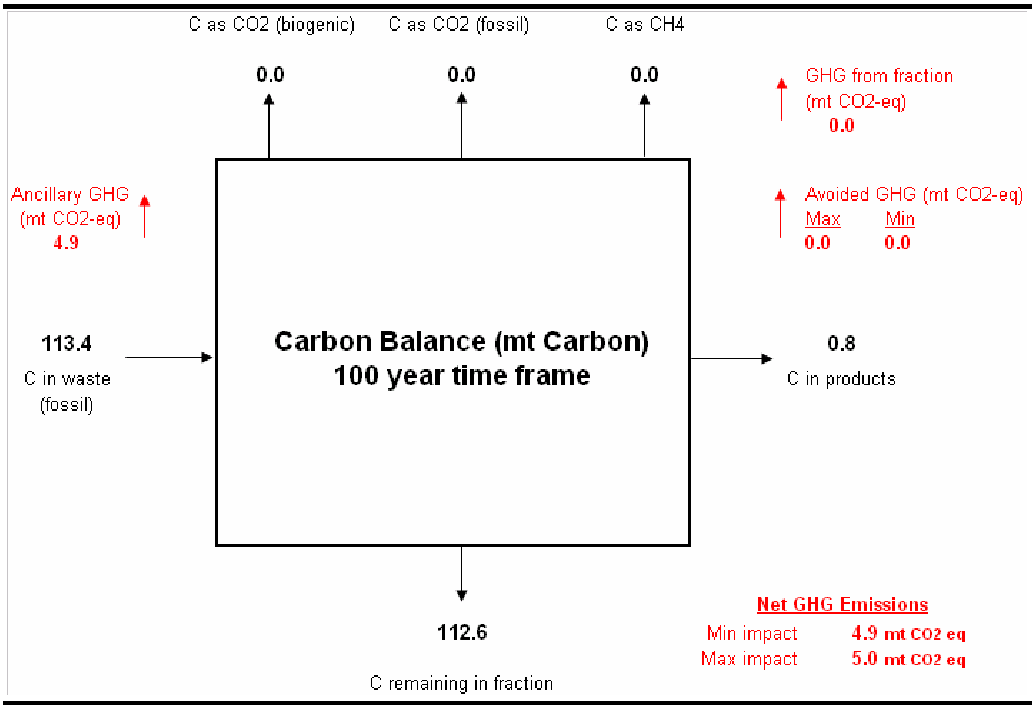


Figure C1.46 High Resource Recovery Scenario



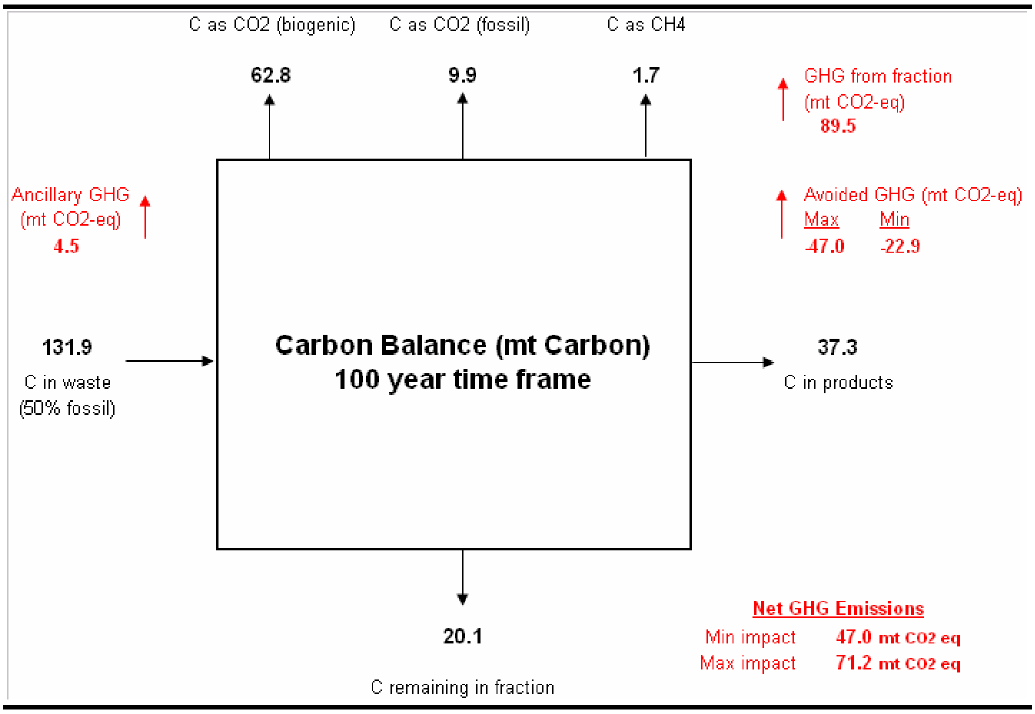
C1.16 *AGGREGATE/MINERALS (MINING, QUARRYING, MARINE DERIVED)*

Figure C1.47 Baseline Scenario



C1.17 *MISCELLANEOUS COMBUSTIBLES*

Figure C1.48 Baseline Scenario



Annex D

Greenhouse Gas Emission and Fossil Energy Demand Estimates

D1 NET GREENHOUSE GAS AND FOSSIL ENERGY DEMAND ESTIMATES OVER TIME

Net greenhouse gas and fossil energy demand estimates quantified over the assessment period for each material and scenario are presented in the following tables. Where appropriate, the net greenhouse gas and energy implications of landfilling waste materials have also been separately detailed.

D1.1 Paper and Card

Table D1.1 Baseline Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	13.7	-3.7	-1.5	-52.3	-19.4	7.4	0.04	0.6
2006	13.7	-3.5	-1.3	-53.7	-20.8	7.4	0.23	-0.9
2007	13.7	-3.3	-1.2	-55.1	-22.2	7.4	0.41	-2.2
2008	13.7	-3.2	-1.0	-56.4	-23.5	7.4	0.57	-3.5
2009	13.7	-3.0	-0.8	-57.6	-24.7	7.4	0.73	-4.8
2010	13.7	-2.9	-0.7	-58.8	-25.9	7.4	0.88	-5.9
2011	13.7	-2.7	-0.5	-59.9	-27.0	7.4	1.02	-7.0
2012	13.7	-2.6	-0.4	-60.9	-28.0	7.4	1.15	-8.1
2013	13.7	-2.5	-0.3	-61.9	-29.0	7.4	1.28	-9.0
2014	13.7	-2.4	-0.2	-62.8	-30.0	7.4	1.40	-10.0
2015	13.7	-2.2	-0.1	-63.7	-30.8	7.4	1.51	-10.9
2016	13.7	-2.1	0.0	-64.6	-31.7	7.4	1.62	-11.7
2017	13.7	-2.0	0.2	-65.4	-32.5	7.4	1.72	-12.5
2018	13.7	-1.9	0.2	-66.1	-33.2	7.4	1.81	-13.3
2019	13.7	-1.8	0.3	-66.8	-33.9	7.4	1.90	-14.0
2020	13.7	-1.8	0.4	-67.5	-34.6	7.4	1.99	-14.6
2021	13.7	-1.7	0.5	-68.1	-35.3	7.4	2.07	-15.3
2022	13.7	-1.6	0.6	-68.7	-35.9	7.4	2.15	-15.9
2023	13.7	-1.5	0.7	-69.3	-36.4	7.4	2.22	-16.5
2024	13.7	-1.5	0.7	-69.9	-37.0	7.4	2.29	-17.0
2025	13.7	-1.4	0.8	-70.4	-37.5	7.4	2.36	-17.5
2026	13.7	-1.3	0.9	-70.9	-38.0	7.4	2.42	-18.0
2027	13.7	-1.3	0.9	-71.3	-38.5	7.4	2.48	-18.5
2028	13.7	-1.2	1.0	-71.8	-38.9	7.4	2.54	-18.9
2029	13.7	-1.2	1.0	-72.2	-39.3	7.4	2.59	-19.4
2030	13.7	-1.1	1.1	-72.6	-39.7	7.4	2.64	-19.8
2031	13.7	-1.1	1.1	-73.0	-40.1	7.4	2.69	-20.1
2035	-	2.3	2.3	-17.9	-17.9	-	2.29	-17.9
2045	-	1.4	1.4	-10.6	-10.6	-	1.35	-10.6
2055	-	0.8	0.8	-6.3	-6.3	-	0.81	-6.3
2065	-	0.5	0.5	-3.8	-3.8	-	0.49	-3.8
2075	-	0.3	0.3	-2.4	-2.4	-	0.30	-2.4
2085	-	0.2	0.2	-1.4	-1.4	-	0.19	-1.4
2095	-	0.1	0.1	-0.9	-0.9	-	0.11	-0.9
2105	-	0.1	0.1	-0.6	-0.6	-	0.07	-0.6

Table D1.2 High Resource Recovery Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	13.7	-3.7	-1.5	-52.3	-19.4	7.4	0.04	0.6
2006	13.7	-3.6	-1.4	-54.7	-21.3	7.3	0.23	-0.9
2007	13.7	-3.5	-1.2	-57.1	-23.0	7.1	0.40	-2.2
2008	13.7	-3.4	-1.1	-59.4	-24.7	7.0	0.56	-3.5
2009	13.7	-3.4	-1.0	-61.6	-26.3	6.9	0.71	-4.7
2010	13.7	-3.3	-0.9	-63.6	-27.7	6.8	0.84	-5.7
2011	13.7	-3.2	-0.8	-65.6	-29.1	6.6	0.97	-6.7
2012	13.7	-3.2	-0.7	-67.5	-30.5	6.5	1.08	-7.7
2013	13.7	-3.2	-0.7	-69.4	-31.7	6.4	1.19	-8.5
2014	13.7	-3.2	-0.6	-71.1	-32.9	6.3	1.29	-9.3
2015	13.7	-3.1	-0.5	-72.8	-34.0	6.1	1.38	-10.0
2016	13.7	-3.1	-0.5	-74.4	-35.0	6.0	1.46	-10.7
2017	13.7	-3.1	-0.5	-75.9	-36.0	5.9	1.53	-11.3
2018	13.7	-3.1	-0.4	-77.4	-36.9	5.8	1.60	-11.8
2019	13.7	-3.2	-0.4	-78.9	-37.8	5.7	1.66	-12.3
2020	13.7	-3.2	-0.4	-80.3	-38.6	5.5	1.72	-12.7
2021	13.7	-3.2	-0.4	-81.6	-39.4	5.4	1.77	-13.1
2022	13.7	-3.2	-0.3	-82.9	-40.1	5.3	1.81	-13.5
2023	13.7	-3.3	-0.3	-84.1	-40.8	5.2	1.85	-13.8
2024	13.7	-3.3	-0.3	-85.3	-41.5	5.1	1.88	-14.1
2025	13.7	-3.3	-0.3	-86.4	-42.1	4.9	1.91	-14.3
2026	13.7	-3.4	-0.3	-87.5	-42.6	4.8	1.94	-14.5
2027	13.7	-3.4	-0.4	-88.6	-43.2	4.7	1.96	-14.7
2028	13.7	-3.5	-0.4	-89.6	-43.7	4.6	1.97	-14.9
2029	13.7	-3.5	-0.4	-90.6	-44.1	4.5	1.99	-15.0
2030	13.7	-3.6	-0.4	-91.6	-44.6	4.4	2.00	-15.1
2031	13.7	-3.7	-0.4	-92.5	-45.0	4.3	2.00	-15.1
2035	-	1.7	1.7	-13.2	-13.2	-	1.69	-13.2
2045	-	1.0	1.0	-7.8	-7.8	-	1.00	-7.8
2055	-	0.6	0.6	-4.7	-4.7	-	0.60	-4.7
2065	-	0.4	0.4	-2.8	-2.8	-	0.36	-2.8
2075	-	0.2	0.2	-1.7	-1.7	-	0.22	-1.7
2085	-	0.1	0.1	-1.1	-1.1	-	0.14	-1.1
2095	-	0.1	0.1	-0.7	-0.7	-	0.09	-0.7
2105	-	0.1	0.1	-0.4	-0.4	-	0.05	-0.4

Table D1.3 High Energy Recovery Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	13.7	-3.7	-1.5	-52.3	-19.4	7.4	0.04	0.6
2006	13.7	-3.5	-1.3	-53.7	-20.8	7.2	0.23	-0.9
2007	13.7	-3.3	-1.2	-55.1	-22.2	7.0	0.40	-2.2
2008	13.7	-3.2	-1.0	-56.4	-23.5	6.8	0.55	-3.4
2009	13.7	-3.0	-0.8	-57.6	-24.7	6.6	0.69	-4.6
2010	13.7	-2.9	-0.7	-58.8	-25.9	6.3	0.82	-5.6
2011	13.7	-2.7	-0.5	-59.9	-27.0	6.1	0.93	-6.5
2012	13.7	-2.6	-0.4	-60.9	-28.0	5.9	1.03	-7.3
2013	13.7	-3.7	-1.5	-52.3	-19.4	5.7	1.12	-8.0
2014	13.7	-3.6	-1.4	-56.1	-21.5	5.5	1.20	-8.7
2015	13.7	-3.6	-1.2	-60.0	-23.6	5.3	1.27	-9.3
2016	13.7	-3.6	-1.1	-63.9	-25.6	5.1	1.33	-9.8
2017	13.7	-3.6	-1.0	-67.9	-27.6	4.9	1.38	-10.2
2018	13.7	-3.6	-0.9	-71.9	-29.5	4.7	1.42	-10.6
2019	13.7	-3.6	-0.8	-76.0	-31.4	4.5	1.46	-10.9
2020	13.7	-3.7	-0.8	-80.1	-33.2	4.3	1.49	-11.1
2021	13.7	-3.8	-0.7	-84.3	-35.0	4.1	1.51	-11.3
2022	13.7	-3.9	-0.7	-88.6	-36.8	3.8	1.52	-11.4
2023	13.7	-4.0	-0.7	-92.9	-38.5	3.6	1.53	-11.5
2024	13.7	-4.1	-0.7	-97.4	-40.2	3.4	1.53	-11.5
2025	13.7	-4.3	-0.7	-101.9	-41.9	3.2	1.52	-11.5
2026	13.7	-4.5	-0.7	-106.5	-43.6	3.0	1.51	-11.4
2027	13.7	-4.7	-0.7	-111.1	-45.3	2.8	1.49	-11.3
2028	13.7	-4.9	-0.8	-115.9	-47.0	2.6	1.47	-11.2
2029	13.7	-5.1	-0.8	-120.8	-48.7	2.4	1.45	-11.0
2030	13.7	-5.3	-0.9	-125.8	-50.3	2.2	1.42	-10.8
2031	13.7	-5.6	-0.9	-130.8	-52.0	2.0	1.39	-10.6
2035	-	-5.9	-1.0	-136.0	-53.7	-	1.14	-8.9
2045	-	-6.2	-1.1	-141.3	-55.4	-	0.68	-5.3
2055	-	-6.5	-1.2	-146.7	-57.1	-	0.41	-3.2
2065	-	-6.8	-1.3	-152.2	-58.8	-	0.25	-1.9
2075	-	-7.1	-1.4	-157.9	-60.5	-	0.15	-1.2
2085	-	-7.5	-1.5	-163.6	-62.3	-	0.09	-0.7
2095	-	-7.8	-1.7	-169.5	-64.0	-	0.06	-0.5
2105	-	-8.2	-1.8	-175.5	-65.8	-	0.04	-0.3

Table D1.4 Combined Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	13.7	-3.7	-1.5	-52.3	-19.4	7.4	0.04	0.6
2006	13.7	-3.6	-1.4	-55.0	-21.3	7.2	0.23	-0.9
2007	13.7	-3.5	-1.2	-57.6	-23.2	7.1	0.40	-2.2
2008	13.7	-3.5	-1.1	-60.1	-24.9	6.9	0.56	-3.5
2009	13.7	-3.4	-1.0	-62.5	-26.6	6.8	0.70	-4.6
2010	13.7	-3.4	-0.9	-64.8	-28.1	6.6	0.84	-5.7
2011	13.7	-3.3	-0.8	-67.0	-29.6	6.5	0.96	-6.7
2012	13.7	-3.3	-0.8	-69.1	-30.9	6.3	1.07	-7.6
2013	13.7	-3.3	-0.7	-71.1	-32.2	6.2	1.18	-8.4
2014	13.7	-3.3	-0.7	-73.1	-33.4	6.0	1.27	-9.2
2015	13.7	-3.3	-0.6	-75.0	-34.6	5.9	1.35	-9.8
2016	13.7	-3.3	-0.6	-76.8	-35.7	5.7	1.43	-10.5
2017	13.7	-3.3	-0.5	-78.5	-36.7	5.6	1.50	-11.0
2018	13.7	-3.4	-0.5	-80.2	-37.6	5.4	1.56	-11.5
2019	13.7	-3.4	-0.5	-81.8	-38.5	5.3	1.61	-12.0
2020	13.7	-3.4	-0.5	-83.4	-39.4	5.1	1.66	-12.4
2021	13.7	-3.5	-0.5	-84.9	-40.2	5.0	1.70	-12.7
2022	13.7	-3.5	-0.5	-86.3	-40.9	4.8	1.74	-13.0
2023	13.7	-3.6	-0.5	-87.7	-41.6	4.7	1.77	-13.3
2024	13.7	-3.6	-0.5	-89.1	-42.3	4.6	1.80	-13.5
2025	13.7	-3.7	-0.5	-90.4	-42.9	4.4	1.82	-13.7
2026	13.7	-3.8	-0.5	-91.7	-43.5	4.3	1.83	-13.8
2027	13.7	-3.8	-0.6	-92.9	-44.1	4.1	1.85	-13.9
2028	13.7	-3.9	-0.6	-94.1	-44.6	4.0	1.85	-14.0
2029	13.7	-4.0	-0.6	-95.3	-45.0	3.9	1.86	-14.0
2030	13.7	-4.1	-0.7	-96.4	-45.5	3.7	1.86	-14.1
2031	13.7	-4.2	-0.7	-97.5	-45.9	3.6	1.85	-14.1
2035	-	1.6	1.6	-12.2	-12.2	-	1.56	-12.2
2045	-	0.9	0.9	-7.2	-7.2	-	0.92	-7.2
2055	-	0.6	0.6	-4.3	-4.3	-	0.55	-4.3
2065	-	0.3	0.3	-2.6	-2.6	-	0.34	-2.6
2075	-	0.2	0.2	-1.6	-1.6	-	0.21	-1.6
2085	-	0.1	0.1	-1.0	-1.0	-	0.13	-1.0
2095	-	0.1	0.1	-0.6	-0.6	-	0.08	-0.6
2105	-	0.0	0.0	-0.4	-0.4	-	0.05	-0.4

D1.2 KITCHEN AND FOOD WASTE

Table D1.5 Baseline Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	11.8	-0.16	0.02	-3.9	-0.1	9.4	0.05	0.7
2006	11.8	0.02	0.21	-5.4	-1.5	9.4	0.24	-0.7
2007	11.8	0.19	0.37	-6.7	-2.8	9.4	0.40	-2.0
2008	11.8	0.33	0.52	-7.8	-4.0	9.4	0.55	-3.1
2009	11.8	0.46	0.65	-8.8	-5.0	9.4	0.68	-4.1
2010	11.8	0.58	0.76	-9.7	-5.9	9.4	0.80	-5.0
2011	11.8	0.68	0.87	-10.5	-6.7	9.4	0.90	-5.8
2012	11.8	0.77	0.96	-11.3	-7.4	9.4	0.99	-6.6
2013	11.8	0.86	1.04	-11.9	-8.1	9.4	1.07	-7.2
2014	11.8	0.93	1.11	-12.5	-8.6	9.4	1.15	-7.8
2015	11.8	0.99	1.18	-13.0	-9.1	9.4	1.21	-8.3
2016	11.8	1.05	1.23	-13.4	-9.6	9.4	1.27	-8.7
2017	11.8	1.10	1.29	-13.8	-10.0	9.4	1.32	-9.1
2018	11.8	1.15	1.33	-14.2	-10.3	9.4	1.37	-9.5
2019	11.8	1.19	1.37	-14.5	-10.6	9.4	1.41	-9.8
2020	11.8	1.23	1.41	-14.8	-10.9	9.4	1.44	-10.1
2021	11.8	1.26	1.44	-15.0	-11.2	9.4	1.48	-10.3
2022	11.8	1.29	1.47	-15.2	-11.4	9.4	1.51	-10.5
2023	11.8	1.31	1.50	-15.4	-11.6	9.4	1.53	-10.7
2024	11.8	1.33	1.52	-15.6	-11.8	9.4	1.55	-10.9
2025	11.8	1.35	1.54	-15.8	-11.9	9.4	1.58	-11.1
2026	11.8	1.37	1.56	-15.9	-12.1	9.4	1.59	-11.2
2027	11.8	1.39	1.57	-16.0	-12.2	9.4	1.61	-11.3
2028	11.8	1.40	1.59	-16.1	-12.3	9.4	1.62	-11.4
2029	11.8	1.42	1.60	-16.2	-12.4	9.4	1.64	-11.5
2030	11.8	1.43	1.61	-16.3	-12.5	9.4	1.65	-11.6
2031	11.8	1.44	1.62	-16.4	-12.6	9.4	1.66	-11.7
2035	-	1.14	1.14	-8.8	-8.8	-	1.14	-8.8
2045	-	0.36	0.36	-2.7	-2.7	-	0.36	-2.7
2055	-	0.11	0.11	-0.8	-0.8	-	0.11	-0.8
2065	-	0.04	0.04	-0.2	-0.2	-	0.04	-0.2
2075	-	0.01	0.01	-0.1	-0.1	-	0.01	-0.1
2085	-	0.003	0.003	-0.01	-0.01	-	0.004	-0.015
2095	-	0.001	0.001	-0.001	-0.001	-	0.002	-0.001
2105	-	0.0003	0.0003	0.002	0.002	-	0.001	0.002

Table D1.6 High Resource Recovery Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	11.8	-0.16	0.02	-3.9	-0.1	9.4	0.05	0.7
2006	11.8	0.04	0.22	-5.3	-1.4	9.2	0.24	-0.7
2007	11.8	0.22	0.39	-6.4	-2.5	9.0	0.40	-2.0
2008	11.8	0.37	0.54	-7.4	-3.4	8.8	0.53	-3.1
2009	11.8	0.51	0.66	-8.3	-4.1	8.5	0.65	-4.0
2010	11.8	0.62	0.77	-9.0	-4.8	8.3	0.75	-4.8
2011	11.8	0.72	0.87	-9.5	-5.3	8.1	0.83	-5.5
2012	11.8	0.81	0.95	-10.0	-5.6	7.9	0.90	-6.0
2013	11.8	0.89	1.02	-10.4	-5.9	7.6	0.95	-6.5
2014	11.8	0.95	1.08	-10.6	-6.1	7.4	1.00	-6.9
2015	11.8	1.00	1.13	-10.8	-6.3	7.2	1.04	-7.2
2016	11.8	1.05	1.17	-10.9	-6.3	7.0	1.06	-7.4
2017	11.8	1.09	1.20	-11.0	-6.3	6.8	1.08	-7.6
2018	11.8	1.12	1.22	-11.0	-6.3	6.5	1.09	-7.7
2019	11.8	1.14	1.24	-11.0	-6.2	6.3	1.10	-7.8
2020	11.8	1.16	1.26	-10.9	-6.0	6.1	1.10	-7.9
2021	11.8	1.18	1.26	-10.8	-5.9	5.9	1.10	-7.9
2022	11.8	1.19	1.27	-10.6	-5.6	5.7	1.09	-7.8
2023	11.8	1.20	1.27	-10.4	-5.4	5.5	1.08	-7.8
2024	11.8	1.20	1.27	-10.2	-5.1	5.3	1.06	-7.7
2025	11.8	1.20	1.26	-9.9	-4.8	5.1	1.05	-7.6
2026	11.8	1.20	1.25	-9.7	-4.5	4.9	1.02	-7.4
2027	11.8	1.19	1.24	-9.4	-4.2	4.7	1.00	-7.3
2028	11.8	1.19	1.23	-9.1	-3.8	4.4	0.98	-7.1
2029	11.8	1.18	1.21	-8.8	-3.5	4.2	0.95	-6.9
2030	11.8	1.17	1.20	-8.4	-3.1	4.0	0.92	-6.7
2031	11.8	1.16	1.18	-8.1	-2.7	3.8	0.89	-6.5
2035	-	0.59	0.59	-4.7	-4.7	-	0.59	-4.7
2045	-	0.19	0.19	-1.5	-1.5	-	0.19	-1.5
2055	-	0.06	0.06	-0.5	-0.5	-	0.06	-0.5
2065	-	0.02	0.02	-0.2	-0.2	-	0.02	-0.2
2075	-	0.01	0.01	-0.1	-0.1	-	0.01	-0.1
2085	-	0.002	0.002	-0.018	-0.018	-	0.0023	-0.0182
2095	-	0.001	0.001	-0.006	-0.006	-	0.0008	-0.0064
2105	-	0.0003	0.0003	-0.002	-0.002	-	0.0003	-0.0024

Table D1.7 High Energy Recovery Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	11.8	-0.16	0.02	-3.9	-0.1	9.4	0.05	0.7
2006	11.8	-0.03	0.19	-6.7	-2.0	9.2	0.25	-0.7
2007	11.8	0.05	0.32	-9.4	-3.9	8.9	0.42	-2.0
2008	11.8	0.12	0.44	-12.0	-5.5	8.5	0.56	-3.1
2009	11.8	0.16	0.52	-14.4	-7.0	8.2	0.68	-4.0
2010	11.8	0.18	0.59	-16.7	-8.3	7.9	0.78	-4.8
2011	11.8	0.18	0.64	-18.8	-9.5	7.6	0.86	-5.4
2012	11.8	0.17	0.68	-20.8	-10.6	7.3	0.92	-6.0
2013	11.8	0.14	0.70	-22.7	-11.6	6.9	0.97	-6.4
2014	11.8	0.10	0.70	-24.5	-12.4	6.6	1.01	-6.7
2015	11.8	0.05	0.70	-26.2	-13.2	6.3	1.04	-7.0
2016	11.8	0.00	0.69	-27.8	-14.0	6.0	1.06	-7.2
2017	11.8	-0.07	0.67	-29.4	-14.6	5.7	1.07	-7.3
2018	11.8	-0.15	0.64	-30.9	-15.2	5.4	1.07	-7.3
2019	11.8	-0.23	0.60	-32.4	-15.8	5.0	1.07	-7.3
2020	11.8	-0.32	0.56	-33.8	-16.3	4.7	1.06	-7.3
2021	11.8	-0.41	0.51	-35.2	-16.7	4.4	1.04	-7.2
2022	11.8	-0.51	0.46	-36.6	-17.1	4.1	1.02	-7.1
2023	11.8	-0.62	0.40	-37.9	-17.5	3.8	0.99	-6.9
2024	11.8	-0.73	0.34	-39.2	-17.9	3.4	0.96	-6.7
2025	11.8	-0.84	0.28	-40.4	-18.2	3.1	0.93	-6.5
2026	11.8	-0.95	0.21	-41.7	-18.5	2.8	0.89	-6.3
2027	11.8	-1.07	0.14	-42.9	-18.8	2.5	0.85	-6.0
2028	11.8	-1.19	0.07	-44.1	-19.1	2.2	0.81	-5.8
2029	11.8	-1.31	-0.01	-45.3	-19.4	1.9	0.77	-5.5
2030	11.8	-1.43	-0.08	-46.4	-19.6	1.5	0.72	-5.2
2031	11.8	-1.60	-0.20	-47.5	-19.8	1.2	0.63	-4.8
2035	-	0.41	0.41	-3.2	-3.2	-	0.41	-3.2
2045	-	0.13	0.13	-1.0	-1.0	-	0.13	-1.0
2055	-	0.04	0.04	-0.3	-0.3	-	0.04	-0.3
2065	-	0.01	0.01	-0.1	-0.1	-	0.01	-0.1
2075	-	0.004	0.004	-0.03	-0.03	-	0.0040	-0.0313
2085	-	0.001	0.001	-0.01	-0.01	-	0.0013	-0.0098
2095	-	0.0004	0.0004	-0.003	-0.003	-	0.0004	-0.0031
2105	-	0.0001	0.0001	-0.001	-0.001	-	0.0001	-0.0010

Table D1.8 Combined Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	11.8	-0.16	0.02	-3.9	-0.1	9.4	0.05	0.7
2006	11.8	0.05	0.23	-5.5	-1.5	9.2	0.25	-0.7
2007	11.8	0.22	0.40	-6.9	-2.7	8.9	0.42	-2.0
2008	11.8	0.36	0.55	-8.2	-3.7	8.6	0.56	-3.1
2009	11.8	0.48	0.67	-9.3	-4.5	8.3	0.68	-4.0
2010	11.8	0.59	0.78	-10.3	-5.2	8.0	0.78	-4.8
2011	11.8	0.67	0.87	-11.1	-5.8	7.7	0.86	-5.4
2012	11.8	0.74	0.94	-11.8	-6.3	7.4	0.93	-6.0
2013	11.8	0.80	1.00	-12.4	-6.6	7.1	0.98	-6.4
2014	11.8	0.84	1.05	-12.9	-6.9	6.8	1.02	-6.7
2015	11.8	0.88	1.09	-13.3	-7.0	6.5	1.05	-7.0
2016	11.8	0.90	1.11	-13.7	-7.1	6.3	1.07	-7.2
2017	11.8	0.91	1.13	-14.0	-7.2	6.0	1.08	-7.3
2018	11.8	0.92	1.14	-14.2	-7.2	5.7	1.08	-7.4
2019	11.8	0.92	1.14	-14.4	-7.1	5.4	1.08	-7.4
2020	11.8	0.92	1.14	-14.5	-7.0	5.1	1.07	-7.3
2021	11.8	0.90	1.13	-14.6	-6.8	4.8	1.05	-7.2
2022	11.8	0.89	1.12	-14.6	-6.6	4.6	1.03	-7.1
2023	11.8	0.87	1.10	-14.6	-6.4	4.3	1.01	-7.0
2024	11.8	0.84	1.08	-14.6	-6.1	4.0	0.98	-6.8
2025	11.8	0.81	1.06	-14.6	-5.9	3.7	0.95	-6.6
2026	11.8	0.78	1.03	-14.5	-5.6	3.4	0.92	-6.4
2027	11.8	0.75	1.00	-14.4	-5.2	3.2	0.88	-6.2
2028	11.8	0.72	0.97	-14.3	-4.9	2.9	0.84	-5.9
2029	11.8	0.68	0.93	-14.2	-4.6	2.6	0.80	-5.6
2030	11.8	0.64	0.90	-14.0	-4.2	2.3	0.76	-5.3
2031	11.8	0.56	0.82	-13.8	-3.8	2.1	0.67	-5.0
2035	-	0.44	0.44	-3.4	-3.4	-	0.44	-3.4
2045	-	0.14	0.14	-1.1	-1.1	-	0.14	-1.1
2055	-	0.05	0.05	-0.4	-0.4	-	0.05	-0.4
2065	-	0.02	0.02	-0.1	-0.1	-	0.02	-0.1
2075	-	0.01	0.01	-0.04	-0.04	-	0.005	-0.041
2085	-	0.002	0.002	-0.01	-0.01	-	0.002	-0.014
2095	-	0.001	0.001	-0.01	-0.01	-	0.001	-0.005
2105	-	0.0003	0.0003	-0.002	-0.002	-	0.0003	-0.002

D1.3 GREEN WASTE

Table D1.9 Baseline Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	10.6	-0.07	0.06	-2.3	0.5	8.4	0.04	0.7
2006	10.6	0.02	0.14	-2.9	-0.1	8.4	0.13	0.0
2007	10.6	0.09	0.22	-3.5	-0.7	8.4	0.20	-0.5
2008	10.6	0.15	0.28	-4.0	-1.2	8.4	0.27	-1.0
2009	10.6	0.21	0.34	-4.5	-1.6	8.4	0.32	-1.5
2010	10.6	0.26	0.39	-4.9	-2.0	8.4	0.37	-1.9
2011	10.6	0.31	0.43	-5.2	-2.4	8.4	0.42	-2.3
2012	10.6	0.35	0.48	-5.5	-2.7	8.4	0.46	-2.6
2013	10.6	0.39	0.51	-5.8	-3.0	8.4	0.50	-2.9
2014	10.6	0.42	0.54	-6.1	-3.3	8.4	0.53	-3.1
2015	10.6	0.45	0.57	-6.3	-3.5	8.4	0.56	-3.3
2016	10.6	0.47	0.60	-6.5	-3.7	8.4	0.58	-3.5
2017	10.6	0.50	0.62	-6.7	-3.9	8.4	0.61	-3.7
2018	10.6	0.52	0.64	-6.8	-4.0	8.4	0.63	-3.9
2019	10.6	0.54	0.66	-7.0	-4.2	8.4	0.65	-4.0
2020	10.6	0.55	0.68	-7.1	-4.3	8.4	0.66	-4.1
2021	10.6	0.57	0.69	-7.2	-4.4	8.4	0.68	-4.3
2022	10.6	0.58	0.70	-7.3	-4.5	8.4	0.69	-4.4
2023	10.6	0.59	0.72	-7.4	-4.6	8.4	0.70	-4.5
2024	10.6	0.60	0.73	-7.5	-4.7	8.4	0.71	-4.5
2025	10.6	0.61	0.74	-7.6	-4.8	8.4	0.72	-4.6
2026	10.6	0.62	0.74	-7.6	-4.8	8.4	0.73	-4.7
2027	10.6	0.63	0.75	-7.7	-4.9	8.4	0.74	-4.7
2028	10.6	0.63	0.76	-7.7	-4.9	8.4	0.74	-4.8
2029	10.6	0.64	0.76	-7.8	-5.0	8.4	0.75	-4.8
2030	10.6	0.64	0.77	-7.8	-5.0	8.4	0.75	-4.9
2031	10.6	0.65	0.77	-7.9	-5.1	8.4	0.76	-4.9
2035	-	0.50	0.50	-3.9	-3.9	-	0.50	-3.9
2045	-	0.16	0.16	-1.3	-1.3	-	0.16	-1.3
2055	-	0.05	0.05	-0.4	-0.4	-	0.05	-0.4
2065	-	0.02	0.02	-0.1	-0.1	-	0.02	-0.1
2075	-	0.01	0.01	-0.05	-0.05	-	0.006	-0.048
2085	-	0.002	0.002	-0.02	-0.02	-	0.002	-0.017
2095	-	0.001	0.001	-0.01	-0.01	-	0.001	-0.006
2105	-	0.0003	0.0003	-0.002	-0.002	-	0.0003	-0.002

Table D1.10 High Resource Recovery Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	10.6	-0.07	0.06	-2.3	0.5	8.4	0.04	0.7
2006	10.6	0.03	0.15	-2.9	0.0	8.2	0.13	0.0
2007	10.6	0.12	0.23	-3.4	-0.4	8.0	0.20	-0.6
2008	10.6	0.19	0.30	-3.8	-0.7	7.7	0.25	-1.0
2009	10.6	0.26	0.37	-4.1	-1.0	7.5	0.30	-1.5
2010	10.6	0.31	0.42	-4.4	-1.2	7.3	0.35	-1.8
2011	10.6	0.36	0.46	-4.6	-1.3	7.1	0.38	-2.1
2012	10.6	0.41	0.50	-4.8	-1.4	6.9	0.41	-2.4
2013	10.6	0.45	0.54	-4.9	-1.5	6.6	0.43	-2.6
2014	10.6	0.48	0.57	-5.0	-1.5	6.4	0.45	-2.7
2015	10.6	0.51	0.59	-5.0	-1.5	6.2	0.47	-2.9
2016	10.6	0.53	0.62	-5.0	-1.4	6.0	0.48	-3.0
2017	10.6	0.56	0.63	-5.0	-1.3	5.8	0.48	-3.1
2018	10.6	0.58	0.65	-5.0	-1.2	5.6	0.49	-3.1
2019	10.6	0.59	0.66	-4.9	-1.1	5.4	0.49	-3.1
2020	10.6	0.61	0.67	-4.8	-1.0	5.2	0.49	-3.2
2021	10.6	0.62	0.68	-4.7	-0.8	5.0	0.48	-3.2
2022	10.6	0.63	0.68	-4.6	-0.6	4.8	0.48	-3.1
2023	10.6	0.64	0.69	-4.5	-0.5	4.6	0.47	-3.1
2024	10.6	0.64	0.69	-4.3	-0.3	4.4	0.46	-3.1
2025	10.6	0.65	0.69	-4.2	0.0	4.2	0.45	-3.0
2026	10.6	0.65	0.69	-4.0	0.2	4.0	0.44	-2.9
2027	10.6	0.66	0.69	-3.8	0.4	3.8	0.43	-2.9
2028	10.6	0.66	0.69	-3.6	0.6	3.6	0.41	-2.8
2029	10.6	0.66	0.69	-3.4	0.9	3.4	0.40	-2.7
2030	10.6	0.66	0.69	-3.2	1.1	3.2	0.38	-2.6
2031	10.6	0.66	0.68	-3.0	1.4	3.0	0.37	-2.5
2035	-	0.25	0.25	-1.9	-1.9	-	0.25	-1.9
2045	-	0.09	0.09	-0.7	-0.7	-	0.09	-0.7
2055	-	0.03	0.03	-0.3	-0.3	-	0.03	-0.3
2065	-	0.01	0.01	-0.1	-0.1	-	0.01	-0.1
2075	-	0.01	0.01	-0.04	-0.04	-	0.005	-0.039
2085	-	0.002	0.002	-0.02	-0.02	-	0.002	-0.016
2095	-	0.001	0.001	-0.01	-0.01	-	0.001	-0.007
2105	-	0.0004	0.0004	-0.003	-0.003	-	0.0004	-0.003

Table D1.11 High Energy Recovery Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	10.6	-0.07	0.06	-2.3	0.5	8.4	0.04	0.7
2006	10.6	-0.08	0.11	-4.8	-0.9	8.1	0.13	0.0
2007	10.6	-0.10	0.14	-7.1	-2.1	7.8	0.20	-0.6
2008	10.6	-0.14	0.16	-9.4	-3.3	7.6	0.27	-1.1
2009	10.6	-0.19	0.17	-11.7	-4.5	7.3	0.32	-1.5
2010	10.6	-0.25	0.17	-13.8	-5.6	7.0	0.36	-1.8
2011	10.6	-0.31	0.16	-15.9	-6.6	6.7	0.40	-2.1
2012	10.6	-0.38	0.15	-18.0	-7.5	6.4	0.42	-2.4
2013	10.6	-0.46	0.13	-20.0	-8.4	6.1	0.45	-2.6
2014	10.6	-0.54	0.10	-21.9	-9.3	5.9	0.46	-2.7
2015	10.6	-0.63	0.07	-23.9	-10.1	5.6	0.47	-2.9
2016	10.6	-0.72	0.04	-25.8	-10.9	5.3	0.48	-3.0
2017	10.6	-0.82	0.00	-27.6	-11.7	5.0	0.49	-3.0
2018	10.6	-0.92	-0.04	-29.5	-12.5	4.7	0.49	-3.1
2019	10.6	-1.02	-0.08	-31.3	-13.2	4.5	0.48	-3.1
2020	10.6	-1.12	-0.13	-33.1	-13.9	4.2	0.48	-3.1
2021	10.6	-1.23	-0.18	-34.9	-14.6	3.9	0.47	-3.0
2022	10.6	-1.34	-0.23	-36.6	-15.2	3.6	0.46	-3.0
2023	10.6	-1.45	-0.28	-38.4	-15.9	3.3	0.45	-2.9
2024	10.6	-1.56	-0.34	-40.1	-16.5	3.0	0.43	-2.9
2025	10.6	-1.68	-0.40	-41.8	-17.2	2.8	0.42	-2.8
2026	10.6	-1.79	-0.46	-43.5	-17.8	2.5	0.40	-2.7
2027	10.6	-1.91	-0.51	-45.2	-18.4	2.2	0.38	-2.6
2028	10.6	-2.03	-0.58	-46.9	-19.0	1.9	0.37	-2.5
2029	10.6	-2.15	-0.64	-48.6	-19.6	1.6	0.35	-2.4
2030	10.6	-2.27	-0.70	-50.3	-20.2	1.3	0.32	-2.3
2031	10.6	-2.41	-0.78	-52.0	-20.8	1.1	0.29	-2.1
2035	-	0.18	0.18	-1.4	-1.4	-	0.18	-1.4
2045	-	0.06	0.06	-0.5	-0.5	-	0.06	-0.5
2055	-	0.02	0.02	-0.1	-0.1	-	0.02	-0.1
2065	-	0.01	0.01	-0.05	-0.05	-	0.006	-0.049
2075	-	0.002	0.002	-0.02	-0.02	-	0.002	-0.016
2085	-	0.001	0.001	-0.01	-0.01	-	0.001	-0.005
2095	-	0.0002	0.0002	-0.002	-0.002	-	0.0002	-0.002
2105	-	0.0001	0.0001	-0.001	-0.001	-	0.0001	-0.001

D1.4 AGRICULTURAL CROP WASTE

Table D1.12 Baseline Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	6.6	-0.15	-0.03	-10.3	-0.5	0.01	0.00005	0.00079
2006	6.6	-0.15	-0.03	-10.3	-0.5	0.01	0.00006	0.00073
2007	6.6	-0.15	-0.03	-10.3	-0.5	0.01	0.00007	0.00066
2008	6.6	-0.15	-0.03	-10.3	-0.5	0.01	0.00008	0.00061
2009	6.6	-0.15	-0.03	-10.3	-0.5	0.01	0.00008	0.00056
2010	6.6	-0.15	-0.02	-10.3	-0.5	0.01	0.00009	0.00051
2011	6.6	-0.15	-0.02	-10.3	-0.5	0.01	0.00009	0.00048
2012	6.6	-0.15	-0.02	-10.3	-0.5	0.01	0.00010	0.00044
2013	6.6	-0.15	-0.02	-10.3	-0.5	0.01	0.00010	0.00041
2014	6.6	-0.15	-0.02	-10.3	-0.5	0.01	0.00011	0.00038
2015	6.6	-0.15	-0.02	-10.3	-0.5	0.01	0.00011	0.00036
2016	6.6	-0.15	-0.02	-10.3	-0.5	0.01	0.00011	0.00034
2017	6.6	-0.15	-0.02	-10.3	-0.5	0.01	0.00011	0.00032
2018	6.6	-0.15	-0.02	-10.3	-0.5	0.01	0.00012	0.00030
2019	6.6	-0.15	-0.02	-10.3	-0.5	0.01	0.00012	0.00028
2020	6.6	-0.15	-0.02	-10.3	-0.5	0.01	0.00012	0.00027
2021	6.6	-0.15	-0.02	-10.3	-0.5	0.01	0.00012	0.00026
2022	6.6	-0.15	-0.02	-10.3	-0.5	0.01	0.00012	0.00025
2023	6.6	-0.15	-0.02	-10.3	-0.5	0.01	0.00012	0.00024
2024	6.6	-0.15	-0.02	-10.3	-0.5	0.01	0.00013	0.00023
2025	6.6	-0.15	-0.02	-10.3	-0.5	0.01	0.00013	0.00022
2026	6.6	-0.15	-0.02	-10.3	-0.5	0.01	0.00013	0.00021
2027	6.6	-0.15	-0.02	-10.3	-0.5	0.01	0.00013	0.00021
2028	6.6	-0.15	-0.02	-10.3	-0.5	0.01	0.00013	0.00020
2029	6.6	-0.15	-0.02	-10.3	-0.5	0.01	0.00013	0.00020
2030	6.6	-0.15	-0.02	-10.3	-0.5	0.01	0.00013	0.00019
2031	6.6	-0.15	-0.02	-10.3	-0.5	0.01	0.00013	0.00019
2035	-	0.0001	0.0001	-0.0004	-0.0004	-	0.00005	-0.00043
2045	-	0.00002	0.00002	-0.0001	-0.0001	-	0.00002	-0.00013
2055	-	0.00001	0.00001	-0.00004	-0.00004	-	0.00001	-0.00004
2065	-	0.000002	0.000002	-0.00001	-0.00001	-	0.000002	-0.000013
2075	-	0.000001	0.000001	-0.000004	-0.000004	-	0.000001	-0.000004
2085	-	0.0000002	0.0000002	-0.000001	-0.000001	-	0.0000002	-0.0000013
2095	-	0.0000001	0.0000001	-0.0000004	-0.0000004	-	0.0000001	-0.0000004
2105	-	0.00000002	0.00000002	-0.0000001	-0.0000001	-	0.00000002	-0.0000001

Table D1.13 High Resource Recovery Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	6.6	-0.15	-0.03	-10.3	-0.5	0.01	0.00005	0.0008
2006	6.6	-0.14	-0.02	-10.1	-0.4	0.02	0.00010	0.0012
2007	6.6	-0.13	-0.02	-9.9	-0.4	0.02	0.00018	0.0014
2008	6.6	-0.12	-0.01	-9.7	-0.3	0.03	0.00029	0.0013
2009	6.6	-0.12	-0.01	-9.5	-0.3	0.04	0.00044	0.0011
2010	6.6	-0.11	-0.01	-9.3	-0.2	0.05	0.00064	0.0005
2011	6.6	-0.10	0.00	-9.1	-0.2	0.05	0.00086	-0.0002
2012	6.6	-0.09	0.00	-8.9	-0.1	0.06	0.0011	-0.0012
2013	6.6	-0.09	0.01	-8.7	-0.1	0.07	0.0014	-0.0024
2014	6.6	-0.08	0.01	-8.5	0.0	0.08	0.0018	-0.0039
2015	6.6	-0.07	0.02	-8.3	0.0	0.09	0.0021	-0.0056
2016	6.6	-0.06	0.02	-8.1	0.1	0.10	0.0026	-0.0075
2017	6.6	-0.05	0.02	-7.9	0.1	0.12	0.0030	-0.0097
2018	6.6	-0.04	0.03	-7.7	0.2	0.13	0.0035	-0.0121
2019	6.6	-0.04	0.03	-7.5	0.2	0.14	0.0040	-0.0148
2020	6.6	-0.03	0.04	-7.3	0.3	0.15	0.0046	-0.0177
2021	6.6	-0.02	0.04	-7.1	0.3	0.17	0.0052	-0.0209
2022	6.6	-0.01	0.05	-6.9	0.4	0.18	0.0058	-0.0243
2023	6.6	-0.003	0.05	-6.7	0.4	0.20	0.0065	-0.0279
2024	6.6	0.005	0.06	-6.5	0.5	0.21	0.0072	-0.0318
2025	6.6	0.01	0.06	-6.3	0.5	0.23	0.0080	-0.0359
2026	6.6	0.02	0.07	-6.0	0.6	0.24	0.0088	-0.0403
2027	6.6	0.03	0.07	-5.8	0.6	0.26	0.0096	-0.0449
2028	6.6	0.04	0.08	-5.6	0.7	0.27	0.0105	-0.0497
2029	6.6	0.05	0.08	-5.4	0.7	0.29	0.0114	-0.0548
2030	6.6	0.06	0.08	-5.2	0.8	0.31	0.0124	-0.0602
2031	6.6	0.06	0.09	-5.0	0.8	0.33	0.0134	-0.0650
2035	-	0.01	0.01	-0.1	-0.1	-	0.0100	-0.0781
2045	-	0.005	0.005	-0.04	-0.04	-	0.0047	-0.0365
2055	-	0.002	0.002	-0.02	-0.02	-	0.0022	-0.0171
2065	-	0.001	0.001	-0.01	-0.01	-	0.0010	-0.0080
2075	-	0.0005	0.0005	-0.004	-0.004	-	0.0005	-0.0037
2085	-	0.0002	0.0002	-0.002	-0.002	-	0.0002	-0.0017
2095	-	0.0001	0.0001	-0.001	-0.001	-	0.0001	-0.0008
2105	-	0.00005	0.00005	-0.0004	-0.0004	-	0.00005	-0.0004

Table D1.14 High Energy Recovery Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	6.6	-0.15	-0.03	-10.3	-0.5	0.01	0.00005	0.0008
2006	6.6	-0.22	-0.05	-11.5	-1.0	0.02	0.00010	0.0012
2007	6.6	-0.31	-0.08	-12.8	-1.4	0.02	0.00014	0.0016
2008	6.6	-0.39	-0.11	-14.1	-1.9	0.03	0.00019	0.0019
2009	6.6	-0.48	-0.14	-15.5	-2.4	0.03	0.00024	0.0022
2010	6.6	-0.57	-0.17	-16.9	-3.0	0.04	0.00030	0.0025
2011	6.6	-0.66	-0.20	-18.4	-3.5	0.05	0.00035	0.0028
2012	6.6	-0.76	-0.23	-19.9	-4.1	0.05	0.00041	0.0030
2013	6.6	-0.86	-0.27	-21.4	-4.7	0.06	0.00048	0.0033
2014	6.6	-0.96	-0.30	-23.1	-5.3	0.06	0.00054	0.0035
2015	6.6	-1.07	-0.34	-24.7	-5.9	0.07	0.00061	0.0037
2016	6.6	-1.17	-0.37	-26.4	-6.5	0.08	0.00067	0.0039
2017	6.6	-1.29	-0.41	-28.2	-7.2	0.08	0.00074	0.0040
2018	6.6	-1.40	-0.45	-30.0	-7.8	0.09	0.00081	0.0042
2019	6.6	-1.52	-0.49	-31.9	-8.5	0.09	0.00088	0.0044
2020	6.6	-1.64	-0.53	-33.8	-9.2	0.10	0.00096	0.0045
2021	6.6	-1.76	-0.57	-35.8	-9.9	0.11	0.00103	0.0047
2022	6.6	-1.88	-0.62	-37.8	-10.7	0.11	0.00110	0.0048
2023	6.6	-2.01	-0.66	-39.9	-11.4	0.12	0.00118	0.0050
2024	6.6	-2.15	-0.70	-42.0	-12.2	0.12	0.00125	0.0051
2025	6.6	-2.28	-0.75	-44.2	-13.0	0.13	0.00133	0.0052
2026	6.6	-2.42	-0.80	-46.4	-13.8	0.14	0.00140	0.0054
2027	6.6	-2.56	-0.85	-48.7	-14.7	0.14	0.00148	0.0055
2028	6.6	-2.70	-0.90	-51.0	-15.5	0.15	0.00155	0.0056
2029	6.6	-2.85	-0.95	-53.4	-16.4	0.15	0.00163	0.0057
2030	6.6	-3.00	-1.00	-55.8	-17.2	0.16	0.00171	0.0058
2031	6.6	-3.15	-1.05	-58.3	-18.1	0.17	0.00179	0.0060
2035	-	0.001	0.001	-0.005	-0.005	-	0.00067	-0.0052
2045	-	0.0002	0.0002	-0.002	-0.002	-	0.00021	-0.0016
2055	-	0.0001	0.0001	-0.001	-0.001	-	0.00007	-0.0005
2065	-	0.00002	0.00002	-0.0002	-0.0002	-	0.00002	-0.0002
2075	-	0.00001	0.00001	-0.0001	-0.0001	-	0.00001	-0.0001
2085	-	0.000002	0.000002	-0.00002	-0.00002	-	0.000002	-0.000016
2095	-	0.000001	0.000001	-0.000005	-0.000005	-	0.000001	-0.000005
2105	-	0.0000002	0.0000002	-0.000002	-0.000002	-	0.0000002	-0.000002

D1.5 MANURE AND SLURRY

Table D1.15 Baseline Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)
2005	83.0	-0.32	0.19	-107.2	2.6
2006	83.0	-0.32	0.19	-107.2	2.6
2007	83.0	-0.32	0.19	-107.2	2.6
2008	83.0	-0.32	0.19	-107.2	2.6
2009	83.0	-0.32	0.19	-107.2	2.6
2010	83.0	-0.32	0.19	-107.2	2.6
2011	83.0	-0.32	0.19	-107.2	2.6
2012	83.0	-0.32	0.19	-107.2	2.6
2013	83.0	-0.32	0.19	-107.2	2.6
2014	83.0	-0.32	0.19	-107.2	2.6
2015	83.0	-0.32	0.19	-107.2	2.6
2016	83.0	-0.32	0.19	-107.2	2.6
2017	83.0	-0.32	0.19	-107.2	2.6
2018	83.0	-0.32	0.19	-107.2	2.6
2019	83.0	-0.32	0.19	-107.2	2.6
2020	83.0	-0.32	0.19	-107.2	2.6
2021	83.0	-0.32	0.19	-107.2	2.6
2022	83.0	-0.32	0.19	-107.2	2.6
2023	83.0	-0.32	0.19	-107.2	2.6
2024	83.0	-0.32	0.19	-107.2	2.6
2025	83.0	-0.32	0.19	-107.2	2.6
2026	83.0	-0.32	0.19	-107.2	2.6
2027	83.0	-0.32	0.19	-107.2	2.6
2028	83.0	-0.32	0.19	-107.2	2.6
2029	83.0	-0.32	0.19	-107.2	2.6
2030	83.0	-0.32	0.19	-107.2	2.6
2031	83.0	-0.32	0.19	-107.2	2.6
2035	-	-	-	-	-
2045	-	-	-	-	-
2055	-	-	-	-	-
2065	-	-	-	-	-
2075	-	-	-	-	-
2085	-	-	-	-	-
2095	-	-	-	-	-
2105	-	-	-	-	-

Table D1.16 High Resource Recovery Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)
2005	83.0	-0.32	0.19	-107.2	2.6
2006	83.0	-0.28	0.22	-106.1	2.9
2007	83.0	-0.25	0.25	-105.0	3.3
2008	83.0	-0.22	0.28	-103.9	3.7
2009	83.0	-0.18	0.31	-102.8	4.0
2010	83.0	-0.15	0.34	-101.7	4.3
2011	83.0	-0.12	0.37	-100.5	4.7
2012	83.0	-0.08	0.40	-99.4	5.1
2013	83.0	-0.05	0.43	-98.3	5.4
2014	83.0	-0.01	0.46	-97.2	5.8
2015	83.0	0.02	0.49	-96.0	6.2
2016	83.0	0.06	0.52	-94.9	6.6
2017	83.0	0.09	0.55	-93.8	6.9
2018	83.0	0.13	0.58	-92.7	7.3
2019	83.0	0.16	0.61	-91.5	7.7
2020	83.0	0.20	0.64	-90.4	8.1
2021	83.0	0.24	0.67	-89.3	8.4
2022	83.0	0.27	0.70	-88.2	8.8
2023	83.0	0.31	0.73	-87.0	9.2
2024	83.0	0.34	0.76	-85.9	9.5
2025	83.0	0.38	0.80	-84.8	9.9
2026	83.0	0.41	0.83	-83.7	10.3
2027	83.0	0.45	0.86	-82.5	10.7
2028	83.0	0.48	0.89	-81.4	11.0
2029	83.0	0.52	0.92	-80.3	11.4
2030	83.0	0.56	0.95	-79.2	11.8
2031	83.0	0.59	0.98	-78.0	12.1
2035	-	-	-	-	-
2045	-	-	-	-	-
2055	-	-	-	-	-
2065	-	-	-	-	-
2075	-	-	-	-	-
2085	-	-	-	-	-
2095	-	-	-	-	-
2105	-	-	-	-	-

Table D1.17 High Energy Recovery Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)
2005	83.0	-0.32	0.19	-107.2	2.6
2006	83.0	-0.77	0.01	-113.5	-0.6
2007	83.0	-1.22	-0.17	-119.9	-3.9
2008	83.0	-1.67	-0.36	-126.3	-7.1
2009	83.0	-2.12	-0.55	-132.7	-10.3
2010	83.0	-2.57	-0.73	-139.1	-13.6
2011	83.0	-3.02	-0.92	-145.4	-16.8
2012	83.0	-3.47	-1.10	-151.8	-20.0
2013	83.0	-3.92	-1.29	-158.1	-23.2
2014	83.0	-4.37	-1.47	-164.5	-26.4
2015	83.0	-4.82	-1.66	-170.9	-29.6
2016	83.0	-5.27	-1.84	-177.2	-32.8
2017	83.0	-5.72	-2.03	-183.5	-36.0
2018	83.0	-6.16	-2.21	-189.9	-39.2
2019	83.0	-6.61	-2.39	-196.2	-42.4
2020	83.0	-7.06	-2.58	-202.6	-45.6
2021	83.0	-7.51	-2.76	-208.9	-48.8
2022	83.0	-7.96	-2.95	-215.3	-52.0
2023	83.0	-8.41	-3.13	-221.7	-55.2
2024	83.0	-8.85	-3.31	-228.0	-58.4
2025	83.0	-9.30	-3.50	-234.4	-61.6
2026	83.0	-9.75	-3.68	-240.7	-64.8
2027	83.0	-10.20	-3.87	-247.1	-68.0
2028	83.0	-10.65	-4.05	-253.4	-71.2
2029	83.0	-11.10	-4.23	-259.8	-74.4
2030	83.0	-11.55	-4.42	-266.1	-77.6
2031	83.0	-11.99	-4.60	-272.5	-80.8
2035	-	-	-	-	-
2045	-	-	-	-	-
2055	-	-	-	-	-
2065	-	-	-	-	-
2075	-	-	-	-	-
2085	-	-	-	-	-
2095	-	-	-	-	-
2105	-	-	-	-	-

D1.6 OTHER ORGANIC WASTE

Table D1.18 Baseline Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	4.0	-0.20	-0.03	-7.4	-0.6	0.4	0.002	0.04
2006	4.0	-0.20	-0.02	-7.5	-0.7	0.4	0.010	-0.03
2007	4.0	-0.19	-0.01	-7.5	-0.7	0.4	0.016	-0.08
2008	4.0	-0.19	-0.01	-7.6	-0.8	0.4	0.022	-0.12
2009	4.0	-0.18	0.00	-7.6	-0.8	0.4	0.027	-0.16
2010	4.0	-0.18	0.00	-7.7	-0.9	0.4	0.031	-0.20
2011	4.0	-0.17	0.01	-7.7	-0.9	0.4	0.035	-0.23
2012	4.0	-0.17	0.01	-7.7	-0.9	0.4	0.039	-0.26
2013	4.0	-0.16	0.01	-7.7	-0.9	0.4	0.042	-0.29
2014	4.0	-0.16	0.02	-7.8	-1.0	0.4	0.045	-0.31
2015	4.0	-0.16	0.02	-7.8	-1.0	0.4	0.048	-0.33
2016	4.0	-0.16	0.02	-7.8	-1.0	0.4	0.050	-0.35
2017	4.0	-0.15	0.02	-7.8	-1.0	0.4	0.052	-0.36
2018	4.0	-0.15	0.03	-7.8	-1.0	0.4	0.054	-0.38
2019	4.0	-0.15	0.03	-7.8	-1.0	0.4	0.055	-0.39
2020	4.0	-0.15	0.03	-7.9	-1.1	0.4	0.057	-0.40
2021	4.0	-0.15	0.03	-7.9	-1.1	0.4	0.058	-0.41
2022	4.0	-0.15	0.03	-7.9	-1.1	0.4	0.059	-0.42
2023	4.0	-0.15	0.03	-7.9	-1.1	0.4	0.060	-0.43
2024	4.0	-0.15	0.03	-7.9	-1.1	0.4	0.061	-0.43
2025	4.0	-0.14	0.03	-7.9	-1.1	0.4	0.062	-0.44
2026	4.0	-0.14	0.03	-7.9	-1.1	0.4	0.063	-0.45
2027	4.0	-0.14	0.03	-7.9	-1.1	0.4	0.063	-0.45
2028	4.0	-0.14	0.04	-7.9	-1.1	0.4	0.064	-0.46
2029	4.0	-0.14	0.04	-7.9	-1.1	0.4	0.064	-0.46
2030	4.0	-0.14	0.04	-7.9	-1.1	0.4	0.065	-0.46
2031	4.0	-0.14	0.04	-7.9	-1.1	0.4	0.065	-0.46
2035	-	0.04	0.04	-0.3	-0.3	-	0.040	-0.32
2045	-	0.01	0.01	-0.1	-0.1	-	0.013	-0.10
2055	-	0.004	0.004	-0.03	-0.03	-	0.004	-0.03
2065	-	0.001	0.001	-0.01	-0.01	-	0.001	-0.010
2075	-	0.0004	0.0004	-0.003	-0.003	-	0.0004	-0.003
2085	-	0.0001	0.0001	-0.001	-0.001	-	0.0001	-0.001
2095	-	0.00004	0.00004	-0.0003	-0.0003	-	0.00004	-0.00030
2105	-	0.00001	0.00001	-0.0001	-0.0001	-	0.00001	-0.00009

Table D1.19 High Resource Recovery Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	4.0	-0.20	-0.03	-7.4	-0.6	0.45	0.002	0.04
2006	4.0	-0.19	-0.01	-7.3	-0.6	0.45	0.010	-0.02
2007	4.0	-0.17	0.00	-7.1	-0.6	0.45	0.016	-0.07
2008	4.0	-0.15	0.01	-7.0	-0.6	0.45	0.022	-0.12
2009	4.0	-0.14	0.02	-6.8	-0.5	0.45	0.027	-0.16
2010	4.0	-0.12	0.03	-6.7	-0.5	0.45	0.032	-0.20
2011	4.0	-0.11	0.03	-6.5	-0.5	0.46	0.036	-0.23
2012	4.0	-0.09	0.04	-6.3	-0.4	0.46	0.040	-0.26
2013	4.0	-0.08	0.05	-6.1	-0.4	0.46	0.043	-0.29
2014	4.0	-0.06	0.06	-6.0	-0.3	0.47	0.046	-0.31
2015	4.0	-0.05	0.07	-5.8	-0.3	0.47	0.049	-0.33
2016	4.0	-0.04	0.07	-5.6	-0.2	0.47	0.052	-0.35
2017	4.0	-0.02	0.08	-5.4	-0.2	0.48	0.054	-0.37
2018	4.0	-0.01	0.09	-5.2	-0.1	0.48	0.056	-0.38
2019	4.0	0.00	0.09	-5.0	-0.1	0.48	0.058	-0.40
2020	4.0	0.01	0.10	-4.9	0.0	0.49	0.060	-0.41
2021	4.0	0.03	0.10	-4.7	0.1	0.49	0.061	-0.42
2022	4.0	0.04	0.11	-4.5	0.1	0.50	0.063	-0.43
2023	4.0	0.05	0.12	-4.3	0.2	0.51	0.064	-0.44
2024	4.0	0.06	0.12	-4.1	0.2	0.51	0.065	-0.45
2025	4.0	0.08	0.13	-3.9	0.3	0.52	0.067	-0.46
2026	4.0	0.09	0.13	-3.7	0.4	0.52	0.068	-0.47
2027	4.0	0.10	0.14	-3.5	0.4	0.53	0.069	-0.48
2028	4.0	0.11	0.15	-3.3	0.5	0.54	0.070	-0.49
2029	4.0	0.12	0.15	-3.1	0.6	0.54	0.071	-0.49
2030	4.0	0.14	0.16	-2.9	0.6	0.55	0.072	-0.50
2031	4.0	0.15	0.16	-2.7	0.7	0.56	0.073	-0.50
2035	-	0.05	0.05	-0.4	-0.4	-	0.051	-0.40
2045	-	0.02	0.02	-0.1	-0.1	-	0.017	-0.13
2055	-	0.01	0.01	-0.04	-0.04	-	0.006	-0.045
2065	-	0.002	0.002	-0.02	-0.02	-	0.002	-0.015
2075	-	0.001	0.001	-0.01	-0.01	-	0.001	-0.006
2085	-	0.0003	0.0003	-0.002	-0.002	-	0.0003	-0.002
2095	-	0.0001	0.0001	-0.001	-0.001	-	0.0001	-0.001
2105	-	0.00004	0.00004	-0.0003	-0.0003	-	0.00004	-0.00032

Table D1.20 High Energy Recovery Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	4.0	-0.20	-0.03	-7.4	-0.6	0.45	0.002	0.04
2006	4.0	-0.25	-0.04	-8.2	-1.1	0.46	0.010	-0.02
2007	4.0	-0.29	-0.05	-9.0	-1.5	0.48	0.017	-0.07
2008	4.0	-0.34	-0.06	-9.8	-1.8	0.50	0.022	-0.12
2009	4.0	-0.39	-0.07	-10.6	-2.2	0.51	0.028	-0.16
2010	4.0	-0.44	-0.09	-11.5	-2.6	0.53	0.032	-0.19
2011	4.0	-0.49	-0.10	-12.4	-2.9	0.54	0.037	-0.22
2012	4.0	-0.54	-0.12	-13.2	-3.3	0.56	0.040	-0.25
2013	4.0	-0.60	-0.13	-14.1	-3.7	0.57	0.044	-0.28
2014	4.0	-0.65	-0.15	-15.1	-4.1	0.59	0.047	-0.30
2015	4.0	-0.71	-0.17	-16.0	-4.5	0.60	0.049	-0.32
2016	4.0	-0.77	-0.19	-17.0	-4.9	0.62	0.052	-0.33
2017	4.0	-0.83	-0.21	-17.9	-5.3	0.64	0.054	-0.35
2018	4.0	-0.90	-0.23	-18.9	-5.7	0.65	0.056	-0.36
2019	4.0	-0.96	-0.25	-19.9	-6.1	0.67	0.058	-0.38
2020	4.0	-1.02	-0.27	-21.0	-6.6	0.68	0.059	-0.39
2021	4.0	-1.09	-0.29	-22.0	-7.0	0.70	0.061	-0.40
2022	4.0	-1.16	-0.32	-23.1	-7.4	0.71	0.062	-0.41
2023	4.0	-1.23	-0.34	-24.2	-7.9	0.73	0.063	-0.41
2024	4.0	-1.30	-0.36	-25.3	-8.3	0.75	0.065	-0.42
2025	4.0	-1.37	-0.39	-26.5	-8.8	0.76	0.066	-0.43
2026	4.0	-1.45	-0.41	-27.6	-9.3	0.78	0.066	-0.43
2027	4.0	-1.52	-0.44	-28.8	-9.7	0.79	0.067	-0.44
2028	4.0	-1.60	-0.46	-30.0	-10.2	0.81	0.068	-0.44
2029	4.0	-1.68	-0.49	-31.2	-10.7	0.82	0.069	-0.44
2030	4.0	-1.76	-0.52	-32.5	-11.2	0.84	0.069	-0.45
2031	4.0	-1.84	-0.55	-33.7	-11.7	0.85	0.070	-0.44
2035	-	0.05	0.05	-0.4	-0.4	-	0.047	-0.36
2045	-	0.01	0.01	-0.1	-0.1	-	0.015	-0.11
2055	-	0.005	0.005	-0.04	-0.04	-	0.005	-0.036
2065	-	0.001	0.001	-0.01	-0.01	-	0.001	-0.011
2075	-	0.0004	0.0004	-0.004	-0.004	-	0.0004	-0.004
2085	-	0.0001	0.0001	-0.001	-0.001	-	0.0001	-0.001
2095	-	0.00004	0.00004	-0.0003	-0.0003	-	0.00004	-0.0003
2105	-	0.00001	0.00001	-0.0001	-0.0001	-	0.00001	-0.0001

Table D1.21 Combined Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	4.0	-0.20	-0.03	-7.4	-0.6	0.45	0.002	0.035
2006	4.0	-0.21	-0.02	-7.6	-0.7	0.46	0.013	0.036
2007	4.0	-0.22	-0.01	-7.8	-0.8	0.47	0.023	0.037
2008	4.0	-0.22	-0.01	-8.0	-0.9	0.47	0.031	0.037
2009	4.0	-0.23	-0.01	-8.2	-1.0	0.48	0.039	0.038
2010	4.0	-0.24	-0.01	-8.4	-1.1	0.49	0.046	0.039
2011	4.0	-0.25	-0.01	-8.7	-1.2	0.50	0.052	0.040
2012	4.0	-0.27	-0.01	-8.9	-1.3	0.51	0.058	0.040
2013	4.0	-0.28	-0.01	-9.1	-1.4	0.53	0.063	0.041
2014	4.0	-0.29	-0.01	-9.4	-1.5	0.54	0.067	0.042
2015	4.0	-0.31	-0.01	-9.6	-1.6	0.55	0.072	0.043
2016	4.0	-0.32	-0.01	-9.9	-1.7	0.56	0.075	0.044
2017	4.0	-0.34	-0.01	-10.1	-1.8	0.57	0.079	0.045
2018	4.0	-0.36	-0.02	-10.4	-1.9	0.58	0.082	0.046
2019	4.0	-0.38	-0.02	-10.6	-2.0	0.59	0.085	0.047
2020	4.0	-0.39	-0.02	-10.9	-2.1	0.61	0.087	0.048
2021	4.0	-0.41	-0.03	-11.2	-2.2	0.62	0.090	0.049
2022	4.0	-0.43	-0.03	-11.5	-2.4	0.63	0.092	0.050
2023	4.0	-0.45	-0.04	-11.8	-2.5	0.65	0.094	0.051
2024	4.0	-0.47	-0.04	-12.1	-2.6	0.66	0.096	0.052
2025	4.0	-0.49	-0.05	-12.4	-2.7	0.67	0.098	0.053
2026	4.0	-0.51	-0.05	-12.7	-2.9	0.69	0.100	0.054
2027	4.0	-0.54	-0.06	-13.0	-3.0	0.70	0.102	0.055
2028	4.0	-0.56	-0.06	-13.3	-3.1	0.72	0.103	0.056
2029	4.0	-0.58	-0.07	-13.7	-3.3	0.73	0.105	0.058
2030	4.0	-0.60	-0.08	-14.0	-3.4	0.75	0.106	0.059
2031	4.0	-0.63	-0.08	-14.3	-3.5	0.76	0.108	0.065
2035	-	0.08	0.08	0.003	0.003	-	0.075	0.003
2045	-	0.02	0.02	0.001	0.001	-	0.025	0.001
2055	-	0.01	0.01	0.0004	0.0004	-	0.008	0.0004
2065	-	0.003	0.003	0.0001	0.0001	-	0.003	0.0001
2075	-	0.001	0.001	0.00005	0.00005	-	0.001	0.00005
2085	-	0.0004	0.0004	0.00002	0.00002	-	0.0004	0.00002
2095	-	0.0002	0.0002	0.00001	0.00001	-	0.0002	0.00001
2105	-	0.0001	0.0001	0.000003	0.000003	-	0.0001	0.000003

D1.7 WOOD

Table D1.22 Baseline Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	7.5	-0.28	-0.03	-4.7	-0.6	6.2	0.03	0.5
2006	7.5	-0.19	0.06	-5.4	-1.3	6.2	0.12	-0.2
2007	7.5	-0.11	0.14	-6.0	-1.9	6.2	0.20	-0.8
2008	7.5	-0.04	0.22	-6.6	-2.5	6.2	0.27	-1.4
2009	7.5	0.03	0.29	-7.1	-3.0	6.2	0.34	-1.9
2010	7.5	0.09	0.35	-7.6	-3.5	6.2	0.41	-2.4
2011	7.5	0.15	0.41	-8.1	-4.0	6.2	0.47	-2.9
2012	7.5	0.21	0.46	-8.5	-4.4	6.2	0.52	-3.3
2013	7.5	0.26	0.52	-8.9	-4.8	6.2	0.58	-3.7
2014	7.5	0.31	0.57	-9.3	-5.2	6.2	0.62	-4.1
2015	7.5	0.36	0.61	-9.6	-5.6	6.2	0.67	-4.5
2016	7.5	0.40	0.65	-10.0	-5.9	6.2	0.71	-4.8
2017	7.5	0.44	0.69	-10.3	-6.2	6.2	0.75	-5.1
2018	7.5	0.47	0.73	-10.6	-6.5	6.2	0.79	-5.4
2019	7.5	0.51	0.76	-10.8	-6.8	6.2	0.82	-5.7
2020	7.5	0.54	0.80	-11.1	-7.0	6.2	0.85	-5.9
2021	7.5	0.57	0.83	-11.3	-7.2	6.2	0.88	-6.1
2022	7.5	0.60	0.85	-11.5	-7.5	6.2	0.91	-6.4
2023	7.5	0.62	0.88	-11.7	-7.7	6.2	0.94	-6.6
2024	7.5	0.65	0.90	-11.9	-7.9	6.2	0.96	-6.8
2025	7.5	0.67	0.93	-12.1	-8.0	6.2	0.98	-6.9
2026	7.5	0.69	0.95	-12.3	-8.2	6.2	1.01	-7.1
2027	7.5	0.71	0.97	-12.4	-8.4	6.2	1.03	-7.3
2028	7.5	0.73	0.99	-12.6	-8.5	6.2	1.04	-7.4
2029	7.5	0.75	1.00	-12.7	-8.6	6.2	1.06	-7.5
2030	7.5	0.76	1.02	-12.8	-8.8	6.2	1.08	-7.7
2031	7.5	0.78	1.03	-13.0	-8.9	6.2	1.09	-7.8
2035	-	0.87	0.87	-6.8	-6.8	-	0.87	-6.8
2045	-	0.44	0.44	-3.4	-3.4	-	0.44	-3.4
2055	-	0.23	0.23	-1.8	-1.8	-	0.23	-1.8
2065	-	0.12	0.12	-0.9	-0.9	-	0.12	-0.9
2075	-	0.06	0.06	-0.5	-0.5	-	0.06	-0.5
2085	-	0.04	0.04	-0.3	-0.3	-	0.04	-0.3
2095	-	0.02	0.02	-0.2	-0.2	-	0.02	-0.2
2105	-	0.01	0.01	-0.1	-0.1	-	0.01	-0.1

Table D1.23 High Resource Recovery Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	7.5	-0.28	-0.03	-4.7	-0.6	6.2	0.03	0.5
2006	7.5	-0.19	0.07	-5.3	-1.2	6.1	0.12	-0.2
2007	7.5	-0.11	0.15	-5.9	-1.7	6.1	0.20	-0.8
2008	7.5	-0.04	0.23	-6.4	-2.2	6.0	0.27	-1.4
2009	7.5	0.03	0.30	-6.8	-2.7	5.9	0.34	-1.9
2010	7.5	0.10	0.36	-7.2	-3.1	5.8	0.40	-2.4
2011	7.5	0.15	0.42	-7.6	-3.5	5.8	0.45	-2.8
2012	7.5	0.21	0.48	-7.9	-3.8	5.7	0.50	-3.2
2013	7.5	0.26	0.53	-8.2	-4.1	5.6	0.55	-3.6
2014	7.5	0.30	0.57	-8.5	-4.4	5.6	0.59	-3.9
2015	7.5	0.34	0.62	-8.8	-4.6	5.5	0.63	-4.2
2016	7.5	0.38	0.66	-9.0	-4.8	5.4	0.66	-4.5
2017	7.5	0.41	0.69	-9.2	-5.0	5.4	0.69	-4.8
2018	7.5	0.44	0.72	-9.3	-5.1	5.3	0.72	-5.0
2019	7.5	0.47	0.75	-9.5	-5.3	5.2	0.75	-5.2
2020	7.5	0.50	0.78	-9.6	-5.4	5.2	0.77	-5.4
2021	7.5	0.52	0.81	-9.7	-5.5	5.1	0.79	-5.6
2022	7.5	0.54	0.83	-9.7	-5.6	5.0	0.81	-5.7
2023	7.5	0.56	0.85	-9.8	-5.6	5.0	0.83	-5.9
2024	7.5	0.58	0.87	-9.9	-5.7	4.9	0.84	-6.0
2025	7.5	0.60	0.89	-9.9	-5.7	4.8	0.85	-6.1
2026	7.5	0.61	0.90	-9.9	-5.7	4.8	0.86	-6.2
2027	7.5	0.62	0.92	-9.9	-5.7	4.7	0.87	-6.2
2028	7.5	0.63	0.93	-9.9	-5.7	4.7	0.88	-6.3
2029	7.5	0.64	0.94	-9.9	-5.7	4.6	0.89	-6.4
2030	7.5	0.65	0.95	-9.9	-5.7	4.5	0.89	-6.4
2031	7.5	0.66	0.96	-9.8	-5.6	4.5	0.90	-6.5
2035	-	0.71	0.71	-5.6	-5.6	-	0.71	-5.6
2045	-	0.36	0.36	-2.8	-2.8	-	0.36	-2.8
2055	-	0.18	0.18	-1.4	-1.4	-	0.18	-1.4
2065	-	0.10	0.10	-0.8	-0.8	-	0.10	-0.8
2075	-	0.05	0.05	-0.4	-0.4	-	0.05	-0.4
2085	-	0.03	0.03	-0.2	-0.2	-	0.03	-0.2
2095	-	0.02	0.02	-0.1	-0.1	-	0.02	-0.1
2105	-	0.01	0.01	-0.1	-0.1	-	0.01	-0.1

Table D1.24 High Energy Recovery Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	7.5	-0.28	-0.03	-4.7	-0.6	6.2	0.03	0.5
2006	7.5	-0.40	-0.01	-8.9	-2.5	6.0	0.12	-0.2
2007	7.5	-0.53	0.00	-13.1	-4.4	5.8	0.20	-0.8
2008	7.5	-0.68	-0.01	-17.4	-6.2	5.6	0.26	-1.4
2009	7.5	-0.85	-0.03	-21.8	-8.0	5.4	0.32	-1.9
2010	7.5	-1.03	-0.06	-26.3	-9.9	5.2	0.37	-2.3
2011	7.5	-1.22	-0.10	-30.8	-11.7	5.0	0.42	-2.7
2012	7.5	-1.43	-0.14	-35.5	-13.5	4.7	0.46	-3.0
2013	7.5	-1.65	-0.20	-40.2	-15.3	4.5	0.50	-3.3
2014	7.5	-1.89	-0.26	-45.0	-17.1	4.3	0.52	-3.6
2015	7.5	-2.14	-0.33	-49.9	-19.0	4.1	0.55	-3.8
2016	7.5	-2.40	-0.41	-54.9	-20.8	3.9	0.57	-4.0
2017	7.5	-2.67	-0.49	-60.0	-22.7	3.7	0.58	-4.1
2018	7.5	-2.95	-0.58	-65.2	-24.5	3.5	0.59	-4.2
2019	7.5	-3.25	-0.68	-70.5	-26.4	3.3	0.60	-4.3
2020	7.5	-3.55	-0.78	-75.9	-28.3	3.1	0.61	-4.4
2021	7.5	-3.87	-0.89	-81.4	-30.3	2.9	0.61	-4.4
2022	7.5	-4.20	-1.01	-87.0	-32.2	2.7	0.61	-4.4
2023	7.5	-4.54	-1.13	-92.7	-34.2	2.5	0.60	-4.4
2024	7.5	-4.89	-1.25	-98.6	-36.2	2.3	0.59	-4.4
2025	7.5	-5.24	-1.38	-104.5	-38.2	2.1	0.58	-4.3
2026	7.5	-5.61	-1.52	-110.6	-40.3	1.9	0.57	-4.2
2027	7.5	-5.99	-1.66	-116.8	-42.4	1.6	0.56	-4.2
2028	7.5	-6.38	-1.81	-123.1	-44.5	1.4	0.54	-4.1
2029	7.5	-6.78	-1.96	-129.5	-46.6	1.2	0.52	-3.9
2030	7.5	-7.18	-2.11	-136.0	-48.8	1.0	0.50	-3.8
2031	7.5	-7.60	-2.27	-142.7	-51.0	0.8	0.48	-3.7
2035	-	0.37	0.37	-2.9	-2.9	-	0.37	-2.9
2045	-	0.19	0.19	-1.5	-1.5	-	0.19	-1.5
2055	-	0.10	0.10	-0.8	-0.8	-	0.10	-0.8
2065	-	0.05	0.05	-0.4	-0.4	-	0.05	-0.4
2075	-	0.03	0.03	-0.2	-0.2	-	0.03	-0.2
2085	-	0.02	0.02	-0.12	-0.12	-	0.02	-0.1
2095	-	0.01	0.01	-0.07	-0.07	-	0.009	-0.07
2105	-	0.01	0.01	-0.04	-0.04	-	0.005	-0.04

Table D1.25 Combined Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	7.5	-0.28	-0.03	-4.7	-0.6	6.2	0.03	0.5
2006	7.5	-0.29	0.03	-7.0	-1.8	6.0	0.12	-0.2
2007	7.5	-0.31	0.08	-9.3	-2.9	5.8	0.20	-0.8
2008	7.5	-0.35	0.12	-11.6	-4.0	5.6	0.26	-1.4
2009	7.5	-0.39	0.15	-13.8	-5.0	5.5	0.32	-1.9
2010	7.5	-0.44	0.17	-16.1	-6.1	5.3	0.38	-2.3
2011	7.5	-0.51	0.18	-18.4	-7.0	5.1	0.43	-2.7
2012	7.5	-0.58	0.19	-20.7	-8.0	4.9	0.47	-3.1
2013	7.5	-0.66	0.19	-23.0	-8.9	4.7	0.50	-3.4
2014	7.5	-0.75	0.18	-25.4	-9.9	4.5	0.54	-3.6
2015	7.5	-0.85	0.17	-27.7	-10.8	4.4	0.56	-3.9
2016	7.5	-0.95	0.15	-30.1	-11.6	4.2	0.58	-4.1
2017	7.5	-1.06	0.13	-32.5	-12.5	4.0	0.60	-4.2
2018	7.5	-1.18	0.10	-34.9	-13.4	3.8	0.62	-4.4
2019	7.5	-1.31	0.07	-37.3	-14.2	3.6	0.63	-4.5
2020	7.5	-1.44	0.03	-39.8	-15.1	3.5	0.64	-4.5
2021	7.5	-1.58	-0.01	-42.3	-15.9	3.3	0.64	-4.6
2022	7.5	-1.73	-0.05	-44.8	-16.8	3.1	0.64	-4.6
2023	7.5	-1.88	-0.10	-47.4	-17.6	2.9	0.64	-4.7
2024	7.5	-2.03	-0.15	-50.0	-18.4	2.7	0.64	-4.7
2025	7.5	-2.19	-0.21	-52.6	-19.3	2.6	0.63	-4.6
2026	7.5	-2.36	-0.27	-55.3	-20.1	2.4	0.63	-4.6
2027	7.5	-2.53	-0.33	-58.0	-21.0	2.2	0.62	-4.5
2028	7.5	-2.71	-0.39	-60.8	-21.8	2.0	0.60	-4.5
2029	7.5	-2.89	-0.46	-63.6	-22.7	1.8	0.59	-4.4
2030	7.5	-3.08	-0.53	-66.4	-23.5	1.7	0.58	-4.3
2031	7.5	-3.27	-0.60	-69.3	-24.4	1.5	0.56	-4.2
2035	-	0.43	0.43	-3.4	-3.4	-	0.43	-3.4
2045	-	0.22	0.22	-1.7	-1.7	-	0.22	-1.7
2055	-	0.11	0.11	-0.9	-0.9	-	0.11	-0.9
2065	-	0.06	0.06	-0.5	-0.5	-	0.06	-0.5
2075	-	0.03	0.03	-0.3	-0.3	-	0.03	-0.3
2085	-	0.02	0.02	-0.1	-0.1	-	0.02	-0.1
2095	-	0.01	0.01	-0.08	-0.08	-	0.01	-0.1
2105	-	0.01	0.01	-0.05	-0.05	-	0.006	-0.046

D1.8 TEXTILES

Table D1.26 Baseline Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	1.4	-0.27	-0.07	-8.0	-2.4	1.09	0.006	0.086
2006	1.4	-0.26	-0.06	-8.1	-2.5	1.09	0.014	0.02
2007	1.4	-0.25	-0.05	-8.1	-2.5	1.09	0.022	-0.04
2008	1.4	-0.24	-0.05	-8.2	-2.6	1.09	0.029	-0.09
2009	1.4	-0.24	-0.04	-8.2	-2.7	1.09	0.036	-0.15
2010	1.4	-0.23	-0.03	-8.3	-2.7	1.09	0.042	-0.20
2011	1.4	-0.22	-0.03	-8.3	-2.8	1.09	0.049	-0.25
2012	1.4	-0.22	-0.02	-8.4	-2.8	1.09	0.055	-0.30
2013	1.4	-0.21	-0.01	-8.4	-2.8	1.09	0.060	-0.34
2014	1.4	-0.21	-0.01	-8.5	-2.9	1.09	0.066	-0.38
2015	1.4	-0.20	0.00	-8.5	-2.9	1.09	0.071	-0.42
2016	1.4	-0.20	0.00	-8.6	-3.0	1.09	0.076	-0.46
2017	1.4	-0.19	0.01	-8.6	-3.0	1.09	0.081	-0.50
2018	1.4	-0.19	0.01	-8.6	-3.0	1.09	0.086	-0.54
2019	1.4	-0.18	0.02	-8.7	-3.1	1.09	0.090	-0.57
2020	1.4	-0.18	0.02	-8.7	-3.1	1.09	0.094	-0.60
2021	1.4	-0.17	0.02	-8.7	-3.1	1.09	0.098	-0.63
2022	1.4	-0.17	0.03	-8.8	-3.2	1.09	0.102	-0.66
2023	1.4	-0.17	0.03	-8.8	-3.2	1.09	0.106	-0.69
2024	1.4	-0.16	0.03	-8.8	-3.2	1.09	0.109	-0.72
2025	1.4	-0.16	0.04	-8.8	-3.3	1.09	0.112	-0.75
2026	1.4	-0.16	0.04	-8.9	-3.3	1.09	0.116	-0.77
2027	1.4	-0.15	0.04	-8.9	-3.3	1.09	0.119	-0.79
2028	1.4	-0.15	0.05	-8.9	-3.3	1.09	0.121	-0.82
2029	1.4	-0.15	0.05	-8.9	-3.3	1.09	0.124	-0.84
2030	1.4	-0.15	0.05	-9.0	-3.4	1.09	0.127	-0.86
2031	1.4	-0.14	0.06	-9.0	-3.4	1.09	0.129	-0.88
2035	-	0.11	0.11	-0.9	-0.9	-	0.109	-0.86
2045	-	0.07	0.07	-0.5	-0.5	-	0.069	-0.54
2055	-	0.04	0.04	-0.3	-0.3	-	0.044	-0.34
2065	-	0.03	0.03	-0.2	-0.2	-	0.028	-0.21
2075	-	0.02	0.02	-0.1	-0.1	-	0.017	-0.13
2085	-	0.01	0.01	-0.1	-0.1	-	0.011	-0.086
2095	-	0.01	0.01	-0.1	-0.1	-	0.0069	-0.054
2105	-	0.004	0.004	-0.03	-0.03	-	0.0044	-0.034

Table D1.27 High Resource Recovery Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	1.4	-0.27	-0.07	-8.0	-2.4	1.09	0.006	0.086
2006	1.4	-0.29	-0.08	-8.7	-2.7	1.08	0.014	0.023
2007	1.4	-0.31	-0.09	-9.3	-2.9	1.07	0.021	-0.037
2008	1.4	-0.33	-0.10	-9.9	-3.1	1.06	0.028	-0.093
2009	1.4	-0.35	-0.11	-10.6	-3.3	1.05	0.035	-0.147
2010	1.4	-0.37	-0.12	-11.2	-3.6	1.04	0.041	-0.197
2011	1.4	-0.39	-0.13	-11.8	-3.8	1.03	0.047	-0.245
2012	1.4	-0.42	-0.14	-12.4	-4.0	1.02	0.053	-0.290
2013	1.4	-0.44	-0.16	-13.0	-4.2	1.01	0.058	-0.332
2014	1.4	-0.46	-0.17	-13.6	-4.4	1.00	0.063	-0.371
2015	1.4	-0.49	-0.18	-14.2	-4.6	0.99	0.068	-0.409
2016	1.4	-0.51	-0.19	-14.8	-4.8	0.98	0.072	-0.444
2017	1.4	-0.53	-0.21	-15.4	-5.0	0.97	0.076	-0.477
2018	1.4	-0.55	-0.22	-16.0	-5.2	0.96	0.080	-0.508
2019	1.4	-0.58	-0.23	-16.6	-5.4	0.95	0.083	-0.537
2020	1.4	-0.60	-0.25	-17.1	-5.6	0.94	0.087	-0.564
2021	1.4	-0.63	-0.26	-17.7	-5.8	0.93	0.090	-0.590
2022	1.4	-0.65	-0.27	-18.3	-6.0	0.92	0.093	-0.613
2023	1.4	-0.67	-0.29	-18.8	-6.2	0.91	0.095	-0.636
2024	1.4	-0.70	-0.30	-19.4	-6.3	0.90	0.098	-0.656
2025	1.4	-0.72	-0.32	-19.9	-6.5	0.89	0.100	-0.676
2026	1.4	-0.75	-0.33	-20.5	-6.7	0.88	0.102	-0.694
2027	1.4	-0.77	-0.35	-21.0	-6.9	0.87	0.104	-0.710
2028	1.4	-0.79	-0.36	-21.6	-7.1	0.86	0.106	-0.726
2029	1.4	-0.82	-0.37	-22.1	-7.2	0.85	0.108	-0.740
2030	1.4	-0.84	-0.39	-22.6	-7.4	0.84	0.109	-0.753
2031	1.4	-0.87	-0.40	-23.2	-7.6	0.83	0.111	-0.765
2035	-	0.09	0.09	-0.7	-0.7	-	0.093	-0.732
2045	-	0.06	0.06	-0.5	-0.5	-	0.059	-0.462
2055	-	0.04	0.04	-0.3	-0.3	-	0.037	-0.292
2065	-	0.02	0.02	-0.2	-0.2	-	0.024	-0.184
2075	-	0.01	0.01	-0.1	-0.1	-	0.015	-0.116
2085	-	0.01	0.01	-0.07	-0.07	-	0.009	-0.073
2095	-	0.01	0.01	-0.05	-0.05	-	0.006	-0.046
2105	-	0.004	0.004	-0.03	-0.03	-	0.004	-0.029

Table D1.28 High Energy Recovery Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	1.4	-0.27	-0.07	-8.0	-2.4	1.09	0.006	0.086
2006	1.4	-0.25	-0.03	-8.4	-2.6	1.06	0.014	0.021
2007	1.4	-0.23	0.00	-8.7	-2.8	1.02	0.021	-0.039
2008	1.4	-0.22	0.03	-9.1	-2.9	0.99	0.027	-0.094
2009	1.4	-0.20	0.06	-9.5	-3.1	0.95	0.033	-0.145
2010	1.4	-0.19	0.09	-9.9	-3.3	0.92	0.039	-0.192
2011	1.4	-0.18	0.12	-10.4	-3.5	0.88	0.044	-0.235
2012	1.4	-0.17	0.15	-10.8	-3.7	0.84	0.048	-0.274
2013	1.4	-0.17	0.18	-11.3	-3.8	0.81	0.052	-0.309
2014	1.4	-0.16	0.20	-11.7	-4.0	0.77	0.056	-0.340
2015	1.4	-0.16	0.23	-12.2	-4.2	0.74	0.059	-0.369
2016	1.4	-0.16	0.25	-12.7	-4.4	0.70	0.061	-0.394
2017	1.4	-0.16	0.28	-13.3	-4.6	0.67	0.063	-0.415
2018	1.4	-0.16	0.30	-13.8	-4.8	0.63	0.065	-0.434
2019	1.4	-0.16	0.32	-14.4	-5.0	0.60	0.067	-0.451
2020	1.4	-0.17	0.34	-14.9	-5.3	0.56	0.068	-0.464
2021	1.4	-0.17	0.37	-15.5	-5.5	0.53	0.069	-0.475
2022	1.4	-0.18	0.39	-16.1	-5.7	0.49	0.069	-0.483
2023	1.4	-0.19	0.41	-16.8	-5.9	0.45	0.070	-0.490
2024	1.4	-0.20	0.42	-17.4	-6.1	0.42	0.070	-0.493
2025	1.4	-0.21	0.44	-18.1	-6.4	0.38	0.069	-0.495
2026	1.4	-0.22	0.46	-18.8	-6.6	0.35	0.069	-0.495
2027	1.4	-0.23	0.48	-19.4	-6.9	0.31	0.068	-0.493
2028	1.4	-0.25	0.49	-20.2	-7.1	0.28	0.067	-0.489
2029	1.4	-0.27	0.51	-20.9	-7.4	0.24	0.065	-0.483
2030	1.4	-0.28	0.52	-21.6	-7.6	0.21	0.064	-0.475
2031	1.4	-0.30	0.54	-22.4	-7.9	0.17	0.062	-0.466
2035	-	0.05	0.05	-0.4	-0.4	-	0.052	-0.406
2045	-	0.03	0.03	-0.3	-0.3	-	0.033	-0.256
2055	-	0.02	0.02	-0.2	-0.2	-	0.021	-0.161
2065	-	0.013	0.013	-0.10	-0.10	-	0.013	-0.102
2075	-	0.008	0.008	-0.06	-0.06	-	0.008	-0.064
2085	-	0.005	0.005	-0.04	-0.04	-	0.005	-0.041
2095	-	0.003	0.003	-0.03	-0.03	-	0.003	-0.026
2105	-	0.002	0.002	-0.02	-0.02	-	0.002	-0.016

Table D1.29 Combined Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	1.4	-0.27	-0.07	-8.0	-2.4	1.09	0.006	0.086
2006	1.4	-0.29	-0.07	-8.9	-2.8	1.06	0.014	0.021
2007	1.4	-0.31	-0.07	-9.9	-3.1	1.03	0.021	-0.039
2008	1.4	-0.33	-0.07	-10.8	-3.4	1.00	0.028	-0.095
2009	1.4	-0.36	-0.07	-11.7	-3.7	0.97	0.034	-0.146
2010	1.4	-0.38	-0.07	-12.7	-4.1	0.93	0.039	-0.194
2011	1.4	-0.41	-0.08	-13.6	-4.4	0.90	0.044	-0.237
2012	1.4	-0.44	-0.08	-14.5	-4.7	0.87	0.049	-0.277
2013	1.4	-0.46	-0.09	-15.5	-5.0	0.84	0.053	-0.313
2014	1.4	-0.49	-0.09	-16.4	-5.3	0.81	0.057	-0.346
2015	1.4	-0.52	-0.10	-17.4	-5.7	0.78	0.060	-0.376
2016	1.4	-0.55	-0.10	-18.3	-6.0	0.75	0.063	-0.403
2017	1.4	-0.58	-0.11	-19.2	-6.3	0.71	0.066	-0.427
2018	1.4	-0.61	-0.11	-20.2	-6.6	0.68	0.068	-0.448
2019	1.4	-0.64	-0.12	-21.1	-6.9	0.65	0.070	-0.466
2020	1.4	-0.68	-0.13	-22.1	-7.2	0.62	0.071	-0.482
2021	1.4	-0.71	-0.14	-23.0	-7.5	0.59	0.073	-0.496
2022	1.4	-0.74	-0.14	-24.0	-7.8	0.56	0.074	-0.507
2023	1.4	-0.78	-0.15	-24.9	-8.2	0.53	0.074	-0.516
2024	1.4	-0.81	-0.16	-25.9	-8.5	0.50	0.075	-0.523
2025	1.4	-0.85	-0.17	-26.9	-8.8	0.47	0.075	-0.528
2026	1.4	-0.88	-0.18	-27.8	-9.1	0.44	0.075	-0.531
2027	1.4	-0.92	-0.19	-28.8	-9.4	0.41	0.074	-0.533
2028	1.4	-0.96	-0.20	-29.8	-9.7	0.38	0.074	-0.532
2029	1.4	-0.99	-0.21	-30.7	-10.0	0.35	0.073	-0.530
2030	1.4	-1.03	-0.22	-31.7	-10.3	0.32	0.072	-0.527
2031	1.4	-1.07	-0.23	-32.7	-10.6	0.29	0.071	-0.522
2035	-	0.06	0.06	-0.5	-0.5	-	0.060	-0.466
2045	-	0.04	0.04	-0.3	-0.3	-	0.038	-0.294
2055	-	0.02	0.02	-0.2	-0.2	-	0.024	-0.186
2065	-	0.01	0.01	-0.1	-0.1	-	0.015	-0.117
2075	-	0.009	0.009	-0.07	-0.07	-	0.009	-0.074
2085	-	0.006	0.006	-0.05	-0.05	-	0.006	-0.047
2095	-	0.004	0.004	-0.03	-0.03	-	0.004	-0.029
2105	-	0.002	0.002	-0.02	-0.02	-	0.002	-0.019

D1.9 DENSE PLASTIC

Table D1.30 Baseline Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	2.8	0.04	0.50	-10.8	-0.5	2.4	0.013	0.19
2006	2.8	0.04	0.50	-10.8	-0.5	2.4	0.013	0.19
2007	2.8	0.04	0.50	-10.8	-0.5	2.4	0.013	0.19
2008	2.8	0.04	0.50	-10.8	-0.5	2.4	0.013	0.19
2009	2.8	0.04	0.50	-10.8	-0.5	2.4	0.013	0.19
2010	2.8	0.04	0.50	-10.8	-0.5	2.4	0.013	0.19
2011	2.8	0.04	0.50	-10.8	-0.5	2.4	0.013	0.19
2012	2.8	0.04	0.50	-10.8	-0.5	2.4	0.013	0.19
2013	2.8	0.04	0.50	-10.8	-0.5	2.4	0.013	0.19
2014	2.8	0.04	0.50	-10.8	-0.5	2.4	0.013	0.19
2015	2.8	0.04	0.50	-10.8	-0.5	2.4	0.013	0.19
2016	2.8	0.04	0.50	-10.8	-0.5	2.4	0.013	0.19
2017	2.8	0.04	0.50	-10.8	-0.5	2.4	0.013	0.19
2018	2.8	0.04	0.50	-10.8	-0.5	2.4	0.013	0.19
2019	2.8	0.04	0.50	-10.8	-0.5	2.4	0.013	0.19
2020	2.8	0.04	0.50	-10.8	-0.5	2.4	0.013	0.19
2021	2.8	0.04	0.50	-10.8	-0.5	2.4	0.013	0.19
2022	2.8	0.04	0.50	-10.8	-0.5	2.4	0.013	0.19
2023	2.8	0.04	0.50	-10.8	-0.5	2.4	0.013	0.19
2024	2.8	0.04	0.50	-10.8	-0.5	2.4	0.013	0.19
2025	2.8	0.04	0.50	-10.8	-0.5	2.4	0.013	0.19
2026	2.8	0.04	0.50	-10.8	-0.5	2.4	0.013	0.19
2027	2.8	0.04	0.50	-10.8	-0.5	2.4	0.013	0.19
2028	2.8	0.04	0.50	-10.8	-0.5	2.4	0.013	0.19
2029	2.8	0.04	0.50	-10.8	-0.5	2.4	0.013	0.19
2030	2.8	0.04	0.50	-10.8	-0.5	2.4	0.013	0.19
2031	2.8	0.04	0.50	-10.8	-0.5	2.4	0.013	0.19
2035	-	-	-	-	-	-	-	-
2045	-	-	-	-	-	-	-	-
2055	-	-	-	-	-	-	-	-
2065	-	-	-	-	-	-	-	-
2075	-	-	-	-	-	-	-	-
2085	-	-	-	-	-	-	-	-
2095	-	-	-	-	-	-	-	-
2105	-	-	-	-	-	-	-	-

Table D1.31 High Resource Recovery Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	2.8	0.04	0.50	-10.8	-0.5	2.4	0.013	0.19
2006	2.8	-0.06	0.53	-13.6	0.1	2.4	0.013	0.19
2007	2.8	-0.16	0.56	-16.4	0.8	2.4	0.013	0.19
2008	2.8	-0.26	0.58	-19.2	1.4	2.3	0.012	0.18
2009	2.8	-0.36	0.61	-21.9	2.1	2.3	0.012	0.18
2010	2.8	-0.46	0.64	-24.7	2.7	2.2	0.012	0.18
2011	2.8	-0.55	0.67	-27.4	3.3	2.2	0.012	0.17
2012	2.8	-0.65	0.70	-30.1	4.0	2.2	0.012	0.17
2013	2.8	-0.75	0.72	-32.8	4.6	2.1	0.011	0.17
2014	2.8	-0.85	0.75	-35.5	5.2	2.1	0.011	0.16
2015	2.8	-0.94	0.78	-38.2	5.9	2.0	0.011	0.16
2016	2.8	-1.04	0.80	-40.9	6.5	2.0	0.011	0.16
2017	2.8	-1.13	0.83	-43.6	7.1	2.0	0.010	0.15
2018	2.8	-1.23	0.86	-46.2	7.7	1.9	0.010	0.15
2019	2.8	-1.32	0.88	-48.8	8.4	1.9	0.010	0.15
2020	2.8	-1.42	0.91	-51.5	9.0	1.8	0.010	0.14
2021	2.8	-1.51	0.94	-54.1	9.6	1.8	0.010	0.14
2022	2.8	-1.61	0.96	-56.7	10.2	1.8	0.009	0.14
2023	2.8	-1.70	0.99	-59.3	10.8	1.7	0.009	0.14
2024	2.8	-1.79	1.01	-61.8	11.4	1.7	0.009	0.13
2025	2.8	-1.88	1.04	-64.4	12.0	1.7	0.009	0.13
2026	2.8	-1.98	1.06	-67.0	12.7	1.6	0.009	0.13
2027	2.8	-2.07	1.09	-69.5	13.3	1.6	0.008	0.12
2028	2.8	-2.16	1.11	-72.0	13.9	1.5	0.008	0.12
2029	2.8	-2.25	1.14	-74.5	14.5	1.5	0.008	0.12
2030	2.8	-2.34	1.16	-77.0	15.1	1.5	0.008	0.12
2031	2.8	-2.43	1.19	-79.5	15.6	1.4	0.008	0.11
2035	-	-	-	-	-	-	-	-
2045	-	-	-	-	-	-	-	-
2055	-	-	-	-	-	-	-	-
2065	-	-	-	-	-	-	-	-
2075	-	-	-	-	-	-	-	-
2085	-	-	-	-	-	-	-	-
2095	-	-	-	-	-	-	-	-
2105	-	-	-	-	-	-	-	-

Table D1.32 High Energy Recovery Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	2.8	0.04	0.50	-10.8	-0.5	2.4	0.013	0.19
2006	2.8	0.11	0.63	-12.5	-1.2	2.4	0.013	0.19
2007	2.8	0.17	0.76	-14.2	-2.0	2.3	0.012	0.18
2008	2.8	0.23	0.89	-16.1	-2.7	2.2	0.012	0.17
2009	2.8	0.29	1.01	-18.0	-3.5	2.1	0.011	0.17
2010	2.8	0.34	1.14	-19.9	-4.3	2.1	0.011	0.16
2011	2.8	0.39	1.26	-21.9	-5.1	2.0	0.011	0.15
2012	2.8	0.43	1.39	-24.0	-5.9	1.9	0.010	0.15
2013	2.8	0.47	1.51	-26.2	-6.8	1.8	0.010	0.14
2014	2.8	0.51	1.63	-28.4	-7.7	1.7	0.009	0.14
2015	2.8	0.54	1.74	-30.7	-8.6	1.7	0.009	0.13
2016	2.8	0.57	1.86	-33.1	-9.5	1.6	0.008	0.12
2017	2.8	0.59	1.98	-35.5	-10.5	1.5	0.008	0.12
2018	2.8	0.61	2.09	-38.0	-11.4	1.4	0.008	0.11
2019	2.8	0.63	2.20	-40.6	-12.4	1.3	0.007	0.11
2020	2.8	0.64	2.31	-43.3	-13.5	1.3	0.007	0.10
2021	2.8	0.65	2.42	-46.0	-14.5	1.2	0.006	0.09
2022	2.8	0.65	2.53	-48.8	-15.6	1.1	0.006	0.09
2023	2.8	0.65	2.64	-51.6	-16.7	1.0	0.005	0.08
2024	2.8	0.65	2.74	-54.5	-17.8	0.9	0.005	0.07
2025	2.8	0.64	2.85	-57.5	-19.0	0.9	0.005	0.07
2026	2.8	0.63	2.95	-60.6	-20.2	0.8	0.004	0.06
2027	2.8	0.61	3.05	-63.7	-21.4	0.7	0.004	0.06
2028	2.8	0.59	3.15	-66.9	-22.6	0.6	0.003	0.05
2029	2.8	0.57	3.25	-70.1	-23.8	0.6	0.003	0.04
2030	2.8	0.54	3.35	-73.5	-25.1	0.5	0.003	0.04
2031	2.8	0.51	3.44	-76.8	-26.4	0.4	0.002	0.03
2035	-	-	-	-	-	-	-	-
2045	-	-	-	-	-	-	-	-
2055	-	-	-	-	-	-	-	-
2065	-	-	-	-	-	-	-	-
2075	-	-	-	-	-	-	-	-
2085	-	-	-	-	-	-	-	-
2095	-	-	-	-	-	-	-	-
2105	-	-	-	-	-	-	-	-

Table D1.33 Combined Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	2.8	0.04	0.50	-10.8	-0.5	2.4	0.013	0.19
2006	2.8	-0.04	0.58	-14.4	-0.1	2.4	0.013	0.19
2007	2.8	-0.12	0.65	-17.9	0.2	2.3	0.012	0.18
2008	2.8	-0.20	0.73	-21.5	0.6	2.2	0.012	0.18
2009	2.8	-0.29	0.80	-25.1	1.0	2.2	0.012	0.17
2010	2.8	-0.37	0.88	-28.7	1.3	2.1	0.011	0.16
2011	2.8	-0.45	0.95	-32.3	1.7	2.0	0.011	0.16
2012	2.8	-0.54	1.03	-35.9	2.0	1.9	0.010	0.15
2013	2.8	-0.62	1.10	-39.5	2.3	1.9	0.010	0.15
2014	2.8	-0.71	1.17	-43.1	2.6	1.8	0.010	0.14
2015	2.8	-0.79	1.25	-46.7	3.0	1.7	0.009	0.14
2016	2.8	-0.88	1.32	-50.3	3.3	1.7	0.009	0.13
2017	2.8	-0.97	1.39	-53.9	3.6	1.6	0.009	0.13
2018	2.8	-1.06	1.46	-57.5	3.8	1.5	0.008	0.12
2019	2.8	-1.15	1.53	-61.2	4.1	1.5	0.008	0.11
2020	2.8	-1.24	1.60	-64.8	4.4	1.4	0.007	0.11
2021	2.8	-1.33	1.67	-68.5	4.6	1.3	0.007	0.10
2022	2.8	-1.42	1.74	-72.1	4.9	1.2	0.007	0.10
2023	2.8	-1.51	1.80	-75.8	5.1	1.2	0.006	0.09
2024	2.8	-1.60	1.87	-79.4	5.4	1.1	0.006	0.09
2025	2.8	-1.69	1.94	-83.1	5.6	1.0	0.006	0.08
2026	2.8	-1.79	2.00	-86.8	5.8	1.0	0.005	0.08
2027	2.8	-1.88	2.07	-90.4	6.0	0.9	0.005	0.07
2028	2.8	-1.98	2.14	-94.1	6.2	0.8	0.004	0.07
2029	2.8	-2.07	2.20	-97.8	6.4	0.8	0.004	0.06
2030	2.8	-2.17	2.26	-101.5	6.6	0.7	0.004	0.06
2031	2.8	-2.27	2.33	-105.2	6.8	0.6	0.00	0.0
2035	-	-	-	-	-	-	-	-
2045	-	-	-	-	-	-	-	-
2055	-	-	-	-	-	-	-	-
2065	-	-	-	-	-	-	-	-
2075	-	-	-	-	-	-	-	-
2085	-	-	-	-	-	-	-	-
2095	-	-	-	-	-	-	-	-
2105	-	-	-	-	-	-	-	-

D1.10 PLASTIC FILM

Table D1.34 Baseline Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	3.1	-0.20	0.52	-18.1	1.8	2.6	0.014	0.21
2006	3.1	-0.20	0.52	-18.1	1.8	2.6	0.014	0.21
2007	3.1	-0.20	0.52	-18.1	1.8	2.6	0.014	0.21
2008	3.1	-0.20	0.52	-18.1	1.8	2.6	0.014	0.21
2009	3.1	-0.20	0.52	-18.1	1.8	2.6	0.014	0.21
2010	3.1	-0.20	0.52	-18.1	1.8	2.6	0.014	0.21
2011	3.1	-0.20	0.52	-18.1	1.8	2.6	0.014	0.21
2012	3.1	-0.20	0.52	-18.1	1.8	2.6	0.014	0.21
2013	3.1	-0.20	0.52	-18.1	1.8	2.6	0.014	0.21
2014	3.1	-0.20	0.52	-18.1	1.8	2.6	0.014	0.21
2015	3.1	-0.20	0.52	-18.1	1.8	2.6	0.014	0.21
2016	3.1	-0.20	0.52	-18.1	1.8	2.6	0.014	0.21
2017	3.1	-0.20	0.52	-18.1	1.8	2.6	0.014	0.21
2018	3.1	-0.20	0.52	-18.1	1.8	2.6	0.014	0.21
2019	3.1	-0.20	0.52	-18.1	1.8	2.6	0.014	0.21
2020	3.1	-0.20	0.52	-18.1	1.8	2.6	0.014	0.21
2021	3.1	-0.20	0.52	-18.1	1.8	2.6	0.014	0.21
2022	3.1	-0.20	0.52	-18.1	1.8	2.6	0.014	0.21
2023	3.1	-0.20	0.52	-18.1	1.8	2.6	0.014	0.21
2024	3.1	-0.20	0.52	-18.1	1.8	2.6	0.014	0.21
2025	3.1	-0.20	0.52	-18.1	1.8	2.6	0.014	0.21
2026	3.1	-0.20	0.52	-18.1	1.8	2.6	0.014	0.21
2027	3.1	-0.20	0.52	-18.1	1.8	2.6	0.014	0.21
2028	3.1	-0.20	0.52	-18.1	1.8	2.6	0.014	0.21
2029	3.1	-0.20	0.52	-18.1	1.8	2.6	0.014	0.21
2030	3.1	-0.20	0.52	-18.1	1.8	2.6	0.014	0.21
2031	3.1	-0.20	0.52	-18.1	1.8	2.6	0.014	0.21
2035	-	-	-	-	-	-	-	-
2045	-	-	-	-	-	-	-	-
2055	-	-	-	-	-	-	-	-
2065	-	-	-	-	-	-	-	-
2075	-	-	-	-	-	-	-	-
2085	-	-	-	-	-	-	-	-
2095	-	-	-	-	-	-	-	-
2105	-	-	-	-	-	-	-	-

Table D1.35 High Resource Recovery Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	3.1	-0.20	0.52	-18.1	1.8	2.6	0.014	0.21
2006	3.1	-0.28	0.55	-21.0	2.4	2.6	0.014	0.20
2007	3.1	-0.36	0.58	-23.8	3.0	2.6	0.014	0.20
2008	3.1	-0.44	0.61	-26.7	3.6	2.5	0.013	0.20
2009	3.1	-0.52	0.65	-29.5	4.3	2.5	0.013	0.19
2010	3.1	-0.59	0.68	-32.3	4.9	2.4	0.013	0.19
2011	3.1	-0.67	0.71	-35.1	5.5	2.4	0.013	0.19
2012	3.1	-0.75	0.74	-37.9	6.1	2.3	0.013	0.18
2013	3.1	-0.83	0.77	-40.7	6.7	2.3	0.012	0.18
2014	3.1	-0.90	0.80	-43.5	7.3	2.3	0.012	0.18
2015	3.1	-0.98	0.84	-46.2	7.9	2.2	0.012	0.17
2016	3.1	-1.06	0.87	-49.0	8.5	2.2	0.012	0.17
2017	3.1	-1.13	0.90	-51.7	9.1	2.1	0.011	0.17
2018	3.1	-1.21	0.93	-54.4	9.7	2.1	0.011	0.16
2019	3.1	-1.28	0.96	-57.1	10.3	2.1	0.011	0.16
2020	3.1	-1.36	0.99	-59.8	10.9	2.0	0.011	0.16
2021	3.1	-1.43	1.02	-62.5	11.5	2.0	0.011	0.16
2022	3.1	-1.51	1.05	-65.2	12.1	1.9	0.010	0.15
2023	3.1	-1.58	1.08	-67.8	12.7	1.9	0.010	0.15
2024	3.1	-1.66	1.11	-70.5	13.3	1.9	0.010	0.15
2025	3.1	-1.73	1.14	-73.1	13.9	1.8	0.010	0.14
2026	3.1	-1.80	1.17	-75.8	14.5	1.8	0.010	0.14
2027	3.1	-1.88	1.20	-78.4	15.0	1.7	0.009	0.14
2028	3.1	-1.95	1.23	-81.0	15.6	1.7	0.009	0.13
2029	3.1	-2.02	1.26	-83.5	16.2	1.7	0.009	0.13
2030	3.1	-2.10	1.28	-86.1	16.8	1.6	0.009	0.13
2031	3.1	-2.17	1.31	-88.7	17.3	1.6	0.008	0.12
2035	-	-	-	-	-	-	-	-
2045	-	-	-	-	-	-	-	-
2055	-	-	-	-	-	-	-	-
2065	-	-	-	-	-	-	-	-
2075	-	-	-	-	-	-	-	-
2085	-	-	-	-	-	-	-	-
2095	-	-	-	-	-	-	-	-
2105	-	-	-	-	-	-	-	-

Table D1.36 High Energy Recovery Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	3.1	-0.20	0.52	-18.1	1.8	2.6	0.014	0.21
2006	3.1	-0.12	0.64	-19.4	1.0	2.6	0.014	0.20
2007	3.1	-0.05	0.77	-20.7	0.3	2.5	0.013	0.19
2008	3.1	0.02	0.89	-22.1	-0.5	2.4	0.013	0.19
2009	3.1	0.09	1.01	-23.6	-1.3	2.3	0.012	0.18
2010	3.1	0.15	1.13	-25.1	-2.1	2.2	0.012	0.17
2011	3.1	0.21	1.25	-26.7	-3.0	2.1	0.011	0.17
2012	3.1	0.26	1.37	-28.4	-3.8	2.1	0.011	0.16
2013	3.1	0.32	1.48	-30.1	-4.7	2.0	0.011	0.15
2014	3.1	0.36	1.60	-31.9	-5.7	1.9	0.010	0.15
2015	3.1	0.41	1.71	-33.8	-6.6	1.8	0.010	0.14
2016	3.1	0.44	1.82	-35.7	-7.6	1.7	0.009	0.14
2017	3.1	0.48	1.94	-37.7	-8.6	1.6	0.009	0.13
2018	3.1	0.51	2.05	-39.7	-9.6	1.6	0.008	0.12
2019	3.1	0.54	2.15	-41.9	-10.6	1.5	0.008	0.12
2020	3.1	0.56	2.26	-44.1	-11.7	1.4	0.007	0.11
2021	3.1	0.58	2.37	-46.3	-12.8	1.3	0.007	0.10
2022	3.1	0.60	2.47	-48.7	-13.9	1.2	0.007	0.10
2023	3.1	0.61	2.57	-51.1	-15.0	1.1	0.006	0.09
2024	3.1	0.62	2.67	-53.5	-16.1	1.1	0.006	0.08
2025	3.1	0.62	2.77	-56.1	-17.3	1.0	0.005	0.08
2026	3.1	0.62	2.87	-58.7	-18.5	0.9	0.005	0.07
2027	3.1	0.62	2.97	-61.3	-19.7	0.8	0.004	0.06
2028	3.1	0.61	3.06	-64.1	-21.0	0.7	0.004	0.06
2029	3.1	0.60	3.16	-66.9	-22.3	0.6	0.003	0.05
2030	3.1	0.58	3.25	-69.7	-23.6	0.6	0.003	0.04
2031	3.1	0.56	3.34	-72.7	-24.9	0.5	0.002	0.04
2035	-	-	-	-	-	-	-	-
2045	-	-	-	-	-	-	-	-
2055	-	-	-	-	-	-	-	-
2065	-	-	-	-	-	-	-	-
2075	-	-	-	-	-	-	-	-
2085	-	-	-	-	-	-	-	-
2095	-	-	-	-	-	-	-	-
2105	-	-	-	-	-	-	-	-

Table D1.37 Combined Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	3.1	-0.20	0.52	-18.1	1.8	2.6	0.014	0.21
2006	3.1	-0.26	0.60	-21.7	2.2	2.6	0.014	0.20
2007	3.1	-0.32	0.68	-25.2	2.5	2.5	0.013	0.20
2008	3.1	-0.38	0.75	-28.8	2.9	2.4	0.013	0.19
2009	3.1	-0.44	0.83	-32.4	3.3	2.3	0.012	0.18
2010	3.1	-0.50	0.91	-36.0	3.6	2.3	0.012	0.18
2011	3.1	-0.56	0.99	-39.6	4.0	2.2	0.012	0.17
2012	3.1	-0.63	1.07	-43.2	4.3	2.1	0.011	0.17
2013	3.1	-0.69	1.14	-46.8	4.6	2.0	0.011	0.16
2014	3.1	-0.76	1.22	-50.5	4.9	2.0	0.010	0.15
2015	3.1	-0.82	1.29	-54.1	5.2	1.9	0.010	0.15
2016	3.1	-0.89	1.37	-57.7	5.5	1.8	0.010	0.14
2017	3.1	-0.96	1.44	-61.4	5.8	1.7	0.009	0.14
2018	3.1	-1.03	1.52	-65.0	6.1	1.7	0.009	0.13
2019	3.1	-1.09	1.59	-68.6	6.4	1.6	0.008	0.12
2020	3.1	-1.16	1.66	-72.3	6.6	1.5	0.008	0.12
2021	3.1	-1.23	1.73	-76.0	6.9	1.4	0.008	0.11
2022	3.1	-1.31	1.80	-79.6	7.1	1.4	0.007	0.11
2023	3.1	-1.38	1.88	-83.3	7.4	1.3	0.007	0.10
2024	3.1	-1.45	1.95	-87.0	7.6	1.2	0.007	0.10
2025	3.1	-1.53	2.02	-90.7	7.8	1.1	0.006	0.09
2026	3.1	-1.60	2.08	-94.4	8.0	1.1	0.006	0.08
2027	3.1	-1.68	2.15	-98.1	8.2	1.0	0.005	0.08
2028	3.1	-1.75	2.22	-101.8	8.4	0.9	0.005	0.07
2029	3.1	-1.83	2.29	-105.5	8.6	0.9	0.005	0.07
2030	3.1	-1.91	2.36	-109.2	8.8	0.8	0.004	0.06
2031	3.1	-1.98	2.42	-113.0	9.0	0.7	0.004	0.06
2035	-	-	-	-	-	-	-	-
2045	-	-	-	-	-	-	-	-
2055	-	-	-	-	-	-	-	-
2065	-	-	-	-	-	-	-	-
2075	-	-	-	-	-	-	-	-
2085	-	-	-	-	-	-	-	-
2095	-	-	-	-	-	-	-	-
2105	-	-	-	-	-	-	-	-

D1.11 FERROUS METALS

Table D1.38 Baseline Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	4.1	-1.80	-1.24	-16.7	-1.89	1.88	0.010	0.15
2006	4.1	-1.80	-1.24	-16.7	-1.89	1.88	0.010	0.15
2007	4.1	-1.80	-1.24	-16.7	-1.89	1.88	0.010	0.15
2008	4.1	-1.80	-1.24	-16.7	-1.89	1.88	0.010	0.15
2009	4.1	-1.80	-1.24	-16.7	-1.89	1.88	0.010	0.15
2010	4.1	-1.80	-1.24	-16.7	-1.89	1.88	0.010	0.15
2011	4.1	-1.80	-1.24	-16.7	-1.89	1.88	0.010	0.15
2012	4.1	-1.80	-1.24	-16.7	-1.89	1.88	0.010	0.15
2013	4.1	-1.80	-1.24	-16.7	-1.89	1.88	0.010	0.15
2014	4.1	-1.80	-1.24	-16.7	-1.89	1.88	0.010	0.15
2015	4.1	-1.80	-1.24	-16.7	-1.89	1.88	0.010	0.15
2016	4.1	-1.80	-1.24	-16.7	-1.89	1.88	0.010	0.15
2017	4.1	-1.80	-1.24	-16.7	-1.89	1.88	0.010	0.15
2018	4.1	-1.80	-1.24	-16.7	-1.89	1.88	0.010	0.15
2019	4.1	-1.80	-1.24	-16.7	-1.89	1.88	0.010	0.15
2020	4.1	-1.80	-1.24	-16.7	-1.89	1.88	0.010	0.15
2021	4.1	-1.80	-1.24	-16.7	-1.89	1.88	0.010	0.15
2022	4.1	-1.80	-1.24	-16.7	-1.89	1.88	0.010	0.15
2023	4.1	-1.80	-1.24	-16.7	-1.89	1.88	0.010	0.15
2024	4.1	-1.80	-1.24	-16.7	-1.89	1.88	0.010	0.15
2025	4.1	-1.80	-1.24	-16.7	-1.89	1.88	0.010	0.15
2026	4.1	-1.80	-1.24	-16.7	-1.89	1.88	0.010	0.15
2027	4.1	-1.80	-1.24	-16.7	-1.89	1.88	0.010	0.15
2028	4.1	-1.80	-1.24	-16.7	-1.89	1.88	0.010	0.15
2029	4.1	-1.80	-1.24	-16.7	-1.89	1.88	0.010	0.15
2030	4.1	-1.80	-1.24	-16.7	-1.89	1.88	0.010	0.15
2031	4.1	-1.80	-1.24	-16.7	-1.89	1.88	0.010	0.15
2035	-	-	-	-	-	-	-	-
2045	-	-	-	-	-	-	-	-
2055	-	-	-	-	-	-	-	-
2065	-	-	-	-	-	-	-	-
2075	-	-	-	-	-	-	-	-
2085	-	-	-	-	-	-	-	-
2095	-	-	-	-	-	-	-	-
2105	-	-	-	-	-	-	-	-

Table D1.39 High Resource Recovery Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	4.1	-1.80	-1.24	-16.7	-1.89	1.88	0.010	0.15
2006	4.1	-1.83	-1.26	-17.0	-1.93	1.84	0.010	0.14
2007	4.1	-1.86	-1.28	-17.3	-1.97	1.80	0.010	0.14
2008	4.1	-1.89	-1.31	-17.6	-2.01	1.76	0.009	0.14
2009	4.1	-1.92	-1.33	-17.8	-2.05	1.73	0.009	0.14
2010	4.1	-1.95	-1.35	-18.1	-2.08	1.69	0.009	0.13
2011	4.1	-1.98	-1.37	-18.4	-2.12	1.65	0.009	0.13
2012	4.1	-2.01	-1.39	-18.7	-2.16	1.61	0.009	0.13
2013	4.1	-2.04	-1.41	-19.0	-2.19	1.58	0.008	0.12
2014	4.1	-2.07	-1.43	-19.2	-2.23	1.54	0.008	0.12
2015	4.1	-2.10	-1.45	-19.5	-2.27	1.50	0.008	0.12
2016	4.1	-2.13	-1.47	-19.8	-2.30	1.47	0.008	0.12
2017	4.1	-2.16	-1.49	-20.1	-2.34	1.43	0.008	0.11
2018	4.1	-2.19	-1.51	-20.3	-2.37	1.40	0.007	0.11
2019	4.1	-2.22	-1.53	-20.6	-2.40	1.36	0.007	0.11
2020	4.1	-2.25	-1.55	-20.9	-2.44	1.33	0.007	0.10
2021	4.1	-2.28	-1.57	-21.1	-2.47	1.29	0.007	0.10
2022	4.1	-2.30	-1.59	-21.4	-2.51	1.26	0.007	0.10
2023	4.1	-2.33	-1.61	-21.7	-2.54	1.22	0.007	0.10
2024	4.1	-2.36	-1.63	-21.9	-2.57	1.19	0.006	0.09
2025	4.1	-2.39	-1.65	-22.2	-2.61	1.15	0.006	0.09
2026	4.1	-2.42	-1.67	-22.4	-2.64	1.12	0.006	0.09
2027	4.1	-2.44	-1.69	-22.7	-2.67	1.08	0.006	0.09
2028	4.1	-2.47	-1.71	-23.0	-2.70	1.05	0.006	0.08
2029	4.1	-2.50	-1.73	-23.2	-2.74	1.02	0.005	0.08
2030	4.1	-2.53	-1.75	-23.5	-2.77	0.98	0.005	0.08
2031	4.1	-2.55	-1.76	-23.7	-2.80	0.95	0.005	0.07
2035	-	-	-	-	-	-	-	-
2045	-	-	-	-	-	-	-	-
2055	-	-	-	-	-	-	-	-
2065	-	-	-	-	-	-	-	-
2075	-	-	-	-	-	-	-	-
2085	-	-	-	-	-	-	-	-
2095	-	-	-	-	-	-	-	-
2105	-	-	-	-	-	-	-	-

D1.12 NON-FERROUS METALS

Table D1.40 Baseline Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	1.99	-16.7	-15.7	-182.4	-168.3	0.71	0.0038	0.056
2006	1.99	-16.7	-15.7	-182.4	-168.3	0.71	0.0038	0.056
2007	1.99	-16.7	-15.7	-182.4	-168.3	0.71	0.0038	0.056
2008	1.99	-16.7	-15.7	-182.4	-168.3	0.71	0.0038	0.056
2009	1.99	-16.7	-15.7	-182.4	-168.3	0.71	0.0038	0.056
2010	1.99	-16.7	-15.7	-182.4	-168.3	0.71	0.0038	0.056
2011	1.99	-16.7	-15.7	-182.4	-168.3	0.71	0.0038	0.056
2012	1.99	-16.7	-15.7	-182.4	-168.3	0.71	0.0038	0.056
2013	1.99	-16.7	-15.7	-182.4	-168.3	0.71	0.0038	0.056
2014	1.99	-16.7	-15.7	-182.4	-168.3	0.71	0.0038	0.056
2015	1.99	-16.7	-15.7	-182.4	-168.3	0.71	0.0038	0.056
2016	1.99	-16.7	-15.7	-182.4	-168.3	0.71	0.0038	0.056
2017	1.99	-16.7	-15.7	-182.4	-168.3	0.71	0.0038	0.056
2018	1.99	-16.7	-15.7	-182.4	-168.3	0.71	0.0038	0.056
2019	1.99	-16.7	-15.7	-182.4	-168.3	0.71	0.0038	0.056
2020	1.99	-16.7	-15.7	-182.4	-168.3	0.71	0.0038	0.056
2021	1.99	-16.7	-15.7	-182.4	-168.3	0.71	0.0038	0.056
2022	1.99	-16.7	-15.7	-182.4	-168.3	0.71	0.0038	0.056
2023	1.99	-16.7	-15.7	-182.4	-168.3	0.71	0.0038	0.056
2024	1.99	-16.7	-15.7	-182.4	-168.3	0.71	0.0038	0.056
2025	1.99	-16.7	-15.7	-182.4	-168.3	0.71	0.0038	0.056
2026	1.99	-16.7	-15.7	-182.4	-168.3	0.71	0.0038	0.056
2027	1.99	-16.7	-15.7	-182.4	-168.3	0.71	0.0038	0.056
2028	1.99	-16.7	-15.7	-182.4	-168.3	0.71	0.0038	0.056
2029	1.99	-16.7	-15.7	-182.4	-168.3	0.71	0.0038	0.056
2030	1.99	-16.7	-15.7	-182.4	-168.3	0.71	0.0038	0.056
2031	1.99	-16.7	-15.7	-182.4	-168.3	0.71	0.0038	0.056
2035	-	-	-	-	-	-	-	-
2045	-	-	-	-	-	-	-	-
2055	-	-	-	-	-	-	-	-
2065	-	-	-	-	-	-	-	-
2075	-	-	-	-	-	-	-	-
2085	-	-	-	-	-	-	-	-
2095	-	-	-	-	-	-	-	-
2105	-	-	-	-	-	-	-	-

Table D1.41 High Resource Recovery Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	1.99	-16.7	-15.7	-182.4	-168.3	0.71	0.0038	0.056
2006	1.99	-16.9	-15.8	-183.9	-169.7	0.70	0.0037	0.055
2007	1.99	-17.0	-16.0	-185.4	-171.1	0.69	0.0037	0.054
2008	1.99	-17.1	-16.1	-186.8	-172.4	0.68	0.0036	0.053
2009	1.99	-17.3	-16.2	-188.3	-173.8	0.67	0.0036	0.053
2010	1.99	-17.4	-16.3	-189.8	-175.1	0.66	0.0035	0.052
2011	1.99	-17.5	-16.5	-191.2	-176.5	0.65	0.0035	0.051
2012	1.99	-17.7	-16.6	-192.7	-177.8	0.64	0.0034	0.050
2013	1.99	-17.8	-16.7	-194.1	-179.1	0.63	0.0034	0.049
2014	1.99	-17.9	-16.8	-195.5	-180.4	0.62	0.0033	0.049
2015	1.99	-18.1	-16.9	-196.9	-181.8	0.61	0.0033	0.048
2016	1.99	-18.2	-17.1	-198.3	-183.1	0.60	0.0032	0.047
2017	1.99	-18.3	-17.2	-199.7	-184.3	0.59	0.0032	0.046
2018	1.99	-18.4	-17.3	-201.1	-185.6	0.58	0.0031	0.046
2019	1.99	-18.6	-17.4	-202.5	-186.9	0.57	0.0031	0.045
2020	1.99	-18.7	-17.5	-203.9	-188.2	0.56	0.0030	0.044
2021	1.99	-18.8	-17.7	-205.3	-189.4	0.55	0.0029	0.043
2022	1.99	-18.9	-17.8	-206.6	-190.7	0.54	0.0029	0.043
2023	1.99	-19.1	-17.9	-208.0	-192.0	0.53	0.0028	0.042
2024	1.99	-19.2	-18.0	-209.3	-193.2	0.52	0.0028	0.041
2025	1.99	-19.3	-18.1	-210.7	-194.4	0.51	0.0027	0.040
2026	1.99	-19.4	-18.2	-212.0	-195.7	0.50	0.0027	0.040
2027	1.99	-19.6	-18.4	-213.3	-196.9	0.50	0.0026	0.039
2028	1.99	-19.7	-18.5	-214.6	-198.1	0.49	0.0026	0.038
2029	1.99	-19.8	-18.6	-215.9	-199.3	0.48	0.0025	0.037
2030	1.99	-19.9	-18.7	-217.2	-200.5	0.47	0.0025	0.037
2031	1.99	-20.0	-18.8	-218.5	-201.7	0.46	0.0025	0.036
2035	-	-	-	-	-	-	-	-
2045	-	-	-	-	-	-	-	-
2055	-	-	-	-	-	-	-	-
2065	-	-	-	-	-	-	-	-
2075	-	-	-	-	-	-	-	-
2085	-	-	-	-	-	-	-	-
2095	-	-	-	-	-	-	-	-
2105	-	-	-	-	-	-	-	-

D1.13 *SILT/SOIL*

Table D1.42 Baseline Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	50.7	0.65	0.65	9.3	9.4	13.71	0.073	1.08
2006	50.7	0.65	0.65	9.3	9.4	13.71	0.073	1.08
2007	50.7	0.65	0.65	9.3	9.4	13.71	0.073	1.08
2008	50.7	0.65	0.65	9.3	9.4	13.71	0.073	1.08
2009	50.7	0.65	0.65	9.3	9.4	13.71	0.073	1.08
2010	50.7	0.65	0.65	9.3	9.4	13.71	0.073	1.08
2011	50.7	0.65	0.65	9.3	9.4	13.71	0.073	1.08
2012	50.7	0.65	0.65	9.3	9.4	13.71	0.073	1.08
2013	50.7	0.65	0.65	9.3	9.4	13.71	0.073	1.08
2014	50.7	0.65	0.65	9.3	9.4	13.71	0.073	1.08
2015	50.7	0.65	0.65	9.3	9.4	13.71	0.073	1.08
2016	50.7	0.65	0.65	9.3	9.4	13.71	0.073	1.08
2017	50.7	0.65	0.65	9.3	9.4	13.71	0.073	1.08
2018	50.7	0.65	0.65	9.3	9.4	13.71	0.073	1.08
2019	50.7	0.65	0.65	9.3	9.4	13.71	0.073	1.08
2020	50.7	0.65	0.65	9.3	9.4	13.71	0.073	1.08
2021	50.7	0.65	0.65	9.3	9.4	13.71	0.073	1.08
2022	50.7	0.65	0.65	9.3	9.4	13.71	0.073	1.08
2023	50.7	0.65	0.65	9.3	9.4	13.71	0.073	1.08
2024	50.7	0.65	0.65	9.3	9.4	13.71	0.073	1.08
2025	50.7	0.65	0.65	9.3	9.4	13.71	0.073	1.08
2026	50.7	0.65	0.65	9.3	9.4	13.71	0.073	1.08
2027	50.7	0.65	0.65	9.3	9.4	13.71	0.073	1.08
2028	50.7	0.65	0.65	9.3	9.4	13.71	0.073	1.08
2029	50.7	0.65	0.65	9.3	9.4	13.71	0.073	1.08
2030	50.7	0.65	0.65	9.3	9.4	13.71	0.073	1.08
2031	50.7	0.65	0.65	9.3	9.4	13.71	0.073	1.08
2035	-	-	-	-	-	-	-	-
2045	-	-	-	-	-	-	-	-
2055	-	-	-	-	-	-	-	-
2065	-	-	-	-	-	-	-	-
2075	-	-	-	-	-	-	-	-
2085	-	-	-	-	-	-	-	-
2095	-	-	-	-	-	-	-	-
2105	-	-	-	-	-	-	-	-

Table D1.43 High Resource Recovery Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	50.7	0.65	0.65	9.3	9.4	13.71	0.073	1.08
2006	50.7	0.65	0.66	9.3	9.5	13.55	0.072	1.06
2007	50.7	0.65	0.66	9.4	9.6	13.40	0.072	1.05
2008	50.7	0.65	0.67	9.4	9.7	13.26	0.071	1.04
2009	50.7	0.65	0.68	9.4	9.8	13.12	0.070	1.03
2010	50.7	0.65	0.69	9.5	10.0	12.99	0.069	1.02
2011	50.7	0.65	0.70	9.5	10.1	12.87	0.069	1.01
2012	50.7	0.65	0.71	9.6	10.2	12.75	0.068	1.00
2013	50.7	0.66	0.71	9.6	10.4	12.64	0.068	0.99
2014	50.7	0.66	0.72	9.6	10.5	12.53	0.067	0.98
2015	50.7	0.66	0.73	9.7	10.6	12.43	0.066	0.98
2016	50.7	0.66	0.74	9.7	10.8	12.34	0.066	0.97
2017	50.7	0.67	0.75	9.8	10.9	12.25	0.065	0.96
2018	50.7	0.67	0.76	9.8	11.0	12.17	0.065	0.96
2019	50.7	0.67	0.77	9.9	11.2	12.09	0.065	0.95
2020	50.7	0.68	0.78	9.9	11.3	12.03	0.064	0.94
2021	50.7	0.68	0.79	10.0	11.4	11.96	0.064	0.94
2022	50.7	0.68	0.80	10.0	11.6	11.91	0.064	0.94
2023	50.7	0.68	0.81	10.1	11.7	11.86	0.063	0.93
2024	50.7	0.69	0.82	10.1	11.8	11.82	0.063	0.93
2025	50.7	0.69	0.83	10.2	12.0	11.78	0.063	0.93
2026	50.7	0.69	0.83	10.3	12.1	11.75	0.063	0.92
2027	50.7	0.70	0.84	10.3	12.3	11.73	0.063	0.92
2028	50.7	0.70	0.85	10.4	12.4	11.71	0.063	0.92
2029	50.7	0.70	0.86	10.4	12.5	11.70	0.063	0.92
2030	50.7	0.71	0.87	10.5	12.7	11.69	0.062	0.92
2031	50.7	0.71	0.88	10.5	12.8	11.69	0.062	0.92
2035	-	-	-	-	-	-	-	-
2045	-	-	-	-	-	-	-	-
2055	-	-	-	-	-	-	-	-
2065	-	-	-	-	-	-	-	-
2075	-	-	-	-	-	-	-	-
2085	-	-	-	-	-	-	-	-
2095	-	-	-	-	-	-	-	-
2105	-	-	-	-	-	-	-	-

D1.14 MINERAL MATERIALS

Table D1.44 Baseline Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	59.9	0.83	1.02	12.06	14.68	10.8	0.058	0.85
2006	59.9	0.83	1.02	12.06	14.68	10.8	0.058	0.85
2007	59.9	0.83	1.02	12.06	14.68	10.8	0.058	0.85
2008	59.9	0.83	1.02	12.06	14.68	10.8	0.058	0.85
2009	59.9	0.83	1.02	12.06	14.68	10.8	0.058	0.85
2010	59.9	0.83	1.02	12.06	14.68	10.8	0.058	0.85
2011	59.9	0.83	1.02	12.06	14.68	10.8	0.058	0.85
2012	59.9	0.83	1.02	12.06	14.68	10.8	0.058	0.85
2013	59.9	0.83	1.02	12.06	14.68	10.8	0.058	0.85
2014	59.9	0.83	1.02	12.06	14.68	10.8	0.058	0.85
2015	59.9	0.83	1.02	12.06	14.68	10.8	0.058	0.85
2016	59.9	0.83	1.02	12.06	14.68	10.8	0.058	0.85
2017	59.9	0.83	1.02	12.06	14.68	10.8	0.058	0.85
2018	59.9	0.83	1.02	12.06	14.68	10.8	0.058	0.85
2019	59.9	0.83	1.02	12.06	14.68	10.8	0.058	0.85
2020	59.9	0.83	1.02	12.06	14.68	10.8	0.058	0.85
2021	59.9	0.83	1.02	12.06	14.68	10.8	0.058	0.85
2022	59.9	0.83	1.02	12.06	14.68	10.8	0.058	0.85
2023	59.9	0.83	1.02	12.06	14.68	10.8	0.058	0.85
2024	59.9	0.83	1.02	12.06	14.68	10.8	0.058	0.85
2025	59.9	0.83	1.02	12.06	14.68	10.8	0.058	0.85
2026	59.9	0.83	1.02	12.06	14.68	10.8	0.058	0.85
2027	59.9	0.83	1.02	12.06	14.68	10.8	0.058	0.85
2028	59.9	0.83	1.02	12.06	14.68	10.8	0.058	0.85
2029	59.9	0.83	1.02	12.06	14.68	10.8	0.058	0.85
2030	59.9	0.83	1.02	12.06	14.68	10.8	0.058	0.85
2031	59.9	0.83	1.02	12.06	14.68	10.8	0.058	0.85
2035	-	-	-	-	-	-	-	-
2045	-	-	-	-	-	-	-	-
2055	-	-	-	-	-	-	-	-
2065	-	-	-	-	-	-	-	-
2075	-	-	-	-	-	-	-	-
2085	-	-	-	-	-	-	-	-
2095	-	-	-	-	-	-	-	-
2105	-	-	-	-	-	-	-	-

Table D1.45 High Resource Recovery Scenario

Year	Waste Arisings (Mt)	Min Net GHG Emissions (Mt CO_2-eq)	Max Net GHG Emissions (Mt CO_2-eq)	Min Net Fossil Energy Demand (PJ-eq)	Max Net Fossil Energy Demand (PJ-eq)	Residual Waste to Landfill	Landfill Net GHG Emissions (Mt CO_2-eq)	Landfill Net Fossil Energy Demand (PJ-eq)
2005	59.9	0.83	1.02	12.06	14.68	10.8	0.058	0.85
2006	59.9	0.83	1.02	12.06	14.69	10.9	0.058	0.85
2007	59.9	0.82	1.02	12.07	14.70	11.0	0.059	0.86
2008	59.9	0.82	1.02	12.07	14.70	11.1	0.059	0.87
2009	59.9	0.82	1.02	12.07	14.71	11.2	0.060	0.88
2010	59.9	0.82	1.02	12.08	14.71	11.3	0.060	0.89
2011	59.9	0.82	1.02	12.09	14.73	11.4	0.061	0.90
2012	59.9	0.82	1.02	12.11	14.75	11.5	0.062	0.91
2013	59.9	0.82	1.02	12.13	14.77	11.6	0.062	0.91
2014	59.9	0.82	1.02	12.14	14.79	11.8	0.063	0.92
2015	59.9	0.82	1.02	12.16	14.81	11.9	0.063	0.93
2016	59.9	0.82	1.02	12.18	14.83	12.0	0.064	0.94
2017	59.9	0.83	1.03	12.20	14.85	12.1	0.065	0.95
2018	59.9	0.83	1.03	12.21	14.87	12.2	0.065	0.96
2019	59.9	0.83	1.03	12.23	14.89	12.3	0.066	0.97
2020	59.9	0.83	1.03	12.25	14.91	12.5	0.067	0.98
2021	59.9	0.83	1.03	12.27	14.93	12.6	0.067	0.99
2022	59.9	0.83	1.03	12.29	14.95	12.7	0.068	1.00
2023	59.9	0.83	1.03	12.30	14.97	12.8	0.068	1.01
2024	59.9	0.83	1.03	12.32	14.99	12.9	0.069	1.02
2025	59.9	0.83	1.04	12.34	15.01	13.1	0.070	1.03
2026	59.9	0.83	1.04	12.36	15.03	13.2	0.070	1.04
2027	59.9	0.83	1.04	12.38	15.05	13.3	0.071	1.05
2028	59.9	0.84	1.04	12.39	15.07	13.4	0.072	1.05
2029	59.9	0.84	1.04	12.41	15.09	13.6	0.072	1.06
2030	59.9	0.84	1.04	12.43	15.11	13.7	0.073	1.07
2031	59.9	0.84	1.04	12.45	15.13	13.8	0.074	1.08
2035	-	-	-	-	-	-	-	-
2045	-	-	-	-	-	-	-	-
2055	-	-	-	-	-	-	-	-
2065	-	-	-	-	-	-	-	-
2075	-	-	-	-	-	-	-	-
2085	-	-	-	-	-	-	-	-
2095	-	-	-	-	-	-	-	-
2105	-	-	-	-	-	-	-	-

Annex E

Additional Landfill Analysis

E1 HOW SHOULD LANDFILLS BE MANAGED AS WASTE COMPOSITION CHANGES?

E1.1 INTRODUCTION

This report has considered the effect of individual wastes being landfilled separately, for example, a hypothetical 'paper & card' landfill would receive all the paper and card wastes generated for the whole UK. In reality, landfills accept a mixture of wastes including biodegradable and non-degradable wastes. As local authorities respond to their LATS obligations, diverting BMW from landfill operators will experience a change in the mix of wastes they receive. The resulting decrease of biodegradable material in wastes being sent to landfill will led to a decrease in landfill gas generation.

The success of active management of landfill gas depends on the commercial viability of power generation schemes and the quantity and quality of the landfill gas generations from landfills. They are likely to be more viable at larger landfills with greater landfill gas generation, a greater capacity gas collection system, and greater power generation capacity, assist both by the concentration of expertise at the site and by certain economies of scale. It is not the purpose of this research to assess the economic benefits of particular sizes of gas installations, but this assessment of the environmental impacts of management options can help in future policy decision making.

This additional analysis examines the effect of managing the MSW waste stream either by diverting BMW from landfill according to the LFD diversion targets, or by concentrating the degradable residues into a degradable waste landfill (and diverting inert material to another landfill). Analyses investigate what the differences could be in terms of greenhouse gas emissions over the life of the landfill, and the differences in potential power generation from the landfill gas recovered.

E1.1.1 Definition of the Scenarios Modelled

Six GasSim models, each representing a different landfill operation scenario, were built to demonstrate the effect of waste input on gas generation, power generation and global warming impact. The influence of gas recovery effectiveness and biodegradable waste composition is examined in these models. The models are defined numerically in *Table E1.1* and *Table E1.2*.

Each hypothetical landfill is assumed to be identical in design, capacity, and fill rate. The waste compositions are varied according to whether Landfill Directive BMW diversion targets are applied (Scenarios A-D) or whether inert wastes are reduced and more biodegradable wastes are accepted at landfill (Scenarios E-F).

Modelling the fate of landfill surface emissions is directly related to understanding gas collection efficiency. Put simply:

Gas Generated (in a given timeframe) =

> *(gas collected at the flare + gas collected at a utilisation scheme + gas lost through lateral emissions + gas lost through surface emissions (subject to methane oxidation) +/- any short term storage in the landfill).*

The flare and gas engine parameters on the right hand side of the equation can be measured directly; lateral emissions are generally small; and short term storage could be considered to be small and effectively constant throughout the site's life. Accurately quantifying gas generated and surface emissions is difficult. Gas collection efficiency is defined as the percentage of gas collected (by flare and other gas utilisation plant) in relation to gas generated. Obviously, if gas generated is an unknown quantity (or rather known between certain limits), the absolute value of the gas collection efficiency is difficult to enumerate as well. In the case of the modelling performed in this study, UK defaults from GasSim, the Environment Agency's risk management tool for landfill gas management, have been used. This approach means that there is an internal consistency between the values quoted, but direct comparison with other sources should not be made without considering the definition of collection efficiency in other studies. For example, collection efficiency can be defined for a given year of landfill operation, a period such as the operational lifetime, a period such as the active gas collection period, or a period of e.g. 100 years or 150 years. Each of these will have a different gas collection efficiency for the same landfill scenario.

Gas collection efficiency is set at 75% over a 100 year period in Scenarios A-B to replicate the approach of the spreadsheet modelling performed elsewhere in this study. In Scenarios C-D, gas collection efficiency is set at 85% when gas can be actively managed at the landfill. This excludes the stage of filling a landfill cell, and the period post closure when gas cannot be collected and combusted. The 85% value is the Environment Agency's expectation of a landfill operator in a current design of landfill. The gas collection efficiency during the active gas management period in earlier decades for previous landfill designs are significantly less than this. Scenarios A-B are compared with Scenarios C-D to demonstrate that the 75% overall collection efficiency is justified in a model representing the effect seen in the population of all current UK landfills (as modelled in the study core scenarios).

Scenarios B, D and F are sensitivity studies on Scenarios A, C and E, to assess the impact of not being able to collect and combust the landfill gas in the tail of gas production. All commercial landfill gas generation models fail to account for the drop in methane content of landfill gas as the production rate decreases. This drop in methane content reflects air ingress during attempts to recover the gas. If the methane content drops below 30%, or the oxygen content rises above 5%, then it is unsafe to flare. The scenarios account for this in the following manner. Scenarios A, C and E allow flaring to continue down to a recovery rate of 200m^3/hr. Scenarios B, D and F allow recovery only down to 500m^3/hr. This is intended to be a surrogate for the degradation in gas quality.

Table E1.1 Scenario Model Definitions

Modelling Parameter	**Scenario**					
	A	**B**	**C**	**D**	**E**	**F**
Voidspace (Mt)	6	6	6	6	6	6
Area (Ha)	25	25	25	25	25	25
Depth (m)	24	24	24	24	24	24
No of Cells	12	12	12	12	12	12
Mass of waste in each cell (Mt)	0.5	0.5	0.5	0.5	0.5	0.5
Begin Filling	2005	2005	2005	2005	2005	2005
End Filling	2034	2034	2034	2034	2034	2034
Cap type	Clay	Clay	Clay	Clay	Clay	Clay
Liner type	Composite	Composite	Composite	Composite	Composite	Composite
Waste Composition	See *Table E1.2*	See *Table E1.2*	See *Table E1.2*	See *Table E1.2*	See *Table E1.2*	See *Table E1.2*
Gas Collection Efficiency	75%	75%	85%	85%	85%	85%
Is the effect of no gas collection during the operational phase modelled?	No	No	Yes	Yes	Yes	Yes
Is the effect of inability to collect landfill gas from the tail of the curve (post utilisation) modelled?	Yes	No	Yes	No	Yes	No

Table E1.2 Waste Compositions Accepted at the Landfills

Waste Component	**Scenarios A-D 2006-2010**	**Scenarios A-D 2010-2015**	**Scenarios A-D 2015-2020**	**Scenarios A-D 2020-2034**	**Scenarios E-F (Diverted Inert Waste) 2005-2034**
Newspapers	11.3	8.5	5.7	4.0	14.8
Magazines	4.8	3.7	2.4	1.7	6.3
Other paper	10.0	7.6	5.0	3.5	13.1
Liquid cartons	0.5	0.4	0.3	0.2	0.7
Card packaging	3.8	2.9	1.9	1.3	5.0
Other card	2.8	2.1	1.4	1.0	3.7
Textiles	2.3	1.8	1.2	0.8	3.0
Disposable nappies	4.3	3.3	2.2	1.5	5.6
Other miscellaneous	3.6	2.7	1.8	1.3	4.7
Garden waste	2.4	1.8	1.2	0.8	3.1
Other putrescible	18.3	13.8	9.2	6.4	24.0
<10mm Fines	7.1	5.3	3.6	2.5	9.3
Non-degradable	28.8	46.2	64.1	74.9	6.6
Total	**100.0**	**100.1**	**100.0**	**99.9**	**100.0**

Scenario A assumes that the landfill achieves the LFD diversion of biodegradable MSW targets. Gas collection efficiency is set at 75% overall and the waste is capped immediately after filling, to replicate the behaviour expected of the whole "landfill population" modelled in the rest of the study.

Scenario B is the same as Scenario A, but in this instance the gas recovery in the tail of the gas generation curve is limited to 500m^3/hr.

Scenario C The landfill achieves the LFD diversion of biodegradable MSW targets. Gas collection efficiency is set at 85% overall, and the availability of gas for utilisation is determined by the degree of capping of the site, to replicate the actual capping procedures expected at a 'normal' landfill site.

Scenario D is the same as Scenario C, but in this instance the gas recovery in the tail of the gas generation curve is limited to 500m^3/hr.

Scenario E. A landfill site is built as a gassing/large biodegradable landfill, which receives larger proportions of degradable waste than the landfills in Scenarios A and B. In this Scenario, the LATS targets are still achieved. More putrescible waste is diverted to the gas-producing landfill, where the landfill gas can be better controlled, and the bulk of the non-degradable fractions are diverted to recycling or the residue to inert landfills. In the GasSim model, non-degradable waste, which stands at 28% for a typical GasSim pre-2010 MSW waste stream (as in Scenarios A and B), is reduced to 6.6%, and the remaining 93.4% of waste is comprised of the same degradable fractions in a typical pre-2010 MSW waste stream scaled up in compositional terms. In this scenario, no compositional biodegradable MSW diversion targets are being followed for this particular landfill. Rather, these would have to be monitored across a portfolio of sites and waste treatment facilities.

Scenario F is the same as Scenario E, but in this instance, the gas recovery in the tail of the gas generation curve is limited to 500m^3/hr.

All the landfills have the same morphology, capacity, and fill rate: 6 Mt of landfill void in a landfill of 25 ha area x 24 m deep, divided into 12 cells each of 20,833 m^3 area and each cell accepting 0.5 Mt waste. Filling commenced in 2005 and is completed in 2034. The assessment period for greenhouse gas impacts is 150 years.

E1.2 RESULTS OF SCENARIO MODELLING

E1.2.1 Scenario A

Figure E1.1 shows the total bulk landfill gas (LFG) produced (top curve), total LFG utilisation by engines (middle curve) and total LFG flared (bottom curve). The landfill is able to support 0.5 MW of gas utilisation (utilising 300 m^3/hr of LFG) almost from the start of filling, with a maximum generating capacity of 1.5 MW. The 1 MW gas engine (utilising 600 m^3/hr of LFG) can be supported from 2010 until 2041 and the 0.5 MW gas engine until 2052. *Figure E1.2* shows the total bulk LFG produced (top curve), surface emissions (middle curve) and lateral emissions bottom curve). The maximum surface emission is predicted to be 450 m^3/hr in 2020. Cumulative global warming impacts for this scenario are 1.1 Mt CO_2-eq.

Figure E1.1 Scenario A: LFG Generation, Utilisation and Flaring

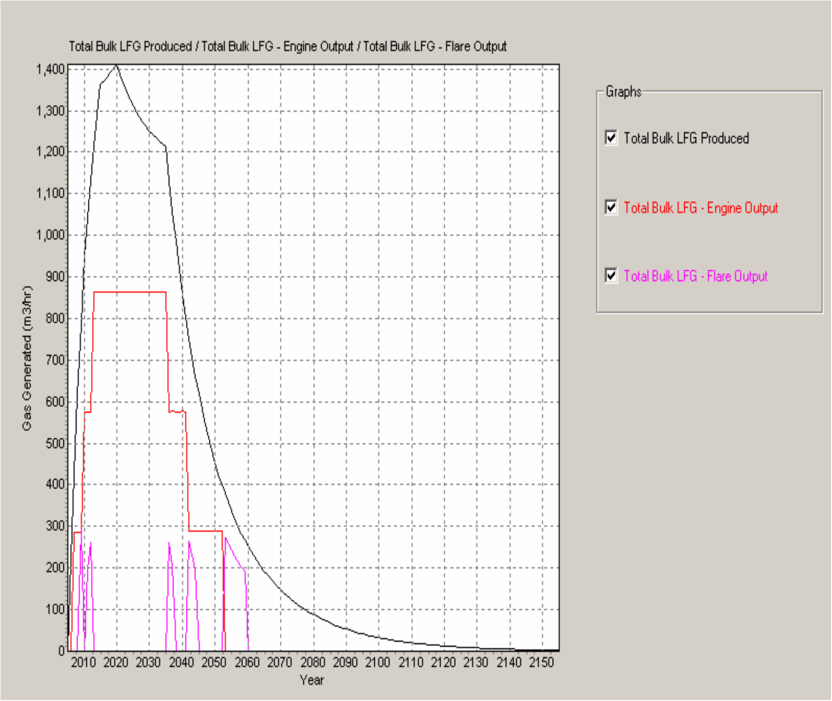
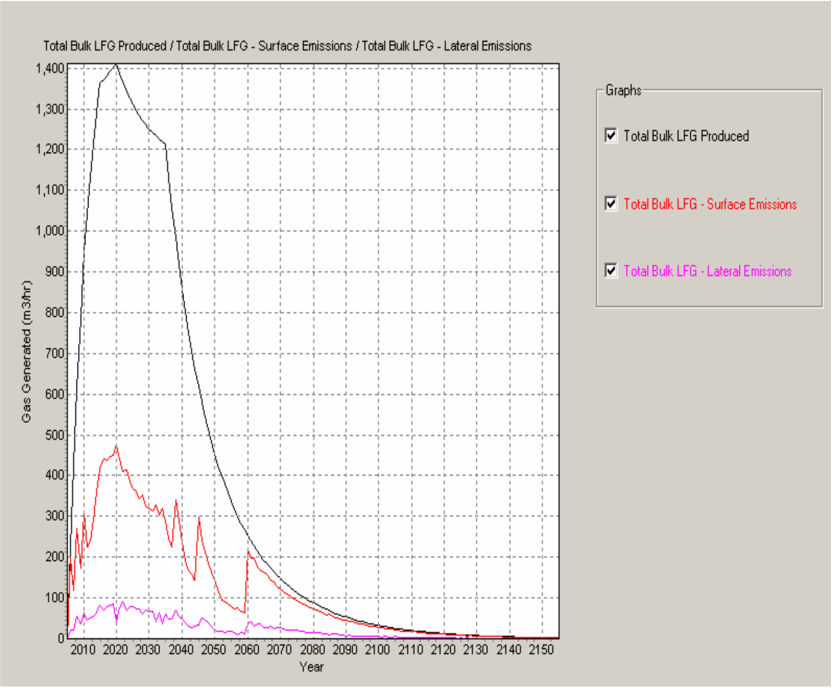


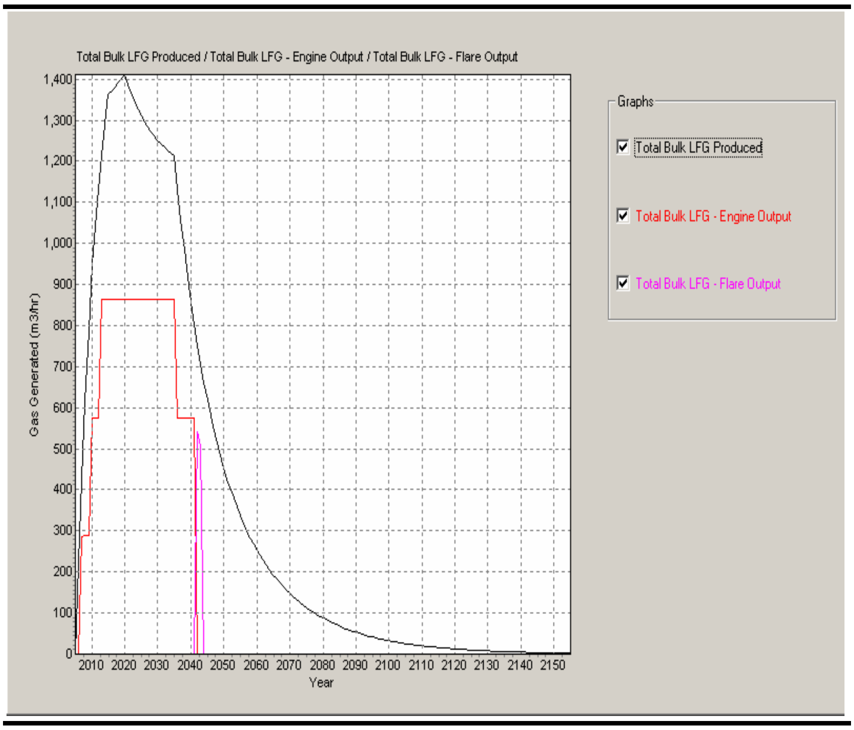
Figure E1.2 Scenario A: LFG Generation, Surface and Lateral Emissions



E1.2.2 *Scenario B*

Scenario B is the same as Scenario A, but with a reduced gas collection efficiency at the end of the landfill's life. In this scenario, the 0.5MW gas engine does not run after 2035, and the flare only operates above 500m^3/hr flowrate (*Figure E1.3*). In this scenario, cumulative global warming impacts of 1.39 Mt CO_2-eq are predicted, compared with 1.11 Mt CO_2-eq in Scenario A, an increase of 25% over the landfill's gassing lifespan. This is ably shown in the surface emissions in *Figure E1.4*.

Figure E1.3 Scenario B: LFG Generation, Utilisation and Flaring

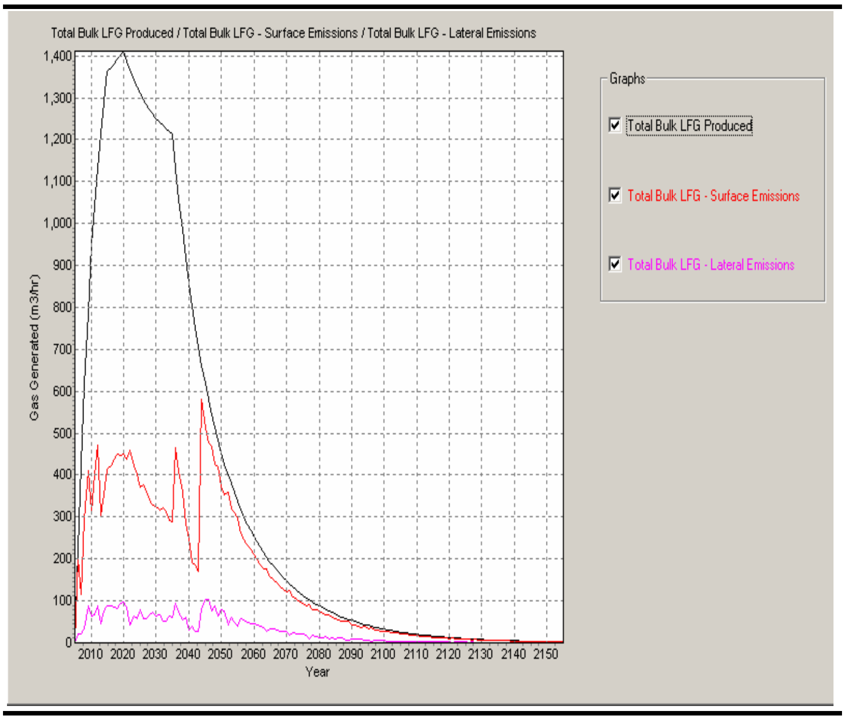


☑ Total Bulk LFG Produced

☑ Total Bulk LFG - Engine Output

☑ Total Bulk LFG - Flare Output

Figure E1.4 *Scenario B: LFG Generation, Surface and Lateral Emissions*



E1.2.3 *Scenario C*

Figure E1.5 shows the total bulk LFG produced, total LFG utilisation by engines and total LFG flared. The landfill is also able to support 0.5 MW of gas utilisation almost from the start of filling, with a maximum generating capacity of 1.5 MW. The 1 MW gas engine can be supported from 2011 until 2041 (except for a gap year in 2023) and the 0.5 MW gas engine until 2054. It can be seen that both Scenario A and C are similar in LFG generation and gas utilisations, suggesting that the 75% average gas collection efficiency value used in modelling was a reasonable assumption to have made.

Figure E1.6 shows the total bulk LFG produced, surface emissions and lateral emissions. The maximum surface emission is predicted to be 750 m^3/hr in 2023. Cumulative global warming impacts of 1.23 Mt CO_2-eq are predicted.

Figure E1.5 Scenario C: LFG Generation, Utilisation and Flaring

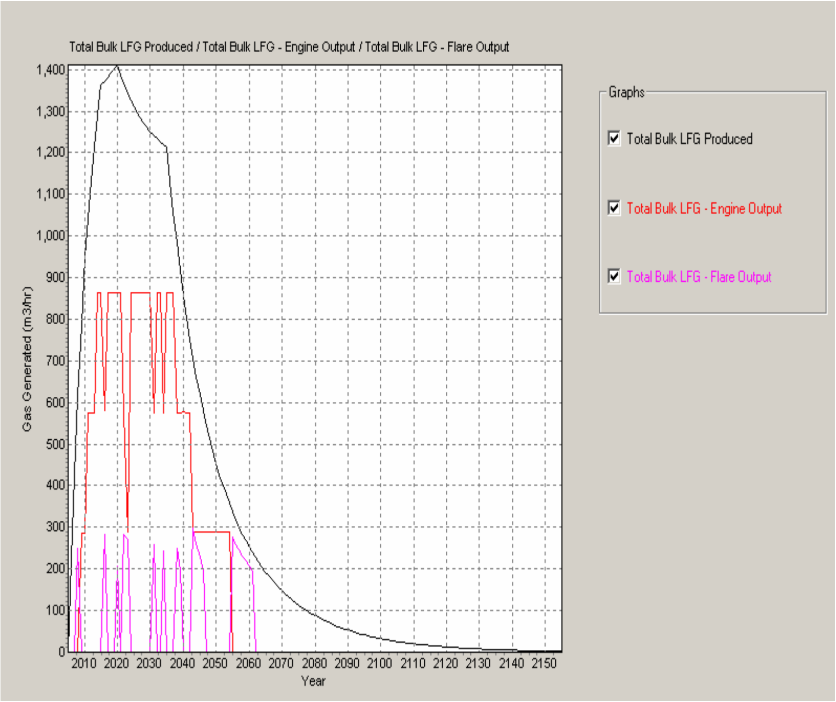
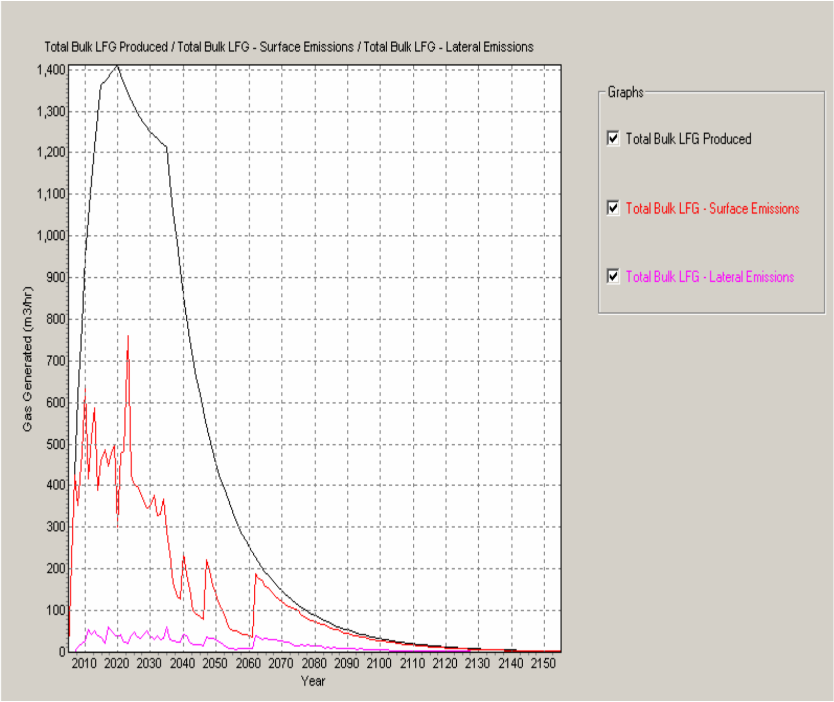


Figure E1.6 Scenario C: LFG Generation, Surface and Lateral Emissions



E1.2.4 Scenario D

Scenario D is the same as Scenario C, but with a reduced gas collection efficiency at the end of the landfill's life. In this scenario, the 0.5MW gas engine does not run after 2038, and the flare only operates above 500m³/hr flowrate (*Figure E1.7*). Cumulative global warming impacts of 1.54 Mt CO_2-eq are predicted, compared with 1.23 Mt CO_2-eq in Scenario C - an increase of 25% over the landfill's gassing lifespan. This is shown in the surface emissions in *Figure E1.8*.

Figure E1.7 Scenario D: LFG Generation, Utilisation and Flaring

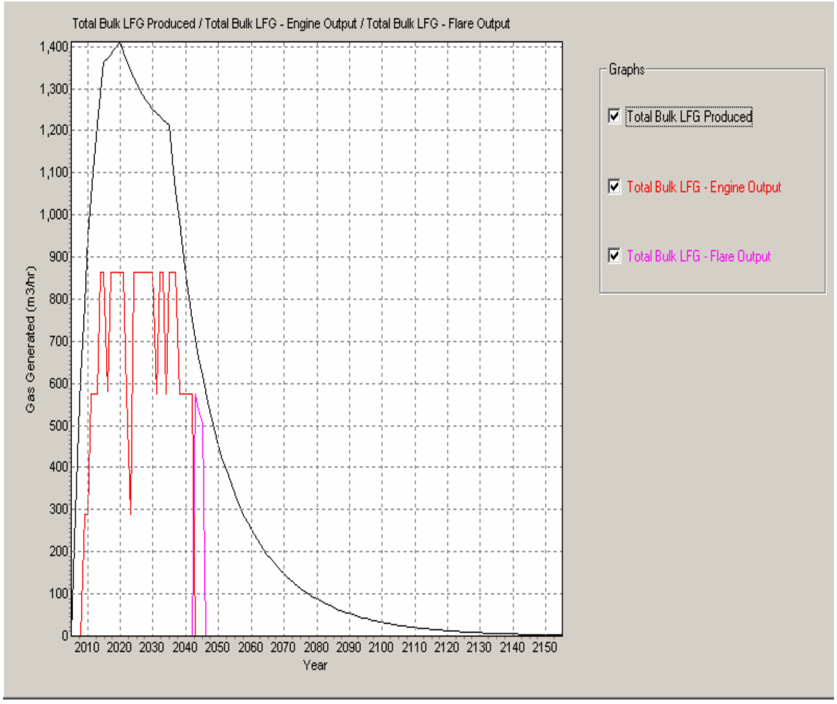
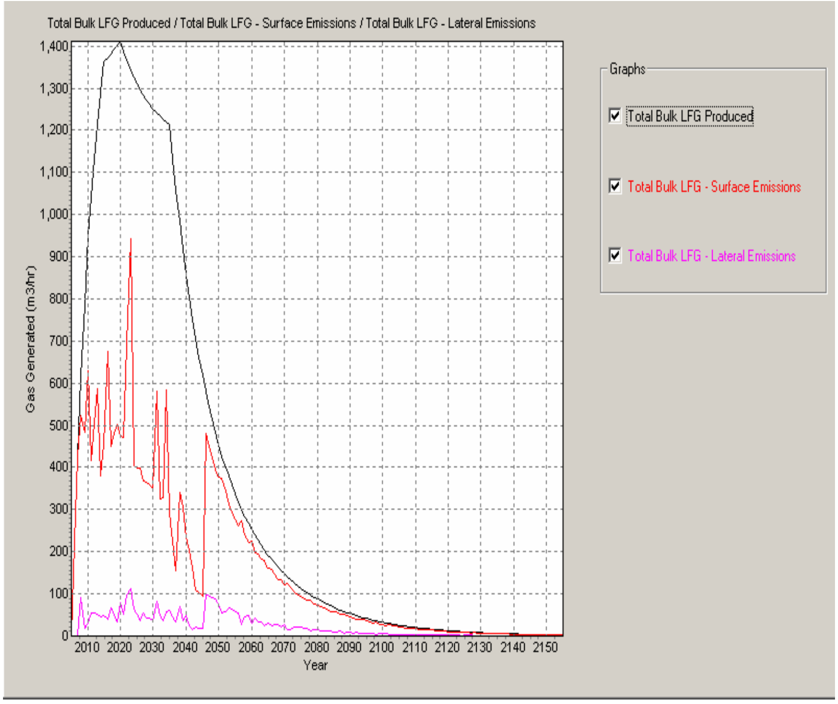


Figure E1.8 Scenario D: LFG Generation, Surface and Lateral Emissions



E1.2.5 Scenario E

Figure E1.9 shows the total bulk LFG produced, total LFG utilisation by engines and total LFG flared and *Figure E1.10* shows the total bulk LFG produced, surface emissions and lateral emissions from this scenario.

It can be seen from *Figure E1.9* that the site grows in gas utilisation capacity, being able to support 0.5 MW in 2008, 1.0 MW in 2011, 1.5 MW in 2014 and continuing to increase until 2032 when 4.5 MW installed capacity is achievable. After 2037, the site steadily loses capacity until 2073, when the last 0.5 MW gas engine is forecast to be decommissioned.

The cumulative global warming impact from the site is higher than that from Scenarios A or C, at 2.33 Mt CO_2-eq.

Figure E1.9 Scenario E: LFG Generation, Utilisation and Flaring

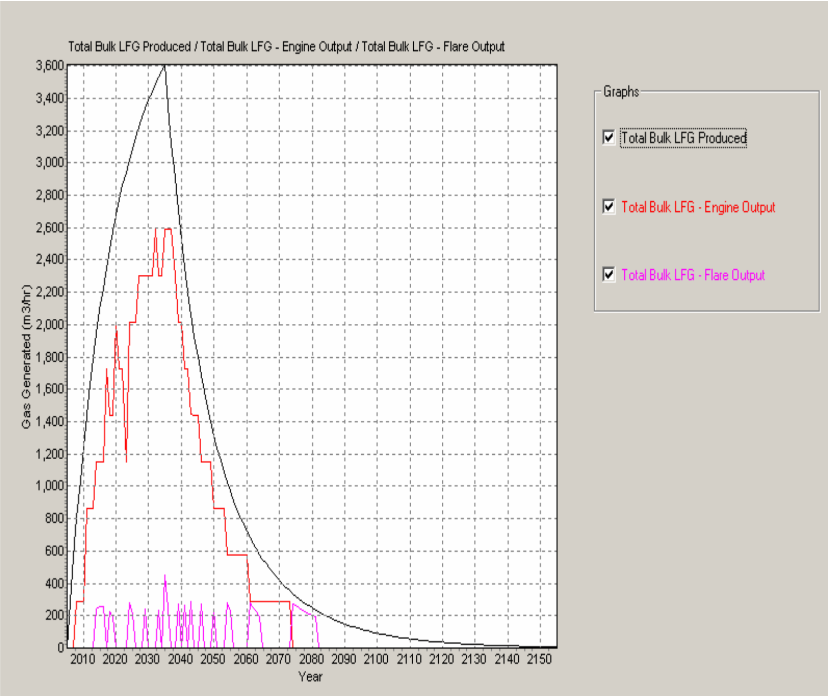
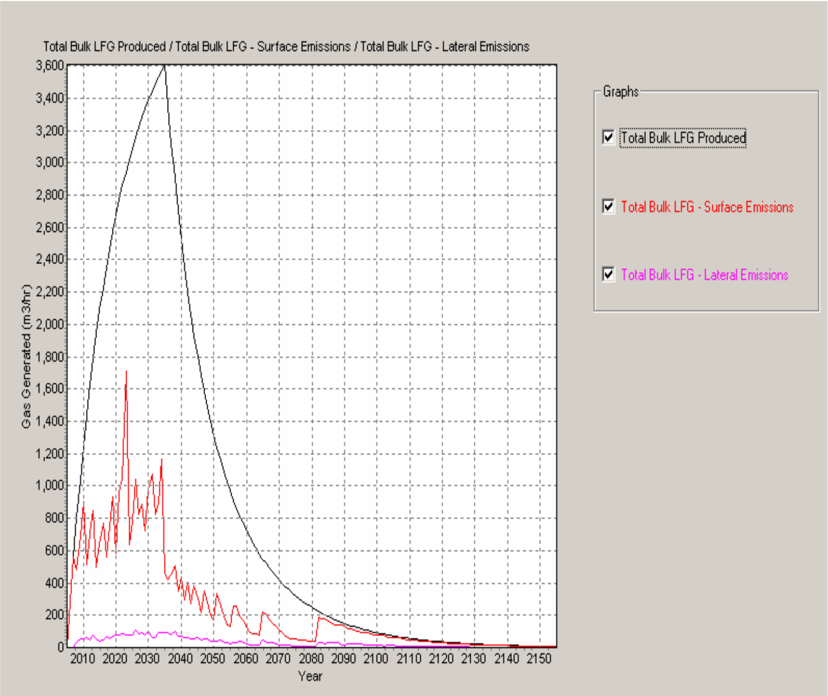


Figure E1.10 Scenario E: LFG Generation, Surface and Lateral Emissions



☑ Total Bulk LFG Produced

☑ Total Bulk LFG - Surface Emissions

☑ Total Bulk LFG - Lateral Emissions

E1.2.6 Scenario F

Scenario F is the same as Scenario E, but with a reduced gas collection efficiency at the end of the landfill's life. In this scenario, the 0.5MW gas engine does not run after 2060 and the flare only operates above 500m^3/hr flowrate (*Figure E1.11*). Cumulative global warming impacts of 2.77 Mt CO_2-eq are predicted, compared with 2.33 Mt CO_2-eq in Scenario E - an increase of 19% over the landfill's gassing lifespan. This is shown in the surface emissions in *Figure E1.12*.

Figure E1.11 Scenario F: LFG Generation, Utilisation and Flaring

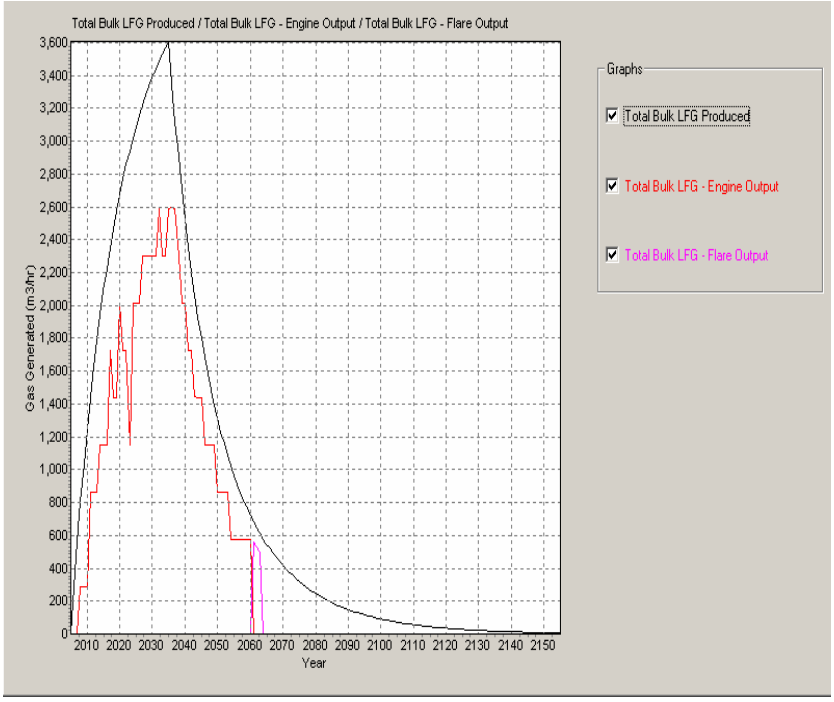
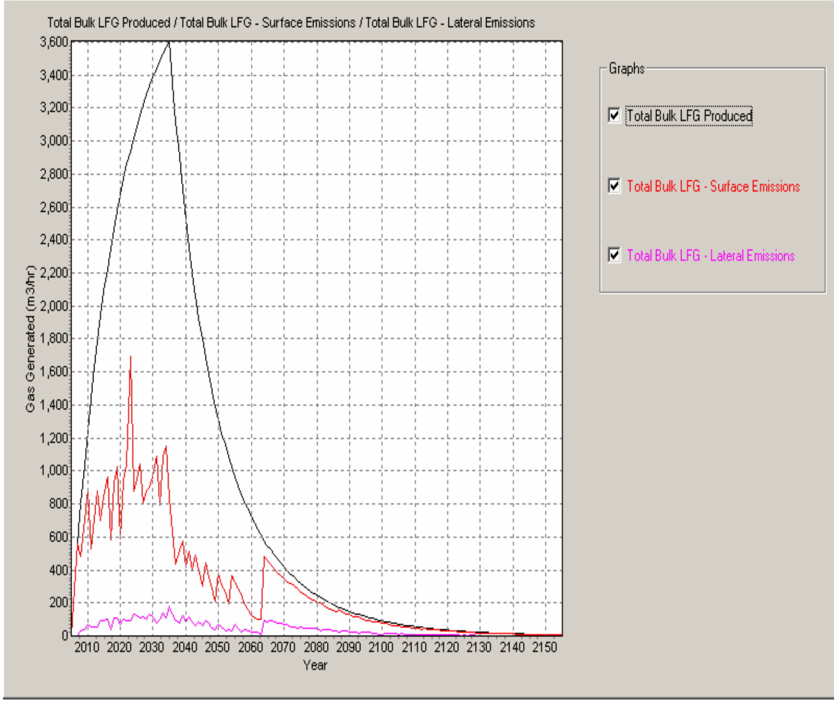


Figure E1.12 Scenario F: LFG Generation, Surface and Lateral Emissions



E1.3 *DISCUSSION AND CONCLUSIONS*

One aim of this modelling exercise was to demonstrate that the approach used in modelling, assuming a 75% collection efficiency over 100 years, for the entire modelled landfill population, is realistic. Scenarios A and C were used to test this hypothesis. Scenario A represents the UK landfill population approach used to model the core study scenarios. Scenario C represents the behaviour of an individual landfill, where gas collection efficiency can be optimised, but operational areas restrict the gas collection efficiency during filling. These scenarios have very similar greenhouse gas impacts and power generation profiles (*Table E1.3*):

- 1.11 and 1.23 Mt CO_2-equivalents respectively emitted (7% variance between the scenarios); and
- 0.42 and 0.40 million MWh energy recovery potential respectively (5% variance).

The permitting regime expects 85% collection efficiency in the operational period of landfilling when active gas management is practicable. This means that during landfilling of individual cells, gas management may not be practicable. In the model example, a landfill with a modelled average of 75% gas collection efficiency, over a 100 year timeframe behaves similarly to a model of the same landfill site where the individual cells are represented and an 85% gas collection efficiency is expected where such gas can be collected by the gas collection infrastructure (but not during filling of the individual cells). On this basis, a 75% gas collection efficiency over 100 years would seem to be a reasonable assumption with regard to current landfill technologies and management. However, the results have been shown to be particularly sensitive to this assumption, and future estimates of climate change impacts associated with landfill would benefit from further work in this area.

There are periods at the start and end of a landfill's life during which gas collection is technologically impractical (at the end of a site's life) or challenging (at the start of a site's life). This modelling shows that a 100-year gas collection value of 75% could result in a lower lifetime (150 year) collection efficiency of approximately 59%. It should be realised that the nature of gas generation and emissions in the late stages of a landfill's life are very site specific, and are not well understood. The modelling assumes first order decay but this is a simplification.

Another aim of this modelling exercise was to examine whether the Landfill Directive BMW targets, aimed at reducing greenhouse gas emissions, might stifle the potential for energy recovery from landfill gas and increase net greenhouse gas emissions. Scenario E was devised to consider greenhouse gas estimates if residual waste is not landfilled in the same fashion as before, but instead the increasing inert fraction is diverted to inert waste landfills and the bioactive component is concentrated at a degradable waste landfill, where additional gas utilisation plant could be employed.

Results show that when inert waste is diverted to inert waste landfills, and the degradable material is concentrated for gas utilisation, greenhouse gas emissions over the 150-year period are higher than those for landfills where diversion of BMW is an exact match with the Landfill Directive diversion targets. For example, Scenario E shows a greenhouse gas burden approximately 1.9 times than that of Scenario C (2.33 and 1.23 Mt CO_2-eq respectively) (*Table E1.3*).

However, these scenarios assume a different quantity of biodegradable waste throughput over the period assessed and so cannot be directly compared without normalising results. We did this by calculating emissions and energy generation potential per tonne of biodegradable waste sent to landfill in each scenario (1). Resulting estimates are shown in *Table E1.4*. These show scenario E to have both reduced greenhouse gas emissions and increased potential for energy generation, leading to further greenhouse gas savings.

From this we can conclude that there is potential for greenhouse gas and energy benefits associated with concentrating degradable wastes in large biodegradable landfills, compared with reducing the biodegradable MSW content at all landfills at an equal rate. There are practical matters to be overcome, primarily relating to gas recovery on a landfill of this type, where there is a lower quantity of inert waste to act as the support medium for the degradable waste (2). However, the effect observed in Scenario E is by no means considered unachievable.

Table E1.3 ***Scenario Greenhouse Gas Emissions and Energy Generation Potential (Total over Period)***

Scenario	Greenhouse Gas Emissions (with gas management) (Mt CO_2-eq)	Energy Generation Potential (Million MWh)	Greenhouse Gas Emissions (without gas management) (Mt CO_2-eq)	Overall Lifetime Gas Collection Efficiency (%)
A	1.11	0.42	2.70	59
B	1.39	0.38	2.71	49
C	1.23	0.40	2.80	56
D	1.54	0.35	2.77	44
E	2.33	1.18	6.57	64
F	2.77	1.12	6.57	58

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(1) Estimates as shown in *Table E1.3*, divided by the total biodegradable waste tonnage sent to landfills over the period assessed

(2) It is also generally acknowledged that inert wastes create pathways for gas transport within the landfill to gas recovery wells

Table E1.4 Scenario Greenhouse Gas Emissions and Energy Generation Potential – per Tonne of Biodegradable Waste Landfilled

Scenario	Greenhouse Gas Emissions (with gas management) (tonnes CO_2-eq)	Energy Generation Potential (MWh)	Greenhouse Gas Emissions (without gas management) (tonnes CO_2-eq)	Overall Lifetime Gas Collection Efficiency (%)
A	0.47	0.18	1.14	59
B	0.59	0.16	1.15	49
C	0.52	0.17	1.19	56
D	0.65	0.15	1.17	44
E	0.42	0.21	1.17	64
F	0.49	0.20	1.17	58

A further aim of the modelling exercise was to ascertain the impact, in terms of gas collection efficiency, of not being able to manage the landfill gas in the tail of the gas production curve. The GasSim model used in this assessment does not automatically account for the dilution of methane content in old landfills. This occurs because the gas field is put under greater pressure to recover smaller amounts of generated gas, and atmospheric air can be drawn into the site when such suctions are applied.

Scenarios A, C and E do not consider this effect, and allow GasSim to operate the abstraction flare down to 200 m^3/hr. Scenarios B, D and F reflect A, C and E but, at the tail end of gas production, do not allow the flare to operate below 500 m^3/hr. This is a surrogate value was designed to simulate the deterioration period for gas abstraction when the methane content and/or oxygen content is such that the gas can no longer be flared.

Results show that for Scenarios B and D, the increase in greenhouse gas emissions is 25% above the corresponding scenarios A and C. For Scenario F, the increase is only 19%. There is a corresponding drop in electricity generation forecast for these scenarios also: between 8% for Scenario B and 5% for Scenarios D and F. The loss in power generation is only forecast at the tail of gas production, and this part of the forecast curve is also the most difficult to estimate.

By modelling landfills without any gas management, we can compare greenhouse gas emissions and assess the overall lifetime gas collection efficiency of scenarios (shown in *Table E1.3* to be between 44-64% for the six scenarios modelled). This range of lifetime gas collection efficiency values is much lower than is achievable during the operational period. While gas collection efficiency can be maintained on modern, engineered sites at 85% during the operational phases when gas collection is efficient, this does not hold when the uncontrollable tail of the gas generation curve is considered.

As we have discussed above, collection efficiency can be different values for different timeframes of consideration. An estimated value for 150 year lifetime gas collection efficiency of between 56 – 64% is predicted if there are no losses of methane resulting from inabilities to collect gas at the tail end of production. An additional 8 – 12% of gas can be lost if the methane is not safely recoverable for flaring (Scenarios B, D and F). This scenario modelling is not only very site specific, but is also dependent on modelling assumptions of the magnitude of uncontrolled gas loss after the active gas management phase. There is very little information other than comparative modelling to substantiate these values, and this is one area where additional research would be beneficial.

Annex F

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