Impact of EU Landfill Directive and National Strategies on UK Greenhouse Gas Emissions

FINAL REPORT

March 2004

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Impact of EU Landfill Directive and National Strategies on UK Greenhouse Gas Emissions

March 2004

Reference 000299

For and on behalf of
Environmental Resources Management
Approved by: SIMON AUMÔNIER
Signed:
Position: PARTNER
Date: 29th MARCH 2004

EXECUTIVE SUMMARY

INTRODUCTION

This report is submitted by Environmental Resources Management (ERM), as one part of two parallel projects commissioned by Defra, namely:

- *Methane Emissions from Landfill Sites in the UK*; and
- *Impact of EU Landfill Directive and National Strategies on UK Greenhouse Gas Emissions*.

Land Quality Management Limited (LQM) was primarily responsible for the first report, which contributed to this work.

This report examines the wider effects and impacts of waste-related policies on greenhouse gas (GHG) emissions and ammonia emissions arising from the life cycle of UK waste management systems. The policies considered include the Landfill directive and those set out as targets in Waste Strategy 2000. The study predated the National Waste Plan for Scotland and the detailed policies set out therein.

WASTE MANAGEMENT IN CONTEXT

Waste management in the UK accounts for approximately 2.5% (1) of the UK GHG inventory. Although waste management is not directly the major source of GHG emissions, waste producers, the industry and others responsible have a significant role to play in reducing GHG emissions. Reductions can be achieved through the displacement of virgin material with recycled material and through the displacement of fossil fuel derived energy with waste derived energy.

Figure 1 shows a typical GHG emission profile for the life cycle of a plastic packaging product (based on 1 tonne of plastic packaging). *Figure 1* demonstrates the rationale behind the promotion of recycling because of its environmental benefits and the need to take a life cycle approach. Although there is some benefit in avoiding waste management GHG emissions, a more significant benefit is achieved through the displacement of the first life cycle stages by recycling materials. However, recovery and reprocessing of materials also results in emissions of GHG and these need to be balanced against the displacement benefit secured by recycling. It is generally accepted that a break point exists, where the effort to extract and process increasing levels of secondary material will outweigh the benefit achieved through the displacement of primary material.

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(1) UK submission of GHG Inventory to UNFCCC for the year 2000.

Figure 1 *Life Cycle Profile*

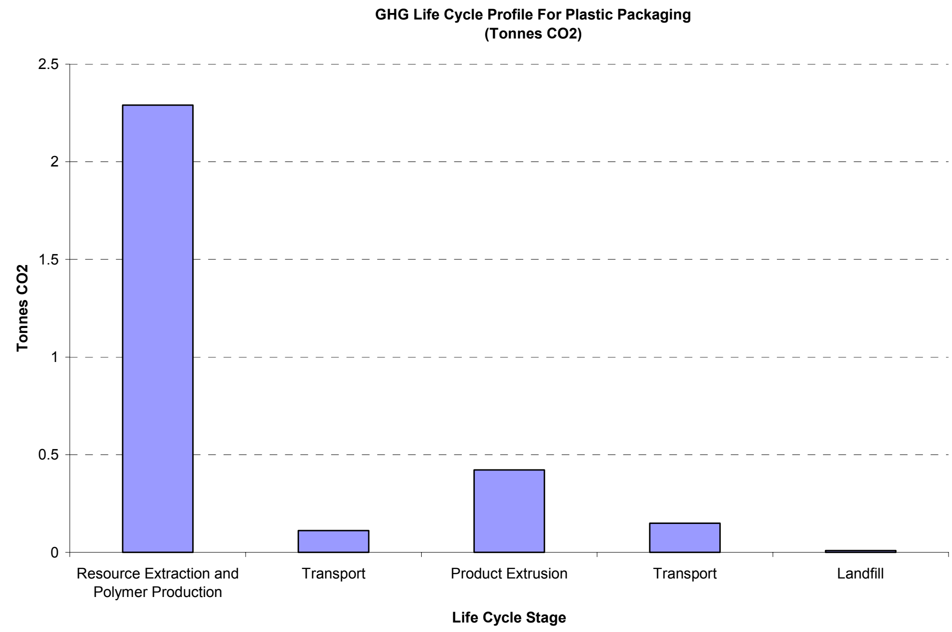
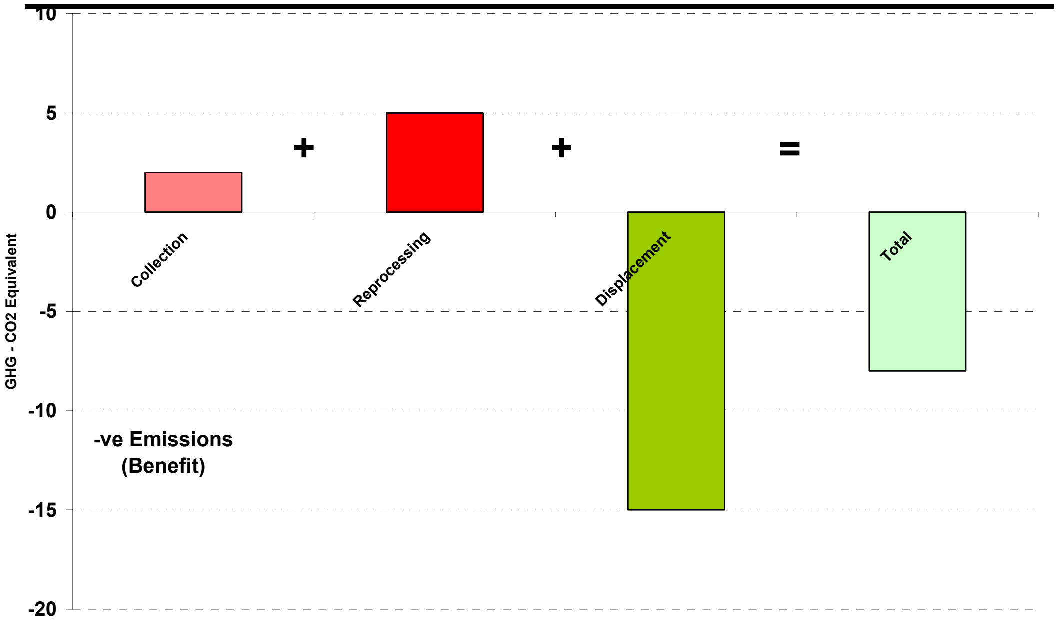


Figure 2 *The Offset Concept (Displacement and Negative Emissions)*



A LIFE CYCLE APPROACH

A life cycle approach has been used to assess the GHG emissions associated with waste management in the UK. The GHG emissions associated with all waste activities (transport, treatment and recycling) have been calculated and a GHG benefit has been attributed to the recovery of energy and the displacement of materials through recycling where this occurs. The processes upstream of waste management have not been studied in detail. GHG emissions from waste disposal activities being significantly lower than the benefit attributed to the displacement of primary material and energy production. As a result, the net GHG emissions are negative (see *Figure 2*) for the scenarios studied.

MODELLING APPROACH

The modelling approach used reflects the previous paragraph and *Figure 2* and was used for both GHGs and ammonia. Several scenarios were defined (see *Table 1*) to examine the different ways in which relevant policy targets might be met. There are eight scenarios for the management of municipal solid waste (MSW) and five scenarios for the management of commercial, industrial and other waste (CIO waste). These scenarios formed the basis of the spreadsheet modelling process to estimate GHG emissions.

Key factors that were included in the spreadsheet model include:

- current waste arisings and management;
- waste composition;
- growth rates over time; and
- emissions factors for each activity within the life cycle.

The spreadsheet modelling process was consistent with the approach adopted by LQM in modelling landfill emissions and with good practice guidance. In order to calculate emissions that best reflect UK waste management practice, emission factors were sourced from elsewhere than the IPCC emission factors database (e.g. life cycle assessment software databases ***WISARD*** and PEMS, and information from the Swedish Defence Agency).

Further, detailed assumptions used in the spreadsheet modelling of GHG emission estimates are elaborated in the main report as well as within the spreadsheet models and the LQM report.

Table 1 MSW and CIO Scenarios used to Calculate GHG Emission Estimates from UK Waste Management Systems

	Scenario Definition
MSW	
Scenario 1	Achieving WS 2000 and Landfill Directive targets with current material recycling rates and higher recovery.
Scenario 2	Achieving WS 2000 and Landfill Directive targets with an emphasis on paper recycling and composting (i.e. diverting degradable waste from landfill).
Scenario 3	Achieving WS 2000 and Landfill Directive targets with an emphasis on paper recycling alone (i.e. diverting degradable waste with an energy benefit).
Scenario 4	Achieving WS 2000 and Landfill Directive targets with an emphasis on energy recovery through mass burn energy from waste.
Scenario 5	Achieving WS 2000 targets with an emphasis on glass, metals and plastics recycling (i.e. diverting non-degradable waste from landfill). The Landfill Directive targets are not achieved in 2013 and 2020.
Scenario 6	Higher growth rate, achieving WS2000 and Landfill Directive targets with current material recycling proportions and excess recovery.
Scenario 7	Higher growth rate, achieving WS2000 and Landfill Directive targets with excess material recycling rates.
Scenario 8	This is the basecase scenario, current ratio of recycling to recovery is maintained and the rate of change in diversion observed between 96/97 to 99/00 is maintained.
CIO Waste	
Scenario 1	WS 2000 target of 15% diversion achieved with current trends in diversion continued.
Scenario 2	WS 2000 target of 15% diversion of C&I wastes from landfill achieved through a mix of digestion, mass burn energy from waste and recycling of food wastes, paper & card and other general biodegradable wastes.
Scenario 3	WS 2000 target of 15% diversion of C&I wastes from landfill achieved through combustion of general biodegradable wastes.
Scenario 4	WS 2000 target of 15% diversion of C&I wastes from landfill to be achieved through recycling general biodegradable wastes.
Scenario 5	WS 2000 target of 15% diversion of C&I wastes from landfill to be achieved through recycling C&D and mineral wastes.

MODELLING RESULTS

Introduction

GHG emission estimates from MSW and CIO waste scenarios, for England and Wales, Scotland, Northern Ireland, and the Channel Islands[1] and the UK[2] as a whole, are presented in chart form in *Annexes C-F* (GHG Estimates) and *H* (ammonia estimates) of this report.

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(1) Gibraltar is not included in this instance as all waste arising is exported to Spain for management (Environmental Agency, Gibraltar).

(3) UK meaning England & Wales, Scotland and Northern Ireland.

The following discussion applies to all results, whether it be individual results for England & Wales, Scotland, Northern Ireland, the Channel Island or the UK as a whole. This is because the estimates for the devolved administrations are scaled from the England & Wales spreadsheet model. Scaling factors were used due to the absence of complete waste statistics, at the time of modelling, for Scotland, Northern Ireland and the Channel Islands[1]. Therefore, the results only differ in the magnitude of the GHG emissions.

Analysis of Results of GHG Emission Estimates

Table 2 summarises the trends observed in estimating emissions of GHGs from the management of MSW (excluding landfilling). The trends are influenced both by waste policies (i.e. achieving the targets of the Landfill Directive and WS 2000) and by waste growth rates.

In the case of landfill emission estimates, which were provided by LQM from the parallel report, the methane estimates showed a contribution to GHG, but one that falls over the time horizon of the study.

The landfill methane estimates also show that waste growth rates have a greater impact on landfill methane emissions than the way in which waste policies are interpreted in the scenarios.

Unlike the landfill methane emissions scenarios, the other waste management activities in MSW management result in a net GHG benefit (2) over time (see *Figure 3*) because of the displacement benefits of energy and materials recovery. *Figure 3* shows the GHG emissions for the scenarios, when the GHG emissions and benefits associated with transport, treatment (landfill not included) and avoidance of primary material and energy production are added together.

As with MSW, the waste management activities other than landfill for the CIO waste scenarios result in a net reduction in GHG emissions over time (see *Figure 4*). The GHG benefit that is achieved through waste management activities other than landfill in the CIO scenarios were approximately three to eight times greater than MSW reductions, depending on the scenario assumptions. This is because of the substantial amounts of commercial and industrial and other waste generated compared to MSW in the wider context of total waste arisings in the UK, rather than the mix of materials that can be recovered or recycled.

(1) It is recognised that since the time of spreadsheet development and modelling, more detailed waste statistics for Scotland and Northern Ireland have emerged. Therefore, although the results of this study may not reflect the current waste statistics and individual targets, it does however provide an indicative and reliable representation of GHG emissions for the different scenarios modelled.

(2) Benefit occurs due to avoided emissions. The avoided emissions are a result of offsetting virgin material and energy production. Where this occurs a negative emission of GHG emissions is allocated in accordance with standard life Cycle Assessment practice.

Figure 3 *GHG Emissions from Waste Management Activities Excluding Landfill for MSW Scenarios 1 -8 for England and Wales*

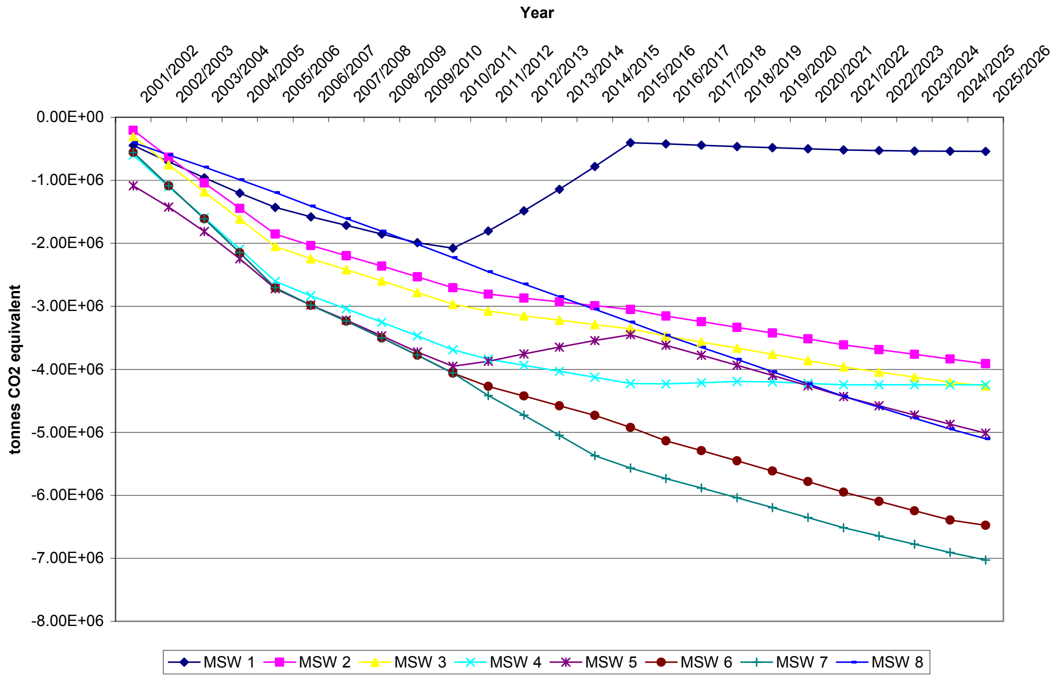
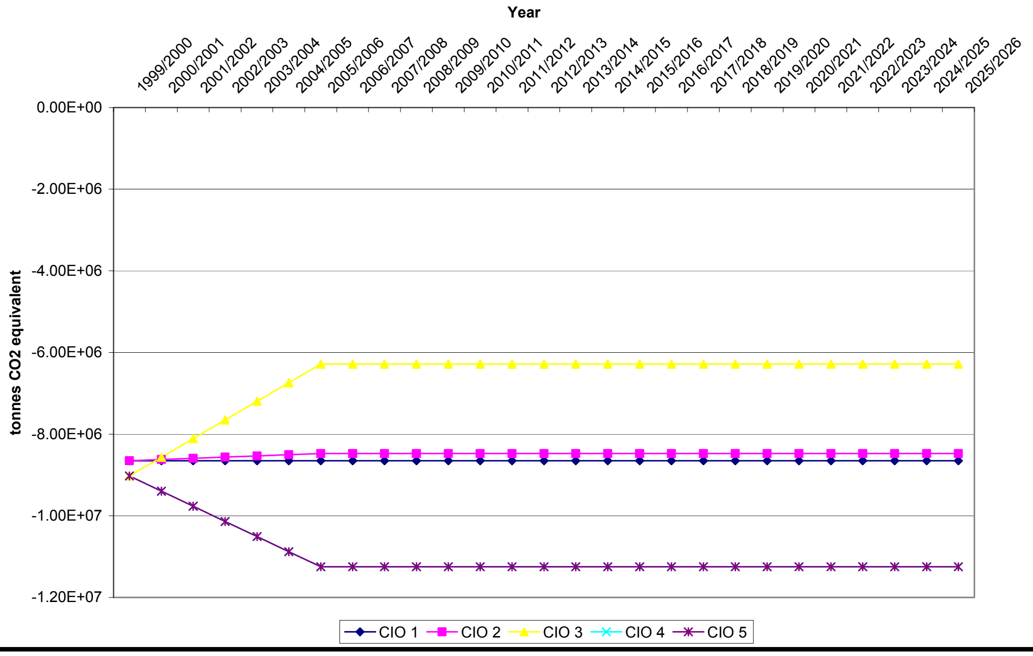


Figure 4 *GHG Emissions from Waste Management Activities Excluding Landfill for C&I and Other waste (CIO) Scenarios 1 –5 for England & Wales*



Note: CIO5 overlaps CIO4

Table 2 Discussion and Comparison of MSW GHG Emissions for England and Wales – According to Scenarios 1 - 8

Scenario	Reference Chart	Governing Scenario Waste Policy	General Observation
1	Figure 6.1	Achieving WS 2000 and Landfill Directive targets with current material recycling rates and higher recovery.	A general downward trend in GHG emissions is observed. However, as the WS 2000 targets require a 66% recovery of MSW in 2015, the increased use of EfW causes a slight increase in CO_2 emissions between 2010 and 2015. The reduction in GHG emissions increases after 2015 as the proportion of waste recycled and recovered increases in the face of declining waste growth.
2	Figure 6.1	Achieving WS 2000 and Landfill Directive targets with an emphasis on paper recycling and composting.	A steady downward trend in GHG emissions as recycling and composting rates increase over time.
3	Figure 6.1	Achieving WS 2000 and Landfill Directive targets with an emphasis on paper recycling alone.	A steady downward trend in GHG emissions as paper recycling rates increase over time.
4	Figure 6.1	Achieving WS 2000 and Landfill Directive targets with an emphasis on energy recovery through mass burn energy from waste.	A steady downward trend in GHG emissions through recycling and recovery, slowing as the recovery rate begins to dominate.
5	Figure 6.1	Achieving WS 2000 targets with an emphasis on glass, metals and plastics recycling. The Landfill Directive targets are not achieved in 2013 and 2020.	A steady downward trend in GHG emissions. However, as the WS 2000 targets require a 66% recovery of MSW in 2015 and 33% recycling of household waste, the increased rate of EfW causes a decrease in the offset emissions between 2010 and 2015. This is due to more paper being diverted through transfer stations for either landfilling/EfW during that period, as the scenario emphasises recycling of glass, metals and plastics. The offset increases after 2015 recycling and recovery rates increase in the context of declining waste growth.
6	Figure 6.1	Higher growth rate, achieving WS2000 and Landfill Directive targets with current material recycling proportions and excess recovery.	A steady downward trend in GHG emissions, where recycling and recovery achieve a higher net benefit of GHGs compared with the other scenarios. The excess recovery rate through EfW contributes to this high net benefit in GHG emissions, despite an assumed higher waste growth rate between 2001 and 2005.
7	Figure 6.1	Higher growth rate, achieving WS2000 and Landfill Directive targets (1) with excess material recycling rates.	A steady downward trend in GHG emissions, where recycling and recovery achieve a greater reduction in GHG emissions compared with the other scenarios. The excess recovery rate through recycling and composting contributes to this high reduction in GHG emissions, despite an assumed higher waste growth rate between 2001 and 2005.
8	Figure 6.1	This is the basecase scenario, current ratio of recycling to recovery is maintained and the rate of change in diversion observed between 96/97 to 99/00 is maintained.	A steady downward trend in GHG. This scenario initially achieves the least emissions reductions, based on current practice, but exceeds the reductions of scenario 1 by 2009, and some of the other scenarios beyond 2013. By 2025, only scenarios 6 and 7 exceed reductions of scenario 8.

Analysis of Results of Ammonia Emission Estimates

Annex H presents the results of ammonia emissions for England and Wales, Scotland, Northern Ireland and the Channel Islands. In all cases the releases are positive, i.e. there is not the same benefit of offset emissions from recycling and energy recovery estimated for GHG emissions. The benefit of recycling for GHG emissions are associated with avoiding energy consumption associated with the use of virgin materials. Recycling and incineration show limited avoidance of ammonia emissions, and hence there is a lower benefit secured.

COST-EFFECTIVENESS ANALYSIS FOR GHG EMISSIONS FOR ENGLAND & WALES

Costs of MSW Scenarios Modelled (excluding Landfill)

Indicative total costs for the MSW waste scenarios were developed for England and Wales but not provided for Scotland, Northern Ireland, Channel Islands and the UK as a whole[1]. The results are presented in *Table 3*. The costs were calculated assuming current waste management costs, landfill costs have been excluded as the modelling undertaken by ERM relates to all other waste management activities and not landfill.

Generally, costs increase over time, as more expensive waste management routes are pursued. However, the rise in costs is accompanied by a decrease in GHG emissions. The cost-effectiveness of scenarios 1 and 2 is shown in *Figures 5* and *6*, respectively. Whilst scenario 1 shows a decrease in cost-effectiveness over 2010 to 2015, scenario 2 demonstrates continuing cost-effectiveness for delivering GHG emissions reductions over the period studied.

The shape of the remaining graphs is strongly influenced by the trend of the GHG emissions reductions for each scenario, as shown in *Figure 3*. With the exception of scenarios 1 and 5, continuing cost-effectiveness is demonstrated by all the scenarios over the period examined and there are increased returns as a result of the rising costs of waste management.

(1) This was due to the complex nature of the presenting spreadsheets developed (derived through the use of scaling down factors and combined scenarios - *Section 6.3*), making it difficult to extract and assess the total costs

Table 3 Total Costs (1) for the Municipal Waste Management Scenarios for England & Wales

MSW Scenarios	**Year**	**Waste arising (x 10^7 tonne / year)**	**GHG Emissions[1] (x 10^{11} g CO_2 equivalent**	**Total Estimated Cost[2] (x 10^9 £)**
Scenario 1 Achieving WS 2000 and Landfill Directive targets with current material recycling rates and higher recovery.	2002	3.22	-4.5	2.0
	2005	3.52	-14.3	3.5
	2010	3.89	-20.8	4.1
	2015	4.09	-4.1	5.4
	2025	4.19	-5.4	5.9
Scenario 2 Achieving WS 2000 and Landfill Directive targets with an emphasis on paper recycling and composting (i.e. diverting degradable waste from landfill).	2002	3.22	-6.33	2.0
	2005	3.52	-18.5	2.6
	2010	3.89	-27.0	3.1
	2015	4.09	-30.5	3.7
	2025	4.19	-39.1	4.0
Scenario 3 Achieving WS 2000 and Landfill Directive targets with an emphasis on paper recycling alone (i.e. diverting degradable waste with an energy benefit).	2002	3.22	-7.6	2.1
	2005	3.52	-20.5	2.7
	2010	3.89	-29.6	3.3
	2015	4.09	-33.6	3.8
	2025	4.19	-42.6	4.3
Scenario 4 Achieving WS 2000 and Landfill Directive targets with an emphasis on energy recovery through mass burn energy from waste.	2002	3.22	-11.0	2.0
	2005	3.52	-26.0	2.6
	2010	3.89	-36.9	3.1
	2015	4.09	-42.3	3.7
	2025	4.19	-42.5	3.9
Scenario 5 Achieving WS 2000 targets with an emphasis on glass, metals and plastics recycling (i.e. diverting non-degradable waste from landfill). The Landfill Directive targets are not achieved in 2013 and 2020.	2002	3.22	-14.3	2.1
	2005	3.52	-27.2	2.7
	2010	3.89	-39.5	3.2
	2015	4.09	-34.5	3.8
	2025	4.19	-50.1	4.2
Scenario 6 Higher growth rate, achieving WS2000 and Landfill Directive targets with current material recycling proportions and excess recovery.	2002	3.3	-10.9	2.0
	2005	3.7	-27.1	2.7
	2010	4.3	-40.6	3.2
	2015	4.7	-49.2	3.9
	2025	5.1	-64.8	4.6
Scenario 7 Higher growth rate, achieving WS2000 and Landfill Directive targets (1) with excess material recycling rates.	2002	3.3	-10.9	2.0
	2005	3.7	-27.1	2.7
	2010	4.3	-40.6	3.2
	2015	4.7	-55.7	4.1
	2025	5.1	-70.3	4.6
Scenario 8 This is the basecase scenario, current ratio of recycling to recovery is maintained and the rate of change in diversion observed between 96/97 to 99/00 is maintained.	2002	3.22	-6.0	1.9
	2005	3.52	-11.9	2.2
	2010	3.89	-22.3	2.7
	2015	4.09	-32.5	3.1
	2025	4.19	-51.0	3.8

Notes:

1 GHG emissions for waste management activities other than Landfill. Includes post transfer site transport emissions

2 Excludes post transfer site transport costs due to unavailable data

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(1) Costs were calculated based on waste management costs in 2001/2. The costs exclude landfill costs.

Figure 5 *Scenario 1 Waste Management Costs per Year Compared with GHG Benefit Achieved Through Diversion from Landfill*

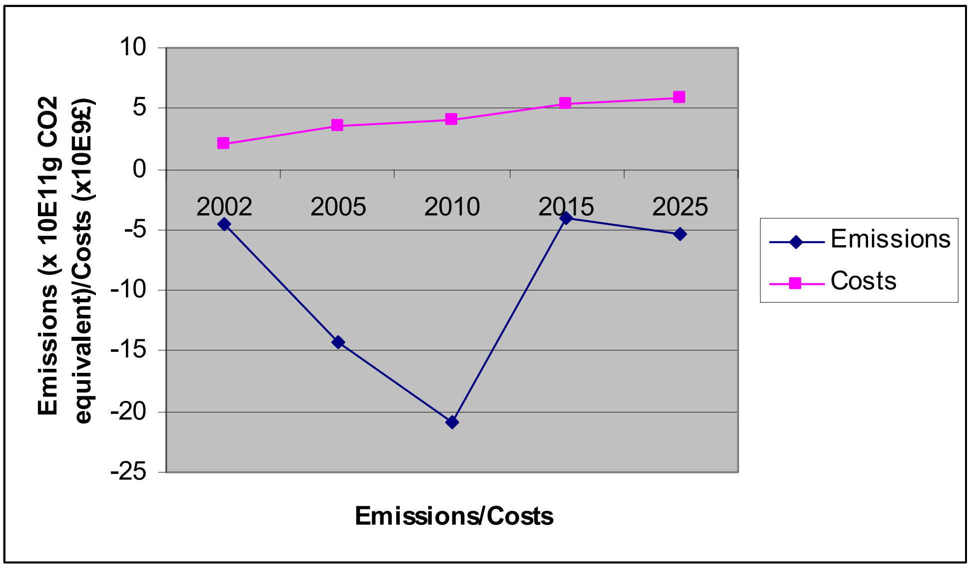
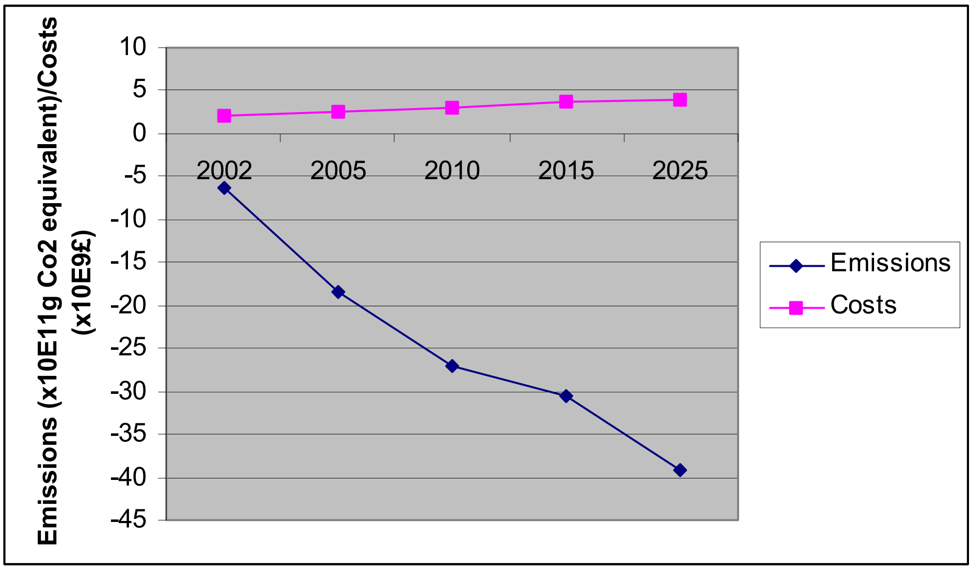


Figure 6 *Scenario 2 Waste Management Costs per Year Compared with GHG Benefit Achieved Through Diversion from Landfill*



This costing exercise has not been repeated for the C&I waste and Other Waste scenarios. This is because waste disposal in these sectors is a commercial spot market, and reliable cost factors are difficult to obtain. Furthermore, recycling, and, to an extent, recovery, methods have a wide range of prices because of variation in the value of the waste itself (e.g. for paper, from clean offcuts to a mixed paper waste stream).

In the absence of other drivers, waste producers will only change management route in response to lower prices. Accordingly, many producers could be expected to change the preferred management route for their wastes in response to changes in the landfill tax, and as a result of other increases in the cost of landfill. The cost at which change will occur will vary depending on the other routes available, and the complexity of these margins is not possible to model within the constraints of this study.

Cost of Landfill Methane Emissions

Two cost models were developed for UK landfill methane emissions, based on varying landfill tax and tax escalator levels. The two models adopted were:

- Based on the current situation i.e. £13/tonne in 2002/03 and a continued annual landfill tax escalator of £1/tonne up to 2024/25; and
- Based on *'Waste Not, Want Not'* recommendations i.e. £35/tonne in the medium term (beginning 2010/11 in this case) and an annual landfill tax escalator of £3/tonne right up to 2024/25.

It was assumed that current gates fees apply to overall cost of landfilling a tonne of waste (£12.67).

Table 4 presents indicative costs for landfilling waste in 2002, 2005, 2010, 2015 and 2025. Unlike costs presented above (i.e. only for individual MSW scenarios for England and Wales), the costs presented in *Table 4* are derived from combinations of MSW and CIO waste scenarios for the UK i.e. 40 combinations. *Table 4* serves as a summary of the costs for the 40 scenarios assessed[1]. The landfill methane emissions of the 40 scenarios can be referred to in the Annexes.

Table 4 ***Landfill Costs for the Quantity of Wastes Landfilled and the Amount of Methane Emissions Produced from Landfill (see Annexes)***

	Combined Scenarios			
Year	**MSW 1-5,8 and CIO1-5**		**MSW 6,7 and CIO 1-5 (x 10^9 £)**	
	Current Situation **(x 10^6 £)**	'Waste Not, Want Not' Recommendations **(x 10^9 £)**	Current Situation **(x 10^6 £)**	'Waste Not, Want Not' Recommendations **(x 10^9 £)**
2002	6.3	6.3	6.2	6.3
2005	7.1	7.1	7.1	7.1
2010	8.5	8.6	1.2	1.2
2015	9.8	10.1	1.6	1.6
2025	1.2	13.0	2.4	2.5

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(1) For scenario combinations: see *Section 6.7*

CONCLUSIONS

All the scenarios modelled result in a negative GHG burden by 2005. The GHG benefit that is achieved, through offsetting the primary production of materials and energy through recycling and energy/material recovery, outweighs the direct GHG emissions associated with transport and waste treatment processes.

The switch from a net emission to a net benefit (negative emission) is due to the increased recovery and recycling capacity that will arise as a result of waste management policy. The results demonstrate that waste management in the UK has a role to play in reducing GHG emissions. However, it should be noted that the study does not study in detail the GHG emissions associated with upstream life cycle stages. It therefore overlooks dynamic effects and the increasing difficulty by which higher levels of recycling and recovery will be achieved.

The growth in waste arisings that are predicted in the UK is accompanied by increased product consumption. Increases in product consumption are likely to result in higher GHG emissions, which may not be mitigated by the benefits achieved through waste management. Without addressing the whole life cycle of products and their consumption, it is impossible to say what recovery and recycling levels would be necessary to mitigate the emissions associated with increased product consumption.

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1 OUTLINE OF THE STUDY

1.1 INTRODUCTION

This report is submitted by Environmental Resources Management (ERM), as one part of two parallel projects commissioned by Defra, i.e.:

- *Methane Emissions from Landfill Sites in the UK; and*
- *Impact of EU* Landfill Directive *and National Strategies on UK Greenhouse Gas Emissions.*

Land Quality Management Limited (LQM) was primarily responsible for the first report. The results of this work fed into ERM's work on the second project, which examines the wider effects / impacts of waste-related strategies on landfill gas and other greenhouse gas (GHG) emissions arising from the life cycle of UK waste management systems. The LQM report provided the landfill gas emission data for this project.

1.2 BACKGROUND TO THE PROJECT

The existing UK greenhouse gas (GHG) inventory includes estimates for methane emissions from UK landfills. AEA Technology, in collaboration with NPL, produced the previous estimates for methane releases using a first order exponential decay model compatible with IPCC guidelines. This model made projections up to 2012, taking into account current and planned policies and measures.

Defra wished in these initial projects to re-assess the national methane emissions estimates to take account of, *inter alia,* the following:

- the latest research on measured methane emissions from landfills;
- the latest statistics on waste arisings and composition;
- the likely effects of the Waste Strategies and the Landfill Directive; and
- actual quantities of methane collected for energy recovery and flaring.

Emissions estimates, and the methodology used to obtain them, were to be consistent with IPCC Guidelines and IPPC Good Practice guidance. This was required to ensure that the assessment model was based on sound scientific principles.

A Earlier work had been undertaken by AEA Technology, entitled "*Implications of the Landfill Directive and the Draft Waste Strategy for UK Greenhouse Gas Emissions.*" ERM's follow-on study has taken account of the finalised waste strategies, disaggregating by scaling to show implications in England and Wales and the other devolved administrations and Crown Dependancies, and considers in more detail the likely impact of the Landfill

Directive and the intended implementation route, together with the Best Value targets on local authorities.

ERM also reviewed the previous estimates of emission factors from the various activities in the waste management system, in collaboration with the Swedish Defence Research Agency (FOI). In addition to calculating emissions of carbon dioxide (CO_2) and methane (CH_4), it has also incorporated a much larger suite of greenhouse gases compared to the AEA Technology study.

ERM and LQM carried out both Defra projects in parallel, thus achieving a co-ordinated output. A number of waste management scenarios, incorporating various key measures to divert waste away from landfill, were developed by ERM. The landfill elements of these scenarios provided the input data for the modelling undertaken by LQM. LQM determined the GHG emissions associated with the landfilling of residual wastes, and ERM determined the GHG emissions associated with the other aspects of the waste management systems (excluding landfill). The results of the LQM project were fed back into this study.

1.3 REQUIREMENTS AND OUTLINE OF THE PROJECT

This study assesses the implications of both the EU Landfill Directive and national waste management strategies with respect to the reduction of greenhouse gases from waste management in the UK to inform the UK Climate Change Programme.

The study covers three key areas:

- waste arisings and statistics;
- greenhouse gas emission factors for activities across the waste management life cycle, as described above; and
- sensitivity analysis and an appreciation of uncertainty.

In more detail, this report:

- discusses the significance of GHGs and the relevant waste management policies which may affect GHG emissions currently and in the future;
- identifies waste streams and waste management systems in the UK;
- describes the GHG emission spreadsheet modelling methodology for each waste stream (including the scenarios modelled and emission factors used); and
- presents and discusses the results of GHG estimates and ammonia emissions for the UK and the devolved administrations.

2 POLICY FRAMEWORK

2.1 INTRODUCTION

This section presents the principal policies and targets in the relevant waste strategy documents and supporting documents for England and Wales, Scotland and Northern Ireland that may have an impact on change in the proportion of waste arisings following each management route. These strategies and supporting documents include the following:

- EU Landfill Directive;
- Waste Strategy 2000 (WS 2000) for England and Wales, the National Waste Strategy for Scotland, Waste Strategy for Northern Ireland and UK Best Value Performance Indicator (BVPI) Targets;
- Renewables Obligation for England & Wales, Renewables Obligations for Scotland and the Climate Change Levy; and
- Aggregates Tax.

2.2 *EU LANDFILL DIRECTIVE*

The EU Landfill Directive (1) was introduced by the European Parliament in 1999, but existed in draft through much of the 1990s. The Directive's principal objective is to prevent, or reduce as far as possible, the negative effects of landfilling waste on the environment and on human health. Accordingly, it introduces a number of restrictions on the type and quantities of wastes that may be landfilled in the future. As a result, alternative management routes will need to be found for wastes that can no longer be landfilled.

Under Article 5, the Directive places an outright ban on landfill on the following:

- liquid wastes;
- explosive, corrosive, oxidising, highly flammable or flammable wastes;
- hospital and other clinical wastes; and
- whole used tyres from July 2003 and shredded used tyres from July 2006.

Where these wastes are currently landfilled, an alternative management or disposal route will have to be employed.

Article 5 also progressively limits the quantity of biodegradable municipal waste (BMW) that can be landfilled, with the aim of reducing the release of gases that affect the global climate and leachate that might pollute groundwater.

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

Under Article 6, the Directive requires landfills to be classified as hazardous, non-hazardous or inert, and to accept only wastes in the appropriate category. This will cause the co-disposal of waste streams to cease. As landfills are re-classified, operators will make commercial decisions about the most beneficial future for their sites, particularly in the light of further requirements in the Directive, and the Landfill Regulations 2002 that implement it in England and Wales, in relation to operations, monitoring and control and aftercare provisions for sites. As a result, there may be a shortage of sites in some categories, particularly those for hazardous waste.

In the UK, BMW is likely to be interpreted as the biodegradable fraction of those wastes collected and managed by local authorities, i.e., largely household waste. Only about 10%, on average, of MSW is from commercial waste sources, although the local authority has an obligation to collect these wastes, for a charge, if it is asked to do so. The mechanism for achieving the Article 5 targets includes tradable permits for the landfill of BMW, which are discussed below.

2.2.1 *National Targets for Diversion from Landfill*

Limits on the landfilling of BMW will act as the major driving force behind UK Government actions in increasing diversion of all wastes from landfill, through recovery, recycling and composting (as enshrined in the waste hierarchy). The targets laid out in Article 5 of the Directive may be summarised as follows:

(a) by 2006(1), BMW going to landfill must constitute less than 75% of the total BMW (by weight) produced in 1995;

(b) by 2009(1) the level of BMW going to landfill must have fallen to 50% of 1995 figures; and

(c) by 2016(1) this level must have been reduced to 35%.

The UK produced 29 million tonnes of MSW in 1995, and assuming 60% of this was biodegradable, the targets in the Directive equate to figures shown in *Table 2.1*.

Table 2.1 ***Future Estimated Tonnages of Waste Allowed for Landfill under the Landfill Directive***

Time horizon (with derogation)	Amount of BMW allowed to landfill under the Landfill Directive Article 5 targets
2006 (2010)	13.05 million tonnes
2009 (2013)	8.70 million tonnes
2016 (2020)	6.09 million tonnes

The Landfill Directive will help reduce landfill emissions from new landfills, but those landfills currently operational will continue to emit gases to

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(1) These dates could be extended by up to four years as a derogation by Member States landfilling over 80% of their BMW in 1995. The targets are therefore likely to apply to 2010, 2013 and 2020 in the UK.

atmosphere in potentially more significant quantities than post-Directive sites. Work on the life cycle inventory for landfill previously performed by LQM showed that (in mass terms at least) landfill gas represents 70 – 80% of the environmental burden from landfilling.

2.2.1.1 *Hazardous and Liquid Waste*

In July 2004, the Landfill Directive will bring to an end the practice of co-disposal of hazardous wastes with non-hazardous wastes. Many operators are expected to choose to categorise their sites as non-hazardous, and there may be a shortage of sites to manage hazardous wastes by landfill as a result. The ban on co-disposal may act in support of the government's target for diverting commercial and industrial waste from landfill.

2.2.2 *Tradable Landfill Permit System*

As a further measure to ensure progress is made towards the BMW diversion targets in the *Landfill Directive*, the Government has also indicated that it will introduce tradable landfill permits. In March 2001, a consultation paper was issued on permits (1), and the approach has been confirmed in the Waste and Emissions Trading Bill introduced into the House of Lords on 14 November 2002. The Bill indicates that Waste Disposal Authorities will be allocated maximum allowances for the landfill of BMW in the Directive target years. A trading scheme will be set up to allow the exchange of permits in target and non-target years, and there will be a legal requirement that allowances may not be breached. As yet, the Government has not decided on the precise mechanism, or the timing, for the introduction of the permit-trading system. In view of this, the impact of this system is not included in this scope of the study.

2.2.3 *Landfill Tax*

The Landfill Tax was introduced in October 1996 as a tax on disposal of waste to landfill. With the objective of changing behaviour, encouraging waste minimisation and diversion away from landfill to treatment, it was initially set at a level designed to reflect the externalities of disposal excluded from the market price of landfill. In July 1997, the Government published its Statement of Intent on Environmental Taxation which made clear its aim to reform the tax system, over time, to move the burden of tax from 'goods' to 'bads', and to increase incentives to reduce environmental damage and encourage innovation to meet higher environmental standards. Consequently, in 1998, the rate of landfill tax was raised to £10 a tonne for active wastes, and an escalator introduced at £1 per tonne per year that will raise it to £15 per tonne in 2004/05.

The landfill tax currently stands at £13 per tonne for active wastes and £2 per tonne for inert wastes. In its recent review of practical and cost-effective measures for waste management in England, *Waste Not, Want Not*, the Strategy Unit has recommended the following in relation to landfill taxes:

(1) Department of the Environment, Transport and the Regions (2001) Tradable Landfill Permits Consultation Paper, DETR

- that the level of landfill tax be raised to £35 per tonne in the medium term; and
- that the landfill tax escalator should increase to £3 per tonne per year from 2005/6.

In November 2002, the Chancellor's pre-budget statement proposed an increase in the landfill tax to £35 per tonne for active waste in the medium term in order to create the economic conditions for industry and local authorities to develop alternatives to landfill.

2.3 *NATIONAL WASTE STRATEGIES*

2.3.1 *England & Wales*

Policy in the UK has been developed through a series of White Papers and draft strategies. In culmination of these, and in response to the Landfill Directive, the Government published *Waste Strategy 2000 (*WS 2000*)*, the national waste strategy for England and Wales, in May 2000. The strategy contained a number of national targets for the recycling and composting of household waste and the recovery of municipal waste. The national recycling/composting targets (1) are as follows:

- to recycle or compost at least 25% of household waste by 2005;
- to recycle or compost at least 30% of household waste by 2010; and
- to recycle or compost at least 33% of household waste by 2015.

The national recovery (2) targets are as follows:

- to recover value from 40% of municipal waste by 2005;
- to recover value from 45% of municipal waste by 2010; and
- to recover value from 67% of municipal waste by 2015.

WS 2000 also provides the following target that:

- by 2005, to reduce the amount of industrial and commercial waste sent to landfill to 85% of that landfilled in 1998.

In order to ensure that the above national targets are met, Local Authorities have been set statutory targets for recycling and composting household waste and introduced through the Best Value framework on 1 April 2000. Proposed targets were set out in the Audit Commission's Joint Consultation on Performance Indicators 2001/2002 for England and Wales. These standards were later refined and statutory targets published in DETR's *Guidance on Municipal Waste Management Strategies (March 2001)*.

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(1) The recycling/composting targets are set for the combination of the rate for recycling household waste and the rate for composting household waste.

(2) The recovery rate for municipal solid waste is comprised of the recycling rate for household waste, the composting rate for household waste, and the percentage of municipal waste from which value is recovered through, inter alia, combustion with energy recovery, anaerobic digestion and other forms of recycling.

2.3.2 *Scotland*

The Scottish Executive adopted the Scotland National Waste Strategy in December 1999. The Strategy is to be delivered through its recently published National Waste Plan 2003, and has as its principal aim a reduction in the amount of waste generated and of managing waste in a sustainable manner. The Plan was created through a consultative process which saw 11 Area Waste Plans being developed by key stakeholders across Scotland. The implementation of the National Waste Plan is anticipated to achieve, among others, a 25% recycling and composting of municipal waste by 2006, and 55% by 2020. Targets for waste reduction and management are such that it is consistent with UK and European legislation.

2.3.3 *Northern Ireland*

The Northern Ireland Waste Management Strategy was launched in 2000 and is subject to a formal review in 2003. Primary strategy goals include the recovery of 25% of household waste by 2005, 40% by 2010 and a reduction in the landfilling of industrial and commercial rubbish to 85% of 1998 levels by 2005 (1). Northern Ireland's Department of the Environment also very recently published its Biodegradable Waste Strategy, in order to promote the sustainable management of biodegradable wastes and comply with its obligations under Article 5 of the Landfill Directive.

2.4 *THE RENEWABLES OBLIGATIONS & CLIMATE CHANGE LEVY*

The Renewables Obligations is part of the UK Climate Change Programme. Under these Obligations, all licensed electricity suppliers must source a certain percentage of their total sales from renewable sources. However, energy from waste is not included as a renewable source. In view of this, the Renewables Obligations is unlikely to impact the proportion of waste in each management route.

Similarly with the Climate Change Levy, waste (as defined by UK statutes) is a non-taxable commodity and therefore need not be further addressed in the scope of this report. The Climate Change Levy is an environmental tax, which came into force in April 2001, and aims to play a major role in reducing greenhouse gas emissions through the efficient and prudent consumption of energy by its suppliers.

2.5 *AGGREGATES TAX*

The aggregates tax is a tax on the sale of primary aggregates extracted in the UK or its territorial waters, or imported into the UK. Primary aggregates include any sand, gravel or crushed rock. This tax is intended to reflect the environmental costs of quarrying and to increase the attractiveness of secondary aggregates, produced from inert mineral wastes and construction

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(1) information sourced from the VALPAK website - www.recycle-more.co.uk.

and demolition wastes. Quarries in Northern Ireland are temporarily exempted from the tax according to Article 87 and 88 of the EC Treaty(1).

The Aggregates Tax is not included in the scope of this study, as certain waste materials, for example, all spoil, waste or other by-products from any industrial combustion /smelting/ refining of metal[2] processes are exempted from the tax (3).

2.6 THE WASTE HIERARCHY - WASTE MINIMISATION

It is apparent at this point that the targets of the Landfill Directive and WS 2000 seem more inclined towards recycling and recovery management routes. However, the foundation of waste management is best illustrated as a hierarchy, which prefers minimisation at source first. The hierarchical structure (see *Figure 2.1*) emphasises the importance of a systematic approach to minimising the environmental impacts of waste upon the environment while avoiding following too restrictive a set of prescriptive rules.

The waste minimisation principle is incorporated in this study through the growth rates applied to future UK waste tonnages. *Section 5.4* elaborates.

Figure 2.1 ***The Waste Hierarchy***

Minimisation / Reduction at Source *Most Acceptable*
↓
Reuse
↓
Recycling / Composting / Recovery
↓
Disposal *Least Acceptable*

2.7 SUMMARY OF TARGETS

Table 2.2 summarises the targets of the national waste strategies for England & Wales, Scotland, Northern Ireland and the Channel Islands. The table shows the various targets and the timing to achieve their respective strategy goals.

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(1) Articles 87-89 of the EC Treaty relates to the provision of state aid with the aim to prevent distortion of the conditions of competition in the EU market.

(2) By-products include industrial slag, pulverised fuel ash and used foundry sand.

(3) Further details can be obtained from HM Customs & Excise: Draft General Guide to Aggregates Levy. URL: http://www.hmce.gov.uk/business/othertaxes/agl-guide.htm#P282_18621.

Table 2.2 Targets of National Waste Strategies and the Landfill Directive

Year End	*England & Wales*	*Scotland*	*Northern Ireland*	*Landfill Directive*
2005	• 25% R&C • 40% Recovery		• 25% recovery • Reduce BMW landfilling to 85%* • Reduce C&I waste landfilling to 85%**	
2006		• 25% R&C • Reduce BMW landfilling to 1.5 million tonnes/yr		• Reduce BMW landfilled to less than 75%*
2009				• Reduce BMW landfilled to 50%*
2010	• 30% R&C • 45% Recovery		• 25% R&C • 15% recovery • Reduce BMW landfilling by 75%	
2013			• Reduce BMW landfilling by 50%	
2015	• 33% R&C • 67% Recovery			
2016				• Reduce BMW landfilled to 35%*
2020		• 55% R&C	• Reduce BMW landfilling by 35%	

Notes:

R&C	Recycle and Compost % of Household Waste Arisings
BMW	Biodegradable Municipal Waste
*	Of 1995 baseline levels of total BMW arisings (by weight)
**	Of 1998 baseline levels of total C&I waste arisings (by weight)

Sources of Information:
England & Wales Waste Strategy 2000
Biodegradable Waste Strategy for Northern Ireland
Scotland National Waste Plan 2003

The targets of the Landfill Directive and WS 2000 have been identified in this study as key indicators on how the proportion of waste arisings following each management route will change in the future for England and Wales. Note that due to incomplete waste statistics for the devolved administrations, coupled with complexities of the spreadsheet development, the WS 2000 and Landfill Directive targets are inevitably incorporated into the GHG emission estimates of Scotland, Northern Ireland and the Channel Islands, rather than their individual targets. *Section 5.8.3* will elaborate.

3 GREENHOUSE GASES

3.1 GREENHOUSE GASES & CLIMATE CHANGE

Anthropogenic releases of greenhouse gases (GHGs) have contributed toan alteration in the composition of the atmosphere, particularly increasing concentrations of carbon dioxide, methane, and nitrous oxide. These gases contribute to global warming through their impact on radiative forcing. Potential consequential impacts include an increased incidence of extreme weather events, and sea level rise affecting coastal and low lying areas and loss of habitats and species.

Since these gases have a global effect, United Nations Framework Convention on Climate Change signatory countries are obliged to report their estimated anthropogenic emissions of a 'basket' of six GHGs to the Secretariat of the convention. The emissions of these six GHGs serve as an indicator of climate change and include:

- carbon dioxide CO_2;
- methane CH_4;
- nitrous oxide N_2O;
- perflourocarbons PFCs;
- hydrofluorocarbons HFCs; and
- sulphur hexafluoride SF_6.

Table 3.1 provides the global warming potential (GWP) of each GHG as well as lifetimes of these GHGs in the atmosphere. The particularly high GWPs for PFCs and HFCs for example, is characterised by their long atmospheric lifetimes. In general, CO_2 is the largest net contributor to global warming, followed by CH_4.

The UK is bound (upon ratification) to the Kyoto Protocol target to reduce GHG emissions by 12.5% below 1990 levels in 2008-2012. The UK Climate Change Programme aims to reduce emissions by 23% by 2010, beyond the Kyoto targets.

The IPCC Guidelines on GHG Emissions (1996 Revision) provide the format by which the GHG contributions are calculated from its six major sources (energy, industrial processes, solvent and other product use, agriculture and forestry; and waste). The UK submits the National Atmospheric Emissions Inventory (NAEI) on an annual basis, incorporating new technical information and adjustments, based on the previous year's inventory.

Table 3.1 *UNFCCC-designated basket of Six GHGs as an Indicator of Climate Change*

GHG	*Principal Anthropogenic Sources/ Uses*	*GWP (100-year time scale)*	*Lifetime (years)*
CO_2	• Fuel burning	1	5-200
CH_4	• Landfill • Farming (particularly enteric fermentation in animals) • Certain industrial operations and • Petroleum systems	23	12
N_2O	• Fuel burning • Fertiliser • Catalytic converters	296	114
PFCs	• Aluminium production industry • Purging agent • Fire suppressants • Refrigerant	11,900 (for C_2F_6)	10,000 (for C_2F_6)
HFCs	• Refrigerants • Foam blowing agent • Fire suppressants and propellants	12,000 (for HFC-23)	260 (for HFC-23)
SF_6	• Magnesium production and casting • Insulating material	22,200	3,200

3.2 *GHG GENERATION IN LANDFILLS*

As anaerobic bacteria act on landfilled biodegradable waste, a mixture of gases is produced. This landfill gas consists primarily of CO_2 and CH_4 in approximately equal proportions, and thus constitutes a substantial greenhouse gas mixture.

Depending on the design of the site and its cap, and the nature of the bacterial colonisation of the landfill, methane may be oxidised to CO_2 by bacterial action in the capping material, prior to release to the atmosphere. Modern landfills have an installed gas collection system, which extracts gas through a system of wells under negative pressure. The gas is burned, at purpose-designed flares (producing CO_2 to atmosphere), or in an engine for the purposes of energy recovery. Fugitive gases migrate through landfills until reaching either the capping material or the side-walls, at which points it may escape to atmosphere through breakages in these boundaries (fissures, cracks or as a result of the intrinsic porosity of the cap/walls[1].

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(1) It must be noted that biogenic CO_2 emissions, produced through the biological processes in landfills, are not included in the waste management scenarios modelled (see *Section 6.2* for further elaboration on the scenarios). IPCC guidelines on greenhouse gas inventories have recommended excluding biogenic CO_2 as it will and should be covered under inventories recording greenhouse gas emission for forests and land use change.

It is important to note that where there is an avoidance of methane emissions from landfills (which can be very substantial[1]) as a result reduced landfilling and increased recycling/composting, this waste management system or scenario will give the lowest net emissions of GHGs, compared to one which is landfill intensive. Studies such as AEAT's report to the EC on Waste Management Options and Climate Change reflect this, and support the results of this study. *Section 6* will show that depending on the different scenarios modelled, substantial benefits are possible when recycling/ composting-intensive policies are applied.

3.3 THE NEED TO STUDY THE IMPACT OF NATIONAL WASTE STRATEGIES ON GHG EMISSIONS FROM WASTE MANAGEMENT SYSTEMS

3.3.1 Measures to Implement Change to Reduce Waste to Landfill

As demonstrated so far in this section of the report, the performance of landfill against various sustainability criteria, including releases of greenhouse gases, has prompted a series of initiatives / drivers to encourage, or oblige, the diversion of wastes from landfill to other management routes that recover value from waste in the form of energy or materials e.g. WS 2000, the Landfill Directive, Landfill Tax and the Aggregates Tax (see *Section 2.5*).

3.3.2 Updating Previous Assessments of GHG Emissions from Waste Management Systems

A number of studies have been carried out in this area, although they seldom have looked at the complete life cycle, or at all waste management options. A lack of rigour has also characterised some approaches, where options have different boundaries (making it difficult for comparison) and where uncertainties have been dealt with unsatisfactorily. It is essential that the life cycle of integrated systems is considered so that releases greenhouse gases upstream and downstream of the waste treatment process itself are included.

AEA Technology's study clearly addresses many of the concerns of earlier work. Nevertheless, it was constrained such that system boundaries were drawn quite tightly, a limited number of scenarios were assessed, and there was little opportunity for examining uncertainty in emission factors and the significance of key assumptions. This has prompted the need for further research to address these limitations.

(1)England and Wales landfilled approximately 81% of its total arising MSW in 1999/00 - Defra Municipal Waste Management Survey

3.4 *STUDY PARAMETERS*

The following assessment of the impact of policies and regulatory measures on the reduction of greenhouse gas emissions takes account of current UK waste management policies, and trends in the growth of waste arisings. This assessment also considers the impact of individual policies and measures on waste arisings and composition. Although municipal wastes are the principal focus of the measures, and give rise to a significant proportion of greenhouse gas from landfill, the management of other waste streams will contribute to the net effect on emissions.

Inert construction and demolition (C&D) waste, for example, is unlikely to produce much landfill gas when landfilled, but the estimated arisings of c. 70 Mt per annum are significant, with the potential for increasing the current recycling rate of about 29%. Recycling C&D waste will lead to reduced emissions from the extraction, processing and transport of primary aggregates, as well as from avoiding transport of waste to landfill and energy consumed in landfill operations. Because the arisings are very significant, in comparison with municipal wastes, these savings may be substantial when set alongside those from diverting the biodegradable and recyclable components of municipal waste.

4.1 WASTE AND GREENHOUSE GASES

4.1.1 *Waste Streams*

UK waste management policy essentially separates controlled wastes into three main streams. These include municipal solid waste (MSW), commercial and industrial waste (C&I Waste) and 'other' wastes, including construction and demolition (C&D) waste, hazardous (or special) wastes and large-scale waste arisings from specific industrial processes (such as blast furnace slag).

Table 4.1 compares the amount of MSW, C&I waste and 'other' waste landfilled or managed through other methods in 1998-99. *Table 4.2* provides the definitions and details on the types of waste classified as MSW, C&I waste and 'other' waste respectively.

Table 4.1 Comparison of waste managed in England and Wales in 1998/99 (kilotonnes)

Waste Stream	Landfilled	Other Management Methods	TOTAL
MSW	23 100	4900	28 000
C&I Waste	32 149	36 593	68 742
Other Waste	23 275	65 108	88 383
TOTAL	**78 524**	**106 601**	**185 125**

Source: Defra Waste Management Survey 1998/99 and EA SWMAs

4.1.2 *The Waste Management Life Cycle*

There are numerous activities associated with the management of municipal waste, from collection, through transport, treatment, the recovery of energy and materials and further transport to final disposal. It is helpful to describe this system as the '*life cycle*' of waste management. These activities are interrelated, and linked to the manufacture and supply of the goods that become wastes and their by-products. The discipline of life cycle assessment (LCA) was developed to enable the study of such complex systems, where changes in one part of the system may have implications elsewhere and should be taken into account.

In this instance, the diversion of waste from landfill to recycling and composting clearly avoids the release of landfill gas, including CO_2 and CH_4. However, there are additional greenhouse gas burdens associated with the provision of collection receptacles, with separate collection by additional vehicles, with increased transport distances to reprocessing facilities and with energy consumption in reprocessing. These need to be taken into account in assessing the net benefit of diversion from landfill, as described below.

4.1.3 *Greenhouse Gas Emissions*

Each sub-system within the life cycle gives rise to environmental burdens associated with the consumption of raw materials and energy, with emissions to air and water, with inert solid wastes and with the recovery and processing of energy and materials. Greenhouse gas emissions are amongst these burdens, released from the production and consumption of energy and materials and as methane and carbon dioxide from carbon in wastes through thermal and biological processes. Landfills are the source of a significant proportion of the UK's methane inventory.

4.1.4 *Greenhouse Gas Benefits*

The recovery of energy and materials from waste has greenhouse gas benefits, through offsetting the requirements for fossil fuels and virgin materials. The substitution of recovered materials for virgin material often confers considerable energy savings, although the recovery and processing of recyclables still gives rise to greenhouse gas emissions. It is generally the case that GHG emissions from disposing of a tonne of waste are completely mitigated by the GHG benefit that is achieved through recycling a tonne of waste. This mitigation is a result of the emissions from waste management being smaller than the emissions associated with the production of virgin material. In addition some carbon may be sequestered in waste and its products, such as compost. This has a beneficial effect on the balance of greenhouse gases through the delayed release of carbon and a net decrease in the equilibrium size of the atmospheric sink.

Table 4.2 Waste Streams Considered in this Study

Waste Category	Waste Material Type	Definition of Waste Category and General Comments
MSW	• Paper and card • Glass • Putrescibles • Metals (Ferrous and non-ferrous) • Plastics • Textiles • Fines • Miscellaneous materials (combustible and non-combustible)	Definition according to the Landfill Directive: *"Waste from households, as well as other waste which, because of its nature or composition, is similar to waste from households".* This is congruent with the definition of household waste already in use in the UK for the purpose of providing information to EUROSTAT and the OECD on its MSW figures for 1995.
C&I Waste	• Inert / Construction & Demolition Material • Paper and card • Food • General industrial and commercial • Other general and biodegradable • Metals and scrap equipment • Contaminated general • Mineral wastes and residues • Chemical and other	Commercial waste is broadly defined in paragraph 2.2 of *Waste Strategy 2000* as: *"Waste arising from wholesalers, catering establishments, shops and offices."* Industrial waste is defined in the same document as: *"Waste arising from factories and industrial plants."* Legal definitions of these waste types are defined in WS 2000 (Section B.19, Annex B). Information pertaining to quantitative and qualitative commercial and industrial waste management was gathered in the National Waste Production Survey conducted by the Environment Agency (EA) between October 1998 and April 1999. The data represented the findings of a programme of site visits and telephone interviews with approximately 20 000 companies. The results were published in 2000 as a series of Strategic Waste Management Assessments, for the Agency's regions in England and Wales. There are no comparable data for Scotland, Northern Ireland and other crown dependencies. According to the EA data, 40% of C&I Waste is recovered overall (most of which is recycled), and about 60% is landfilled. However, the nature of the EA survey methodology has resulted in the data for C&I Waste approximating only a broad estimate of waste arisings for UK companies. These are currently the best data available for use in any modelling of CIW; they provide total waste arisings figures, a quantitative breakdown of wastes by type and an indication of how this waste is treated and/or the routes by which it is disposed of. However, the data does feature inherent quantitative limitations, which have necessitated certain assumptions to be made for the purposes of this modelling exercise.

Waste Category	Waste Material Type	Definition of Waste Category and General Comments
Other Waste	• Pulverised Fuel Ash • Furnace bottom ash • Industrial slags • Construction and demolition waste • Paper pulp • Sewage Sludge	There is no specific definition of this category of waste since this category is included in this report for emission estimates purposes. According to the Environment Agency's Strategic Waste Management Assessments, the waste types are typically homogenous (except construction and demolition waste) i.e. produced by a particular industry and managed at dedicated facilities. However, it is noteworthy to observe that the figures produced by the EA are purely indicative and factors such as whether such materials are truly 'wastes' or industrial by-products may have implications when formulating or applying waste policies.

4.2 *ELEMENTS WITHIN WASTE MANAGEMENT SYSTEMS*

In order to evaluate the impacts of different policies on GHG emissions from waste management systems, a number of scenarios were developed for each waste stream, ie MSW, C&I waste and Other waste.

These scenarios, for MSW in particular, have incorporated a range of current waste management options, including:

- recycling;
- composting;
- energy from waste (EfW);
- refuse derived fuel (RDF); and
- landfilling.

Other elements also incorporated within the waste management systems are as follows:

- transport within the different waste management routes, inclusive of waste collection;
- operation of transfer stations; and
- operation of materials recovery facilities (MRF).

The following sub-sections present a brief description of these management options, including their present situation in the UK (for example market availability and economic viability).

4.2.1 *Recycling*

The materials recycling industry is faced with ever increasing amounts of recyclables as the pressure on local authorities to recycle increases under new legislation. These result in high volatility of market prices for certain recyclables, consistently low prices per tonne of recycled product, and poor consistency in supply of recyclables. In this economic climate, the targets set by UK Government (see *Table 4.3*) may present a considerable challenge to all concerned in waste management.

Table 4.3 WS 2000 Targets for Recycling for England and Wales

Year	WS 2000 Targets for Recycling
2005	Interim target for recycling and composting of 25% of MSW total arisings.
2010	Target for recycling and composting of 30% of MSW total arisings.

Recyclable materials considered in this study include ferrous metals, aluminium, glass, paper & card, plastics, putrescibles and textiles. These materials represent the major constituents of MSW, and thus most commonly incorporated into local authority strategies. These materials also form the majority of general commercial waste.

The collection of these materials is carried out by one of two methods: bring systems and kerbside collection of waste. A bring system is a facility to which the public bring their own recyclables for subsequent collection in bulk, whereas kerbside collection involves the collection of recyclables by local authorities, saving the resident the trip to a bulking/ MRF facility.

In estimating GHG emissions from transporting recyclables to bulking/ MRF facilities, no distinction was been made between the distances travelled. Instead, a fixed distance was adopted and only the mass of recyclables sent to MRFs varied. *Section 4.3* will elaborate.

4.2.2 Composting

Composting is increasingly considered to be a viable option for the reduction of putrescible MSW going to landfill, as required under the obligations of the Landfill Directive. As a result, composting is a growth industry in the UK. The different kinds of composting currently used in the UK are:

- centralised composting;
- community composting; and
- home composting.

Centralised composting is generally run as a large-scale commercial operation. The biodegradable wastes composted in central composting operations tend to originate from green wastes collected at civic amenity sites, from local authority parks and gardens and some kerbside collection of green waste.

Community composting is operated by local residents who pool their organic waste resources and thus generate a larger amount of compost than would be possible in their own gardens.

Home composting is carried out in a householder's own garden and allows them to deal with their biodegradable wastes at very close proximity to the source. Local authorities may distribute their own composting bins to householders to encourage them to manage their own garden waste and putrescibles. Home composting was not included in this study due to the absence of specific data detailing the type of composting accounted for in waste management(1).

4.2.3 Thermal Treatment and Alternatives

The thermal destruction of waste is widely used to recover energy from wastes with an appropriate calorific value. Energy is recovered as heat, and

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(1) Waste arisings and management tonnages were sourced from Defra's Municipal Waste Management Survey 1999/2000. See Section 6.3 for elaboration.

either used directly, or, more commonly at the large scale, for generating electricity. Thermal treatment also results in significant decreases in mass and volume as organic material is converted to gas.

4.2.3.1 *Mass Burn Energy from Waste (EfW)*

EfW incinerators may be a large-scale mixed waste input mass burn systems, or smaller modular burn system. Conventional energy from waste is proven and deliverable in the UK, and remains a popular model with parts of the industry. There are 13 operating plants in the UK and many more are proposed and/or in planning. The mass-burn, moving grate technology is the most common, and has the advantage of being robust and relatively inexpensive. In many cases, EfW incinerators operate in association with either materials recovery facilities (MRFs) before burning, and/or metals and ash recovery after burning.

There has been significant regulatory pressure on combustion over the last decade, leading to much tighter emissions standards. The Waste Incineration Directive (WID) is required to apply to existing incinerators from 28 December 2005, and presents another step in this process.

Although it is possible to incinerate waste with no energy recovery, this is a practice that WS 2000 for example, describes as an option that authorities in England and Wales would generally wish to discourage for non-hazardous wastes. SEPA's thermal treatment plants and EfW guidelines similarly encourages facilities that recover/ generate energy, in line with Scotland's National Waste Strategy.

4.2.3.2 *Refuse Derived Fuel (RDF)*

RDF is produced from municipal solid waste after recyclables and other materials have been recovered. The product is, usually, a pelletised fuel that is then burned in an incinerator or other heat/power plant. The approach may have some advantages in that combustion does not have to be on site, and RDF may be stored for some time. However, despite considerable research in the 1980s, the technology has not been widely adopted.

In the absence of RDF-specific data, and taking into account the fact that RDF pellets have been used in cement kilns and mass burn incinerators, the study has applied the incineration emission factor (mass burn) to calculate the resulting GHG emissions from the use of RDF.

4.2.3.3 *Fluidised Bed Combustion*

Fluidised bed combustion has been proposed as offering certain advantages over mass burn in terms of combustion efficiency and energy recovery. The technology has been demonstrated successfully for other, more homogenous waste streams (sewage sludge, for example) and, rather more rarely, and generally after commissioning delays, for municipal wastes. Currently there is only one operating plant in the UK, at Dundee, although there is a proposal for a significant scale facility at Allington in Kent. Fluidised bed combustion was therefore not taken into account in this study.

4.2.3.4 *Pyrolysis and Gasification*

There are a great many variants on the two principal advanced thermal treatment processes, pyrolysis and gasification, and, indeed, the two may be found combined. Although there has been interest in applying the techniques (which operate in the absence of oxygen) to mixed wastes for over a decade, there are no demonstrated facilities in the UK other than at a pilot scale. As a result, this study did not reflect the application of these treatment processes to waste management systems.

4.2.3.5 *Ash Recovery*

Bottom ash resulting from the incineration process have the potential to be further processed in order to recover materials (e.g. metals) that were, prior to combustion, difficult to recover. Ash may also be used in a raw or processed form (depending on its composition) as an aggregate in the construction industry. Otherwise it will require landfilling, as will the fly ash, which is the material trapped by flue gas emissions control systems.

4.2.3.6 *Combined Heat and Power (CHP)*

Use of combined heat and power (CHP) further increases the amount of energy that can be recovered from incinerated waste through use of heat directly, for example in a district heating system such as that at Nottingham. Such systems are encouraged by WS 2000 where combustion plants are proposed. Use of heat from an incinerator offsets direct use of fuels for heating, or the use of electricity and combustion of fossil fuels as part of the UK electricity mix.

However, there are few instances where CHP is implemented as part of waste combustion in the UK, and the majority of proposals for new combustion plant do not include direct use of heat. As a result, this study did not consider CHP further, and the potential greenhouse gas benefits of CHP for waste combustion was not been included in the study.

4.2.4 *Accounting for Energy Recovery in this Study*

Within the context of this study, the incineration modelling has been based on research conducted by the Swedish Defence Research Agency (FOI). The FOI has conducted numerous, credible and in-depth research projects on life cycle assessments and integrated solid waste management systems. *Annex A* provides details on FOI's development of incineration emission factors.

In this study, it has been assumed that the greenhouse gas benefits of mass burn energy from waste and RDF occur as a result of offsetting electricity generation according to the current UK fuel mix.

Recovery of energy from landfill gas incineration is accounted for in the LQM study of *Methane Emissions from Landfill Sites in the UK*.

4.2.4.1 Energy from Landfill Gas

Landfill gas may be used to drive reciprocating engines or turbines for generating electricity, or as a fuel in other industrial processes.

Although both the Landfill Directive and WS 2000 drive for a net reduction of waste going to landfill, in some instances landfilling will remain the management route for some wastes. Clearly, residual wastes from other processes will need to be landfilled, and landfill may represent the Best Practicable Environmental Option (BPEO) for some mixed waste streams after separation of some materials.

4.3 TRANSPORT OF WASTE

WS 2000 maintains that, in order to manage waste sustainably, management choices taken should represent the BPEO. This overarching principle requires consideration of three further concepts, viz. the waste hierarchy, self-sufficiency and the proximity principle. The Proximity Principle requires that waste should be managed and disposed of as near as possible to its place of origin, in order to minimise the environmental and financial costs of transport. Clearly, releases of greenhouse gases from vehicles will be amongst the impacts reduced through fulfilling the Proximity Principle. Strict accordance with the principle would mean having local collection systems, materials reclamation facilities (MRFs), incinerators and/or landfills as close as is practicable to waste sources.

ERM's experience of BPEO assessments of waste transport in the UK has suggested that the typical distances travelled by wastes are as follows:

- collection - 2 km/tonne of waste collected;
- transport to recovery/composting/landfill - 30 km/tonne of waste treated; and
- transport to reprocessors/recyclers - 100 km/tonne of waste landfilled.

In this study, it has been assumed transport of waste for transfer/treatment/ disposal is only via road. Currently, there is little waste transport using other transport modes, although some waste is transported by river and rail (e.g. a proportion of London's waste downriver to landfill in Essex, and by rail to Oxfordshire).

Waste transport may be categorised according to the following routes of movement:

- transport from the households to the waste transfer sites / MRFs;
- transport of recyclables from the MRF to the reprocessors; and

- transport from waste transfer sites to the compost site/EfW/ landfill.

It has been assumed that in the transport of waste, all waste streams cause the same amount of emissions per km from the vehicles used, i.e. the only variable here is the mass of the waste streams transported.

However, the different wastes may well travel different distances, depending on the types of processes and disposal that are appropriate for a particular type of waste. It has been assumed that all waste is transported the same distance to the MRF, and only after this stage is there a difference between distances travelled to reprocessors/recyclers, composting and landfill sites.

5 DEVELOPMENT OF SCENARIOS FOR THE ESTIMATION OF TOTAL GHG EMISSIONS IN THE UK

5.1 INTRODUCTION

A number of scenarios were developed in order to estimate total GHG emitted over the life cycle of the wastes arising in England & Wales, Scotland, Northern Ireland and the Channel Islands (1). The scenarios were modelled using a series of linked spreadsheets, combining the quantities of waste arising, the management routes they are assumed to follow, and emissions factors for the activities involved in their management. The scenarios varied in terms of waste materials diverted (away from landfill) to the different waste management options available and the requirements of WS 2000 and Landfill Directive targets.

In order for the spreadsheet model to operate effectively, the following elements were established from the onset of the development of the spreadsheet, to ensure a common template for all the scenarios:

- a waste 'policy / strategy' (varying in the type and amount of waste to be diverted away from landfill, the method of management of diverted waste, and the compliance with legislative targets);
- current waste arisings and management;
- waste composition;
- growth rates over time; and
- GHG emissions factors for each activity within the life cycle

As previously highlighted in *Table 4.2*, the three main waste streams focused on are:

- municipal solid waste (MSW);
- commercial & industrial (C&I) Waste; and
- 'other' waste.

The MSW management system modelled for the purposes of this study is shown in *Figure 6.1*. Household waste and recyclables collected by Waste Collection Authorities and/or charitable organisations (through kerbside collection schemes, door-to-door collection, bring systems and so on) are transported to either material recovery facilities (MRFs) or transfer stations.

For the purposes of this study, waste designated for composting, incineration and landfilling are moved via transfer stations, whereas wastes designated for recycling / reprocessing is sorted via materials recovery facilities (MRFs).

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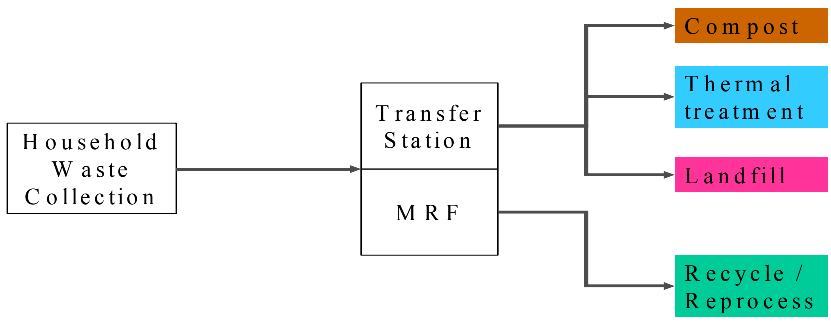
(1) Gibraltar is not included in this instance as all waste arising is exported to Spain for management (Environmental Agency, Gibraltar).

This model may not be representative of all waste collection and management systems in the UK, as there are many variations. However, the system is typical, and, in order to ensure consistent modelling and to allow comparisons between the various scenarios modelled based on different waste policies (as explained in *Section 5.2.1*), the MSW system in *Figure 5.1* was adopted for the UK.

Figure 5.1 *MSW Management System Modelled for the UK*



The following sections will contain the main assumptions applied in the development of the waste scenarios for estimation of GHGs, based on the above MSW management system (*Figure 5.1*) and varying waste policy options.

Detailed assumptions in modelling can be found in *Annex B* as well as in the spreadsheets used to model the scenarios.

5.2 WASTE POLICY/STRATEGY

5.2.1 MSW Scenarios

Eight scenarios were developed for the MSW waste stream in order to explore a variety of combinations of the management routes available. The waste policy basis that determined the mix of routes in each scenario is described below. The objective in defining the scenarios was to examine different ways in which relevant policy targets might be met, i.e. through focusing on diversion from landfill through recycling or through energy recovery, and by investigating the impact of achieving recycling targets through separation of different materials. The potential outcomes of different waste growth rates were also tested to establish the importance of this factor in relation to management route.

- *Scenario 1* Achieving WS 2000 and Landfill Directive targets (1) with current material recycling rates and higher recovery.

- *Scenario 2* Achieving WS 2000 and Landfill Directive targets (1) with an emphasis on paper recycling and composting (i.e. diverting degradable waste from landfill).

- *Scenario 3* Achieving WS 2000 and Landfill Directive targets (1) with an emphasis on paper recycling alone (i.e. diverting degradable waste with an energy benefit).

- *Scenario 4* Achieving WS 2000 and Landfill Directive targets (1) with an emphasis on energy recovery through mass burn energy from waste.

- *Scenario 5* Achieving WS 2000 targets with an emphasis on glass, metals and plastics recycling (i.e. diverting non-degradable waste from landfill). The Landfill Directive targets are not achieved in 2013 and 2020.

- *Scenario 6* Higher growth rate, achieving WS2000 and Landfill Directive targets (1) with current material recycling proportions and excess recovery.

- *Scenario 7* Higher growth rate, achieving WS2000 and Landfill Directive targets (1) with excess material recycling rates.

- *Scenario 8* - This is the basecase scenario, current ratio of recycling to recovery is maintained and the rate of change in diversion observed between 96/97 to 99/00 is maintained.

A detailed, quantitative, description of the scenarios is provided in ***Annex J***.

5.2.2 *Commercial and Industrial (C&I) Waste and Other Waste Scenarios*

Five scenarios applying to both C&I Waste and Other Waste were developed. As with MSW, the objective in defining the scenarios was to examine the influence on GHG emissions of meeting targets through the diversion of different components of the waste stream.

- *Scenario 1* WS 2000 target of 15% diversion achieved with current trends in diversion continued (i.e. current ratios of recycling to recovery maintained).

- *Scenario 2* WS 2000 target of 15% diversion of C&I wastes from landfill achieved through a mix of digestion, mass burn energy from waste and recycling of food wastes, paper & card and other general biodegradable wastes.

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(1)The targets apply to 2010, 2013 and 2020 in the UK, owing to the four year extension (derogation) of the European targets. See *Section 3.2.1*, footnote (1).

- *Scenario 3* WS 2000 target of 15% diversion of C&I wastes from landfill achieved through combustion of general biodegradable wastes.

- *Scenario 4* WS 2000 target of 15% diversion of C&I wastes from landfill to be achieved through recycling general biodegradable wastes.

- *Scenario 5* WS 2000 target of 15% diversion of C&I wastes from landfill to to be achieved through recycling C&D and mineral wastes.

5.3 CURRENT WASTE ARISINGS AND MANAGEMENT

The spreadsheet model was first developed based on waste arisings in England and Wales. *Section 6.3* will outline the calculation of GHG emission estimates for the devolved administrations of Scotland, Northern Ireland, and the Channel Islands.

In developing the spreadsheet model, current waste arisings form the basis of the growth of waste for the next 20 years. For MSW, the current England and Wales waste arisings were derived from Defra's Municipal Waste Management Survey for the year 1999/00. At the time of the development of the spreadsheets, these were the most up-to-date statistics available.

In the case of England & Wales C&I Waste, the most up-to-date figures available were derived from the National Waste Production Survey conducted by the Environment Agency (EA) in 1998/99 and reported in the EA's Strategic Waste Management Assessments (SWMAs). Statistics for Other Waste were also obtained from the EA for the year 1998/99.

It is noted that since the time these spreadsheets were developed, more recent data has become available. The results of this study may not reflect this more up to date data, however, it is ERM's belief that the study provides a reliable and indicative estimate of GHG emissions for the different waste management scenarios. Though the new data sets would improve the accuracy, we do not believe they would change the conclusions of the study, or the scale of the emissions.

5.4 WASTE GROWTH RATES

In order to generate meaningful predictions of GHG emissions over time, future waste arisings were modelled using anticipated levels of growth. It was assumed that WS 2000 and Landfill Directive targets would be met under the projected levels of growth. For example, the quantity of BMW requiring diversion is determined against a baseline of 1998 production, and is therefore dependent on growth in MSW production from that point until the target year.

5.4.1 *MSW*

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 increased consumption. High consumer spending, a fashion for home improvements and increased consumption of ready meals are clear drivers of waste growth. However, since waste statistics are poor, the relationship between these factors remains to be explained quantitatively and there are no reliable algorithms for predicting future waste production.

A typical annual growth rate of 3% for MSW was quoted in WS 2000 and the EA's SWMAs, although the average rate over the previous 5 years was 3.4%. Subsequently, Defra's survey results for 2000/01 show that the average rate in England dipped below this, although this might be a temporary blip. There is no robust method of forecasting future growth rates on the basis of existing statistics. Nevertheless, as a result of various producer responsibility measures and powers given to local authorities under the Waste Minimisation Act 1998, the growth rate across the country might be expected to decline from the average of the last 5 years as waste minimisation initiatives are brought to bear.

The speed of the decline in growth rate in waste production over time will depend on the timing of the introduction of measures such as, *inter alia*, producer responsibility measures such as the Packaging Regulations and promotion of home composting and nappy laundering schemes etc. In addition, the element of waste growth that is driven by increased consumption is likely to decline if consumer confidence falls following, for example, rises in interest rates or an end to the rise in house prices. *Table 5.1* shows the growth rates applied to the MSW scenarios in this study, which reflect the expected decline in growth. Scenarios 1 – 5 and 8 assume growth is already slowing, and continues to fall, whereas scenarios 6 and 7 assume growth continues at, or above, current rates in the short to medium term, before falling.

Table 5.1 Growth in MSW Arisings for Scenarios 1 –8 over 5 year periods

Period	**Percentage growth of total municipal waste arisings**	
	Scenarios 1 –5, 8	Scenarios 6, 7
2000/2001 to 2005/2006	3.0 %	4.0 %
2006/2007 to 2010/2011	2.0 %	3.0 %
2011/2012 to 2015/2016	1.0 %	2.0 %
2016/2017 to 2020/2021	0.5 %	1.0 %
2021/2022 to 2025/2026	0.0 %	0.5 %

5.4.2 *C&I and Other Wastes*

Statistics on C&I and 'other waste' arisings are very poor. The Environment Agency conducted its National Waste Production Survey (NWPS) in 1998/99, examining waste production in a substantial sample of businesses across various sectors, stratified by size and standard industrial code (SIC). The sample was extrapolated across the UK to provide an assessment of waste production by type. Out of a total commercial and industrial waste production of 69 million tonnes (Mt), approximately 32Mt are landfilled and 21Mt recycled. Some of the Environment Agency data on waste disposals is in the course of being updated. However, there are no new survey data on waste production or other management routes that could be used in this report.

The NWPS does not give a reliable time series from which to extrapolate future waste growth, but represents the best available data on waste production for these sectors. There are no data of similar quality with which to compare the NWPS data *published* earlier or since. Earlier data indicate lower arisings in the recent past, but these estimates were not made on the same basis, included different sources of waste and provide no certainty that arisings have increased. It is not possible, therefore, to make reliable projections about future changes in the arisings of these waste streams. As a result, this study has assumed that there is no growth or decline in these waste streams over the time horizon of the study.

There is a common opinion that C&I waste production is linked to economic growth. However, there are growing pressures to break the link between economic growth and waste production, a declared aim of the European Communities 6th Environmental Action Programme, and one embraced by the Government in its recent waste strategy documents and its sustainable development strategy, and which is reflected in the landfill tax.

Clearly, if C&I waste production is linked to economic growth, any slow down in the economy will result in reduced waste production. However, the relationship cannot be quantified from the statistics available, for example for the early 1990s recession. Furthermore, any slowing of growth, or recession, is likely to reduce investment in clean technologies and waste minimisation measures with a long pay-back, and, as a result, waste generation may well not reduce.

The WS 2000 target for diversion of C&I waste from landfill has already been introduced. Clearly, the main pressures through which diversion will be achieved are the landfill tax and the aggregates levy. Pressure may also be exerted through mandatory and voluntary producer responsibility initiatives, and through the European Commission's focus on Integrated Product Policy (IPP).

Producer responsibility measures, including the Packaging Directive, the Waste Electronic and Electrical Equipment (WEEE) Directive, and the End of Life Vehicles Directive, are setting targets for the recycling of post-consumer products and packaging. Such measures place an obligation on manufacturers and retailers to ensure target levels of recycling and/or recovery. One response may be to reduce the amount of waste arising, and hence their obligation, through re-design, product take-back and refurbishment, re-use and product leasing.

The European Commission's green paper on Integrated Product Policy (IPP) reflects its intention to continue to target the life cycle environmental impacts of products and services, and to aim to reduce waste production and the impacts of disposal. Any requirements to be placed on business as a result of IPP are still several years off.

Clearly, there are significant pressures that may result in these waste streams declining over time. Should this be the case, GHG emissions from these sources can also be expected to decline. However, the current statistical base does not allow any justifiable assumption about the rate of decline.

5.5 *EMISSIONS FACTORS*

5.5.1 *Introduction*

A number of activities in the waste management life cycle may be responsible for emitting or avoiding releases of greenhouse gases. These activities include:

- waste transport (e.g. to transfer stations, MRFs);
- recycling and composting;
- thermal treatment (mass burn incineration); and
- ultimate disposal (landfilling).

In order to quantify the emissions from each of these activities, emission factors (EFs) for each life cycle stage of the waste management system were used. EFs are defined as the mass of GHG released/ avoided for every tonne of waste arising in a specific activity in the waste management life cycle, for example, x g of NO_2 emitted for every tonne of plastic waste incinerated.

Before the EFs were applied to obtain total emissions, these EFs were converted to CO_2 equivalents to allow for a weighted comparison of emissions for the different GHGs emitted from/ avoided in the various activities within the life cycle of a waste management system.

5.5.2 *Source of incineration emissions factors*

EFs in this study were sourced from the following:

- Environment Agency's LCA software tool, ***WISARD***;
- Pira International's LCA software tool, PEMS 4; and
- Swedish Defence Research Agency (FOI).

All EFs used in this study were sourced from ***WISARD*** and PEMS, with the exception for incineration EFs. Incineration EFs were sourced from the FOI rather than any other source due to the fact that the FOI has conducted numerous comprehensive studies of this nature (1), including LCAs of energy from waste for the Swedish National Energy Administration. The FOI used Sima Pro 4.0, another LCA tool, to calculate the incineration EFs of newspaper, polyethylene and putrescible waste. Data from Finnveden *et al.*, (2000), the study for the Swedish National Energy Administration, was also used in forming the basis of these calculations. *Annex A* provides a description of how the incineration EFs were determined and what assumptions were applied.

Note that all EFs were sourced from ***WISARD***, PEMS and the FOI rather than the database of the *IPCC Guidelines for National GHG Inventories*. This was because LCA tools like ***WISARD*** were developed in the context of (similar) UK waste management systems, waste processes and waste generation. Furthermore, FOI's database of rigorous technical studies on incineration and its emissions was regarded as the best source of such information (as previously highlighted).

5.6 UNITS

Units throughout the modelling were such that emissions factors were calculated in grams per tonne of waste (or specific material) processed (e.g. paper recycled, mixed waste incinerated, etc.). All waste arisings figures were converted from thousands of tonnes to tonnes, so as to be appropriate for the application of emissions factors. Emissions factors for transported wastes were calculated as grams per tonne of waste.

5.7 OUTPUT OF SPREADSHEET MODELS

5.7.1 Overview

The linked spreadsheets for each scenario for each waste stream (totalling 13 scenarios – 8 MSW scenarios and 5 C&I Waste and Other Waste scenarios) produce a total estimate of GHG emissions for all stages of the waste management life cycle apart from landfill gas.

Landfill methane emission estimates were provided separately by LQM (see LQM report *'Methane Emissions from Landfill Sites in the UK' - 2002*). These landfill emissions (2) were produced for the UK (including England and Wales, Northern Ireland and Scotland) and therefore required scaling down in order for ERM to predict GHG emission estimates for England and Wales, Scotland, Northern Ireland and the Channel Island separately.

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(1) As previously highlighted in *Section 4.2.4*

(2) Biogenic CO_2 emission estimates from landfills were excluded according to IPCC guidelines on greenhouse gas inventories (see footnote (1), *Section 3.2*).

5.7.2 *Scenario Combinations*

In order to provide an estimate of total GHG emissions for the management of all wastes, and to allow assessment of the impacts of different 'waste policies', MSW and C&I Waste /Other Waste scenarios were combined. The effect of combining scenarios is to produce 40 new composite scenarios, i.e.:
'MSW' Scenario 1 & 'C&I Waste /Other Waste' Scenario 1
'MSW' Scenario 2 & 'C&I Waste /Other Waste' Scenario 1
'MSW' Scenario 3 & 'C&I Waste /Other Waste' Scenario 1 etc. through to
'MSW' Scenario 8 & 'C&I Waste /Other Waste' Scenario 1

and

'MSW' Scenario 1 & 'C&I Waste /Other Waste' Scenario 2
'MSW' Scenario 2 & 'C&I Waste /Other Waste' Scenario 2
'MSW' Scenario 3 & 'C&I Waste /Other Waste' Scenario 2 etc. through to
'MSW' Scenario 8 & 'C&I Waste /Other Waste' Scenario 2

and so on.

LQM's methane emissions figures were added to the corresponding ERM composite scenarios to produce a grand total of GHG emissions. The process of combining LQM scenarios was more complicated than the combination of ERM's scenario results. The combination of LQM scenarios involved a change in methane capture rates and residual oxidation percentages for each of the 40 LQM scenario combinations of landfill methane emissions(1). This process is demonstrated clearly in the spreadsheets.

In effect, 40 charts representing the scenario combinations were produced for England and Wales, Northern Ireland, Scotland and the Channel Islands. Each illustrates the estimates of GHG emissions from a defined waste management system, for MSW and C&I/Other Waste, including landfilling.

The results are discussed in *Section 6*.

5.8 ESTIMATING UK GHG EMISSIONS

5.8.1 *Introduction*

GHG emissions were estimated for Scotland, Northern Ireland and the Channel Islands by applying a multiplier or a 'scaling-down' factor to England and Wales' total GHG emission for a given combined scenario for any given year.

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(1) Although the total amount of methane captured/recovered through flaring and utilisation remains fixed, the total methane generated varies according to the waste input (ie waste scenario). Because the residual oxidation rate is calculated after the amount of methane recovered is subtracted from the methane generated - then this too will vary according to waste input (ie waste scenario).

5.8.2 *Scaling-down factor/ multiplier*

The multiplier was simply equated as:

$$\frac{\text{Total Waste Arisings}_{\text{Scotland/Northern Ireland/Channel Islands}}}{\text{Total Waste Arisings}_{\text{England and Wales}}}$$

Total UK GHG Emissions was then the sum of:

$$\sum(\text{GHG Emissions}_{\text{England \& Wales}}, \text{GHG Emissions}_{\text{Scotland}}, \text{GHG Emissions}_{\text{Northern Ireland}})$$ (1)

5.8.3 *Indicative Results - Scotland, Northern Ireland and the Channel Islands*

It must be noted that in using the scaling factor, the WS2000 recycling and composting targets for England and Wales were inevitably applied to the Scotland, Northern Ireland and Channel Islands scenarios, thus disregarding their own targets. The use of this scaling factor could not be avoided due to the absence (or unavailability) of specific data on waste management routes and tonnages for Scotland, Northern Ireland and the Channel Islands respectively.

It is recognised that since the time of spreadsheet development and modelling, more detailed waste statistics for Scotland and Northern Ireland have emerged. Therefore, although the results of this study may not truly reflect the current waste statistics and individual targets, it does however provide an indicative and reliable representation of GHG emissions for the different scenarios modelled.

5.8.4 *Output/ Results - Charts*

Annexes C - E contain the output in chart form. *Figure 5.2* illustrates an example of the output, to demonstrate the final output of the scenario combinations, as well as to visually provide an idea of how the separate scenarios ('MSW2', 'CIO1', 'Landfill Emissions') have contributed to the final GHG emissions ('Total MSW2 and CIO1'). *Section 6* discusses the output/ results of the spreadsheet modelling and scenario combinations.

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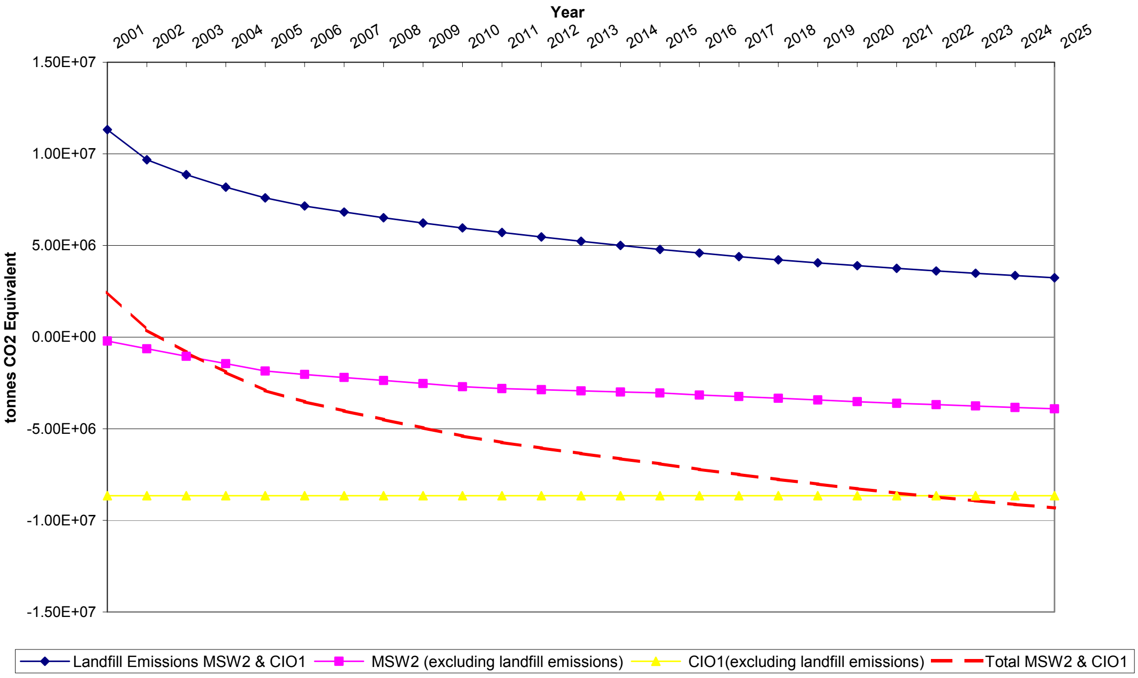
(1) GHG emissions for Channel Islands are presented separately as it is a Crown Dependancy.

Figure 5.2 Example Output: Total GHG Emission Estimates for England and Wales - MSW Scenario 2 & CIO (C&I and Other Waste combined) Scenario 1



Note: Negative numbers arise due to the avoided emissions associated with displacement of virgin material production and energy generation from fossil fuels by recycling and energy recovery. The landfilling of waste is a net emitter of GHG emissions. However the emissions from landfilling a tonne of waste are significantly smaller than the avoided emissions that result from recycling a tonne of waste. The net GHG emissions of all waste management activities (landfilling, recycling, energy recovery, composting) therefore become more negative as alternatives to landfill are utilised.

6 RESULTS AND ANALYSIS OF SCENARIO COMBINATION ESTIMATES OF GHG EMISSIONS FROM WASTE MANAGEMENT SYSTEMS

6.1 CURRENT GHG UK ESTIMATES

In 2000, the *UK Greenhouse Gas Inventory, 1990-2000: Annual Report for Submission Under the Framework Convention on Climate Change* (1) estimated total emission estimates of 652 Mtonnes of CO_2 equivalent of GHGs (CO_2, CH_4, N_2O, HFCs, PFCs and SF_6). Six sectors have been identified by the IPCC as major sources or sinks of GHGs. The six are:

- Energy;
- Industrial Processes;
- Solvent and Other Product Use;
- Agriculture;
- Land-Use Change and Forestry; and
- Waste.

The waste sector contributed to approximately 2.5% of the total UK GHG estimate (i.e. 16 Mtonnes CO_2 equivalent). *Table 6.1* presents a breakdown of emissions from waste activities, which have been classified as solid waste disposal on land, wastewater handling and waste incineration.

Table 6.1 ***National Waste GHG Emissions for 2000 (Mtonnes CO_2 Equivalent)***

'Basket' of GHGs (Mtonnes CO_2 Equiv.)	**Waste Activity**			**TOTAL (Mtonnes CO_2 Equiv.)**
	Solid waste disposal on land	Wastewater handling	Waste Incineration	
CO_2	0		0.208	0.208
CH_4	13.86	0.775	0.002	0.777
N_2O		1.127	0.054	1.181
HFCs				
PFCs				
SF_6				
TOTAL (Mtonnes CO_2 Equiv.)	13.86	1.902	0.264	**16.026**

6.2 FUTURE GHG UK ESTIMATES

6.2.1 *England & Wales*

The results of the spreadsheet modelling (see *Section 5* for methodology and assumptions) are compiled in *Annexes C - F*. Results are presented in the following chart formats:

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(1) This is an AEA Technology report for Defra. The full report can be found at http://www.aeat.co.uk/netcen/airqual/reports/ghg/ghg3.html. The summary report can be found at http://www.aeat.com/netcen/airqual/statbase/emissions/ghouse1.html.

- landfill methane emissions over time;
- GHG emission estimates for MSW over time, excluding landfill methane emissions;
- GHG emission estimates for C&I Waste and Other Waste (abbreviated as CIO) over time, excluding landfill methane emissions; and
- total GHG emissions over time, including landfill methane emissions and GHG emissions estimates for MSW and CIO over time.

General trends for each chart are discussed below, with the following main key factors:

- scenario waste policies (as listed in *Section 5.2*); and
- scenario growth rates (as in *Section 5.4*).

6.2.1.1 Landfill Methane Emission Trend

In all scenario combinations for MSW and CIO, the landfill methane emissions reduce over time, as demonstrated by the downward smooth curve for this source. This is partly attributed to the assumption that 77% of landfill gas generated is flared or utilised by 2005. After 2005, the curve continues its downward trend mainly because the quantity of waste sent to landfill is predicted to reduce year on year (with the flaring/utilisation of landfill gas being maintained at a constant 77% after 2005). The high utilisation/flaring of methane predicted in the future plays a substantial role in reducing landfill methane emissions, both from previously deposited waste and from new deposits.

The methane estimates in all combined scenarios show a consistently positive contribution to greenhouse gas emissions over the time horizon of the study, but one that falls over time. In all of the combined scenarios, methane contributions fall from approximately 12 Mt CO_2 equivalent in 2001 to around 4 Mt CO_2 equivalent in 2025. There is no significant difference in gas generation between the scenarios.

The modelling showed that waste growth will have a larger influence on landfill methane emissions, in the time period studied, than high diversion targets as a result of strategic policy. For example, excess material recycling rates in MSW Scenario 7 do not seem to have a significant impact on landfill methane emissions. This is because waste landfilled in previous years contributes strongly to emissions over the time period studied. Landfill emissions of methane continue to play a role in all the scenarios modelled.

Further information on the landfill methane emissions employed in the study can be found in the LQM report *Methane Emissions from Landfill Sites in the UK*.

6.2.1.2 *MSW GHG Emission Trend (Excluding Landfill Methane Emission Estimates)*(1)

Table 6.2 summarises the trends observed in estimating emissions of GHGs from the management of MSW (excluding landfilling). The trends seem to be influenced by both waste policies (i.e. achieving the targets of the Landfill Directive and WS 2000) and waste growth rates. By contrast with the landfill methane emissions scenarios, all MSW management scenarios excluding landfill (see *Figure 6.1*) contribute to a net benefit in relation to GHG emissions over time. This means that, overall, the mix of activities in waste management scenarios contribute to a reduction in greenhouse gas emissions. This is a result of the GHG benefits of recycling materials and recovering energy from waste.

Scenarios 6 and 7, with their mixture of higher growth rates and emphasis on excess recovery and/or material recycling rates clearly demonstrate a higher net benefit in terms of GHG emissions compared to other scenarios (approximately 6 Mt CO_2 equivalent in 2025). Clearly, this can only be achieved where there is sufficient capacity to accommodate the recycling and recovery of the proportion of waste assumed to follow these management routes.

By contrast, scenario 1, based on current recycling rates and increased recovery rates, is estimated to only yield a benefit of approximately 0.5 Mt of CO_2 equivalent by 2025.

In summary, if emissions from landfill are excluded, the other waste management activities (recycling, composting etc) result in a GHG emissions offset, with the offset generally increasing over time as more material is recycled and recovered. Scenarios 1 and 5 are a slight exception. These two scenarios demonstrate a smaller greenhouse gas emissions offset between 2010 and 2015, which is related to the recycling of inert materials and to energy recovery of materials (largely putrescibles) that have a low energy benefit. Nevertheless, the overall result is continued net benefit/offset. *Table 6.2* explains further.

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(1) These results are presented and discussed separate from landfill emission estimates, and not combined with the CIO scenarios. This is due to the different methodology employed in obtaining these figures. Please see *Section 4.7* for further explanation.

Figure 6.1 *MSW Scenarios 1 -8 for England and Wales*

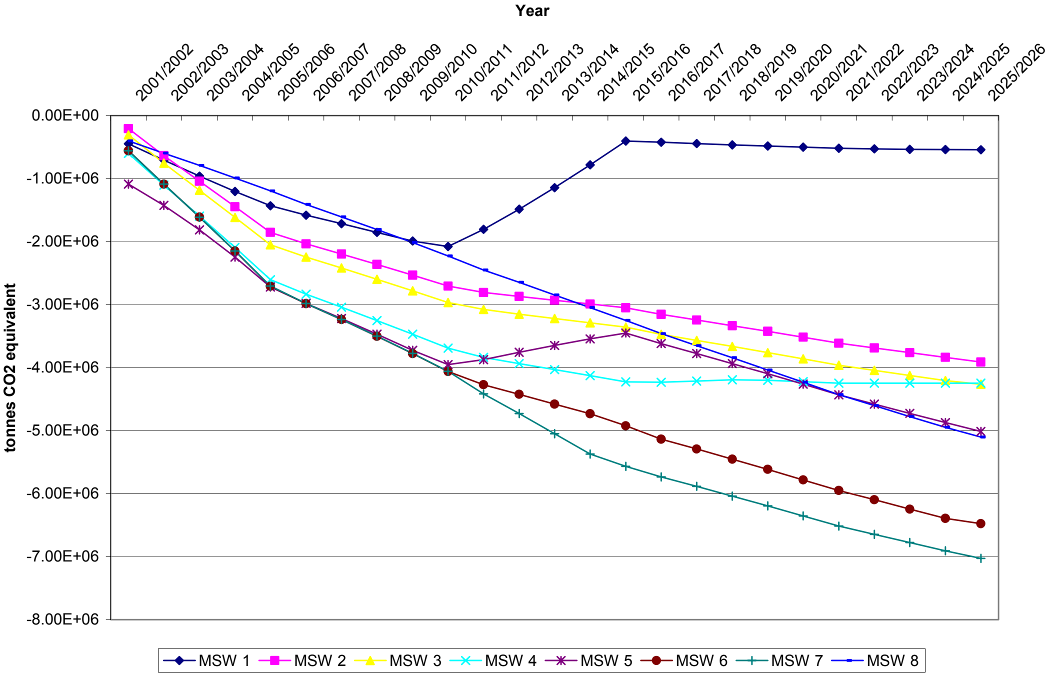


Table 6.2 Discussion and Comparison of MSW GHG Emissions for England and Wales – According to Scenarios 1 - 8

Scenario	Reference Chart	Governing Scenario Waste Policy	General Observation
1	Figure 6.1	Achieving WS 2000 and Landfill Directive targets with current material recycling rates and higher recovery.	A general downward trend in GHG emissions is observed. However, as the WS 2000 targets require a 66% recovery of MSW in 2015, the increased use of EfW causes a slight increase in CO_2 emissions between 2010 and 2015. The reduction in GHG emissions increases after 2015 as the proportion of waste recycled and recovered increases in the face of declining waste growth.
2	Figure 6.1	Achieving WS 2000 and Landfill Directive targets with an emphasis on paper recycling and composting.	A steady downward trend in GHG emissions as recycling and composting rates increase over time.
3	Figure 6.1	Achieving WS 2000 and Landfill Directive targets with an emphasis on paper recycling alone.	A steady downward trend in GHG emissions as paper recycling rates increase over time.
4	Figure 6.1	Achieving WS 2000 and Landfill Directive targets with an emphasis on energy recovery through mass burn energy from waste.	A steady downward trend in GHG emissions through recycling and recovery, slowing as the recovery rate begins to dominate.
5	Figure 6.1	Achieving WS 2000 targets with an emphasis on glass, metals and plastics recycling. The Landfill Directive targets are not achieved in 2013 and 2020.	A steady downward trend in GHG emissions. However, as the WS 2000 targets require a 66% recovery of MSW in 2015 and 33% recycling of household waste, the increased rate of EfW causes a decrease in the offset emissions between 2010 and 2015. This is due to more paper being diverted through transfer stations for either landfilling/EfW during that period, as the scenario emphasises recycling of glass, metals and plastics. The offset increases after 2015 recycling and recovery rates increase in the context of declining waste growth.
6	Figure 6.1	Higher growth rate, achieving WS2000 and Landfill Directive targets with current material recycling proportions and excess recovery.	A steady downward trend in GHG emissions, where recycling and recovery achieve a higher net benefit of GHGs compared with the other scenarios. The excess recovery rate through EfW contributes to this high net benefit in GHG emissions, despite an assumed higher waste growth rate between 2001 and 2005.
7	Figure 6.1	Higher growth rate, achieving WS2000 and Landfill Directive targets (1) with excess material recycling rates.	A steady downward trend in GHG emissions, where recycling and recovery achieve a greater reduction in GHG emissions compared with the other scenarios. The excess recovery rate through recycling and composting contributes to this high reduction in GHG emissions, despite an assumed higher waste growth rate between 2001 and 2005.
8	Figure 6.1	This is the basecase scenario, current ratio of recycling to recovery is maintained and the rate of change in diversion observed between 96/97 to 99/00 is maintained.	A steady downward trend in GHG. This scenario initially achieves the least emissions reductions, based on current practice, but exceeds the reductions of scenario 1 by 2009, and some of the other scenarios beyond 2013. By 2025, only scenarios 6 and 7 exceed reductions of scenario 8.

6.2.1.3 *GHG Emission Estimates for C&I Waste and Other Waste Over Time, Excluding Landfill Methane Emissions*

In contrast to the landfill methane emissions scenarios, all C&I waste and 'other waste' (CIO) management scenarios excluding landfill contributed to a net reduction in GHG emissions over time (see *Figure 6.2*). It was assumed for all CIO scenarios that there was no waste growth over time (see *Section 5.4.2*). Hence, the GHG emissions in scenario 1, where current trends in diversion were assumed to continue, remain constant over time. In the other scenarios, the net benefit changes over time as the nature of materials recycled and/or recovered changes.

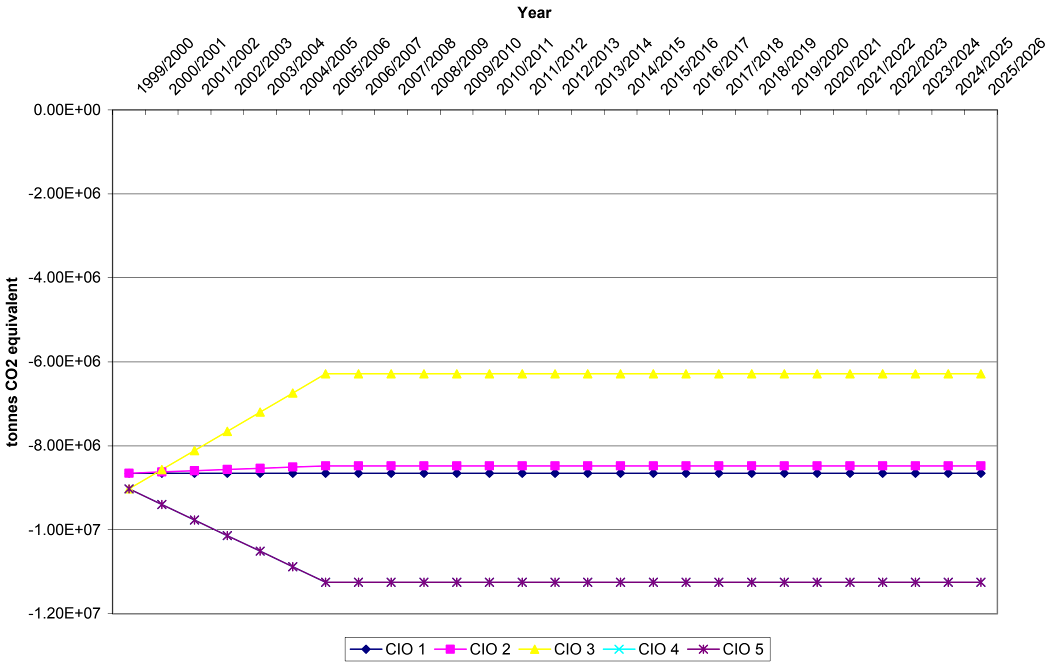
The net benefits of the CIO scenarios in terms of GHGs were approximately three to eight times greater than MSW reductions, depending on the scenario assumptions. This is because of the substantial amounts of commercial and industrial and other waste generated compared to MSW in the wider context of total waste arisings in the UK, rather than the mix of materials that can be recovered or recycled.

Scenario 2, assuming that the WS 2000 target of diverting 15% of C&I waste is achieved through anaerobic digestion, EfW and recycling of biodegradable wastes yielded a very slight increase in GHG emissions. However, the overall trend was similar to that of scenario 1 (maintaining current trends).

Scenario 3 demonstrates a decline in the offset GHG emissions between 2001 and 2005, when the WS 2000 target of diverting 15% of general biodegradable wastes to combustion is applied. Nevertheless, the total net benefit is maintained.

In contrast, both Scenarios 4 and 5, which emphasise recycling, produce a larger net benefit compared to the other scenarios, and one that increases over time. This reflects the greater offset GHG emissions that result from recycling than recovery.

Figure 6.2 *C&I and Other waste (CIO) Scenarios 1 –5 for England & Wales*



Note: CIO 5 overlaps CIO4

6.2.1.4 *Total GHG Emissions Over Time, Including Landfill Methane Emissions and GHG Emissions Estimates for MSW and CIO*

Annex G compiles the total GHG emissions for each scenario combination (in total there are 40 combinations). Each chart shows the individual elements of the MSW, CIO and landfill methane emission scenarios, which contribute to this total. In essence, the total GHG emissions graph reflects the attributes of the individual elements as discussed in the preceding paragraphs.

It must be noted that at this point, this is as far as the results are analysed or discussed. The nature in which the individual elements were developed makes it difficult to compare the 40 combined scenarios.

6.3 *SCOTLAND, NORTHERN IRELAND AND THE CHANNEL ISLANDS*

As the GHG emissions estimates for Scotland, Northern Ireland and the Channel Islands were derived from the total GHG estimates of England & Wales by scaling, the analysis of this section's results is the same as *Section 6.2.1* for England & Wales. The only differences lies in the magnitude of GHG emissions, characterised by the proportionately larger /smaller waste tonnages generated. See *Annex D-F* for results in chart form.

6.4 *UK GHG EMISSION ESTIMATES*

Annex G presents the total GHG emission estimates for the UK, which includes England & Wales, Northern Ireland and Scotland. The Channel Islands are not included in the final UK GHG Emission Estimates due to their status as Crown Dependency.

Overall, the same conclusions and observations are applied to the UK GHG emissions.

7 AMMONIA

7.1 MODELLING APPROACH AND ASSUMPTIONS

The estimates of ammonia emissions (to water and air) were derived in the same way as the GHG emissions were estimated for England and Wales (see *Section 5*). The modelling approach employed the same concept as previously described, including using the same waste management scenarios, transport distances and waste quantities.

Note that a different set of emission factors, which were sourced from ***WISARD***[1], were used specifically for ammonia releases from each activity. In addition, for reasons previously highlighted in *Section 5.8.3*, the use of scaling-down factors to obtain GHG emissions for Scotland, Northern Ireland, and the Channel Islands, incorporates WS 2000 targets rather than the targets contained in their respective national waste strategies.

Furthermore, note that the ammonia emissions modelling and output are different than what was done for GHG emissions, in that ammonia emissions from landfill were included. The assumptions used to estimate emissions fro landfill can be found in *Annex I.*

7.2 PRESENTATION OF RESULTS

Due to the complex nature of presenting the scenario combinations from the spreadsheets, ammonia results are instead presented for the scenarios individually, i.e. for MSW (8 scenarios), and for C&I and Other Wastes (5 scenarios)[2].

7.3 DISCUSSION OF RESULTS

Annex H presents the ammonia emissions results for England and Wales, Scotland, Northern Ireland and the Channel Islands. In all cases the releases are positive. The results are different from those observed for GHG emissions, as there is not the same benefit for ammonia emissions from recycling and energy recovery (avoidance of virgin material and fossil fuels).

Ammonia emissions from MSW to water and air have been observed to slightly reduce over time in scenarios 2 - 4 and 6 - 8. However, emissions in scenarios 1 and 5 increase over time, reflecting the nature of the materials recovered under the governing 'waste policies'. These scenarios have an emphasis on recycling inert material by comparison with the other scenarios,

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(1) Environment Agency's LCA software tool

(2) Also known as CIO Waste

and this leads to a higher proportion of putrescible material being sent to combustion.

- *Scenario 1* Achieving WS 2000 and Landfill Directive targets with current material recycling rates and higher recovery; and
- *Scenario 5* Achieving WS 2000 targets with emphasis on glass, metals and plastics recycling.

For CIO ammonia emissions both to air and to water, scenarios 2 and 3 show a marked increase over time compared to other scenarios, because the WS 2000 target of diverting 15% of C&I waste from landfill is met through biological and thermal treatment.

8.1 COSTS FOR WASTE MANAGEMENT

This section presents indicative total costs for the MSW waste scenarios that were developed for England and Wales. Costs are not provided for Scotland, Northern Ireland, Channel Islands and the UK as a whole, due to the lack of specific policy modelling for these areas.

Costs per tonne of waste managed by different routes (collection, recycling, composting etc.) were obtained from the Eunomia report '*Costs for Municipal Waste Management in the EU: Final Report to the Directorate General Environment European Commission*'. The relevant cost factors are presented in *Table 8.1* and are presented as 2002 prices. The cost factors are UK specific.

Table 8.1 Costs per Tonne of Management Routes for MSW

Waste Management Route	£/tonne
Collection	34.19
Transfer Station Operations	9.36
Materials Recycling Facility (MRF) Operations	33.64
Recycling	104.92
Composting	28.61
Energy from Waste (EfW)[1]	38.00
Landfill	
- Landfill Tax at £ 14[2]/tonne	26.67
- Landfill Tax at £ 35/tonne	47.67

Notes:

1 For annual capacity of up to 200 ktpa

2 As of April 2003

Due to the absence of data relating to future changes in price as a result of inflation, economies of scale and market development, have been ignored. Current costs (2001/2002) have been assumed for all years.

Total aggregate costs for each of the MSW scenarios have been derived using the quantity of waste assumed to follow each management route and the indicative costs for each route presented in *Table 8.1*. The costs were calculated assuming current waste management costs, landfill costs have been excluded as the modelling undertaken by ERM relates to all other waste management activities and not landfill. Aggregate costs have been derived for 2002, 2005, 2010, 2015 and 2025, as example headline years. In each case, costs are given as 2002 prices. It is assumed that there are no price rises. The aggregate costs are presented in *Table 8.2* together with net GHG emissions for the MSW activities excluding landfill (since these results are inextricably linked to CIO waste emissions).

The results show that, generally, costs increase over time, as more expensive waste management routes are pursued. However, the rise in costs is accompanied by a decrease in GHG emissions. The cost-effectiveness of scenarios 1 and 2 is shown in *Figures 8.1* and *8.2*, respectively. Whilst scenario 1 shows a decrease in cost-effectiveness over 2010 to 2015, scenario 2 demonstrates continuing cost-effectiveness for delivering GHG emissions reductions over the period studied.

Table 8.2 Total Costs for Waste Management Scenarios for England & Wales (excluding landfill costs)

MSW Scenarios	Year	Waste arising (x 10^7 tonne / year)	GHG Emissions[1] (x 10^{11} g CO_2 equivalent	Total Estimated Cost[2] (x 10^9 £)
Scenario 1	2002	3.22	-4.5	2.0
Achieving WS 2000 and Landfill Directive targets with current material recycling rates and higher recovery.	2005	3.52	-14.3	3.5
	2010	3.89	-20.8	4.1
	2015	4.09	-4.1	5.4
	2025	4.19	-5.4	5.9
Scenario 2	2002	3.22	-6.33	2.0
Achieving WS 2000 and Landfill Directive targets with an emphasis on paper recycling and composting (i.e. diverting degradable waste from landfill).	2005	3.52	-18.5	2.6
	2010	3.89	-27.0	3.1
	2015	4.09	-30.5	3.7
	2025	4.19	-39.1	4.0
Scenario 3	2002	3.22	-7.6	2.1
Achieving WS 2000 and Landfill Directive targets with an emphasis on paper recycling alone (i.e. diverting degradable waste with an energy benefit).	2005	3.52	-20.5	2.7
	2010	3.89	-29.6	3.3
	2015	4.09	-33.6	3.8
	2025	4.19	-42.6	4.3
Scenario 4	2002	3.22	-11.0	2.0
Achieving WS 2000 and Landfill Directive targets with an emphasis on energy recovery through mass burn energy from waste.	2005	3.52	-26.0	2.6
	2010	3.89	-36.9	3.1
	2015	4.09	-42.3	3.7
	2025	4.19	-42.5	3.9
Scenario 5	2002	3.22	-14.3	2.1
Achieving WS 2000 targets with an emphasis on glass, metals and plastics recycling (i.e. diverting non-degradable waste from landfill). The Landfill Directive targets are not achieved in 2013 and 2020.	2005	3.52	-27.2	2.7
	2010	3.89	-39.5	3.2
	2015	4.09	-34.5	3.8
	2025	4.19	-50.1	4.2
Scenario 6	2002	3.3	-10.9	2.0
Higher growth rate, achieving WS2000 and Landfill Directive targets with current material recycling proportions and excess recovery.	2005	3.7	-27.1	2.7
	2010	4.3	-40.6	3.2
	2015	4.7	-49.2	3.9
	2025	5.1	-64.8	4.6
Scenario 7	2002	3.3	-10.9	2.0
Higher growth rate, achieving WS2000 and Landfill Directive targets (1) with excess material recycling rates.	2005	3.7	-27.1	2.7
	2010	4.3	-40.6	3.2
	2015	4.7	-55.7	4.1
	2025	5.1	-70.3	4.6
Scenario 8	2002	3.22	-6.0	1.9
This is the basecase scenario, current ratio of recycling to recovery is maintained and the rate of change in diversion observed between 96/97 to 99/00 is maintained.	2005	3.52	-11.9	2.2
	2010	3.89	-22.3	2.7
	2015	4.09	-32.5	3.1
	2025	4.19	-51.0	3.8

Notes:

1 Includes Post transfer site transport emissions

2 Excludes Post transfer site transport costs due to unavailable data

The shape of the remaining graphs is strongly influenced by the trend of the GHG emissions reductions for each scenario, as shown in *Figure 6.1*. With the exception of scenarios 1 and 5, continuing cost-effectiveness is demonstrated by all the scenarios over the period examined and there are increased returns as a result of the rising costs of waste management.

Figure 8.1 Cost-Effectiveness for MSW Scenario 1

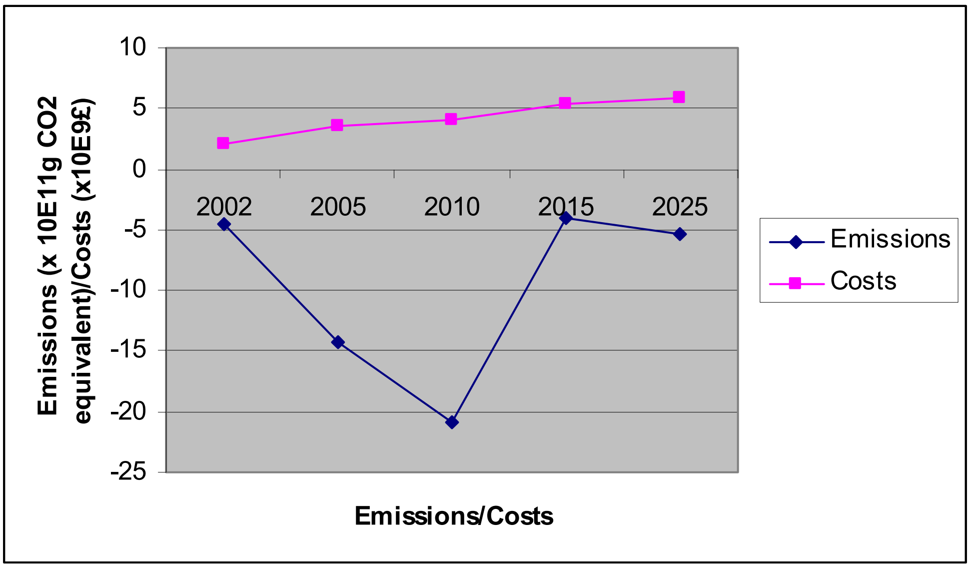
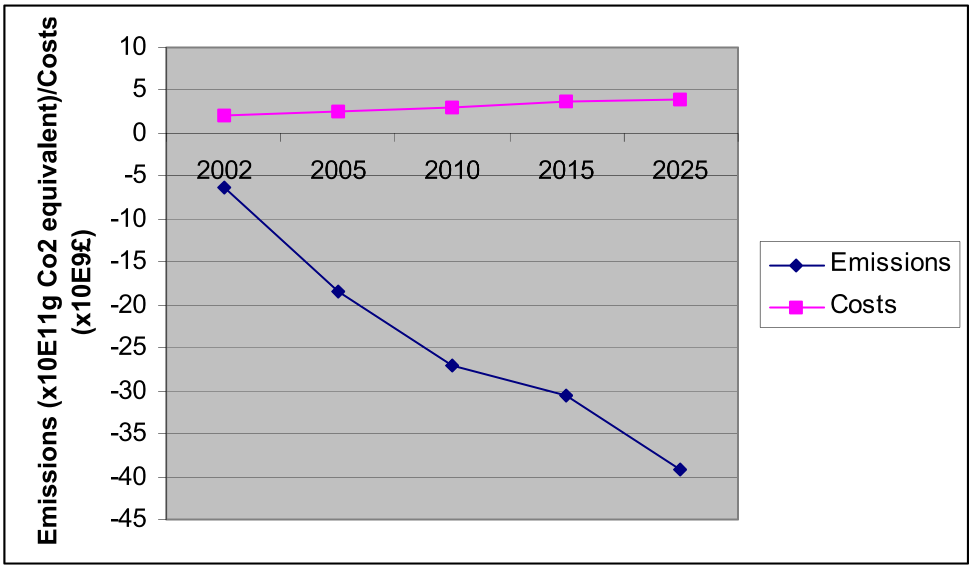


Figure 8.2 Cost-Effectiveness for MSW Scenario 2



This exercise has not been repeated for the C&I waste and Other Waste scenarios. This is because waste disposal in these sectors is a commercial spot market, and reliable cost factors are difficult to obtain. Furthermore, recycling, and, to an extent, recovery, methods have a wide range of prices because of variation in the value of the waste itself (e.g. for paper, from clean offcuts to a mixed paper waste stream).

Because there are no statutory drivers of change, generally waste producers will only change management route in response to lower prices. Accordingly, many producers could be expected to change the preferred management route for their wastes in response to changes in the landfill tax, and as a result of other increases in the cost of landfill. The cost at which change will occur will vary depending on the other routes available, and the complexity of these margins is not possible to model within the constraints of this study.

8.2 *LANDFILL COSTS*

Two cost models were developed for UK landfill methane emissions, based on varying landfill tax and tax escalator levels. The two models adopted were:

- Based on the current situation i.e. £13/tonne in 2002/03 and a continued annual landfill tax escalator of £1/tonne right up to 2024/25; and
- Based on *'Waste Not, Want Not'* recommendations i.e. £35/tonne in the medium term (beginning 2010/11 in this case) and an annual landfill tax escalator of £3/tonne right up to 2024/25.

It was assumed that current gates fees apply to overall cost of landfilling a tonne of waste (£12.67). *Table 8.3* presents landfill costs for a tonne of waste for the years 2002, 2005, 2010, 2015, 2025 as a result of these assumptions with regard to the landfill tax.

Table 8.3 Landfill Cost per Tonne of Waste for Selected Years

Year	**Current Situation** £/tonne	***'Waste Not, Want Not'*** **recommendations** £/tonne
2002	25.67	25.67
2005	28.67	28.67
2010	33.67	47.67
2015	38.67	62.67
2025	48.67	92.67

Table 8.4 presents indicative costs for landfilling waste in 2002, 2005, 2010, 2015 and 2025. Unlike costs presented in above (i.e. only for individual MSW scenarios for England and Wales), the costs presented in *Table 8.4* are derived from scenario combinations for the UK i.e. 40 combinations. *Table 8.4* serves as a summary of the costs for the 40 scenarios assessed (scenario combinations: see *Section 6.7*). The landfill methane emissions of the 40 scenarios can be referred to in the Annexes.

Table 8.4 ***Landfill Costs for the Quantity of Wastes Landfilled and the Amount of Methane Emissions Produced from Landfill (see Annexes)***

	Combined Scenarios			
Year	**MSW 1-5,8 and CIO1-5**		**MSW 6,7 and CIO 1-5 (x 10^9 £)**	
	Current Situation **(x 10^6 £)**	'Waste Not, Want Not' Recommendations **(x 10^9 £)**	Current Situation **(x 10^6 £)**	'Waste Not, Want Not' Recommendations **(x 10^9 £)**
2002	6.3	6.3	6.2	6.3
2005	7.1	7.1	7.1	7.1
2010	8.5	8.6	1.2	1.2
2015	9.8	10.1	1.6	1.6
2025	1.2	13.0	2.4	2.5

Annex A

Development of Incineration (With Energy Recovery) Emission Factors

A1 EMISSION FACTORS FOR INCINERATION OF NEWSPAPER, PE AND PUTRESCIBLE WASTE

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A1.1 GENERAL DESCRIPTION

Emission factors for the incineration of newspaper, PE and putrescible waste have been obtained through calculations in SimaPro 4.0 software. The data used by Finnveden et al. (2000) form the basis for the calculations. For the purpose of this study operating energy and offset energy have been altered compared to Finnveden et al. (2000) and transportation of the waste to the incineration plant has been excluded. The below description of the data and models used is taken mainly from Finnveden et al. (2000) (the full report is available at www.fms.ecology.su.se/eng/index.html).

A1.2 THE INCINERATION MODEL

The incineration process is based on an ORWARE (ORganic WAste REsearch model) sub-model for incineration (Björklund, 1998). The inventory data for this sub-model was collected at the Uppsala incineration plant in 1993, and the model is specific for the plant in Uppsala. Incineration plants are normally individually constructed and may vary. Notable for the Uppsala incineration plant is the flue gas condensation, which is rather common in Sweden, but rarely used elsewhere (Björklund, 1998). It enhances the efficiency of energy recovery, but generates an additional flow of wastewater. According to Björklund (1998) modern waste incineration plants may differ in technical solutions, but it may be assumed that emissions are kept within the limits of legal restrictions, regardless of the composition of the incinerated waste. This suggests that, despite a site-specific approach, the model is rather general regarding emissions to air and water, for plants working under the same legal restrictions. Residual products, consumption of additives and energy recovery are more site-specific.

The elementary composition of the waste fractions studied, presented below, is used as input in the incineration model. The model is divided into two parts; the *kiln* which generates outputs of bottom ash and raw gas, and the *air emission control system*, generating outputs of fly ash, condensed water and cleaned gas. Generation of heat and consumption of energy and additives are calculated within the kiln sub-model. The consumption of energy and additives within the incineration plant is calculated as depending only on the incoming amount of waste, except for urea which depends on the total nitrogen content in a waste material.

The heat released in the kiln is calculated either using higher heating values (HHV) of the carbon compounds in the incinerated waste material, or one HHV-value for the material in its entirety. For food waste the content of different carbon compounds is used to calculate the HHV-value. For the other waste materials included in this study the other procedures have been used. The HHV-values for the studied waste materials are presented in Table 1. The generating efficiency of the incineration process is set to 15% (according to eg (Otoma et al., 1997).

In the kiln, the waste is transformed into bottom ash and raw gas. The main parts of the nitrogen end up in the raw gas. All carbohydrates, fats and proteins in the waste are assumed to be completely combusted, forming biological CO_2.

The air emission control system consists of SNCR (Selective Non-Catalytic Reduction) with urea, acid removal by lime addition in the kiln, electrostatic precipitators, wet scrubbers, flue gas condensation and fabric filter.

The condensed water is flocculated, filtered and emitted to a recipient. Nearly 70% of the ammonia is removed from the condensed water. The condense water sludge is mixed with the fly ash and TMT 15 (Trimercapto-s-triazine-tri-sodium-salt) which reduces the leachability of the metals. The fly ash, which in the text here after also includes the sludge, is then transported by truck to a landfill. The transport distance is assumed to be 13 km.

Landfilling of the fly ash and the bottom ash is modelled according to Björklund (1998). The whole landfill model is described in more detail in (Finnveden et al., 2000). Fly ash and bottom ash are modelled separately since the leachability is differing for metals and some other substances. Leakage from the landfilling of ashes is assumed to be treated in a municipal sewage treatment plant with following landfilling of the formed sludge.

In the landfill model we have used two time-perspectives (Finnveden, 1992; Finnveden et al., 1995; Finnveden, 1996; Sundqvist et al., 1994; Sundqvist et al., 1997):

1) "The surveyable time period", which is defined as the time period it takes to reach a pseudo steady state in the landfill. The surveyable time period should correspond to approximately one century. In this case the time period is defined by the processes in the landfill. For municipal solid waste landfills, the surveyable time period is defined as the time it takes to reach the later part of the methane phase when gas production is diminishing. For some types of solid wastes, it may be difficult to define a pseudo steady state within this time frame. In such cases 100 years is used as default.

2) "The hypothetical infinite time period" is defined by total degradation and emission of the landfilled materials. This time period is introduced to get the maximum, potential impacts. This time period is split into the surveyable time period (ST) and the remaining time period (RT) in order to facilitate the inventory analysis.

A1.2.1 *Allocations and system boundaries*

A specific waste material is usually combusted as a part of a mixed waste and a problem arises concerning the allocation of emissions to the different waste fractions. In the incineration sub-model allocation is done either on a weight basis for a waste material or on an elemental basis, where elemental parameters describe a waste. The allocation methods used are thought to be best estimates (Björklund, 1998).

Since the demand for energy recovered at the plant varies during a year, baling of the incoming waste is a storage option. Baling of waste is however excluded in this study. Consumption of energy and process additives are included. Production of the additives TMT 15 and Polyflock are excluded, due to lack of data. Process data for production of *urea*, *limestone B250* ($CaCO_3$) and *calciumhydroxide* are described in (Finnveden et al., 2000), Appendices 1 and 5). The electricity consumed at the incineration facility, 0.28 MJ/ kg waste, has the same composition as the offset energy production. Landfilling of the bottom ash and the fly ash, including transport work, are also included in the system.

Generated amounts of ashes for the different waste materials are presented in *Table A1.1***.** The clay (chaolin) in newspaper is assumed by us to be left in the slag after incineration. In the case of incineration of PVC we assume a best case for the additives DEHP (Dietylhexylftalat) and DOM (Dioktyltinmaliat), assuming that these components will be completely combusted.

Table A1.1 Generated amounts of ashes for the included waste materials in the study

Waste material	Bottom ash (kg/kg TS)	Fly ash (kg/kg TS)
Food waste	$1.8 \cdot 10^{-1}$	$2.0 \cdot 10^{-2}$
Newspaper	$1.2 \cdot 10^{-1}$	$1.3 \cdot 10^{-2}$
PE	$9.0 \cdot 10^{-4}$	$1.0 \cdot 10^{-4}$

A1.2.2 *Composition of waste fractions*

The elementary composition of the constituents of the studied waste is presented in *Table A1.2* and in the text below. These data are used as input in the incineration model. Explanations of the abbreviations used for the composition are given in *Table A1.3*, as well as explanations for the different materials. To describe the composition of the different waste materials a modified version from Sundqvist et al. (2000, Appendix 2) is used.

Table A1.2 Composition of the fractions of the average household waste studied

Parameter	Putrescible waste (kg/kg unless stated)	Newspaper (kg/kg unless stated)	PE (kg/kg unless stated)
HHV (MJ/kgTS)	18.9[13]	19.0[8]	46.0[11]
TS	0.3[8]	0.88[9]	0.95[8]
C-fossil		0,008[7]	0,856[1]
C-tot bio	0,434[8]	0,44[7]	-
-lignin	0,029[8]	0,14[7]	-
-cellulose	0,107[8]	0,3[7]	-
-starch and sugar	0,097[8]	0,002[7]	-
-fat	0,135[8]	-	-
-protein	0,066[8]	-	-
H	0,058[8]	0,05[7]	0,142[1]
O	0,287[8]	0,38[7]	0,0030[1]
VOC	2,00E-6[8]	-	-
CHX	1,00E-8[8]	-	-
PAH	5,00E-7[8]	-	-
Phenols	2,75E-5[8]	-	-
PCB	4,35E-8[8]	-	-
Dioxin	9,00E-14[8]	-	-
Cl	3,9E-3[8]	6E-6[7]	-
N-tot	0,020[8]	-	-
P-tot	3,8E-3[8]	-	-
S-tot	2,4E-3[8]	-	-
Al		0,015[7]	-
K	9,3E-3[8]	-	-
Ca	0,028[8]	0,006[7]	-
Pb	1,00E-5[8]	3,5E-6[5]	1,9E-4[5]
Cd	1,30E-7[8]	5E-8[5]	1,2E-7[5]
Hg	2,80E-8[8]	1,1E-8[5]	7,1E-8[5]
Cu	3,40E-5[8]	3,5E-5[5]	1,8E-4[5]
Cr	1,00E-5[8]	5,9E-6[5]	1,3E-5[5]
Ni	7,00E-6[8]	6,2E-6[5]	7,7E-6[5]
Zn	8,00E-5[8]	4,2E-5[5]	1,9E-4[5]
Clay		0,07[7]	
DEHP			
DOM			

- Indicates no data available

[1] (Zevenhoven et al. 1995, p 8 to 9).

[2] Own calculations from the chemical formula $(C_{10}O_4H_4)_n$ gives the C, O and H values.

[3] (RVF 1996, p 19-20 and appendix 2).

[4] Own calculations from Naturvårdsverket (1996) and Kemikalieinspektionen (1996). Based on assumptions presented in the section on PVC composition.

[5] from Berg et al. (1998).

[6] (Olsson, 1999) personal communication.

[7] calculated from Sundqvist et al. (1997 p 96).

[8] (Sundqvist et al. 2000, Appendix 2).

[9] (Ekvall et al., 1993).

[10] (FEFCO et al. 1997p 17).

[11] (Björklund 1998, Appendix G, p G-2).

[12] (Björklund, 1998) Appendix E, p E-8.

[13] calculated from (Björklund, 1998) Appendix F, p F-1, using the HHV-values (MJ/kg C) for C-lignin: 40.89, C-cellulose: 37.51, C-starch and sugar: 39,57, C-fat: 51,25, C-protein: 45,07, VOC: 50,1 and CHX: 35.0.

Table A1.3 Explanation of the abbreviations used for the description of compositions

Substance	Explanation
HHV	Higher heating value. Value for energy content including energy in steam produced in combustion.
TS	Total solids. Weight after evaporating moisture.
C-fossil	Carbon of fossil origin, eg carbon in plastics.
C-tot bio	Carbon of biological origin.
-lignin	Carbon in stable carbohydrates, eg lignin
-cellulose	Carbon in semi-stable carbohydrates, eg cellulose.
-starch and sugar	Carbon in degradable carbohydrates, eg starch and sugars
-fat	Carbon in fat
-protein	Carbon in proteins
H	Hydrogen (except hydrogen in water)
O	Oxygen (except oxygen in water)
VOC	Volatile organic compounds, including methane
CHX	Volatile halogenated hydrocarbons
PAH	Polyaromatic hydrocarbons
Phenols	
PCB	Polychlorinated biphenyls, existing in organic waste
Dioxin	TCDD equivalents, measured according to Eadon
Cl-tot	Total chlorine
N-tot	Total nitrogen
P-tot	Total phosphorous
S-tot	Total sulphur
Al	Aluminium
K	Potassium
Ca	Calcium
Pb	Lead
Cd	Cadmium
Hg	Mercury
Cu	Copper
Cr	Chromium
Ni	Nickel
Zn	Zinc
Clay	Chaolin, $Al_2(OH)_4Si_2O_5$, used in magazine paper
DEHP	Dietylhexylftalat, exemplifies the total of plasticisers in PVC
DOM	Dioktyltinmaliat, exemplifies the total of stabilisers in PVC

Putrescible waste

For putrescible waste the composition given in Sundqvist et al. (2000, Appendix 2) is used.

Newspaper

Newspaper makes out a rather large part of the total household waste, measured in weight.

In this study a waste mix of 70% newspaper and 30% magazine paper is assumed. Data for the elementary composition of these two fractions are from Sundqvist et al. (1997, p 96).

Newspaper is made up to 99% of mechanical pulp, which in turn is made up of 73% cellulose ($C_6H_{10}O_5$) and 26% lignin ($C_{10}H_{11}O_3$). Magazine paper is composed of 29% bleached mechanical pulp and 38% mechanical pulp. The rest is mostly china clay (24%), lime (5%) and polystyrene-butadiene (3%). Only part of these three contents is used in the composition data. China clay, or chaolin, has the chemical formula $Al_2(OH)_4Si_2O_5$, and is contributing to the composition data as clay, but also as aluminium. Lime, ($CaCO_3$), is included as carbon and calcium. Polystyrene-butadiene $(C_{12}H_{14})_n$ contributes with fossil carbon to the newspaper composition data.

Cationic starch, $(C_6H_{10}O_6)_n$, is part of both newspaper and magazine paper and is reported as starch-carbon.

Some constituents presented in Sundqvist et al. (1997 p 96), polyacrylicamid, polyacrylicacid, CMC (carboxymethyl cellulose), PE (polyethylene), and PE-imin, are left out of the here defined composition of newspaper. The amounts are small and are considered to be of little importance here.

Data on heavy metals content are from Berg et al. (1998 p18). The data given there are averages for newspaper, journals and magazines and is assumed to be suitable as an approximation of the heavy metal content of the newspaper fraction studied here.

PE

PE constitutes the largest part of plastics in packaging, which is the approximation used here for household waste. Data for HDPE (High-Density PE) from (Sundqvist et al., 2000) is used as an approximation for PE.

A1.2.3 Transport

Data on resource use and emissions connected to road transports by truck are taken from Frees and Weidema (1998). They have collected and verified their combustion data from a few different sources but the basis is CORINAIR (1996). Fuel consumption for different sizes of trucks are supplied by Volvo (de Val, 1992) and updated by Rydberg (1997). Volvo has not provided fuel consumption for all driving modes of each truck and the fuel consumption is therefore adjusted with factors from CORINAIR (1996). Emission factors from CORINAIR (1996) are used, updated with the emission standards given by the EU 1 norm (European Commission, 1993). An efficiency of the engine of 33% is assumed. According to Frees and Weidema this is a, maybe somewhat conservative, average efficiency for a diesel truck engine. The precombustion data is taken from Frischknecht et al. (1994) and covers exploration, extraction, refining and transport to stock of the diesel fuel.

A1.2.4 Offset energy

The offset energy is assumed to be the fuel mix for the UK electricity sector in 2000 as stated by 'Digest of UK Energy Statistics, 2001':

• Coal	34%
• Natural gas	33%

• Nuclear	27%
• Oil	2%
• Other non renewable fuels	1%
• Hydro	1.41%
• Onshore wind	0.26%
• Landfill gas	0.60%
• Sewage	0.10%
• Municipal solid waste	0.38%
• Other renewable fuels	0.14%

In order to get data with similar assumptions and system boundaries, data based on (Frischknecht et al., 1994), reflecting European conditions in 1993, were used in one set of calculations. These calculations include data on electricity production from coal, natural gas, uranium, and hydro. This accounts for 97.41% of the fuel mix. As a sensitivity analysis calculations were also made where data on wind power was included and where other non renewable fuels were assumed to be natural gas, and all renewables, besides wind and hydro power was approximated to biomass. For comparison calculations have also been made where the offset energy is assumed to be wind power.

Data on electricity production from hard coal in a modern coal condensing power plant is taken from Frees and Weidema (1998). The efficiency of the power plant is 47 % and the lower calorific value of the coal considered is 24.3 MJ/kg. The CO_2 emission is calculated using the value 94g CO_2 per MJ lower calorific value (Eurostat, 1997). Other emissions are taken from Frischknecht et al. (1994). The data covers production and use of the fuel.

Data on electricity generation from natural gas is taken from Frees and Weidema (1998). The efficiency of the plant is 45% and Lower calorific value of the natural gas is 39.6 MJ/m^3 and density 800 g/m^3. The data is based on Frischknecht et al. (1994). The data covers production and use of the fuel.

For electricity derived from nuclear and oil data from BUWAL 250 (BUWAL, 1996), available in Sima Pro 4.0, was used. This data originates from (Frischknecht et al., 1994) and (Frischknecht et al., 1995) and include energy use for the production of the fuels and efficiency losses. Data for electricity from hydropower is derived from the same source.

Data on electricity generation from wind power and biomass are taken from (Vattenfall, 1996) and reflect Swedish conditions in 1995. This data include the building, maintenance, and demolition of the power plants, as well as fuel production in the case of bio fuel. The wind power plant is on 500 kW, with an assumed effective operation time of 1500 h. This will generate 18 750 MWh during a life span of 25 years. The electricity from bio mass comes from a combined power and heat plant with gasification and combi cycle, fuelled with forest residues.

A1.3 BUILDING AND DEMOLITION

The building and demolition of the incineration plant is not included in the calculations. The energy turnover and CO_2 emissions connected to these phases, as well as the collection of the municipal solid waste (MSW) is discussed by (Otoma et al., 1997). They make calculations for a plant with a capacity of 600 t/day per incinerator, using a full continuous feed stoker system. With a standard waste quality of 2300 kcal/kg and steam conditions at 30 kgf/cm^2 and 300^{o}C, the power generated comes to 10 300 kW (generating end efficiency, 15.4%). The plant service life is set at 15 years. The assumptions regarding MSW collection vehicle were 2 t capacity, and a distance of 20 km per trip, gasoline-powered engines with a fuel efficiency of 5 km/l, and 100 000 km lifetime distance travelled. Regarding the manufacture of the collection vehicles a weight of 1.5 t was assumed, to be able too use data already calculated.

Under these assumptions they state that the total carbon emission is 1517 ton C/year, where 50% is from material, 25% from construction, 4% from maintenance, 2% from the production of the MSW collection vehicle, and 19% from MSW collection. The energy use under these conditions are calculated to 13 918 Gcal/year, where 43% is for material, 22% for construction, 6% for maintenance, 3% for production of MSW collection vehicle, and 26% is for MSW collection.

Because of insufficient data Otoma et al assumed that the energy needed for dismantling equals the energy recovered by recycling of the materialised energy, which makes the total energy of dismantling and recycling zero.

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Annex B

MSW and C & I/Other Waste Scenario Assumptions

B1 MSW ASSUMPTIONS

What follows below are notes that will aid review of the excel worksheets that have been used for modelling. The worksheets should be referred to for all numerical data regarding, composition, emission factors, transport distances and waste management routes by material.

The waste incineration figures for each option represent the current situation with regard to the proportion of waste following the management routes below:

- EfW;
- RDF; and
- Incineration without energy recovery (less than 0.5%).

Current recycling by material for MSW was used as basis for calculating MSW recycling for each of the options.

Composition of residual waste, provided by DEFRA, was used as the indicative composition of wastes going to both landfill and incineration.

Generic travel distances for transporting waste have been assumed for the purpose of this study.

No specific emissions factors were available for textiles. Conversations with textile recyclers suggest that textile waste has a general composition of 50% synthetic and 50% natural fibres, to account for this, textiles that are incinerated have been assumed to have emissions factors as though they were composed of 50% plastic and 50% paper.

For the purpose of determining non-landfill emissions the category of waste described as fines in the DEFRA data have been assumed to be 100% non-combustible, non-compostable and non-recyclable.

Non-ferrous metals have been assumed to be aluminium (since this represents the largest proportion of non-ferrous metals).

Emission factors for the composting of putrescible waste were available and have been used, see worksheets.

B2 C & I AND OTHER WASTE ASSUMPTIONS

Almost half of the total C & I Waste is categorised in the Environment Agency SWMA as general commercial and industrial waste, and 80% of this goes to landfill (15% is recycled). The composition of 'general commercial and industrial' is not defined in the study, and this presents obvious problems in modelling the greenhouse emissions associated with managing this waste stream. In order to generate some indicative emissions, ERM has assumed, based on its experience, that 'general commercial and industrial waste' is composed of 35% paper and card, 35% polyethylene (which ordinarily constitutes the majority of plastic packaging waste), 20% putrescibles, and 10% textiles (rags and other packaging). This may well represent an oversimplification, but in the absence of more conclusive data serves as a useful indicator.

The emissions associated with the recycling of inert and C&D wastes have been calculated using emission factors developed for aggregate recycling.

'Food' plus 'general and biodegradable' waste categories are amalgamated and attributed emissions factors for putrescible waste.

Metals and scrap equipment have been assigned emissions factors for 80% ferrous metals and 20% non-ferrous (eg aluminium).

Mineral wastes and residues have been assigned the emissions factors for miscellaneous non-combustibles.

The basis of the above assumptions is based on ERM's professional judgment, to generate meaningful and defined results.

Annex C

Scenarios for England & Wales

C1 SCENARIO 1

Figure C1.1 GHG Contributions for MSW Scenario 1 – CIO 1

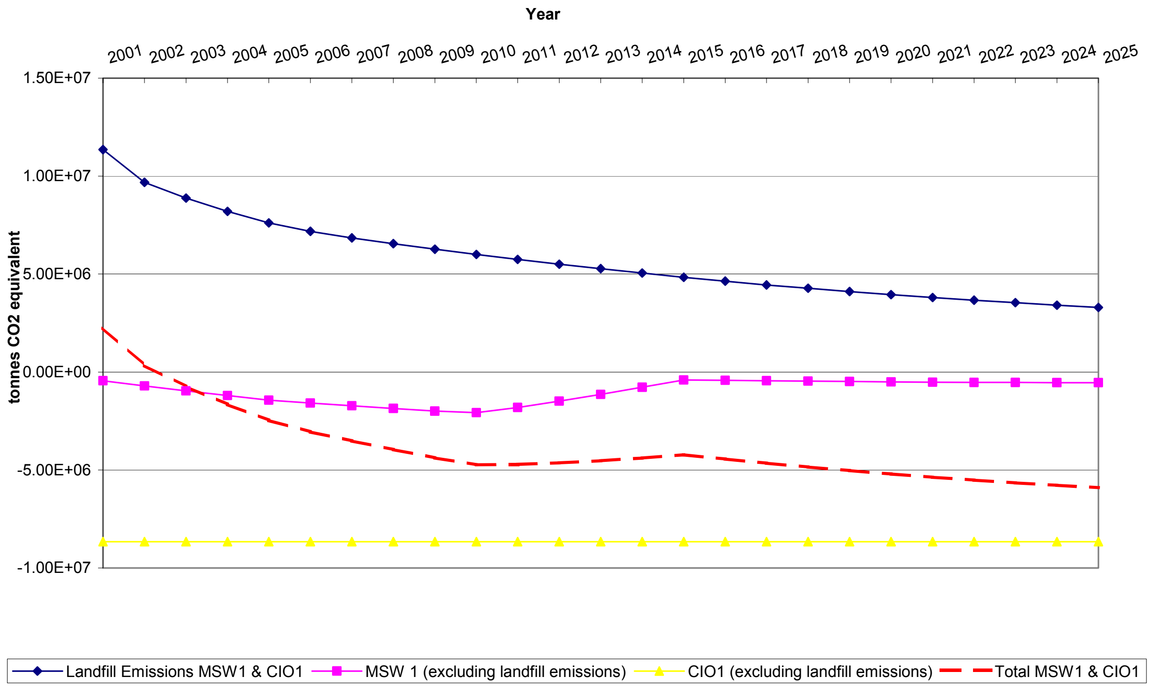


Figure C1.2 GHG Contributions for MSW Scenario 1 – CIO 2

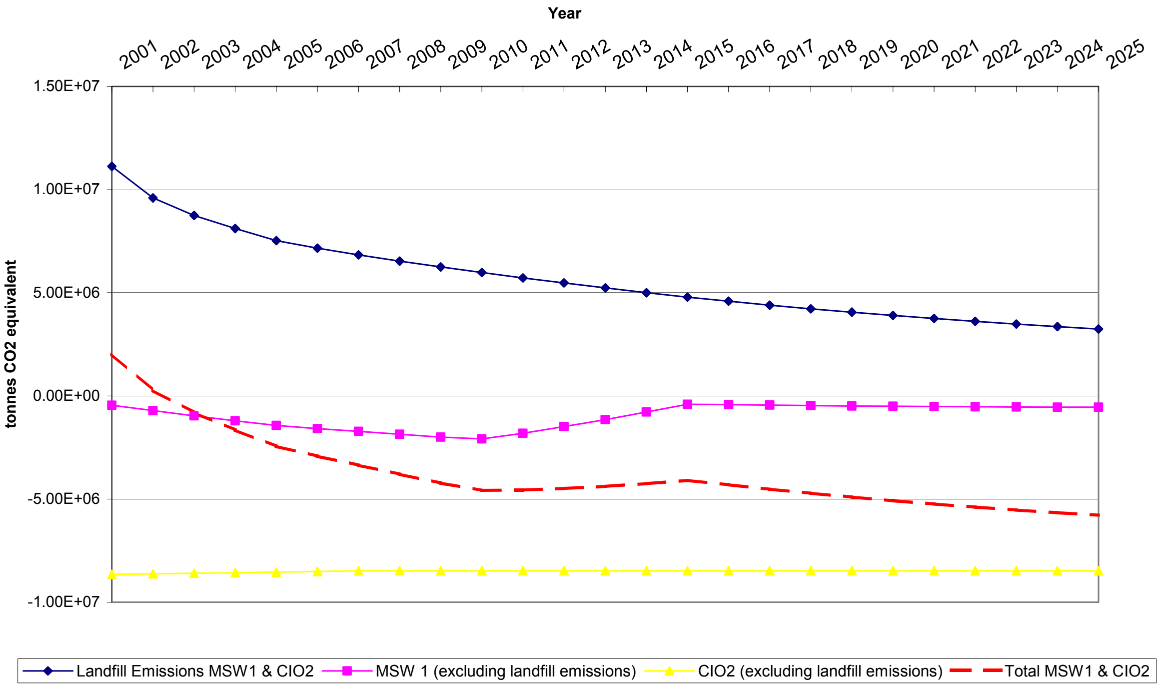


Figure C1.3 GHG Contributions for MSW Scenario 1 – CIO 3

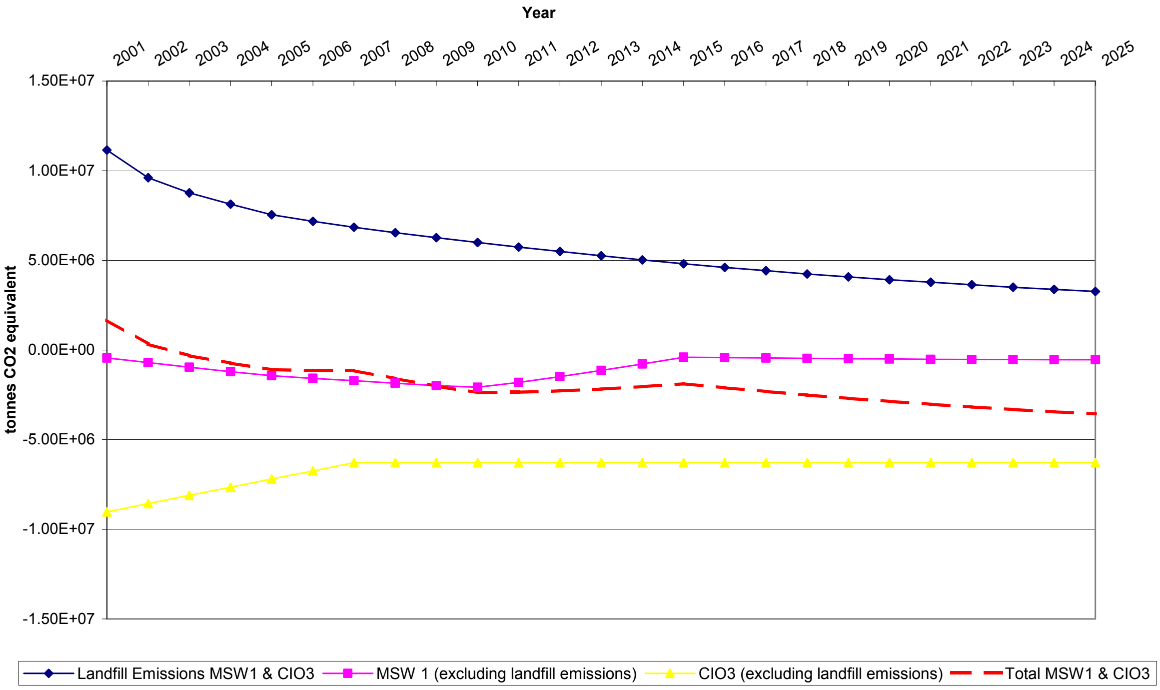


Figure C1.4 GHG Contributions for MSW Scenario 1 – CIO 4

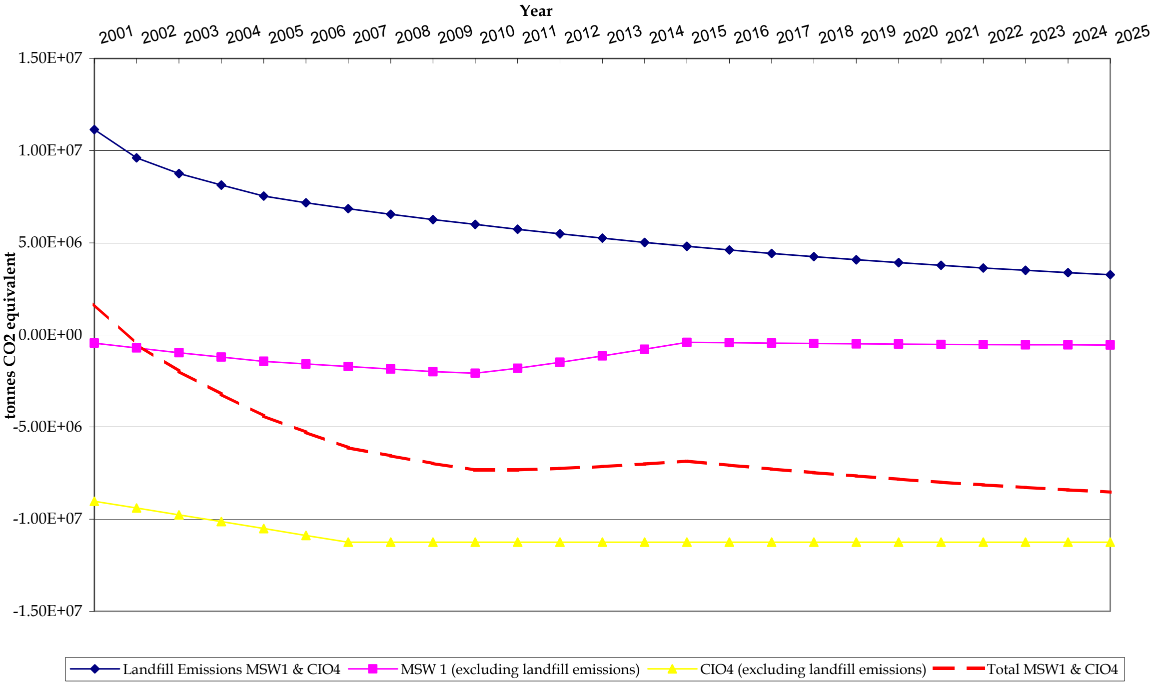
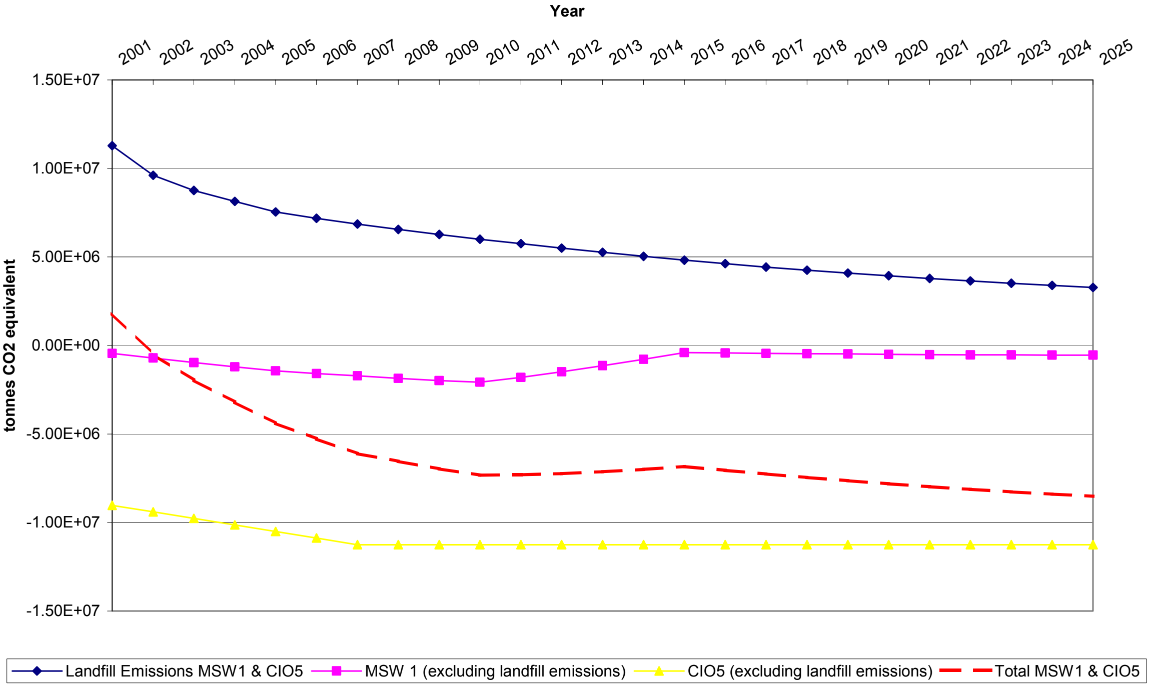


Figure C1.5 GHG Contributions for MSW Scenario 1 – CIO 5



C2 SCENARIO 2

Figure C2.1 GHG Contributions for MSW Scenario 2 – CIO 1

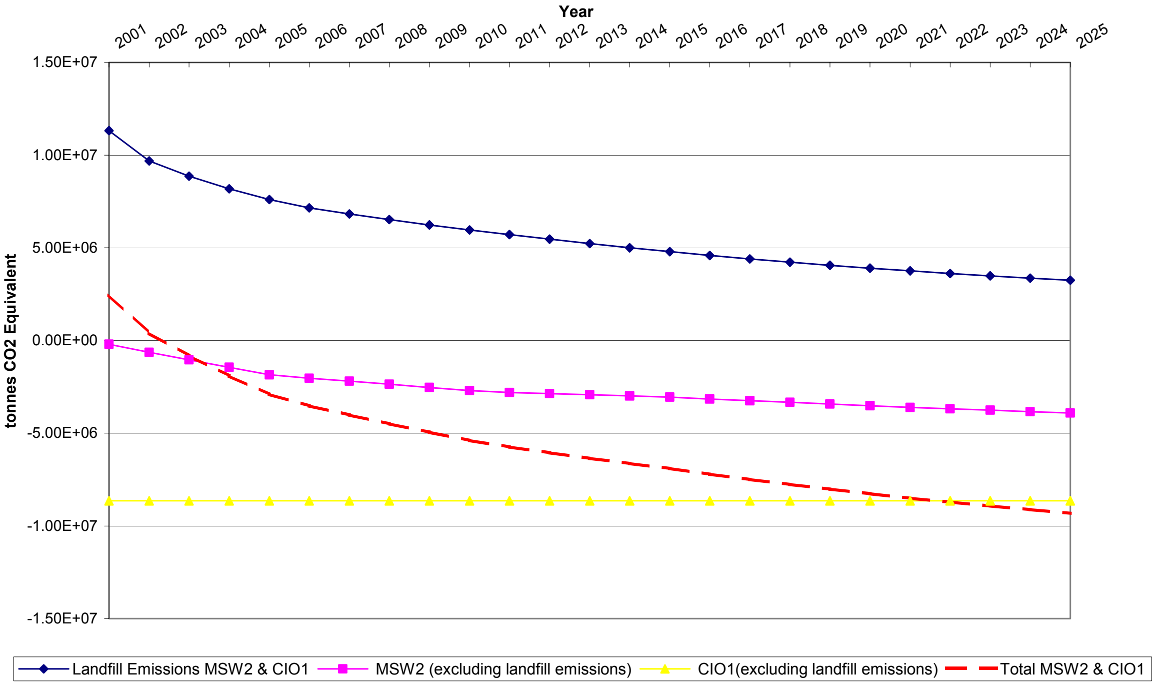


Figure C2.2 GHG Contributions for MSW Scenario 2 – CIO 2

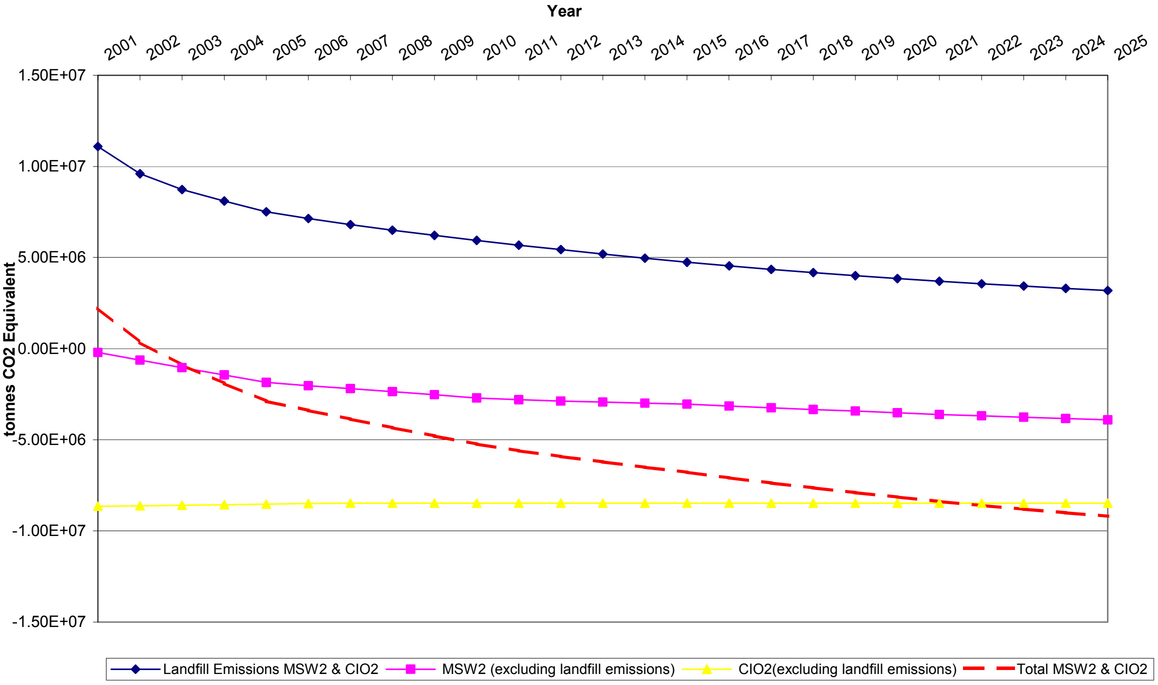


Figure C2.3 GHG Contributions for MSW Scenario 2 – CIO 3

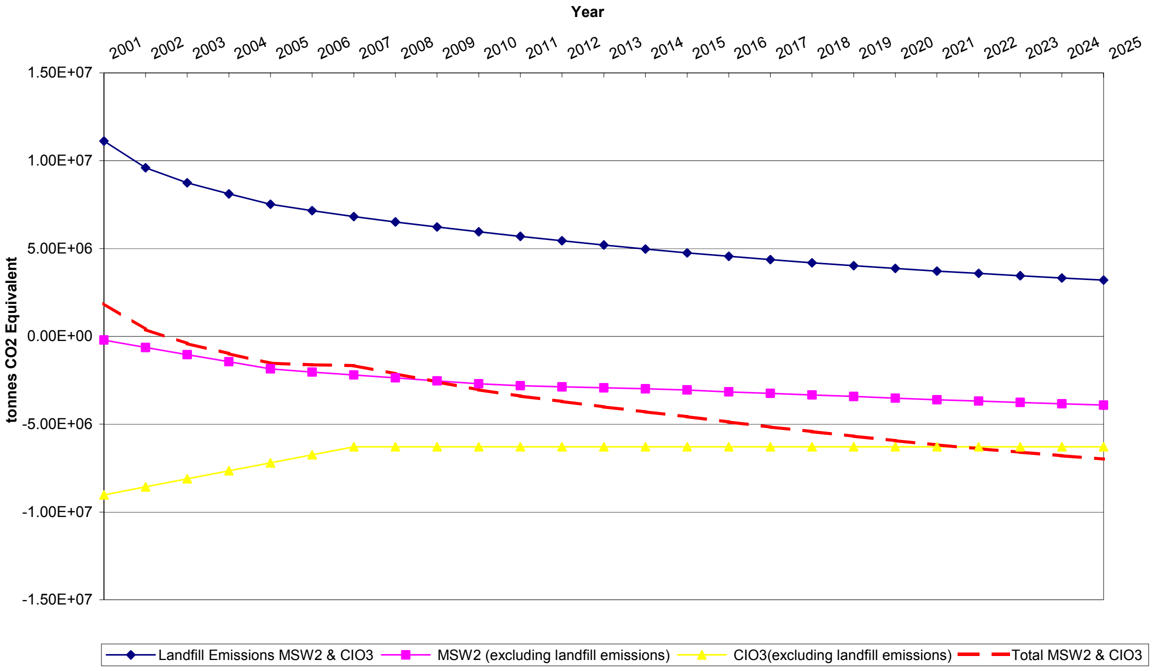


Figure C2.4 GHG Contributions for MSW Scenario 2 – CIO 4

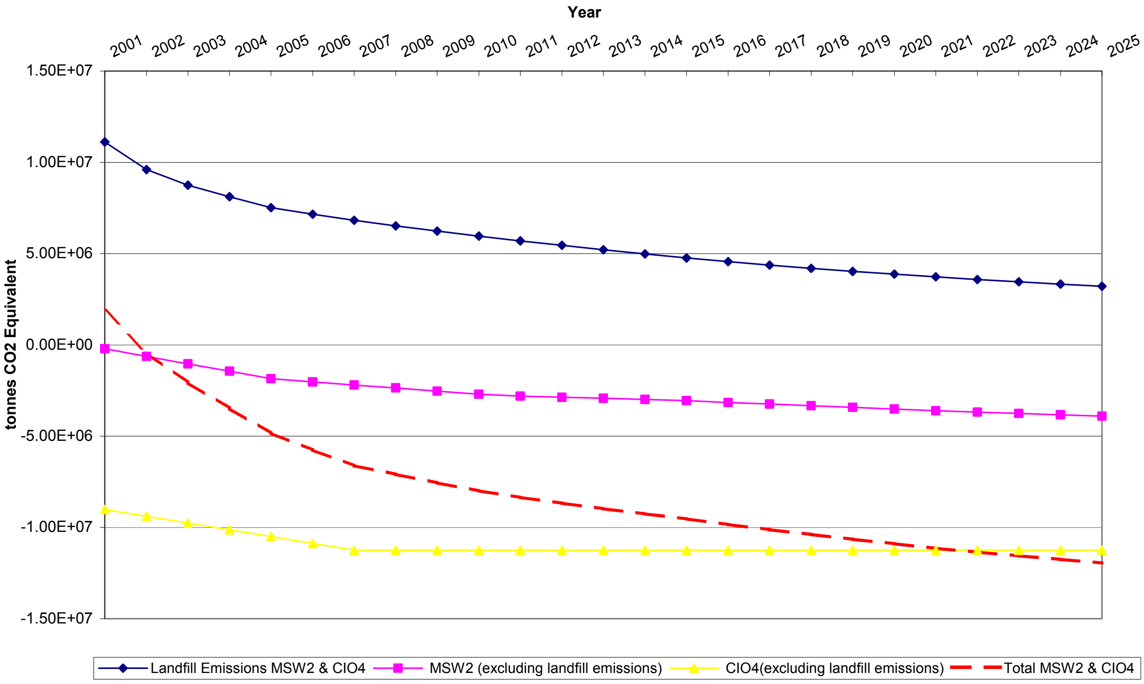


Figure C2.5 GHG Contributions for MSW Scenario 2 – CIO 5

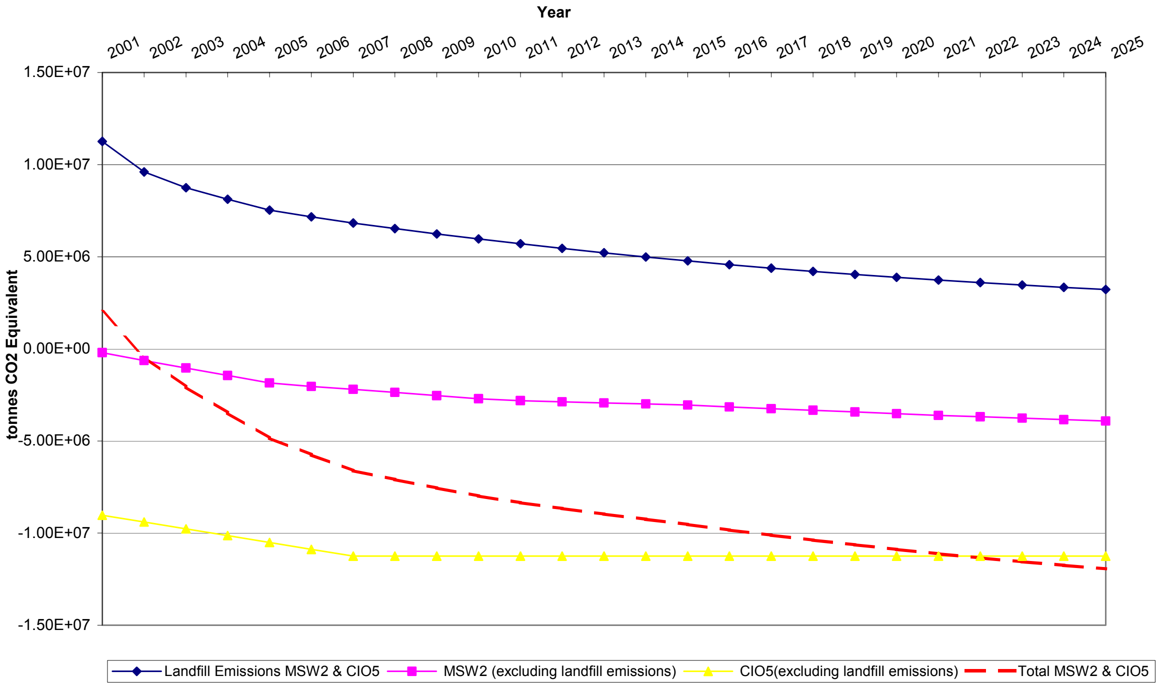


Figure C3.1 GHG Contributions for MSW 3 - CIO 1

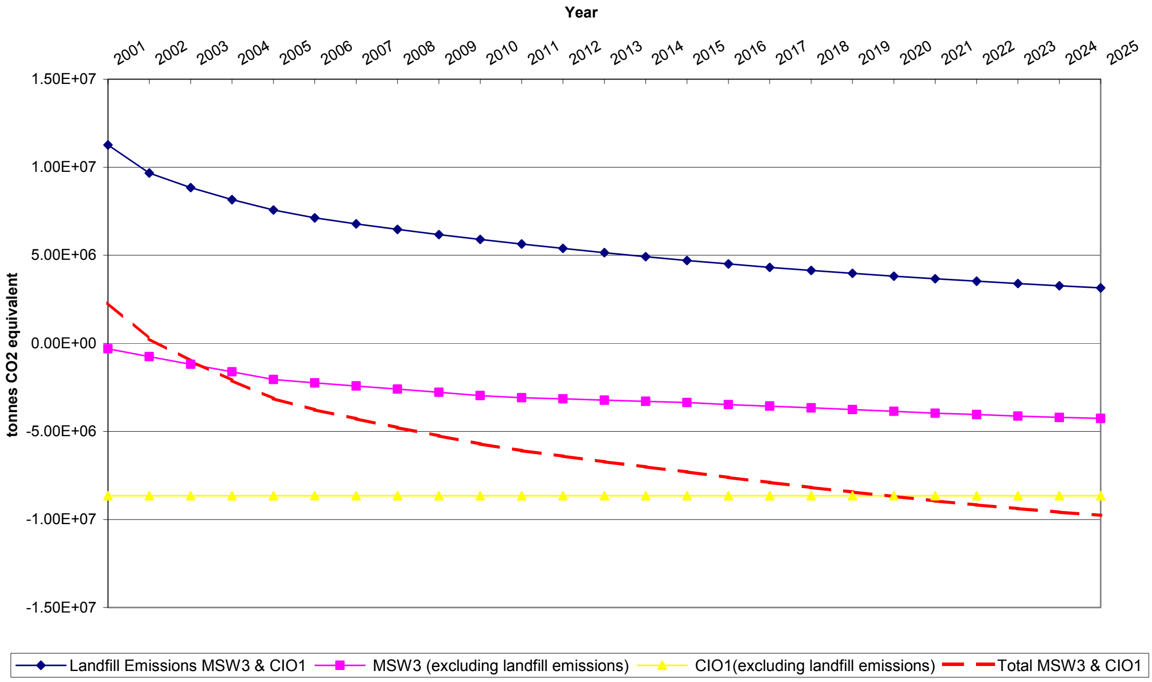
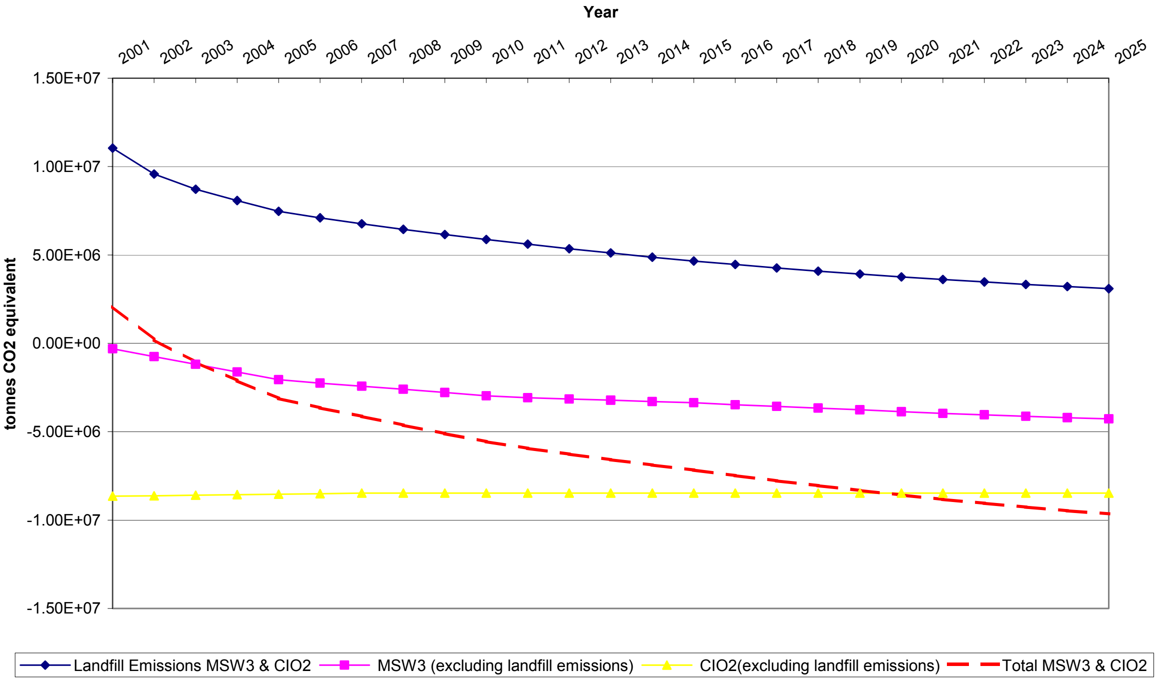


Figure C3.2 GHG Contributions for MSW 3 - CIO 2



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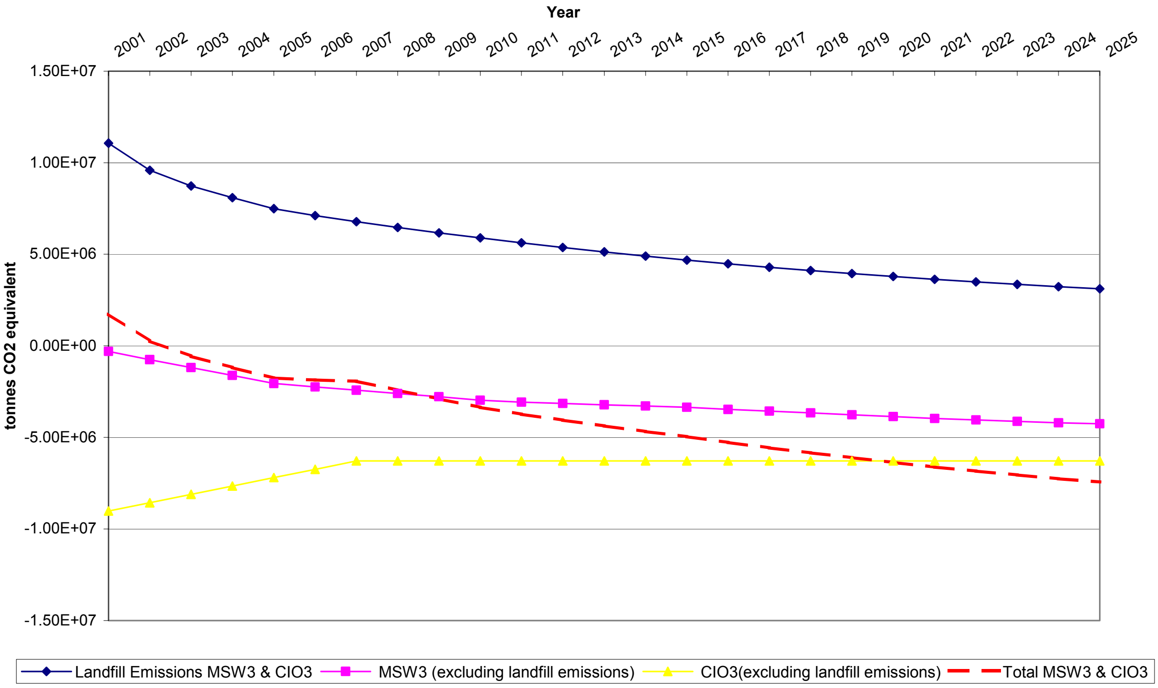


Figure C3.4 GHG Contributions for MSW 3 - CIO 4

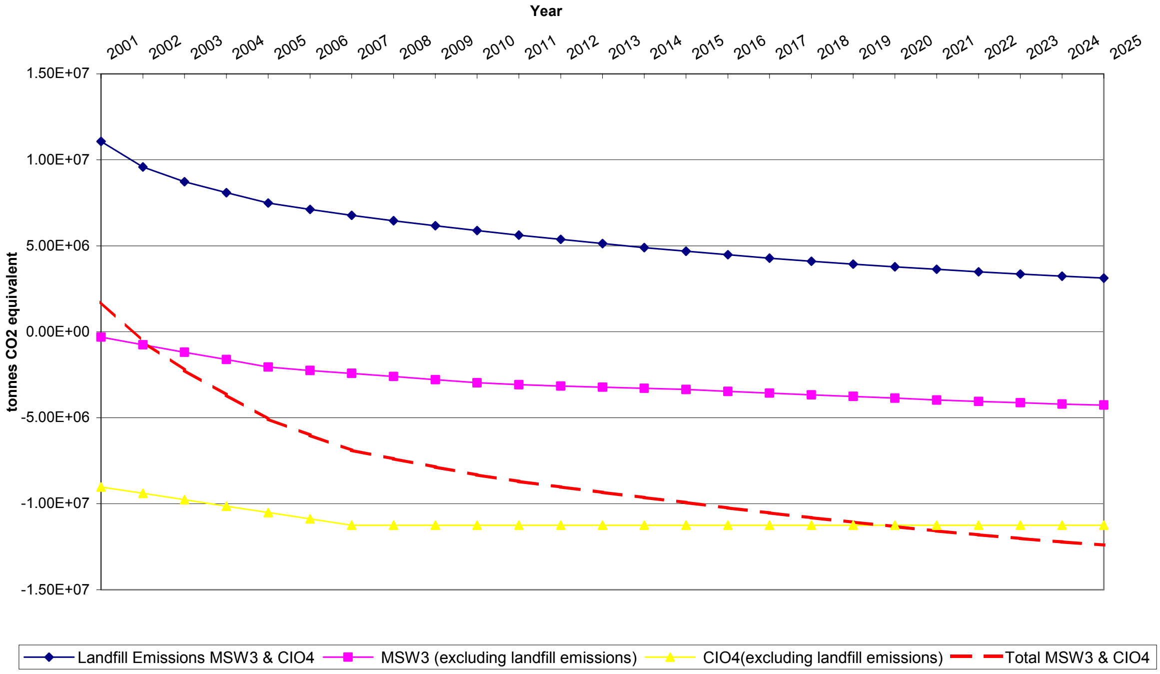


Figure C3.5 GHG Contributions for MSW 3 - CIO 5

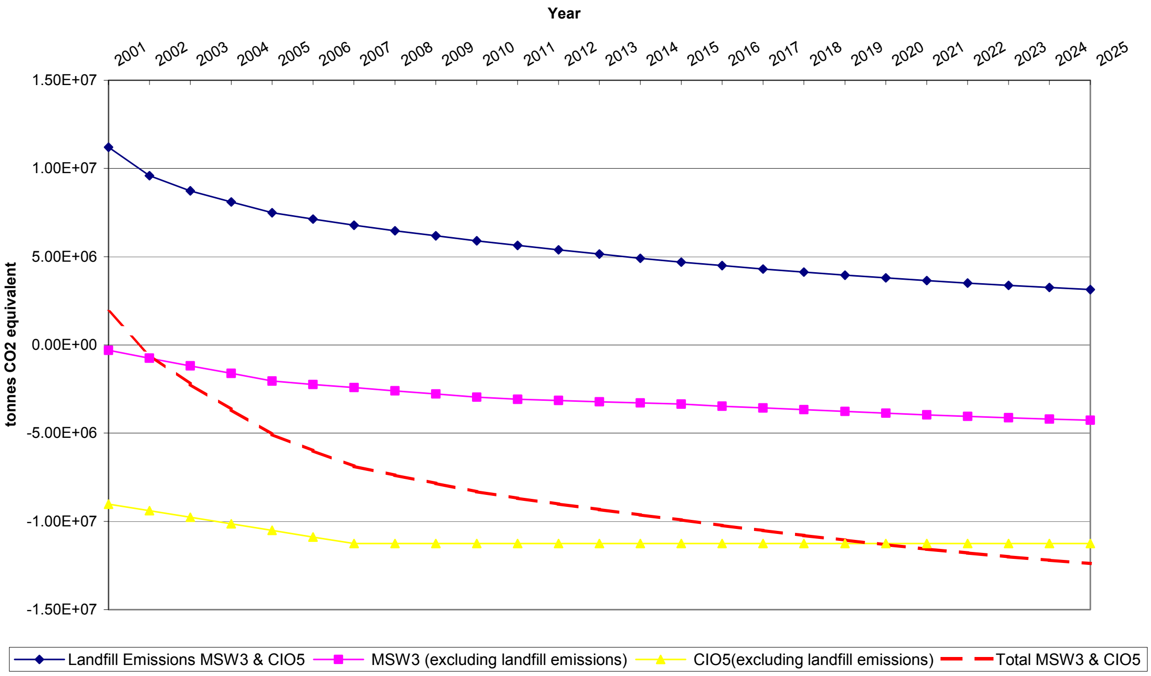


Figure C4.1 GHG Contributions for MSW 4 - CIO 1

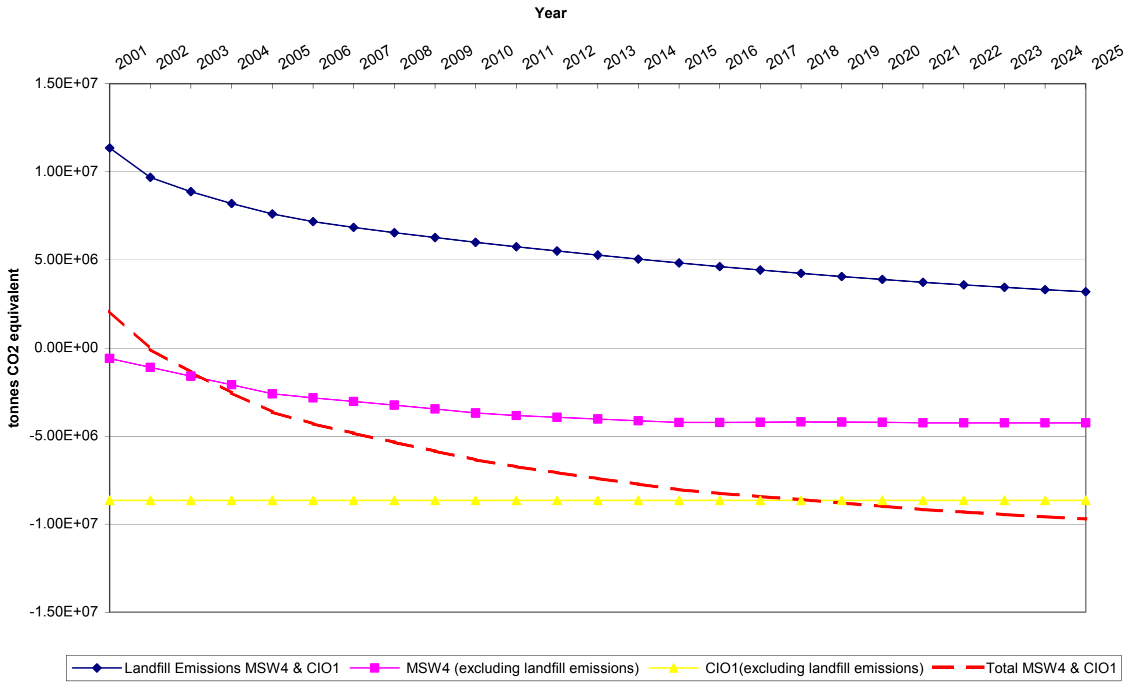


Figure C4.2 GHG Contributions for MSW 4 - CIO 2

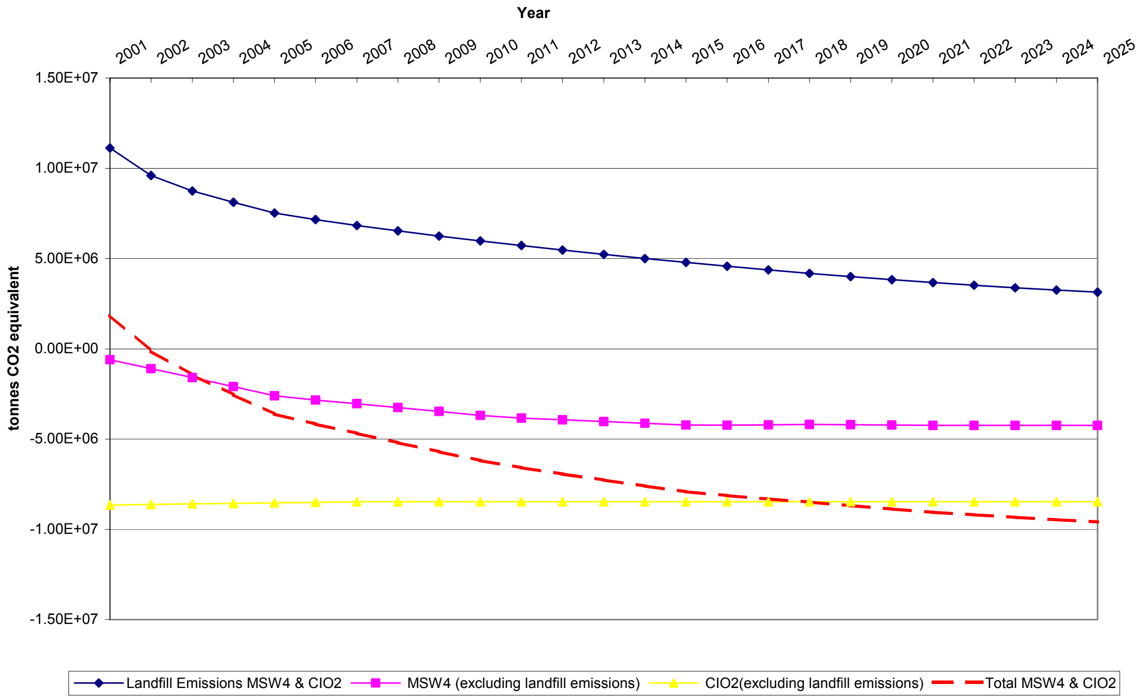


Figure C4.3 GHG Contributions for MSW 4 - CIO 3

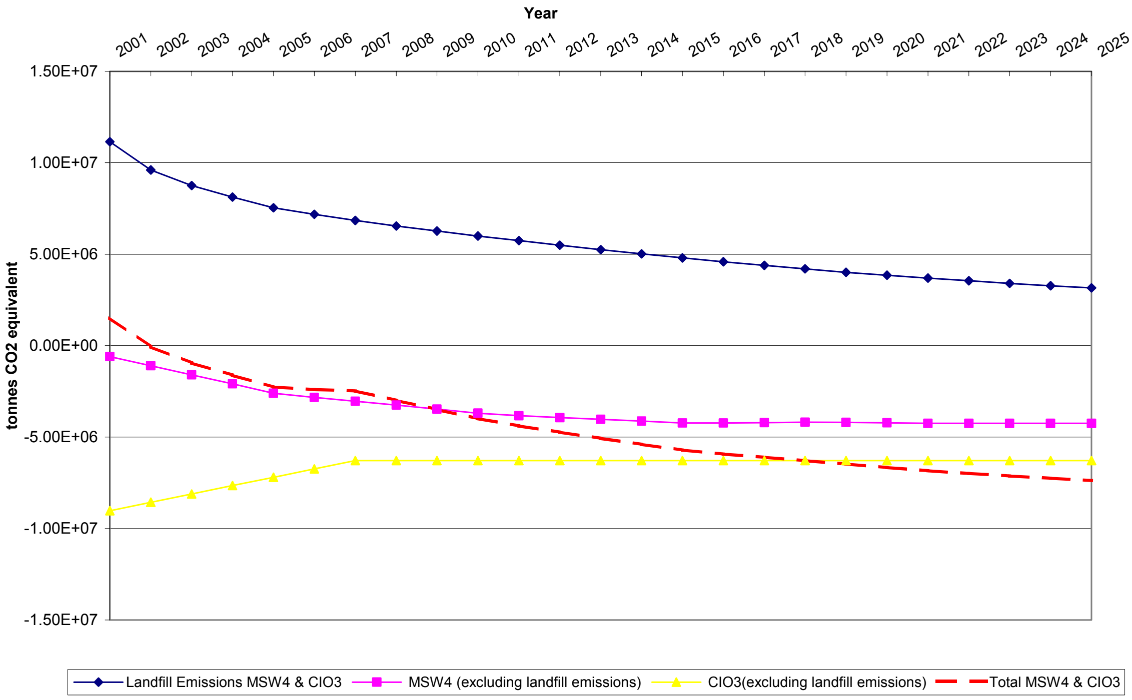


Figure C4.4 GHG Contributions for MSW 4 - CIO 4

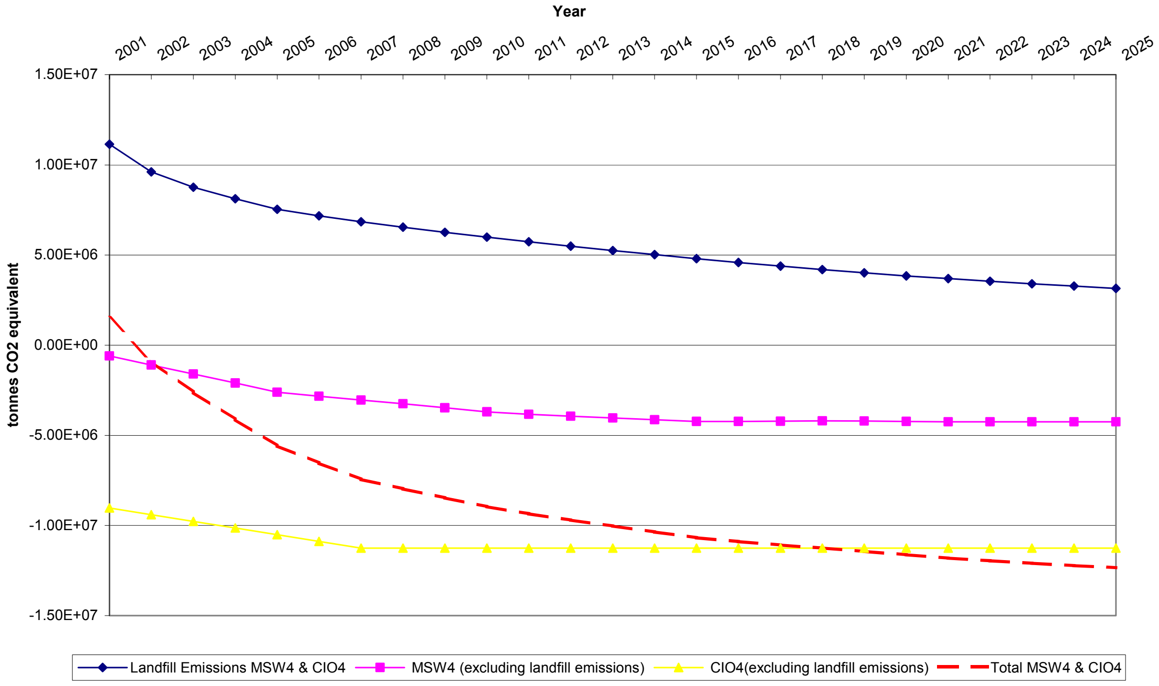


Figure C4.5 GHG Contributions for MSW 4 - CIO 5

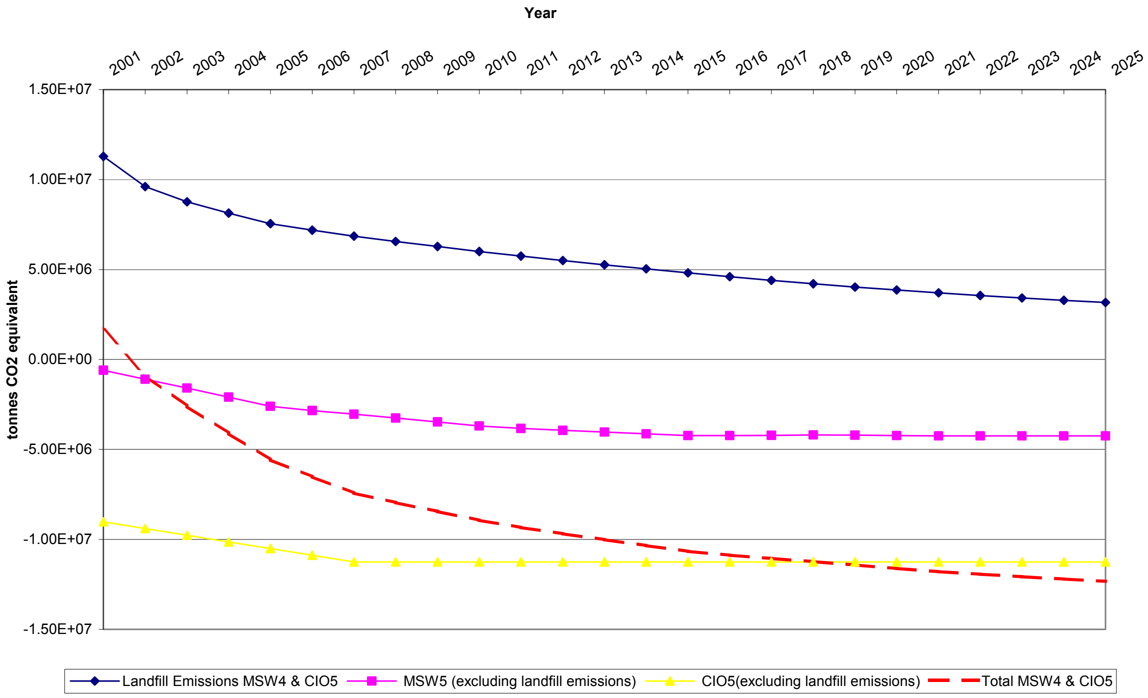


Figure C5.1 GHG Contributions for MSW 5 - CIO 1

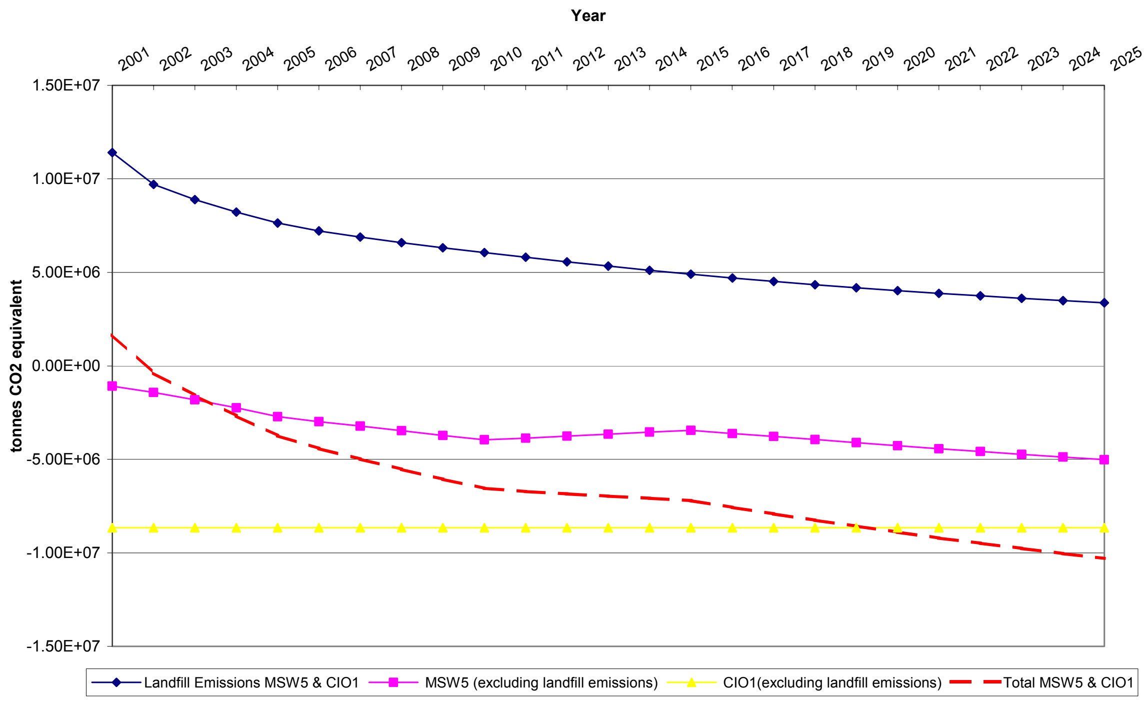


Figure C5.2 GHG Contributions for MSW 5 - CIO 2

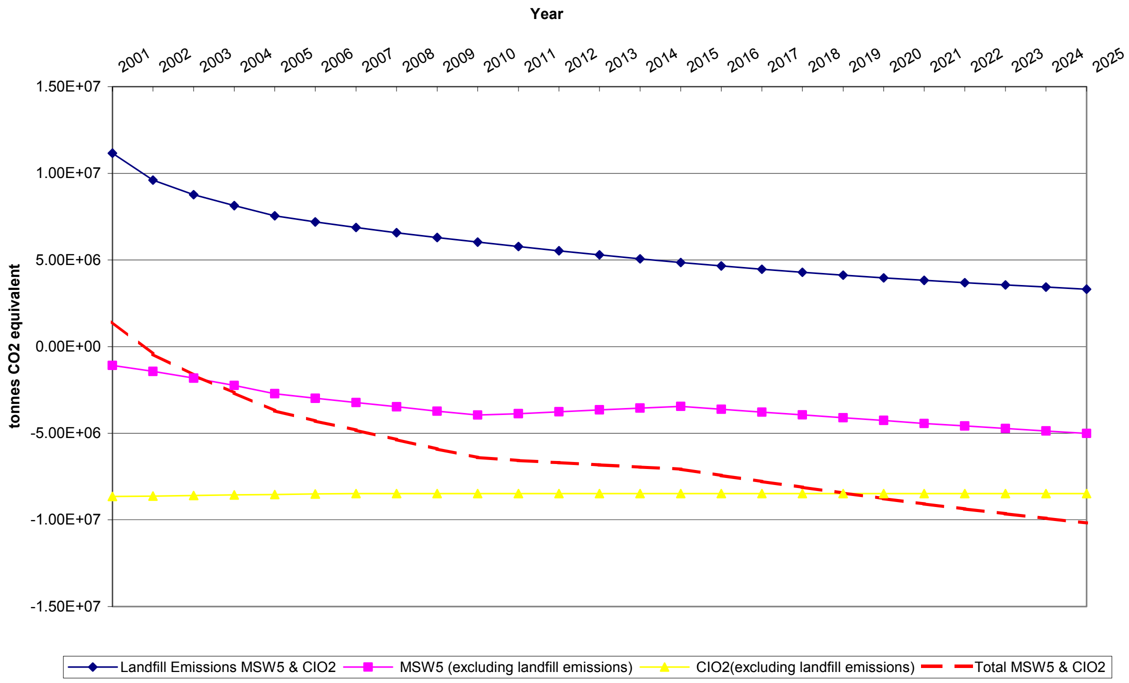


Figure C5.3 GHG Contributions for MSW 5 - CIO 3

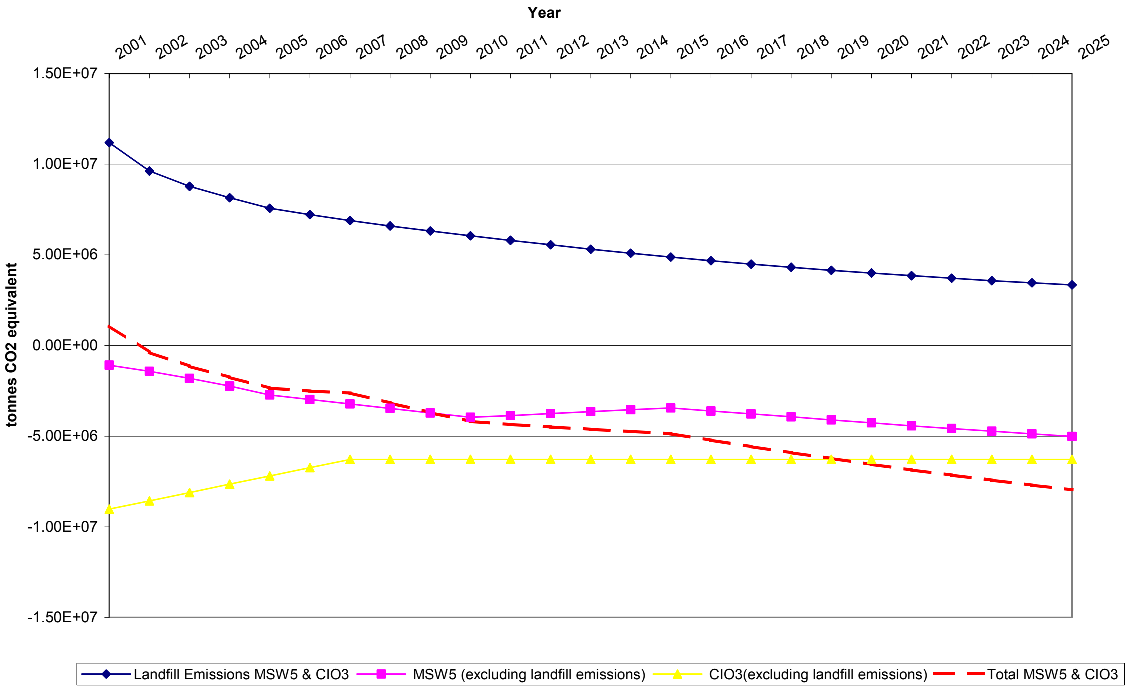


Figure C5.4 GHG Contributions for MSW 5 - CIO 4

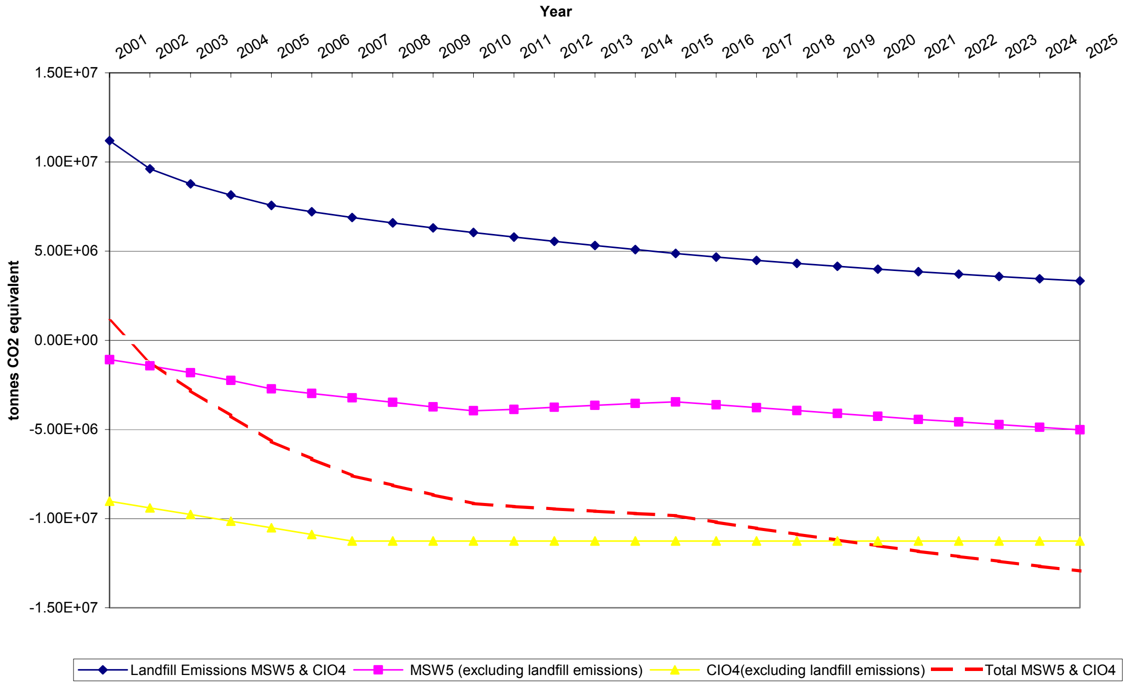


Figure C5.5 GHG Contributions for MSW 5 - CIO 5

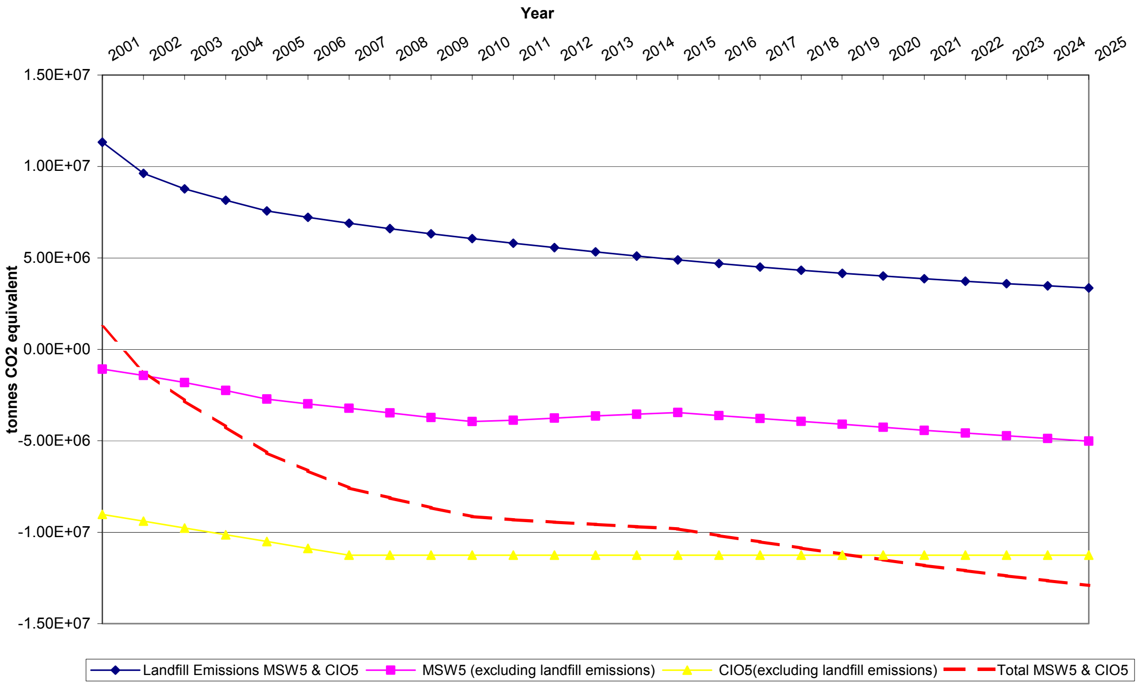


Figure C6.1 GHG Contributions for MSW 6 - CIO 1

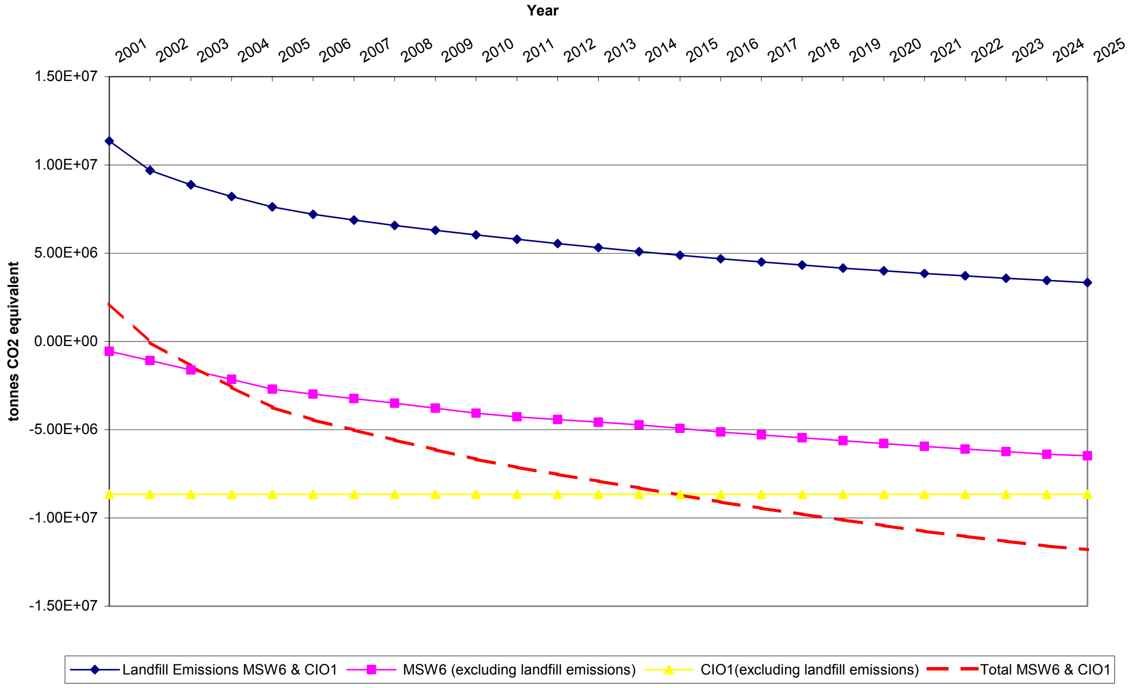


Figure C6.2 GHG Contributions for MSW 6 - CIO 2

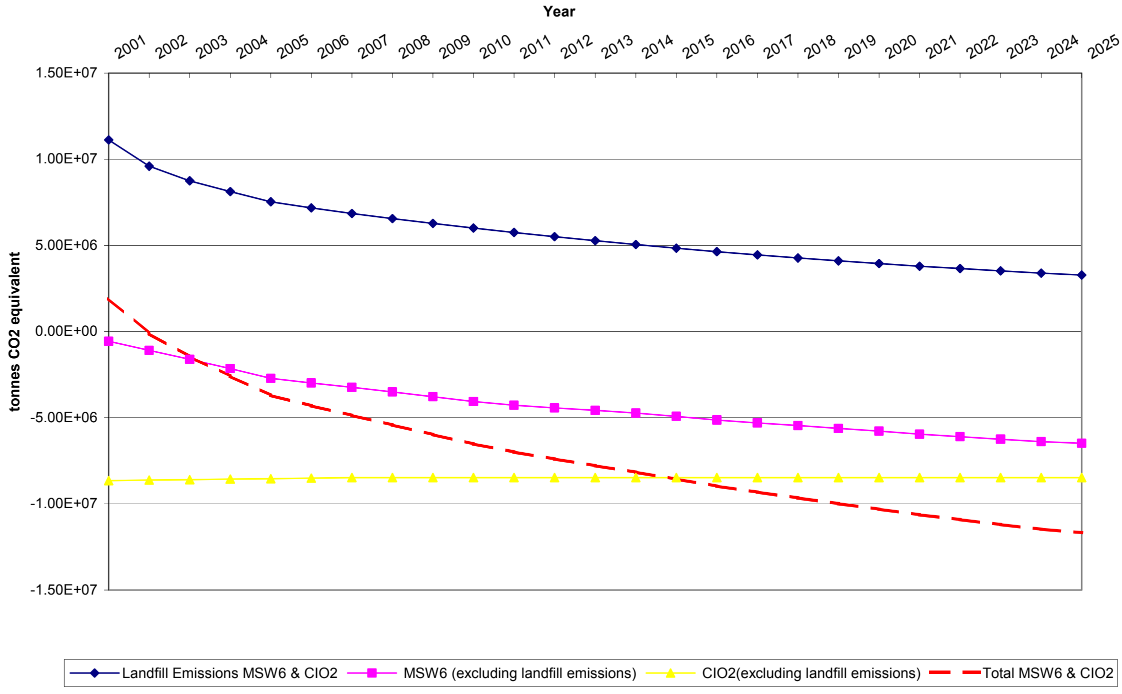


Figure C6.3 GHG Contributions for MSW 6 - CIO 3

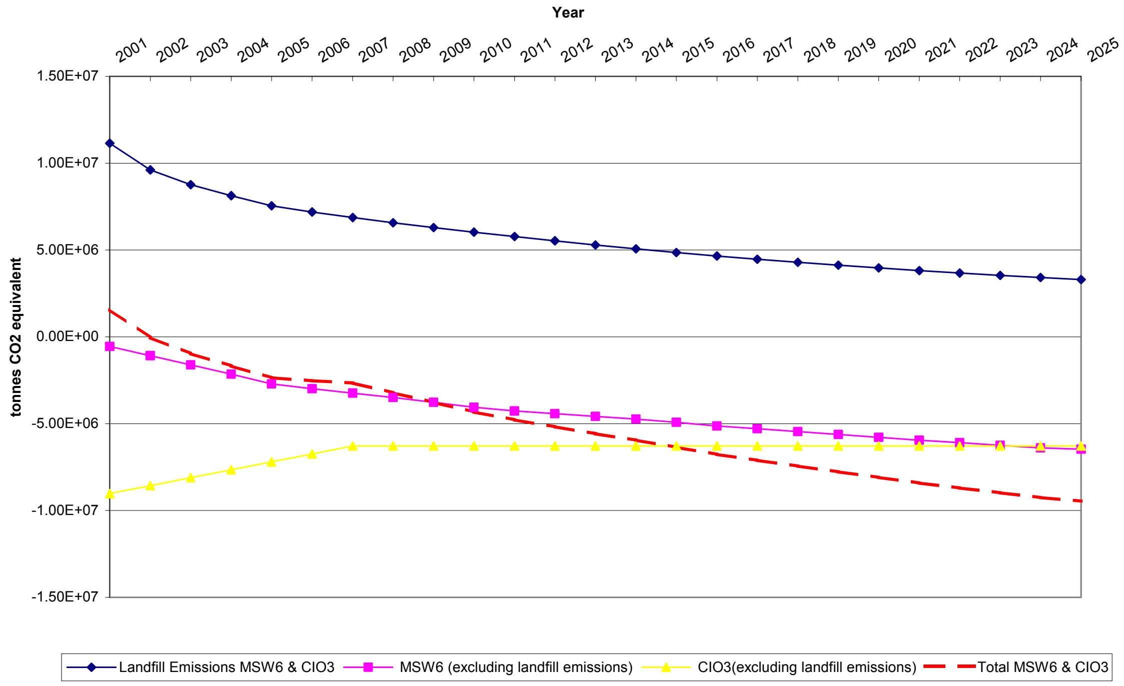


Figure C6.4 GHG Contributions for MSW 6 - CIO 4

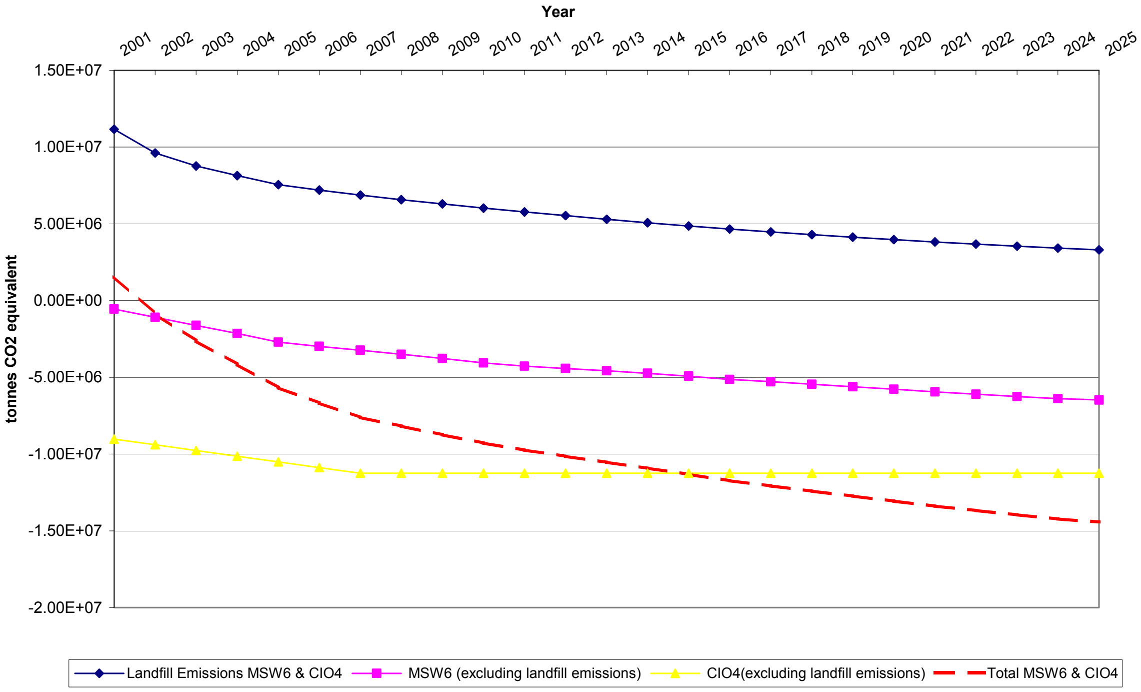
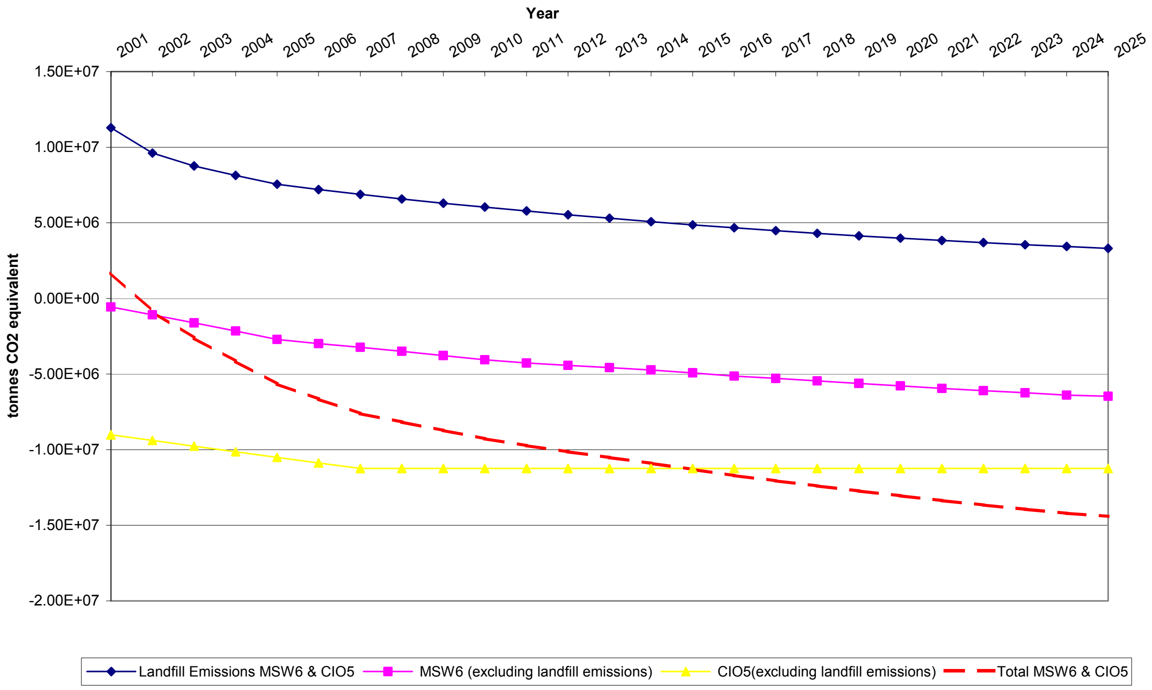


Figure C6.5 GHG Contributions for MSW 6 - CIO 5



C7 SCENARIO 7

Figure C7.1 GHG Contributions for MSW 7 - CIO 1

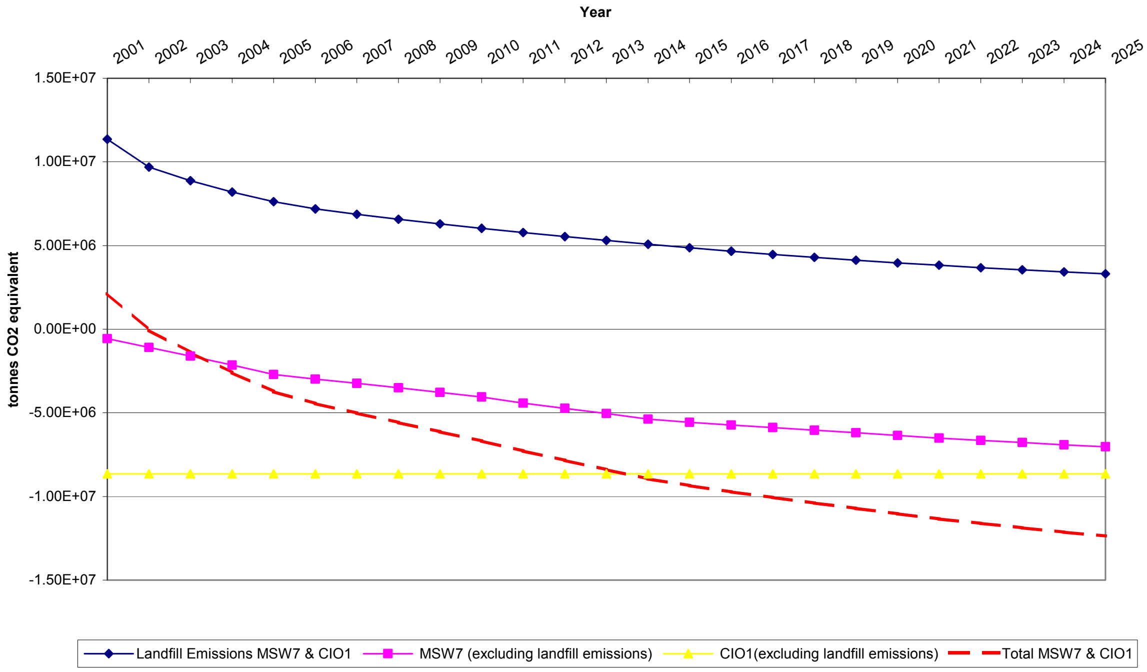


Figure C7.2 GHG Contributions for MSW 7 - CIO 2

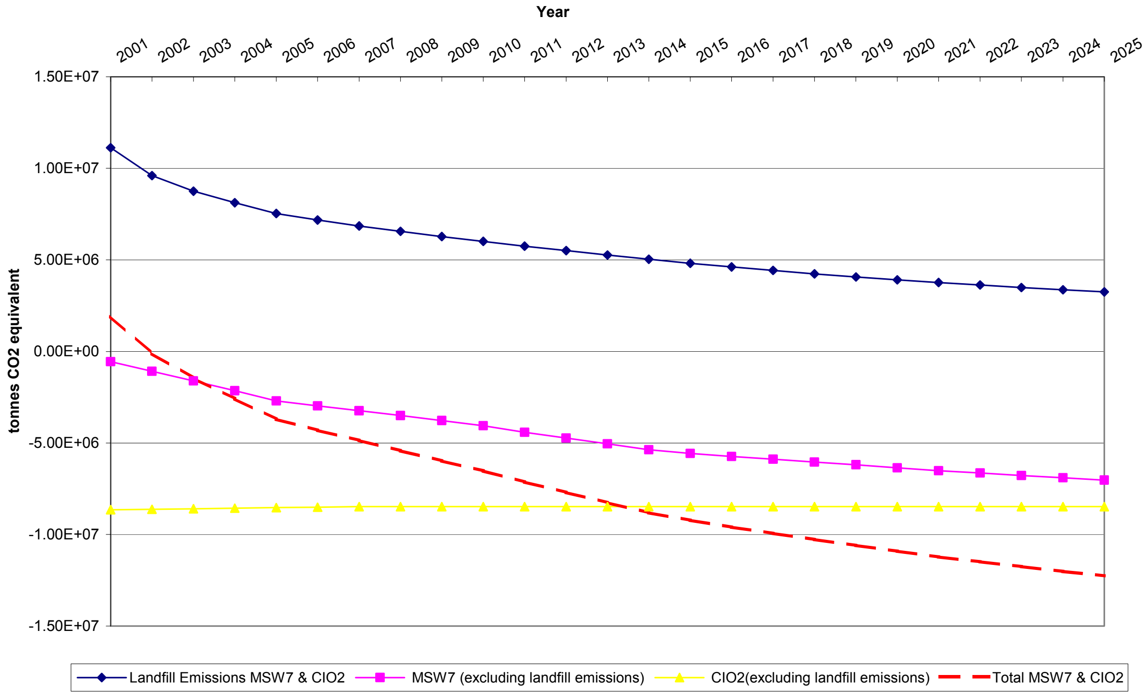


Figure C7.3 GHG Contributions for MSW 7 - CIO 3

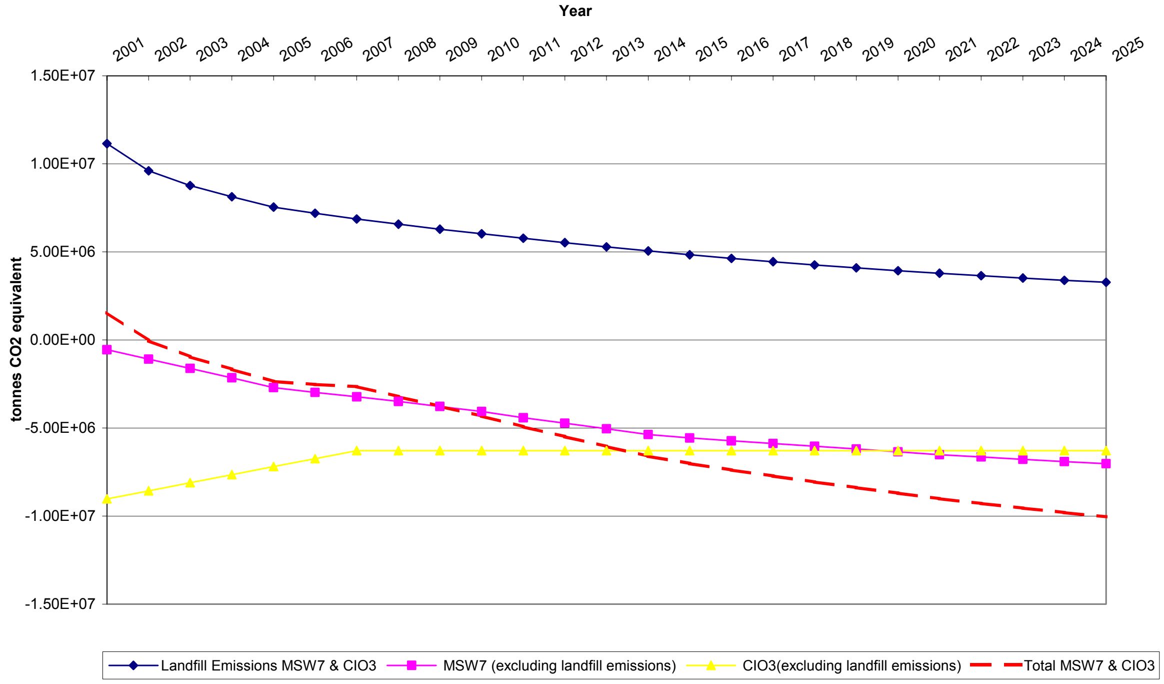


Figure C7.4 GHG Contributions for MSW 7 - CIO 4

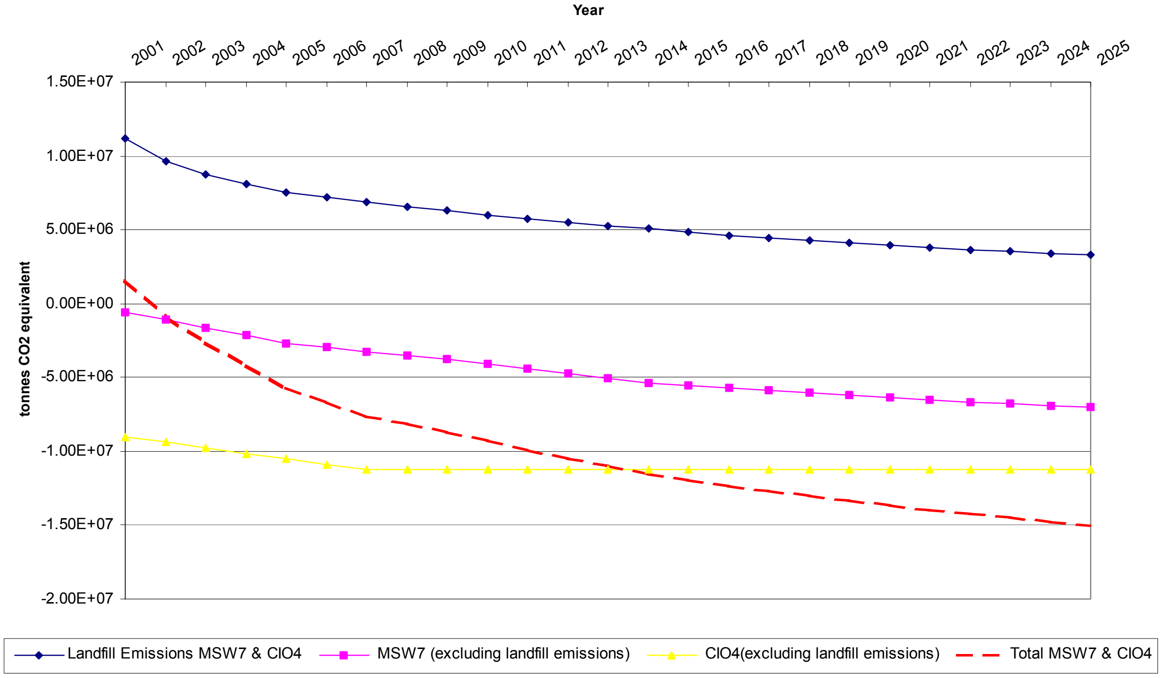
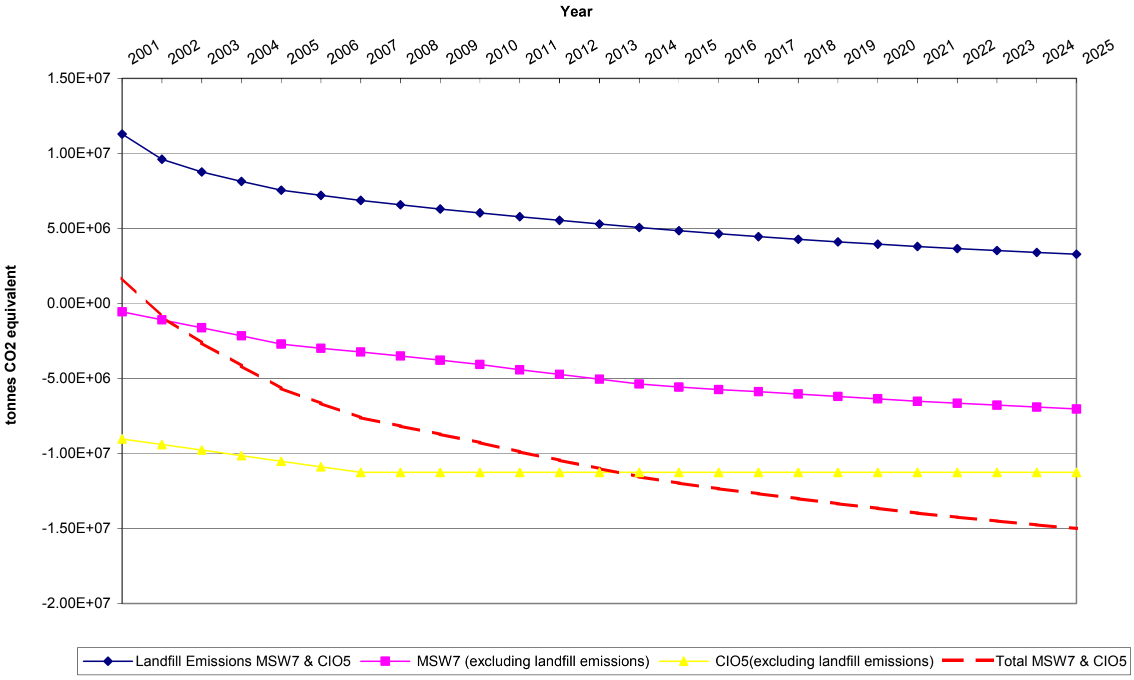


Figure C7.5 GHG Contributions for MSW 7 - CIO 5



C8 SCENARIO 8

Figure C8.1 GHG Contributions for MSW 8 - CIO 1

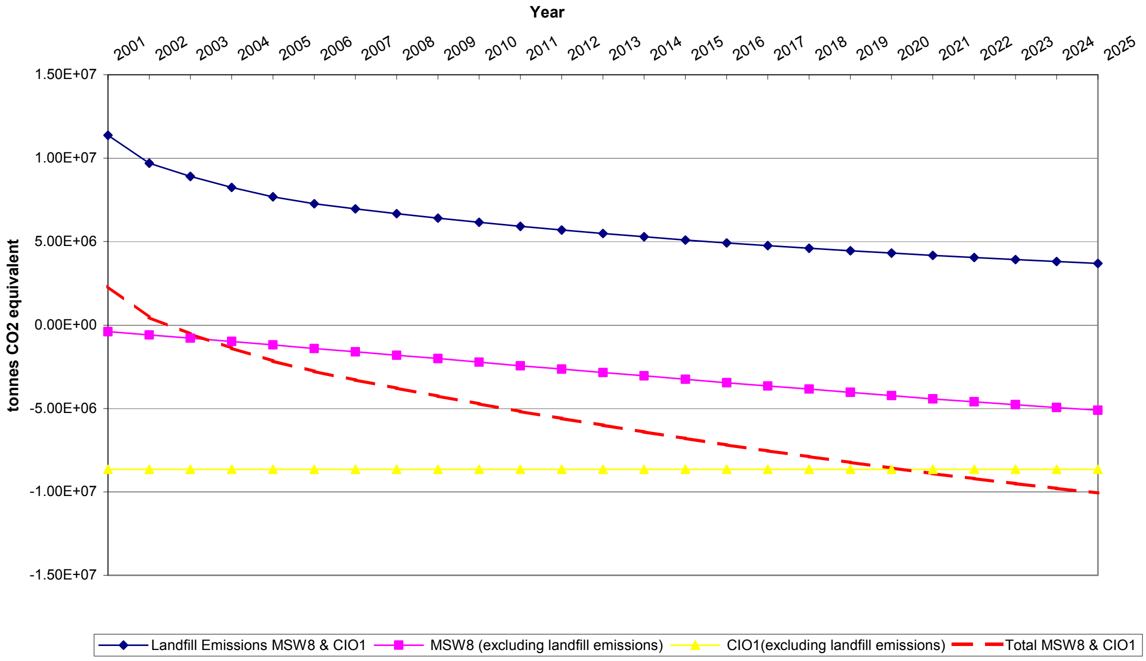


Figure C8.2 GHG Contributions for MSW 8 - CIO 2

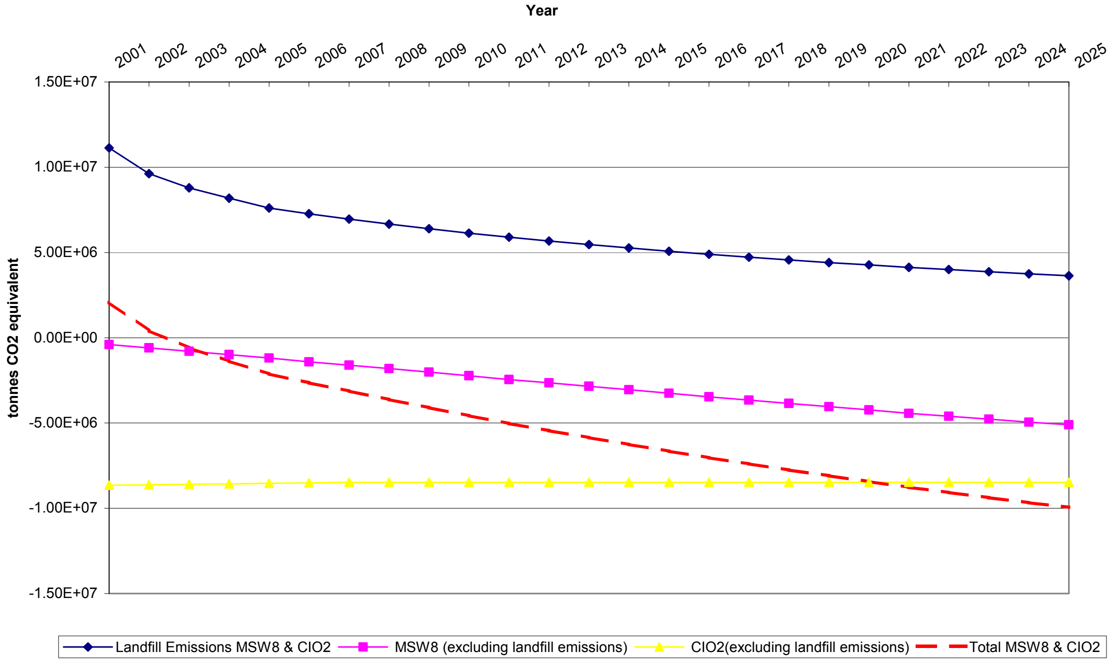


Figure C8.3 GHG Contributions for MSW 8 - CIO 3

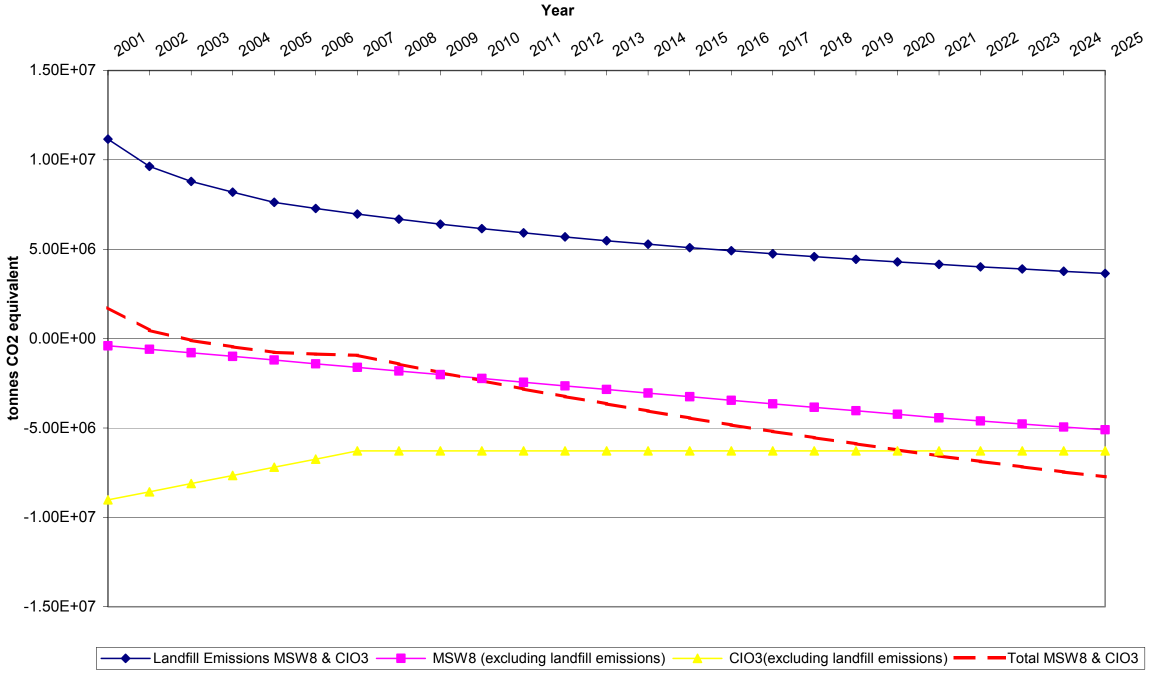


Figure C8.4 GHG Contributions for MSW 8 - CIO 4

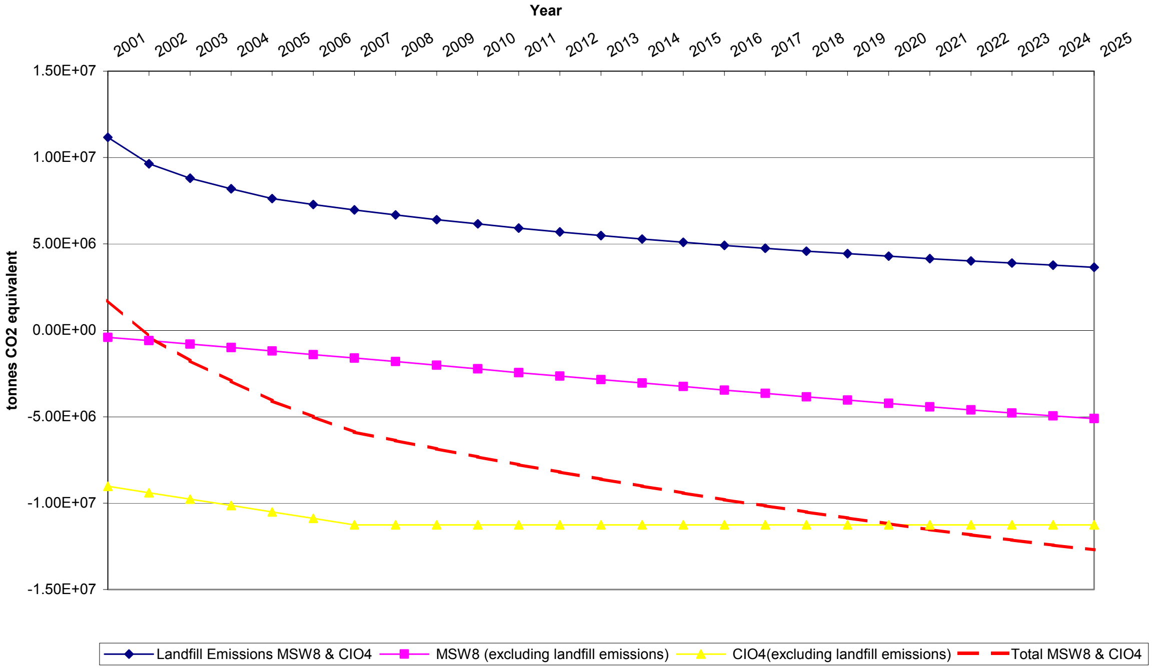
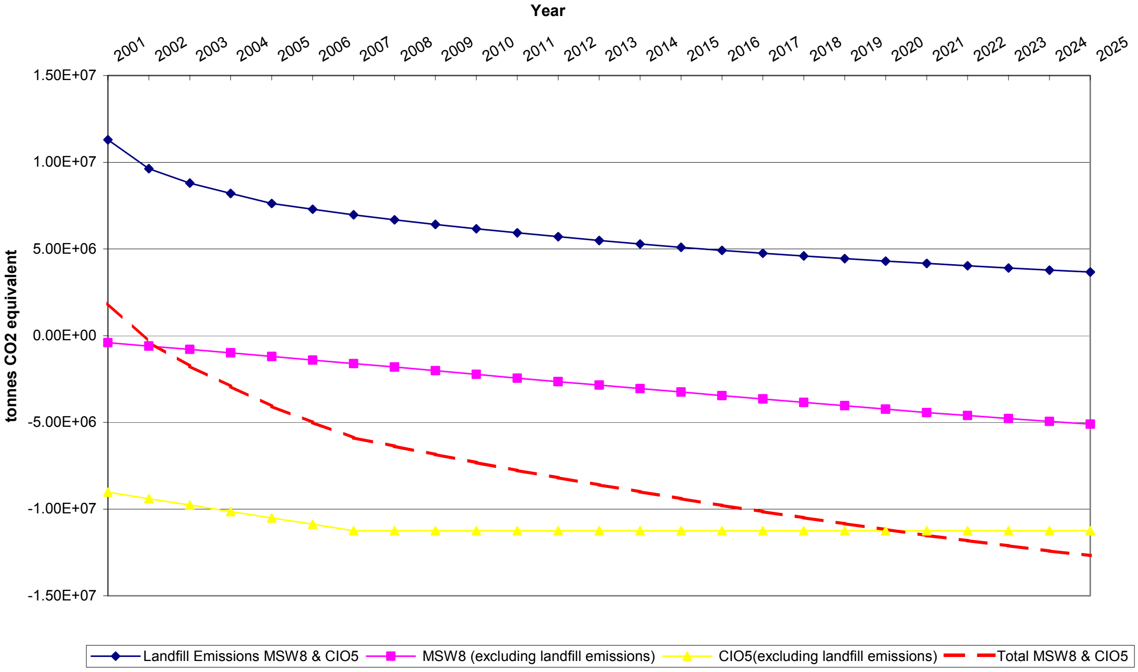


Figure C8.5 GHG Contributions for MSW 8 - CIO 5



Annex D

Scenarios for Scotland (excluding methane emissions from landfill)

Figure D1.1 GHG Contributions for MSW Scenario 1 and CIO 1-5

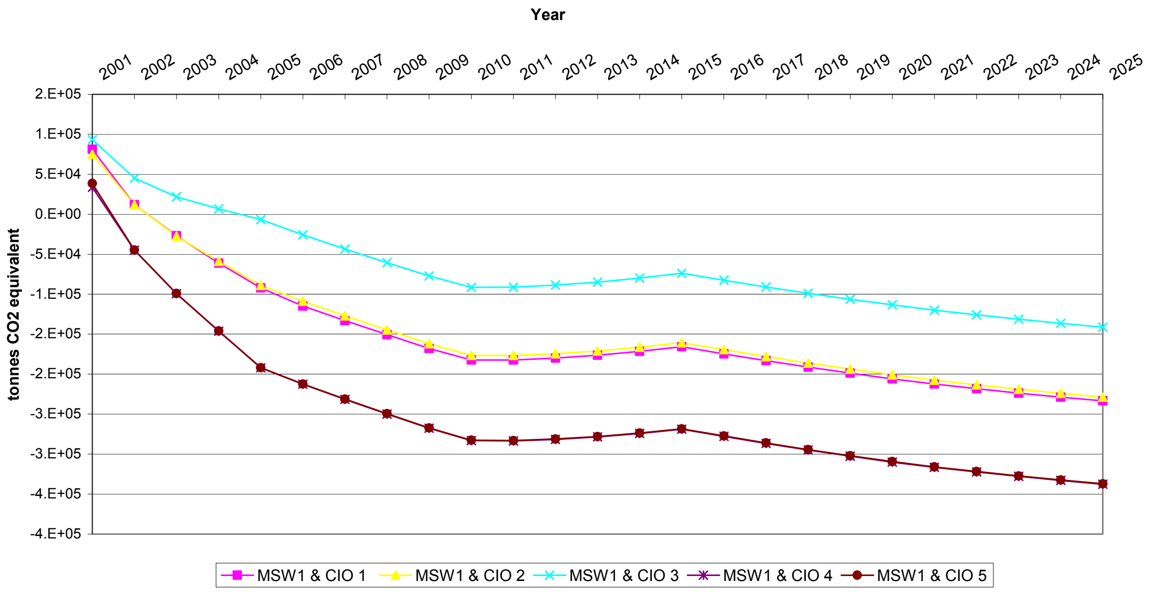


Figure D1.2 GHG Contributions for MSW Scenario 2 and CIO 1-5

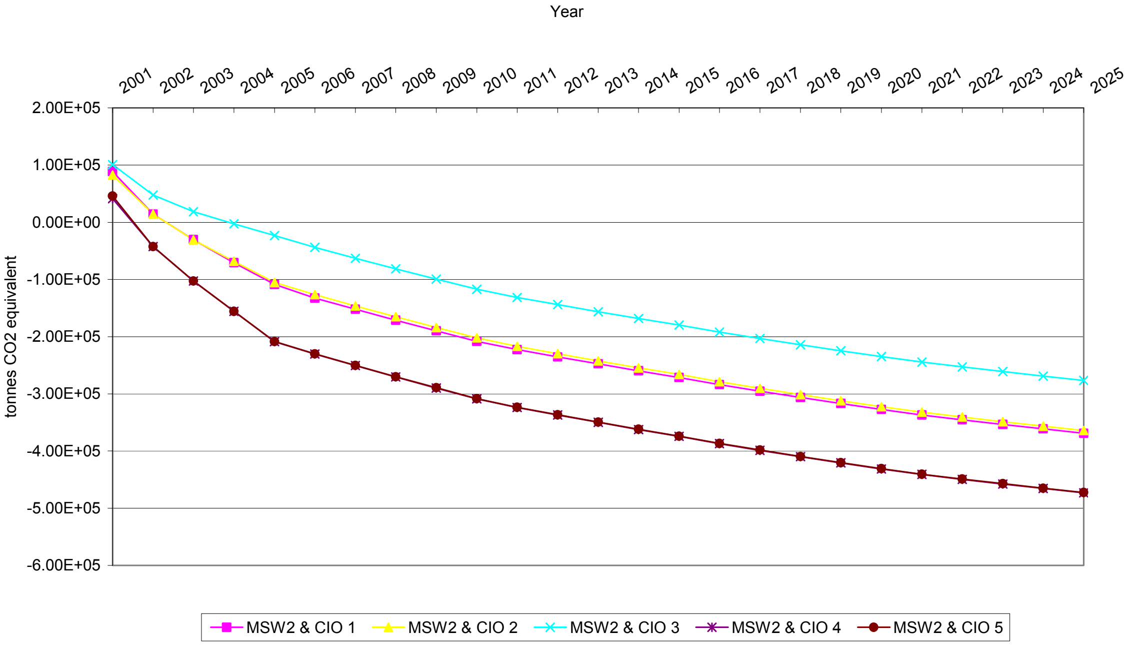


Figure D1.3 GHG Contributions for MSW Scenario 3 and CIO 1-5

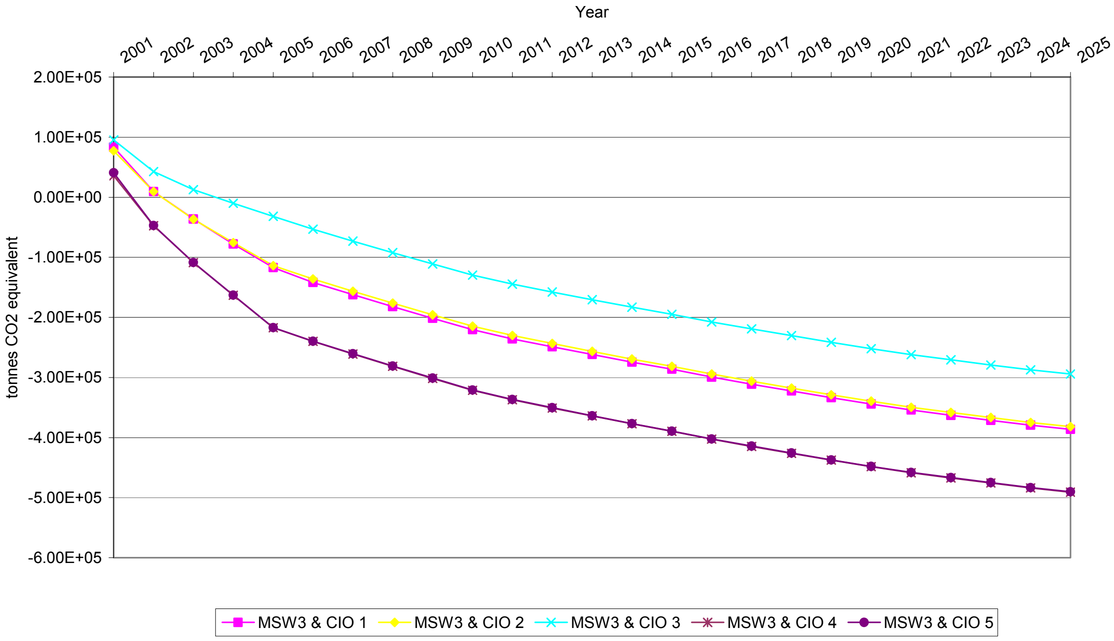


Figure D1.4 GHG Contributions for MSW Scenario 4 and CIO 1-5

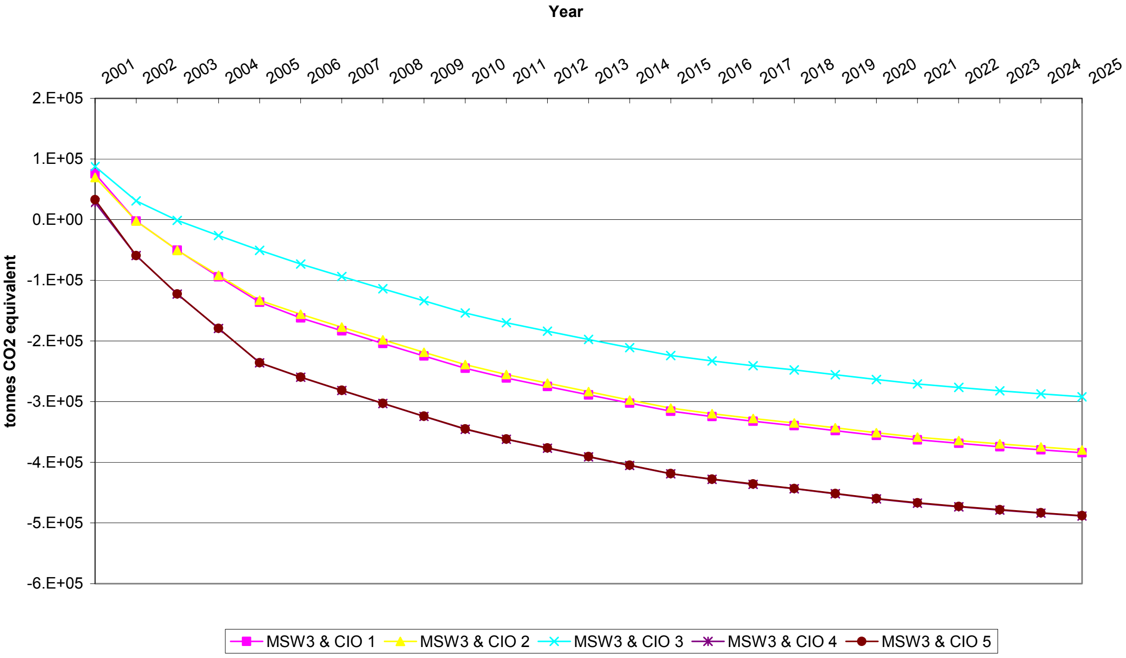


Figure D1.5 GHG Contributions for MSW Scenario 5 and CIO 1-5

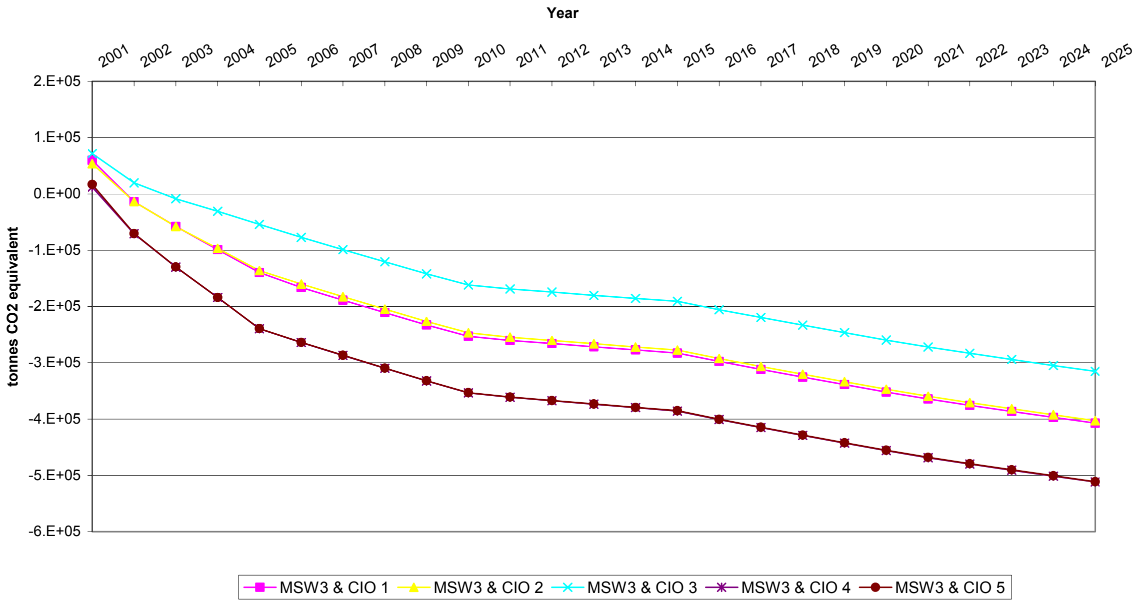


Figure D1.6 GHG Contributions for MSW Scenario 6 and CIO 1-5

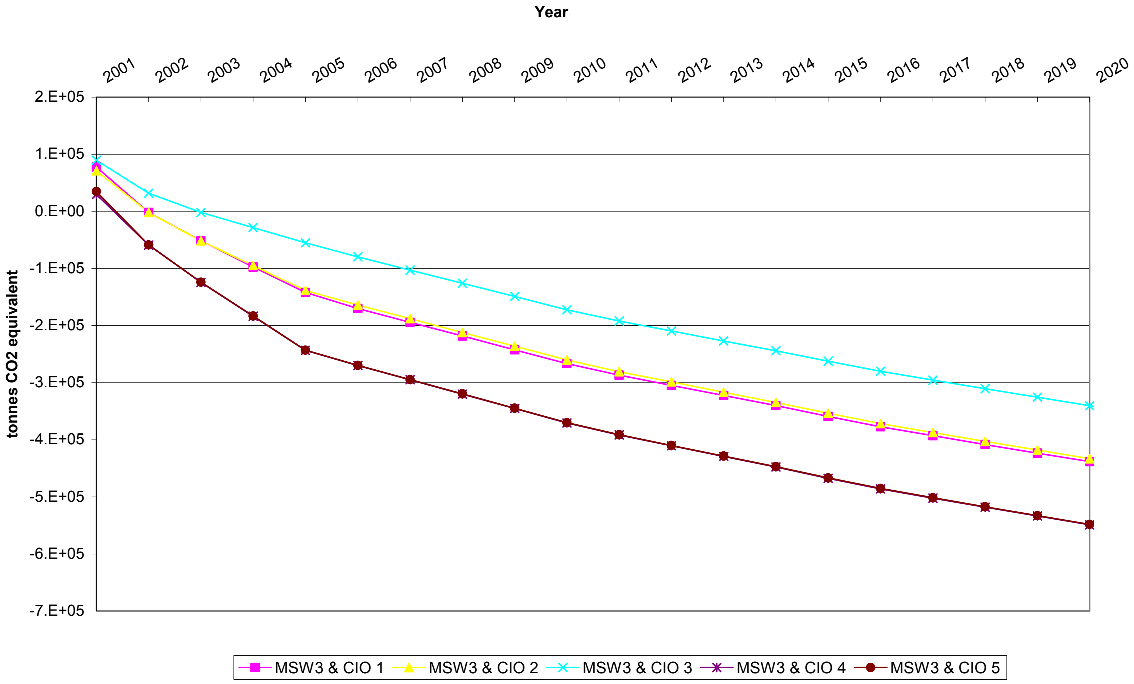


Figure D1.7 GHG Contributions for MSW Scenario 7 and CIO 1-5

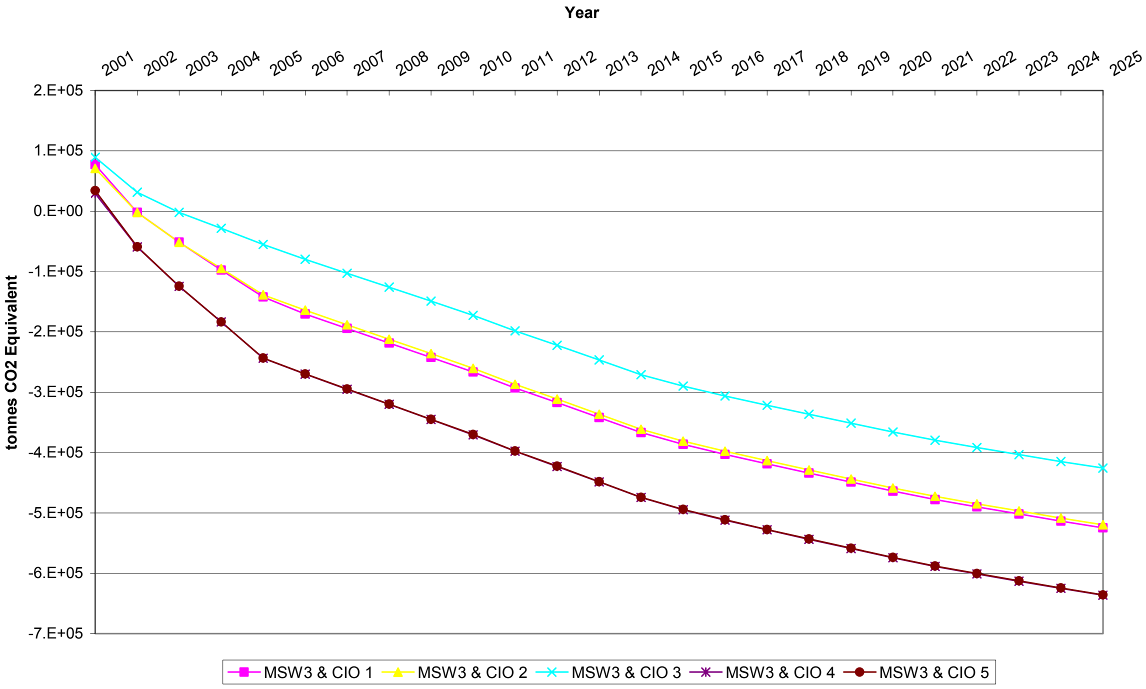
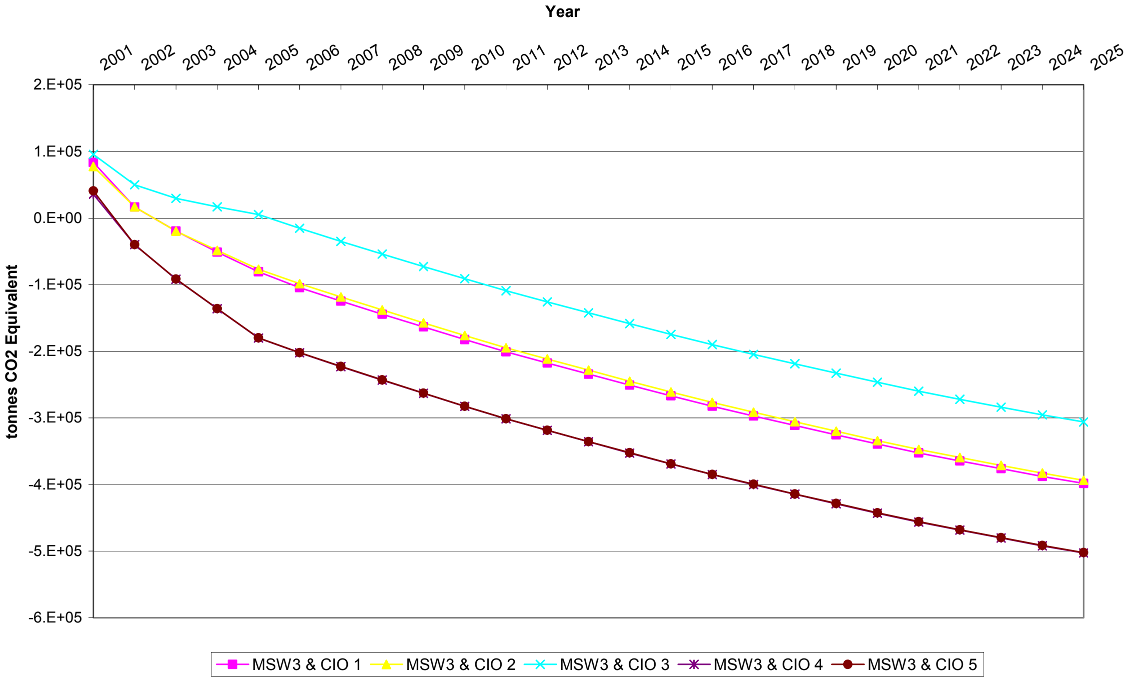


Figure D1.8 GHG Contributions for MSW Scenario 8 and CIO 1-5



Annex E

Scenarios for Northern Ireland (excluding methane emissions from landfill)

Figure E1.1 GHG Contributions for MSW Scenario 1 and CIO 1-5

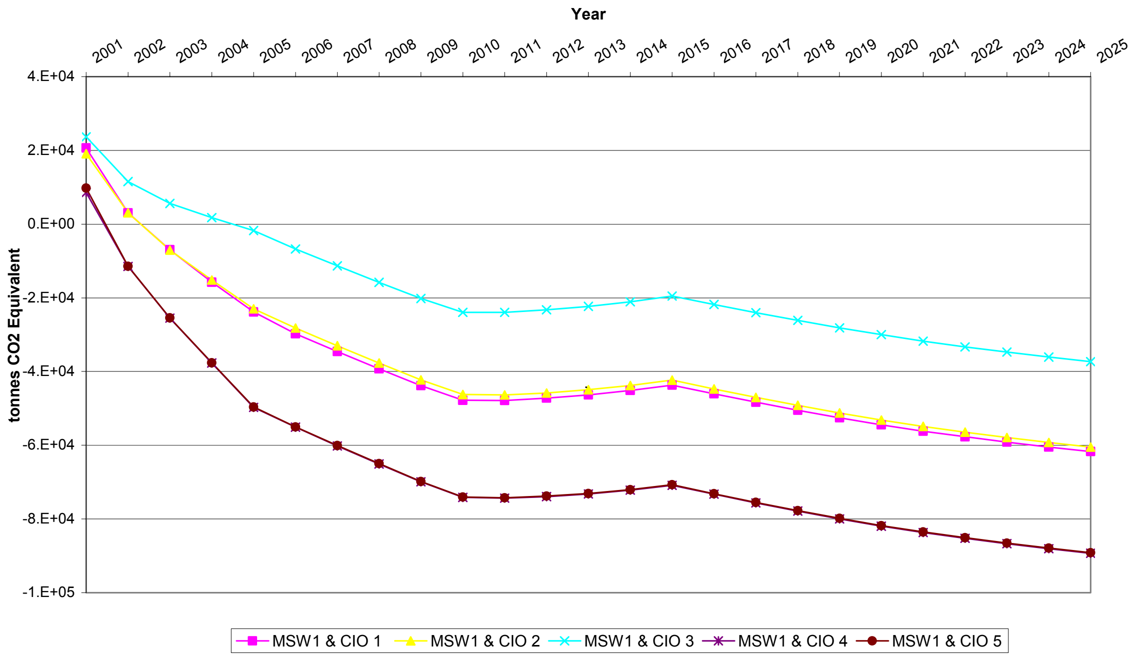


Figure E1.2 GHG Contributions for MSW Scenario 2 and CIO 1-5

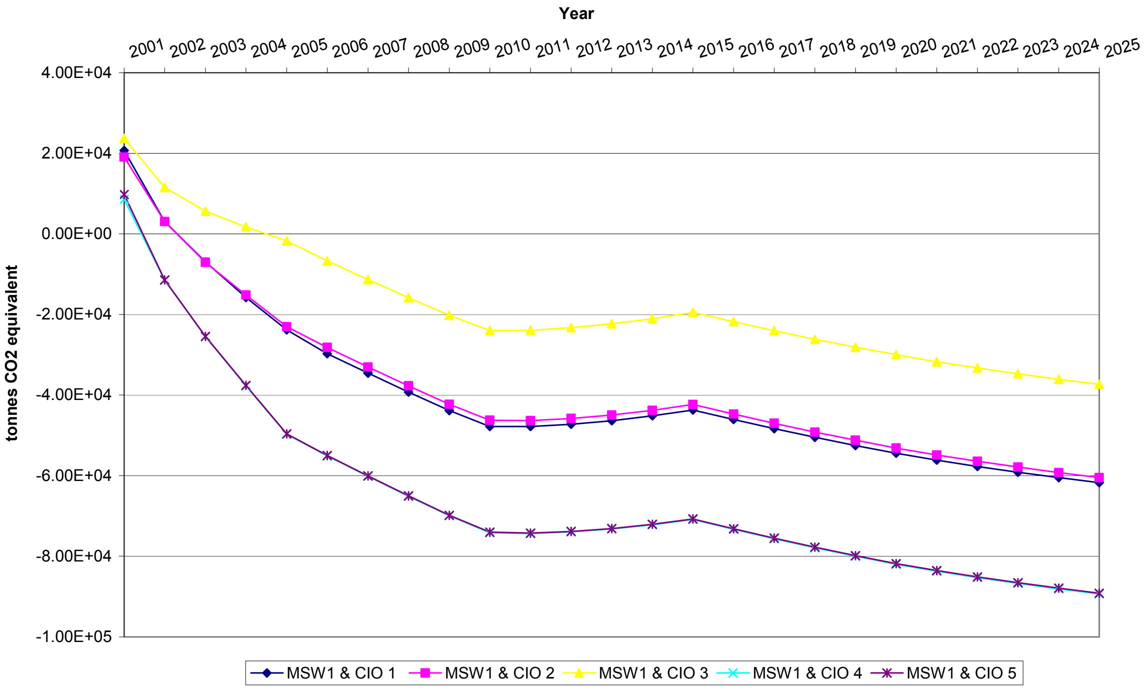


Figure E1.3 GHG Contributions for MSW Scenario 3 and CIO 1-5

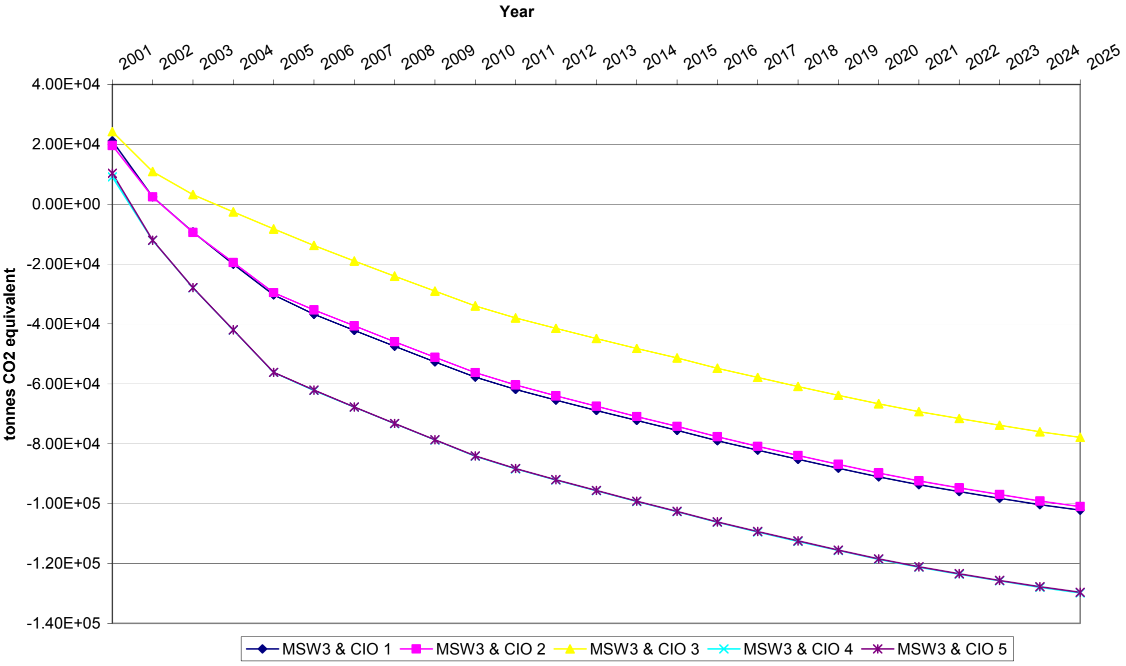


Figure E1.4 GHG Contributions for MSW Scenario 4 and CIO 1-5

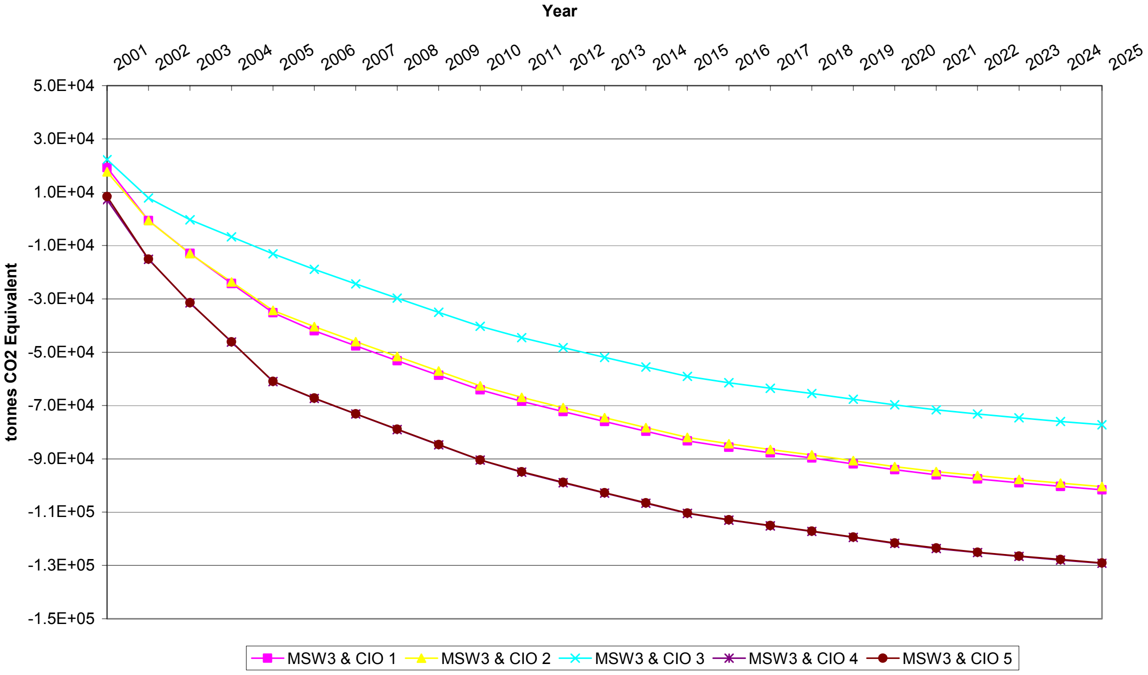


Figure E1.5 GHG Contributions for MSW Scenario 5 and CIO 1-5

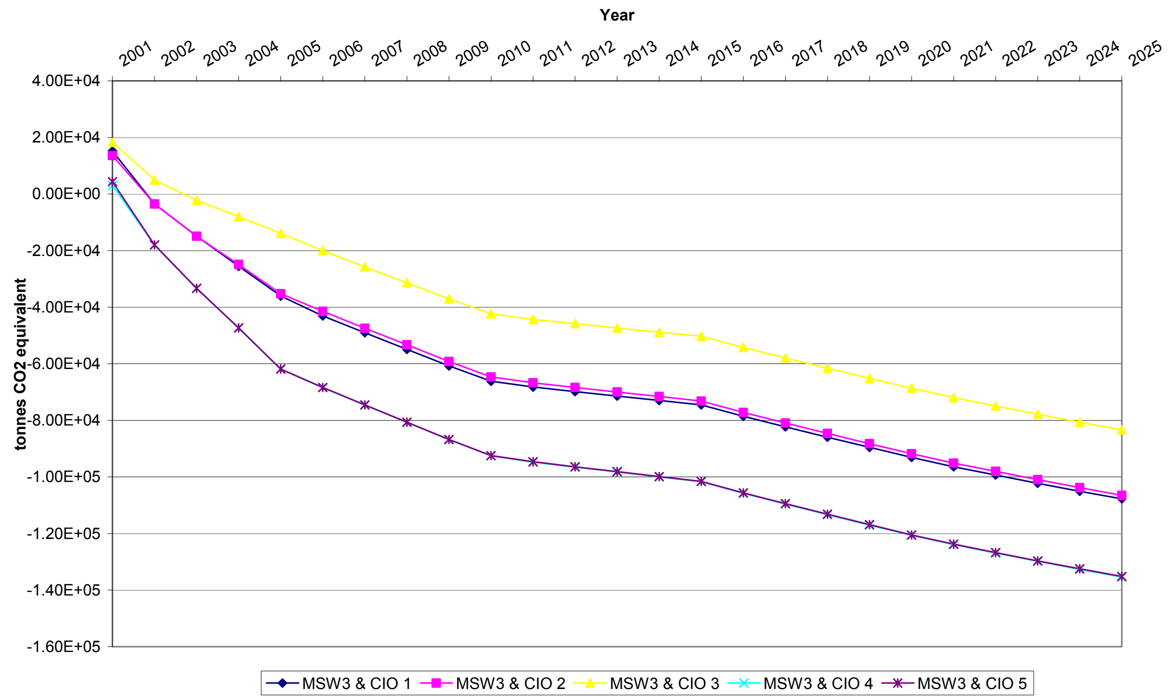


Figure E1.6 GHG Contributions for MSW Scenario 6 and CIO 1-5

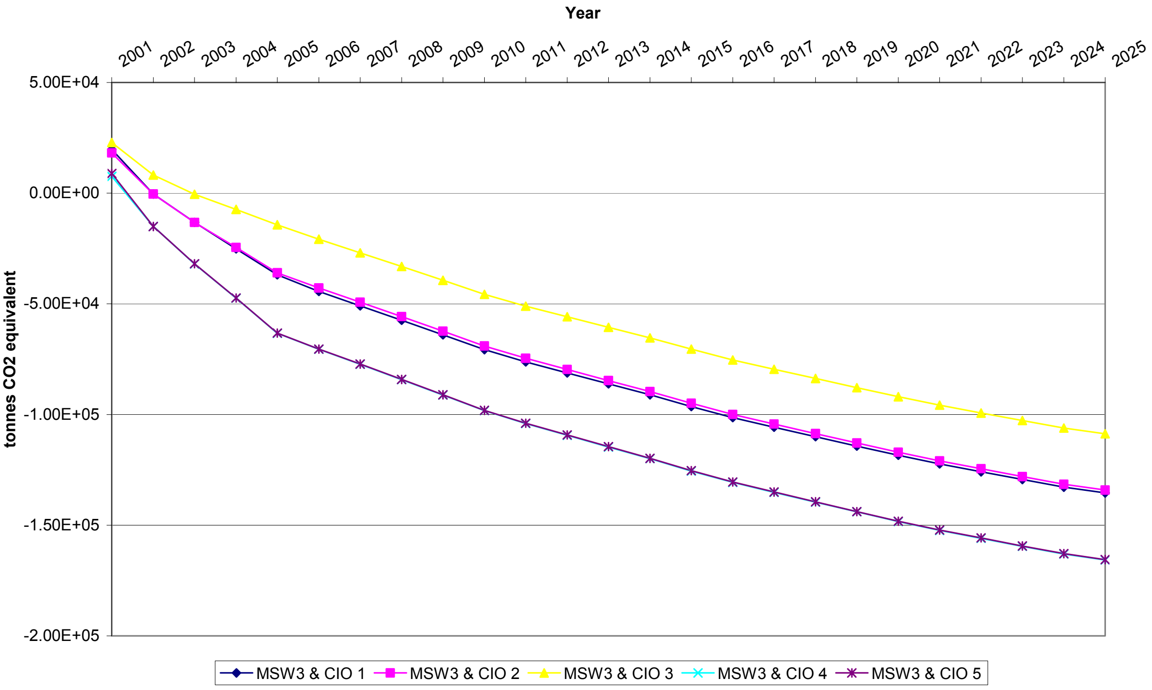


Figure E1.7 *GHG Contributions for MSW Scenario 7 and CIO 1-5*

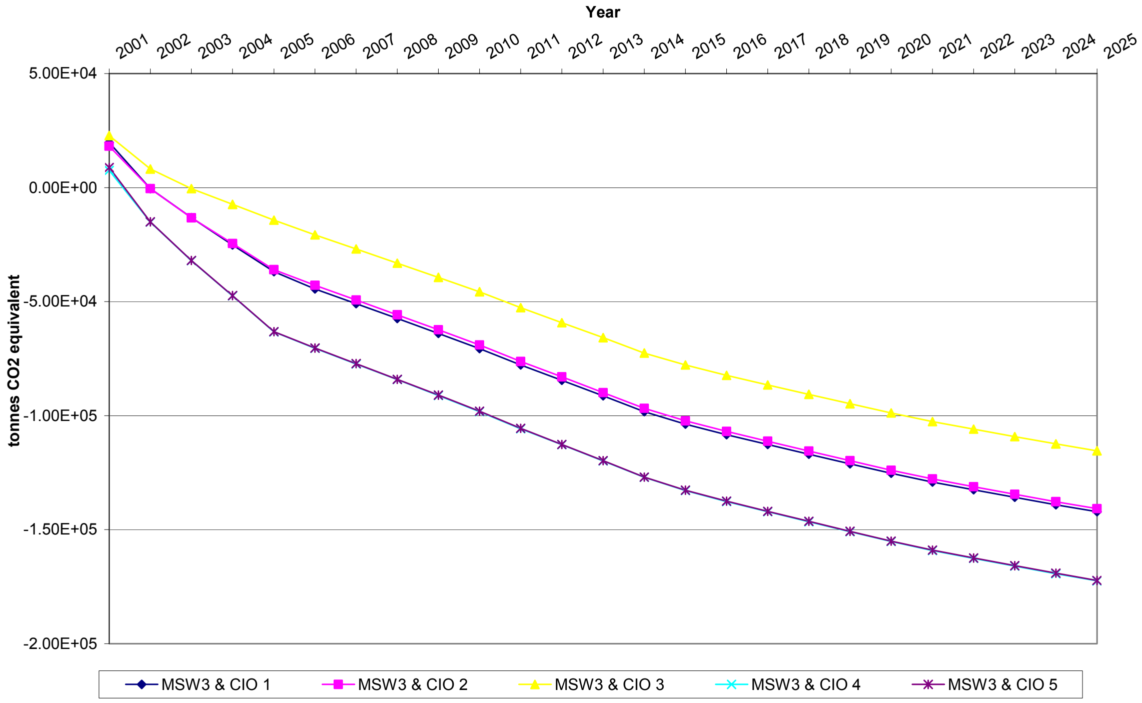
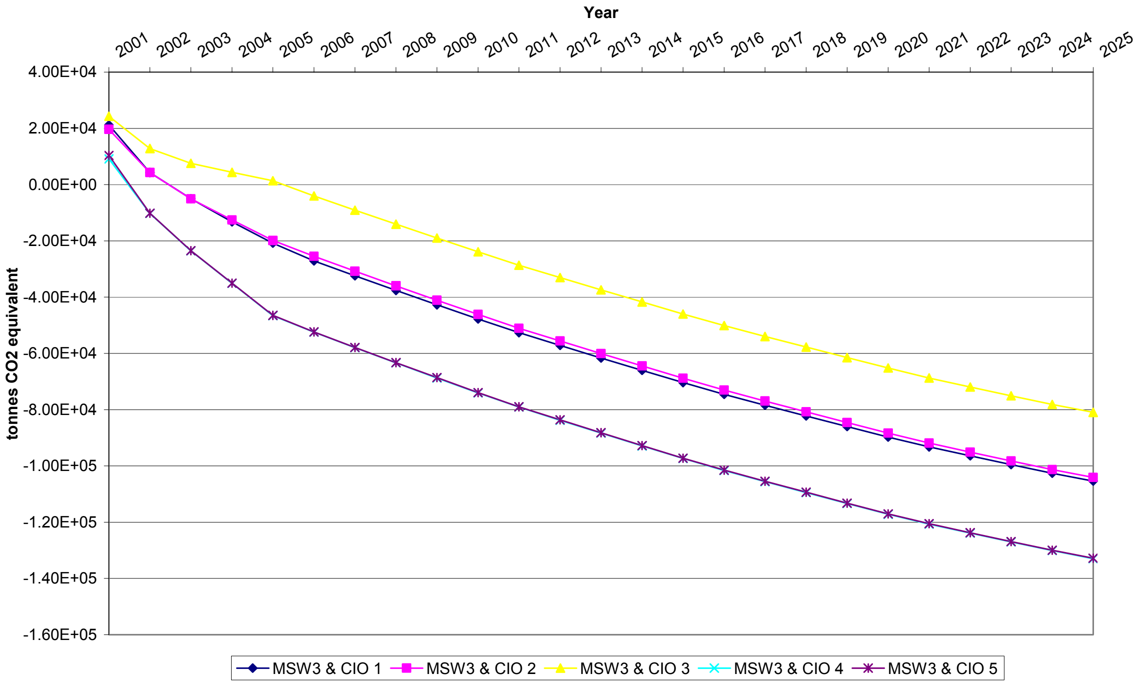


Figure E1.8 *GHG Contributions for MSW Scenario 8 and CIO 1-5*



Annex F

Scenarios for the Channel Islands (excluding methane emissions from landfill)

Figure E1.1 GHG Contributions for MSW Scenario 1 and CIO 1-5

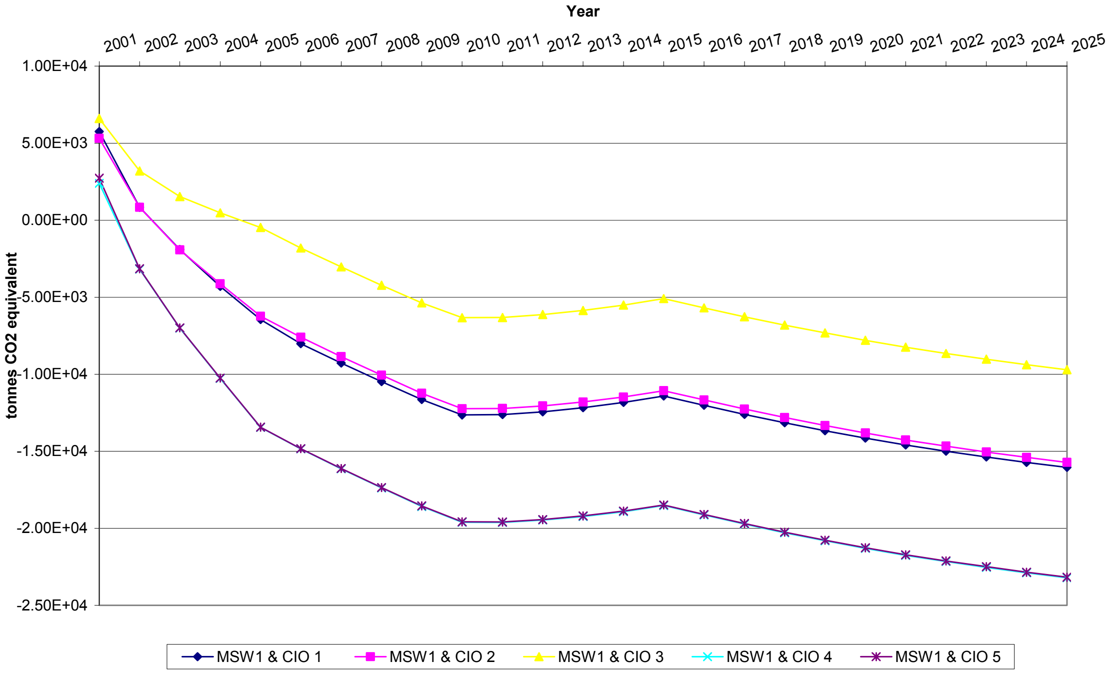


Figure E1.2 GHG Contributions for MSW Scenario 2 and CIO 1-5

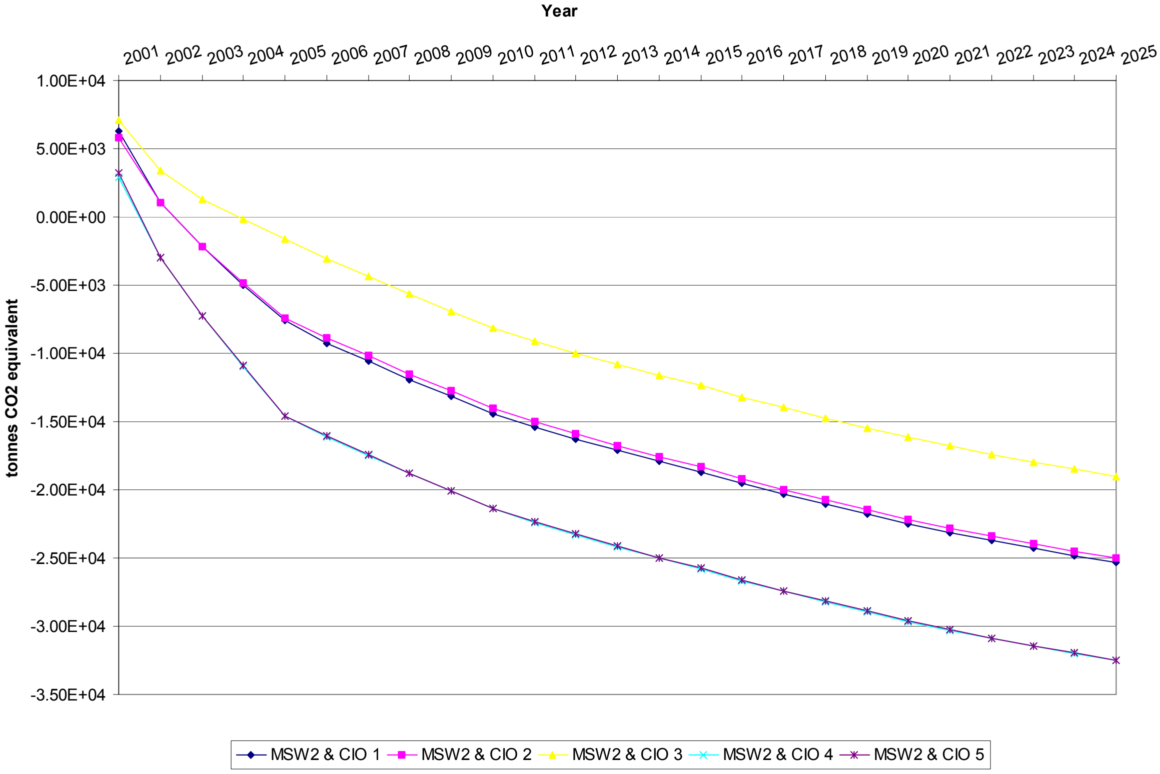


Figure E1.3 GHG Contributions for MSW Scenario 3 and CIO 1-5

Figure E1.4 GHG Contributions for MSW Scenario 4 and CIO 1-5

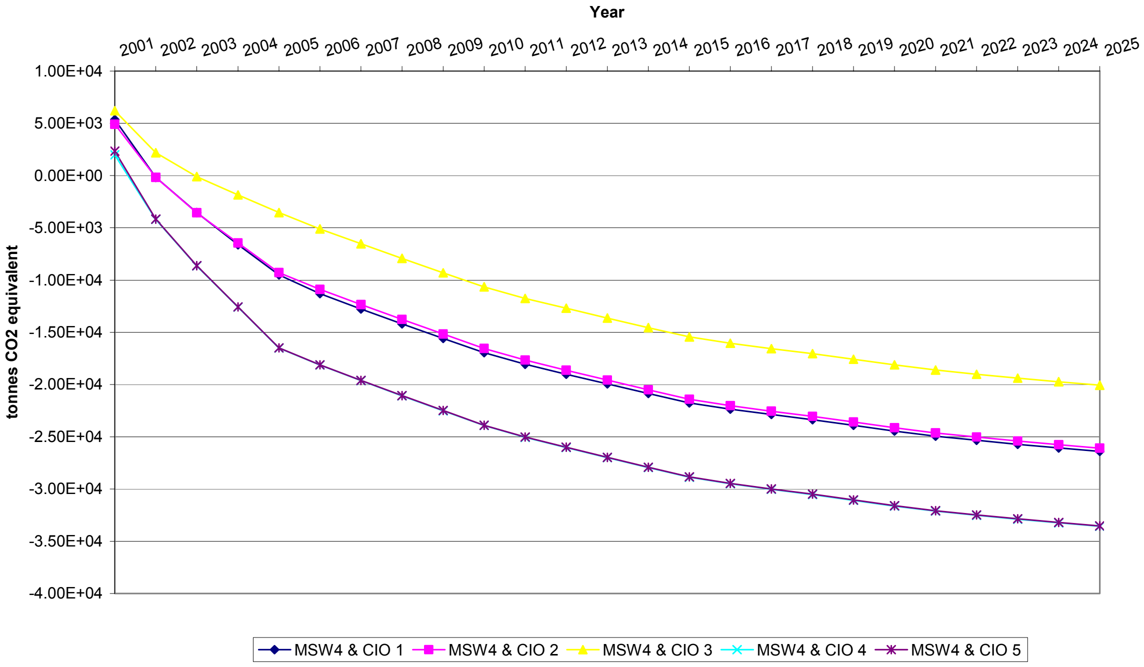


Figure E1.5 GHG Contributions for MSW Scenario 5 and CIO 1-5

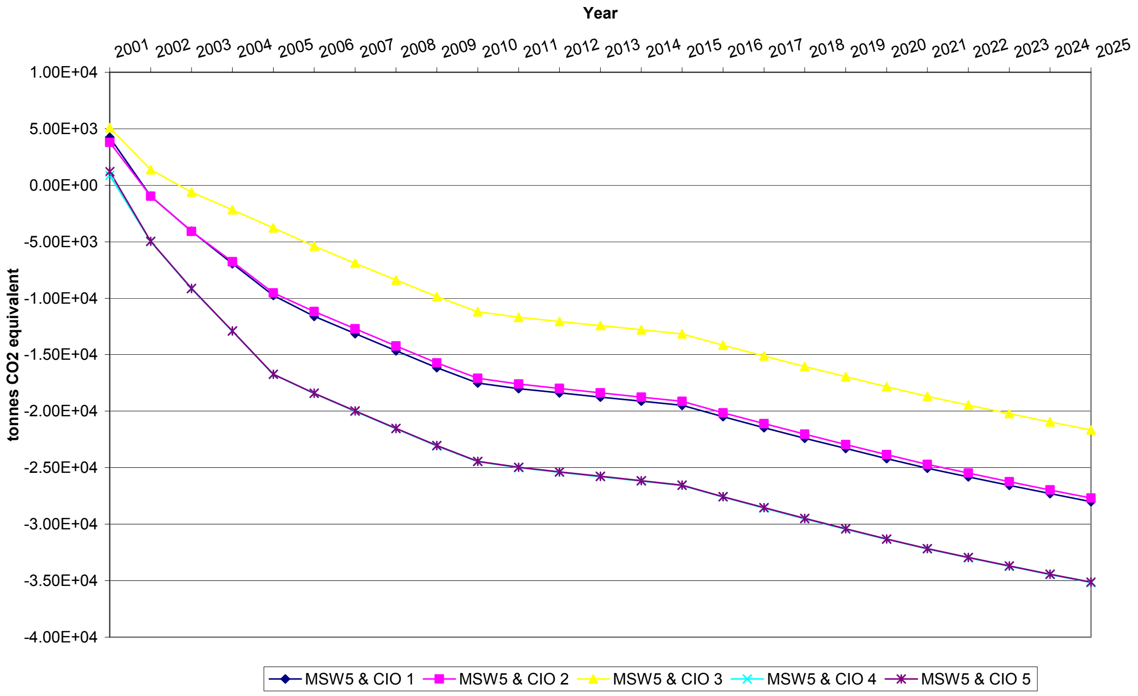


Figure E1.6 GHG Contributions for MSW Scenario 6 and CIO 1-5

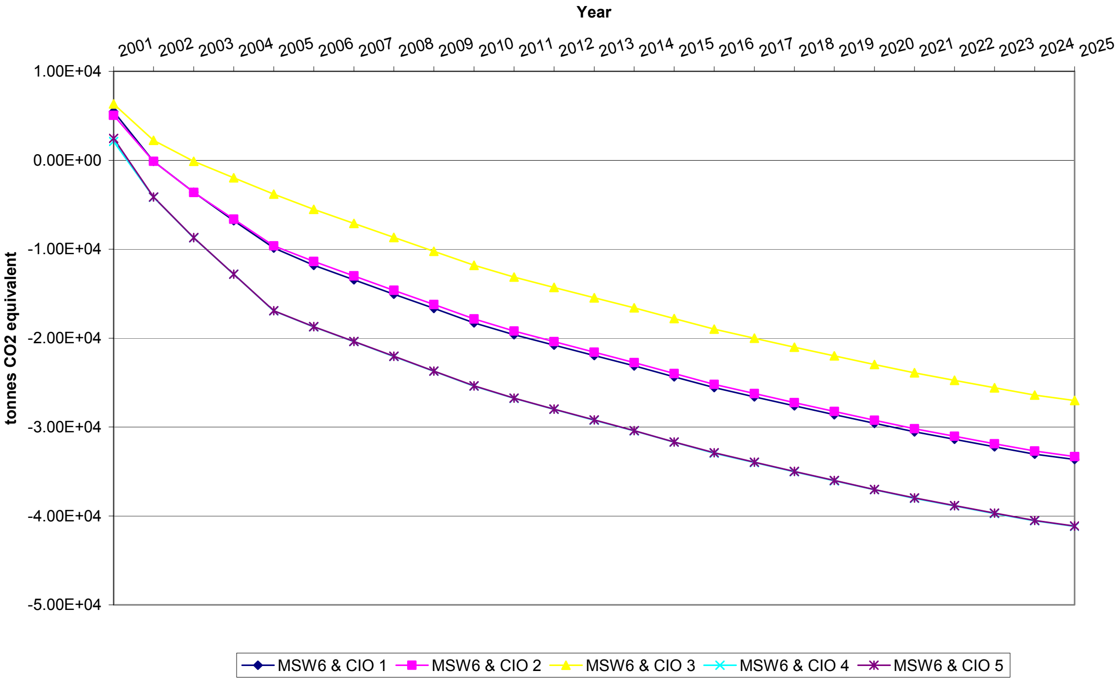


Figure E1.7 GHG Contributions for MSW Scenario 7 and CIO 1-5

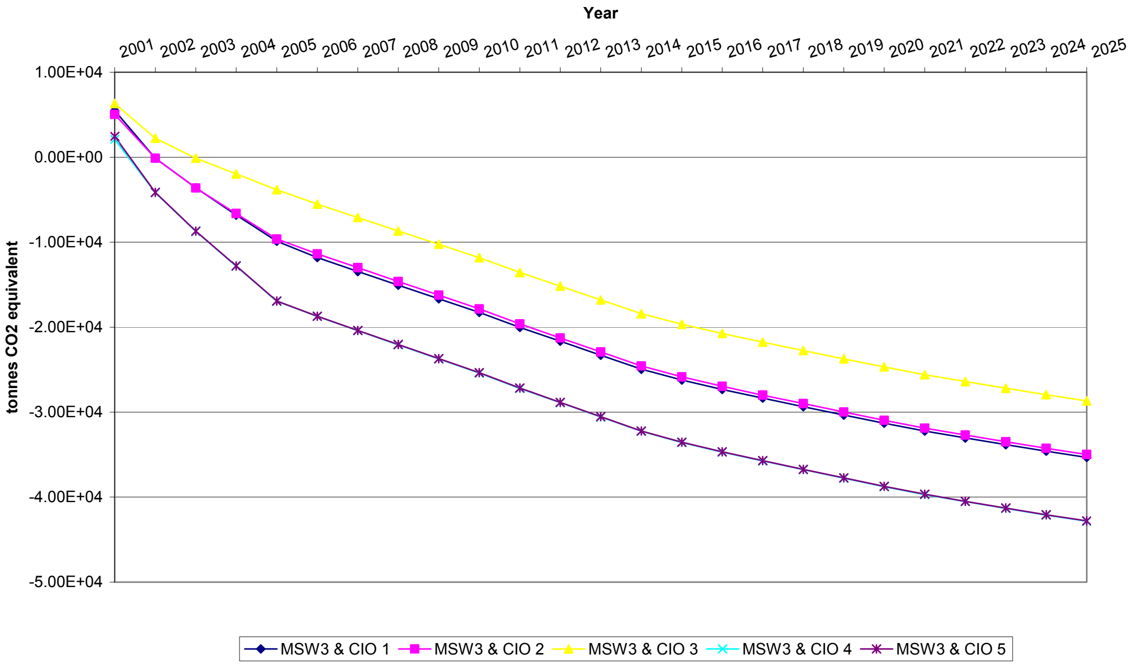
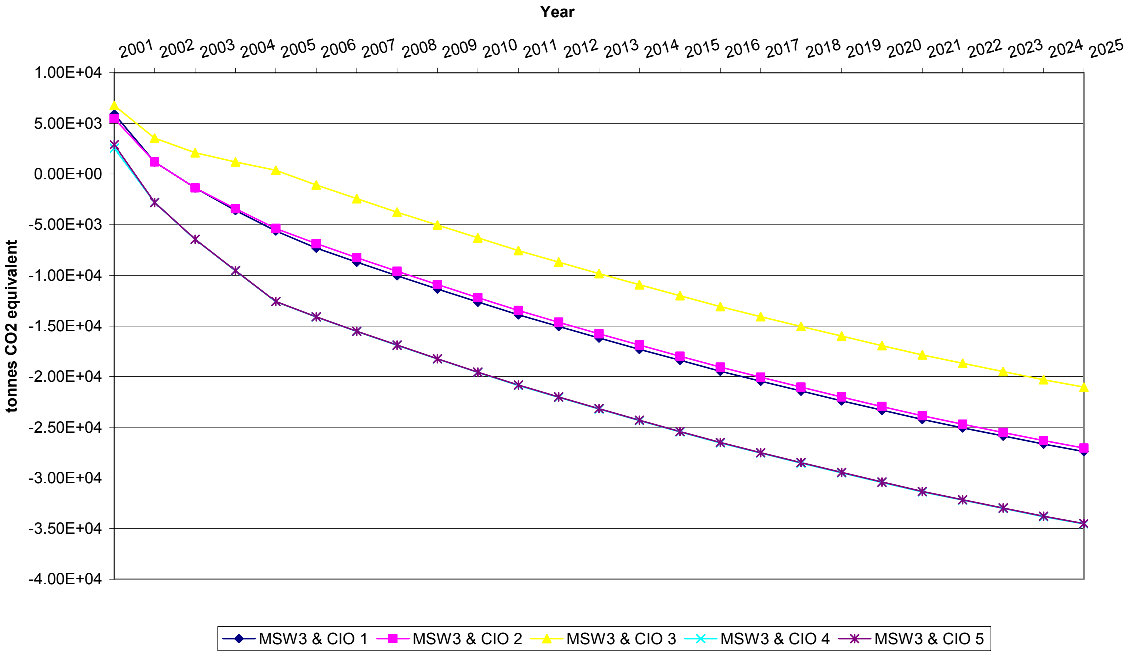


Figure E1.8 GHG Contributions for MSW Scenario 8 and CIO 1-5



Annex G

UK Total GHG Emission Estimates (excluding methane emissions from landfill)

Figure G1.1 GHG Contributions for MSW Scenario 1 and CIO 1-5

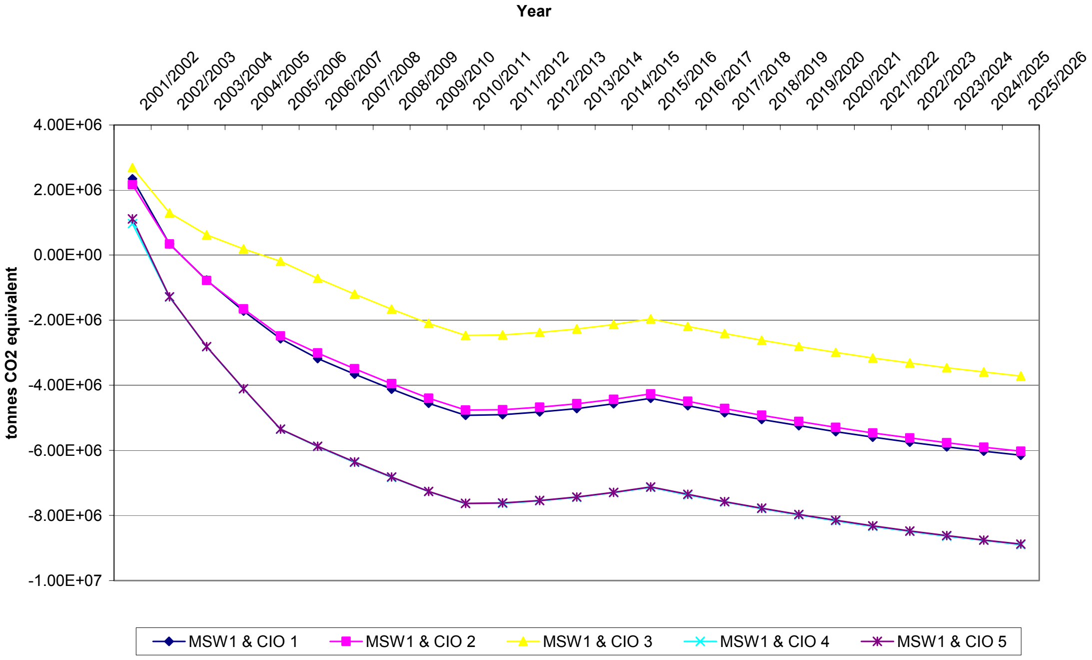


Figure G1.2 GHG Contributions for MSW Scenario 2 and CIO 1-5

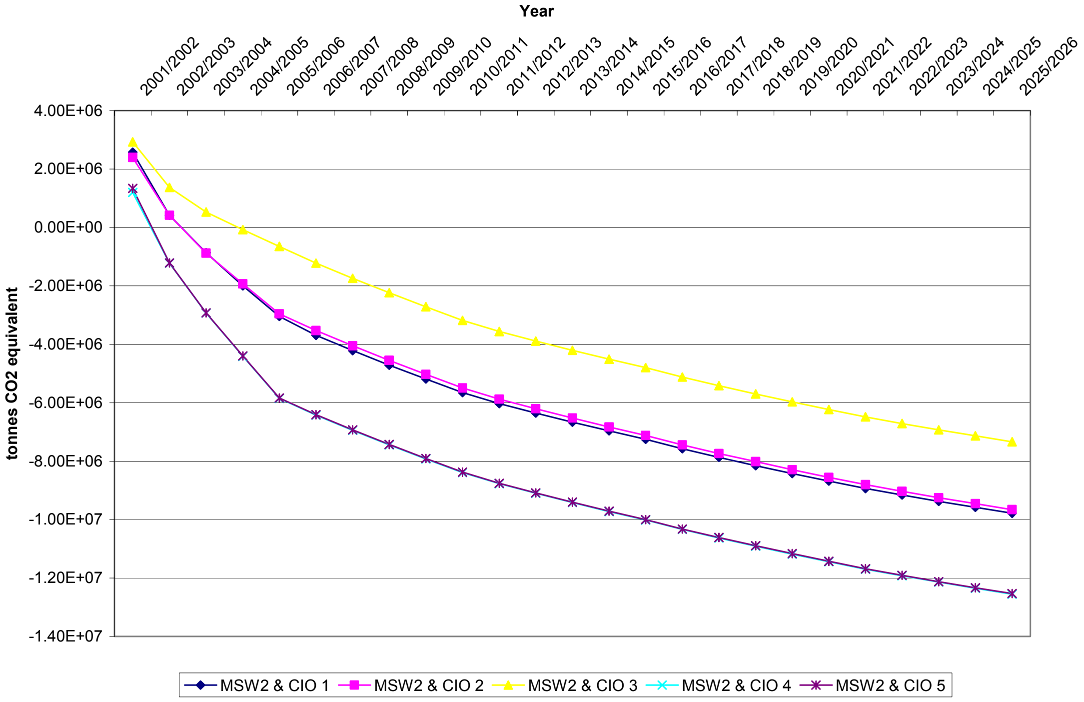


Figure G1.3 GHG Contributions for MSW Scenario 3 and CIO 1-5

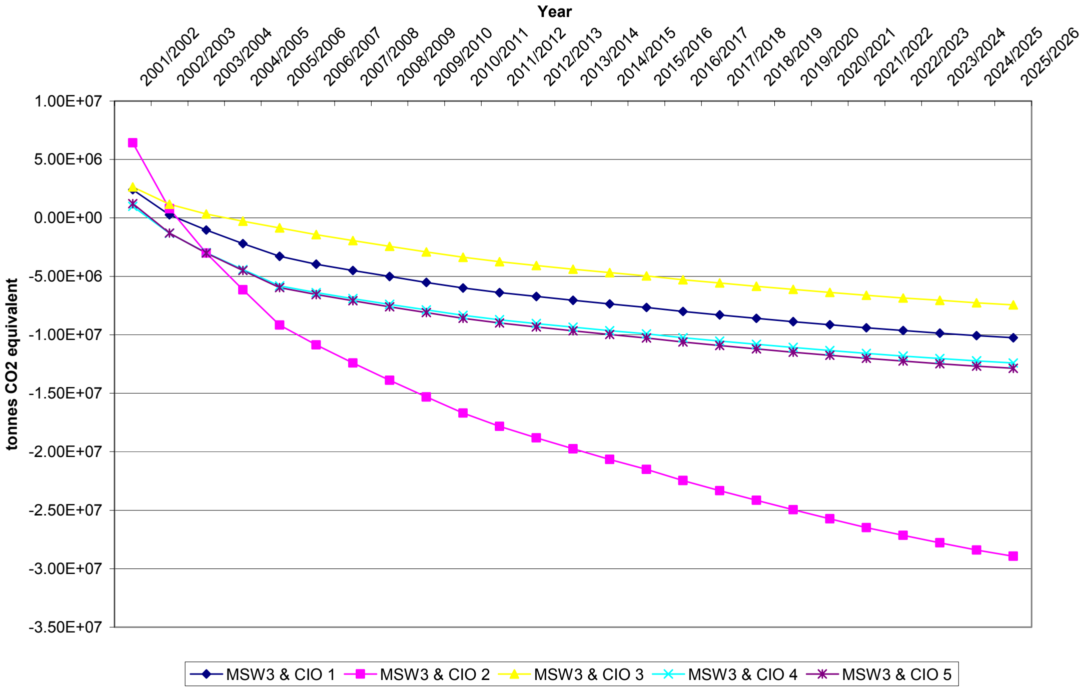


Figure G1.4 GHG Contributions for MSW Scenario 4 and CIO 1-5

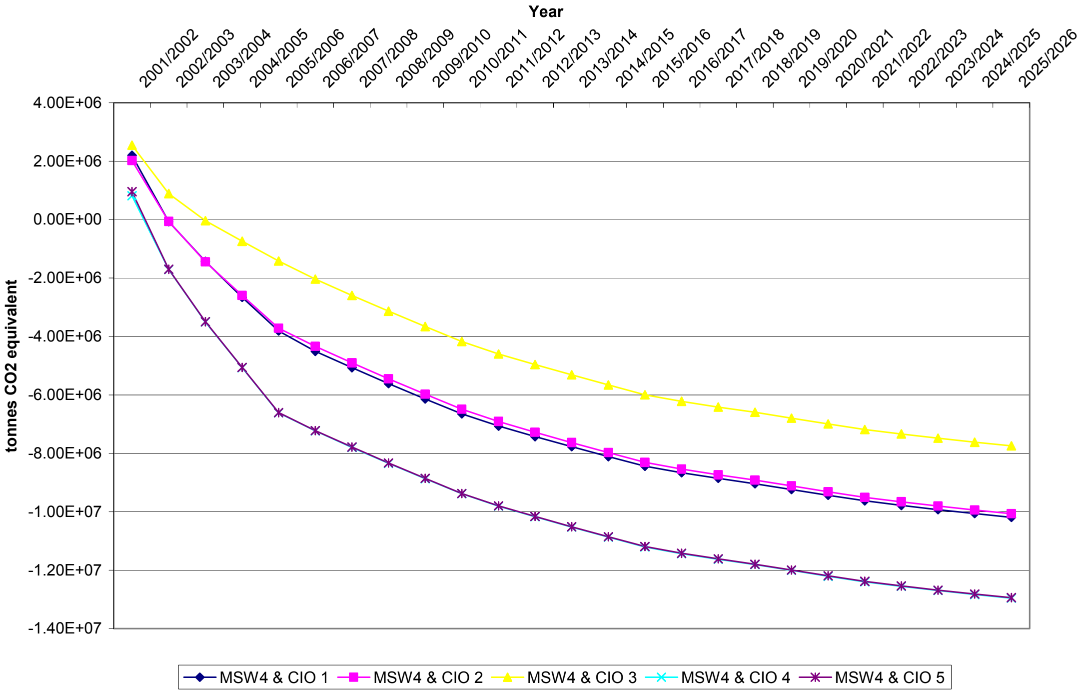


Figure G1.5 GHG Contributions for MSW Scenario 5 and CIO 1-5

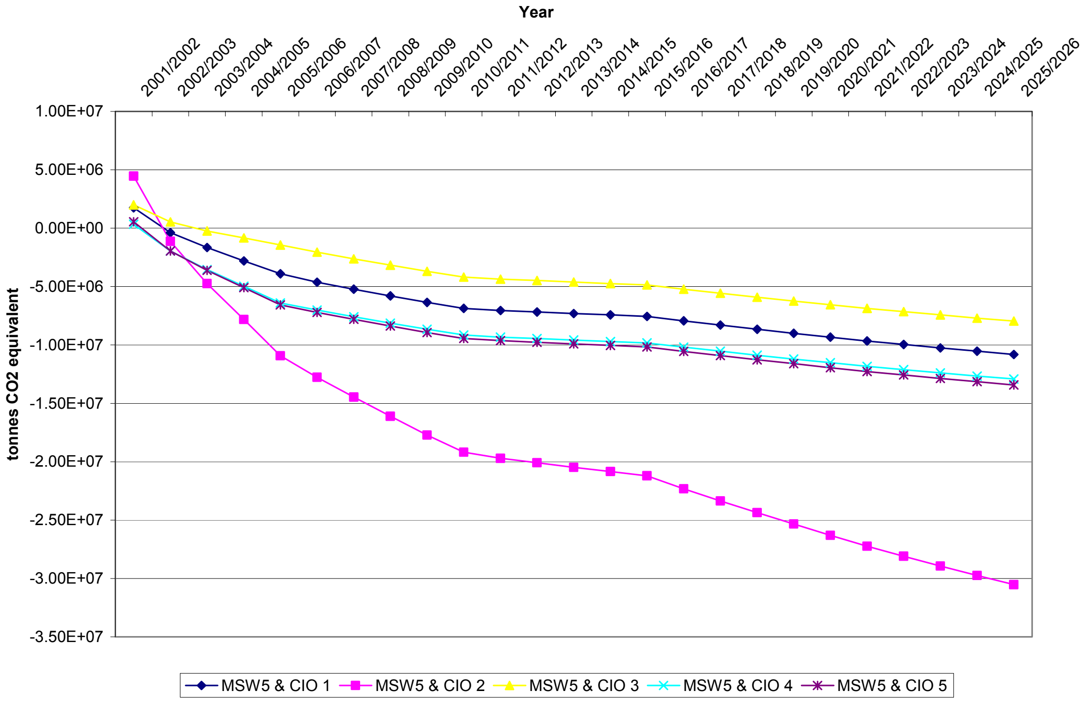


Figure G1.6 GHG Contributions for MSW Scenario 6 and CIO 1-5

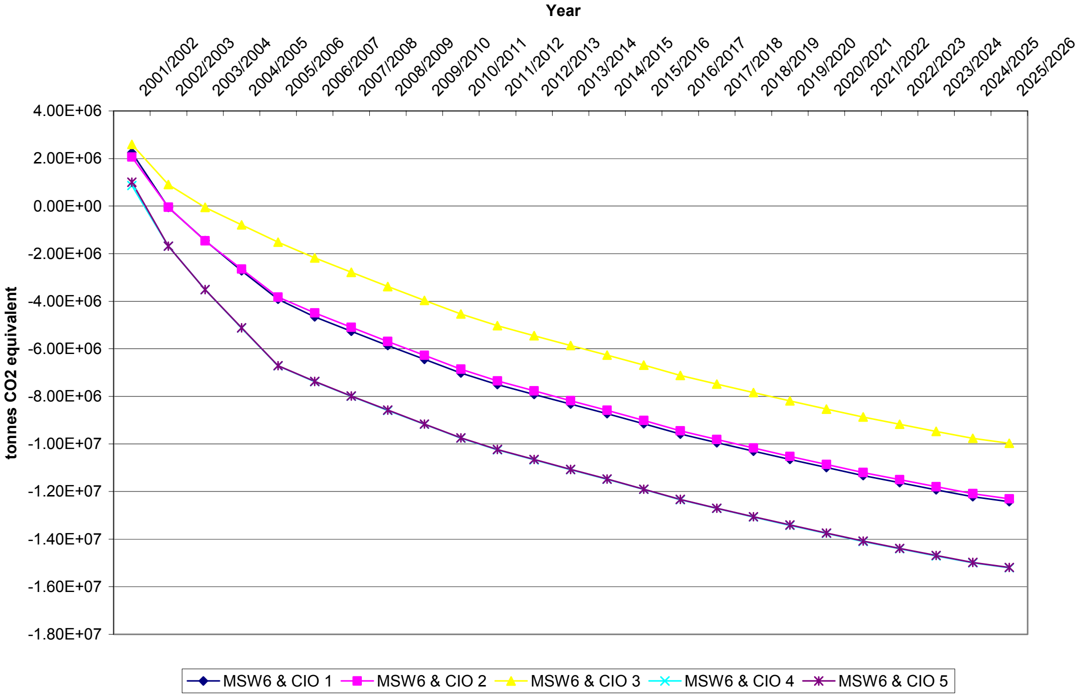


Figure G1.7 *GHG Contributions for MSW Scenario 7 and CIO 1-5*

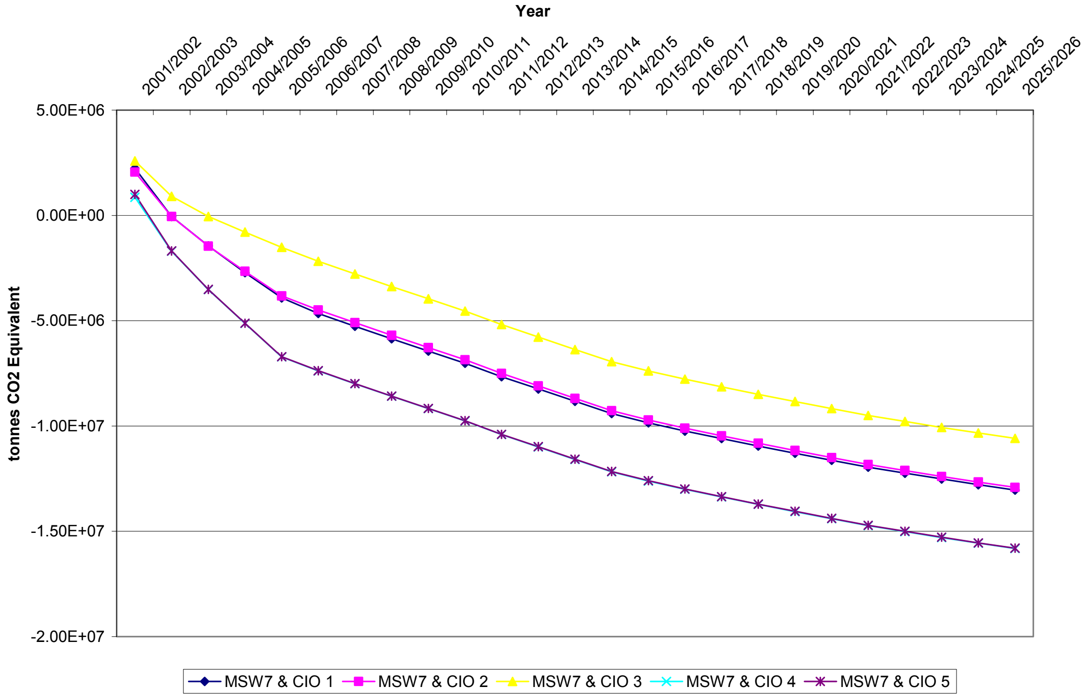
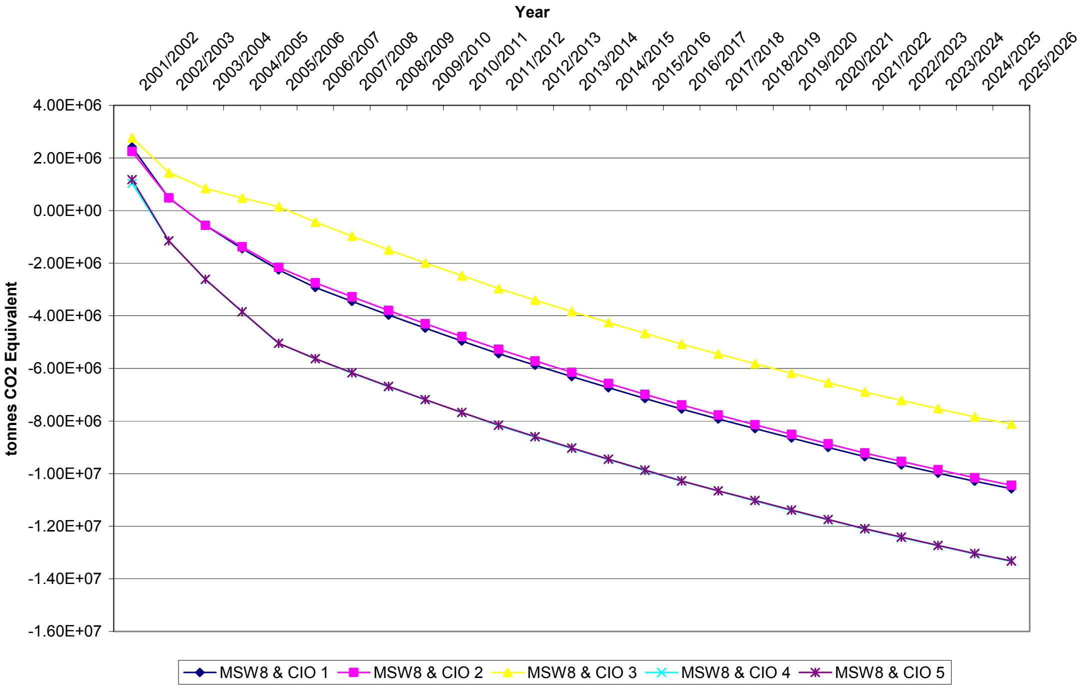


Figure G1.8 *GHG Contributions for MSW Scenario 8 and CIO 1-5*



Annex H

Ammonia Emissions

Figure H1.1 MSW Ammonia Emissions to Air for England and Wales

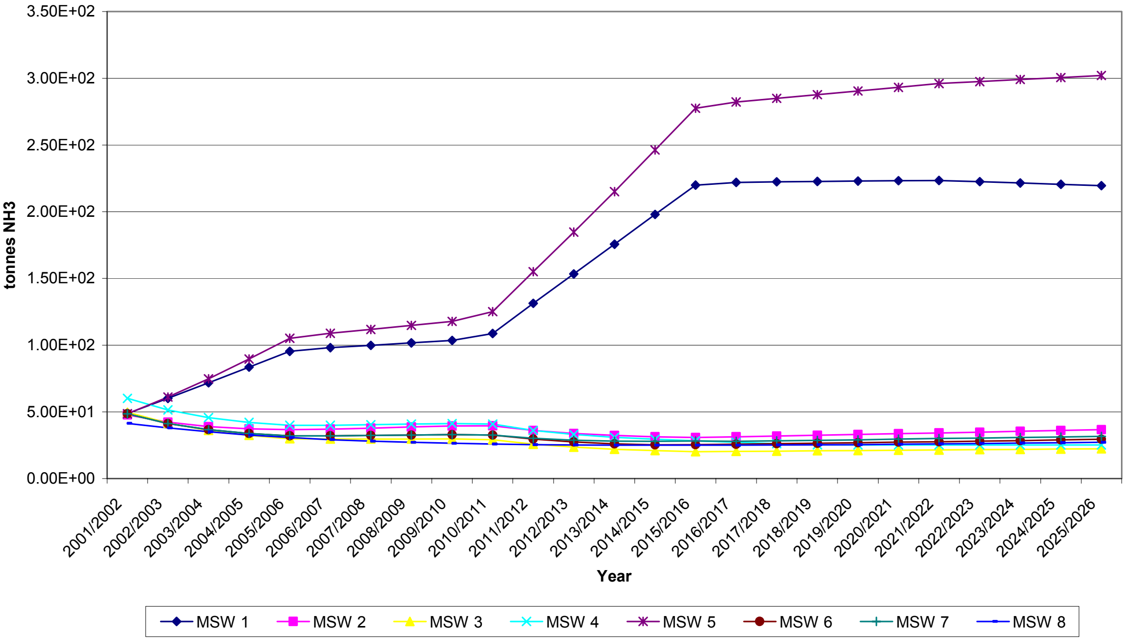


Figure H1.2 MSW Ammonia Emissions to Water for England and Wales

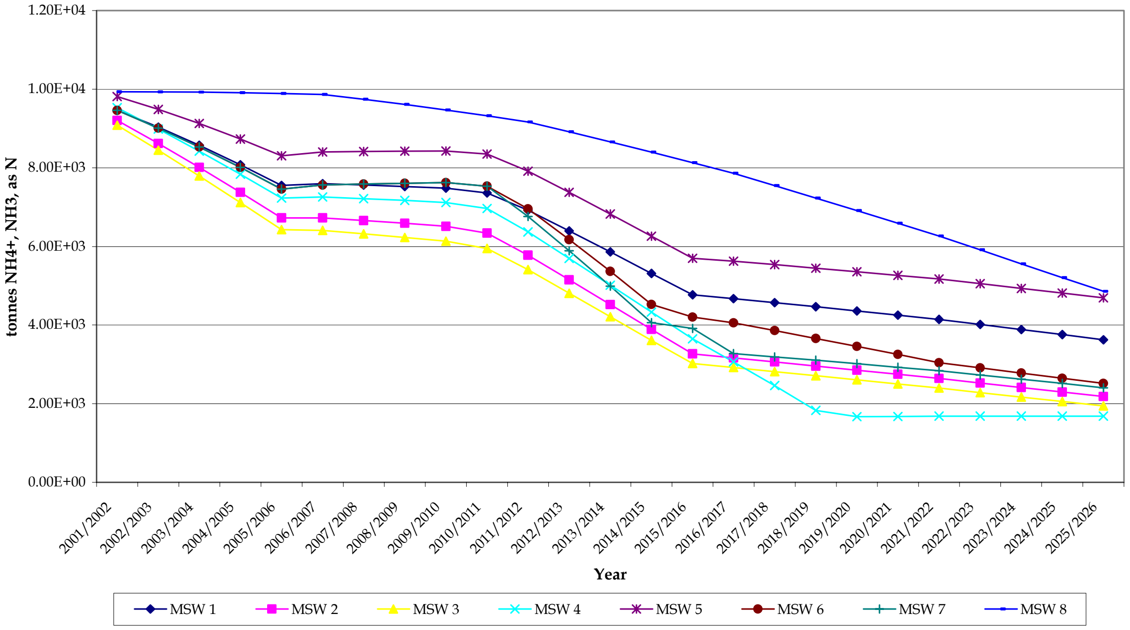


Figure H1.3 CIO Ammonia Emissions to Air for England and Wales

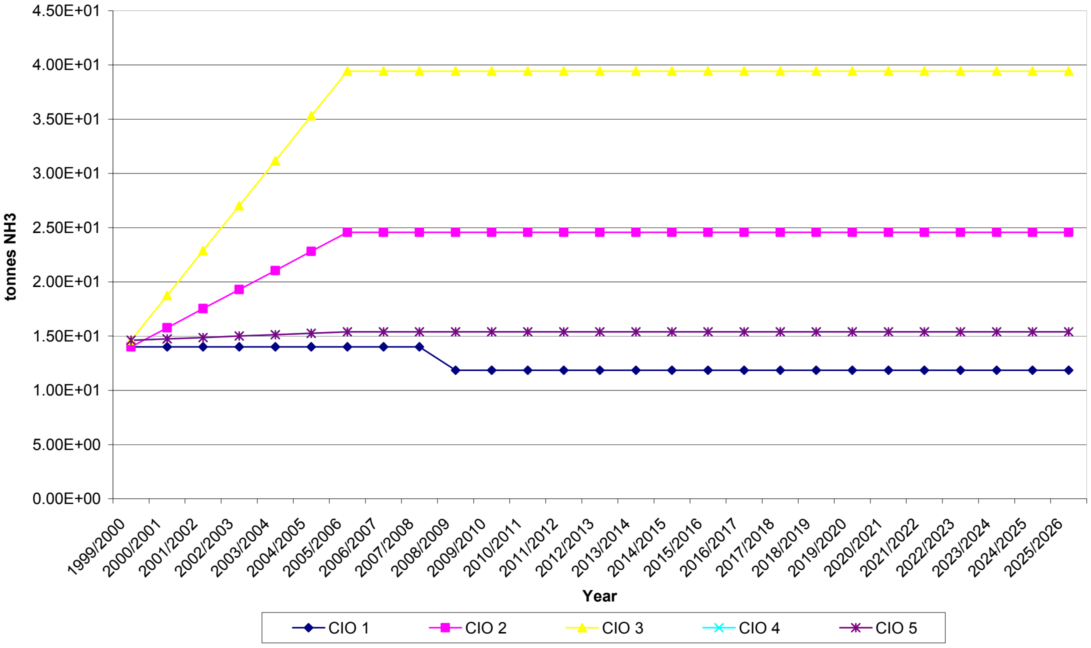


Figure H1.4 CIO Ammonia Emissions to Water for England and Wales

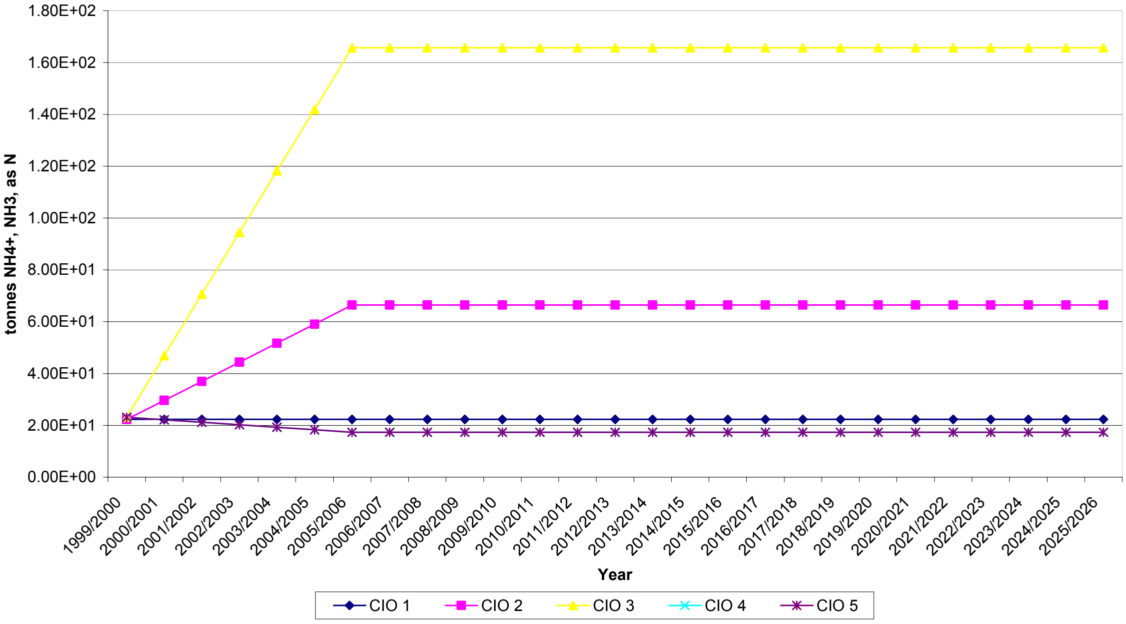


Figure H2.1 MSW Ammonia Emissions to Air for Scotland

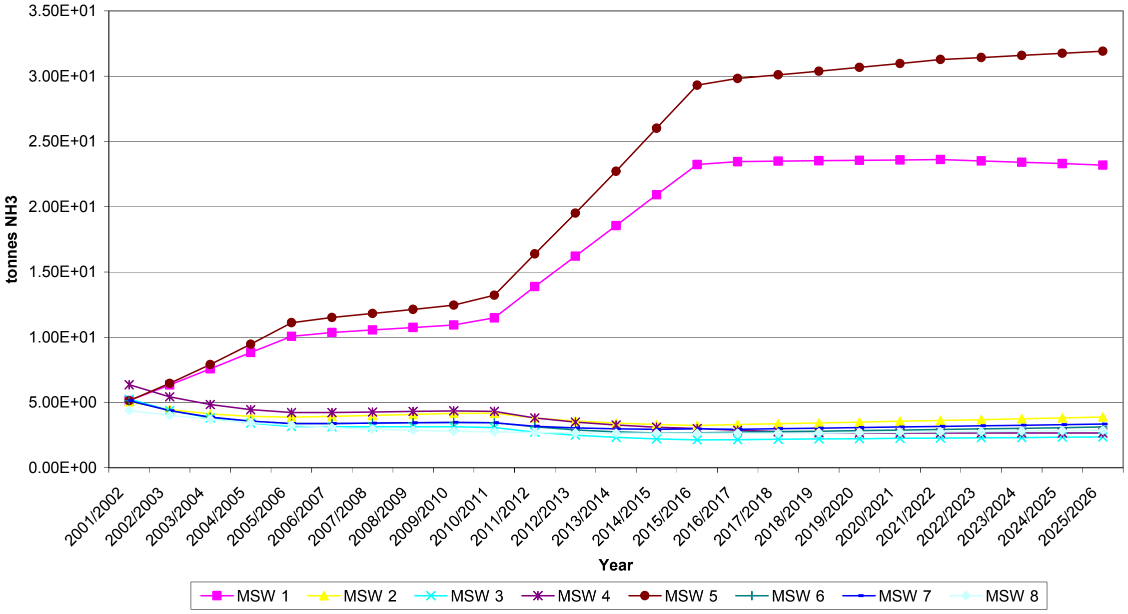


Figure H2.2 MSW Ammonia Emissions to Water for Scotland

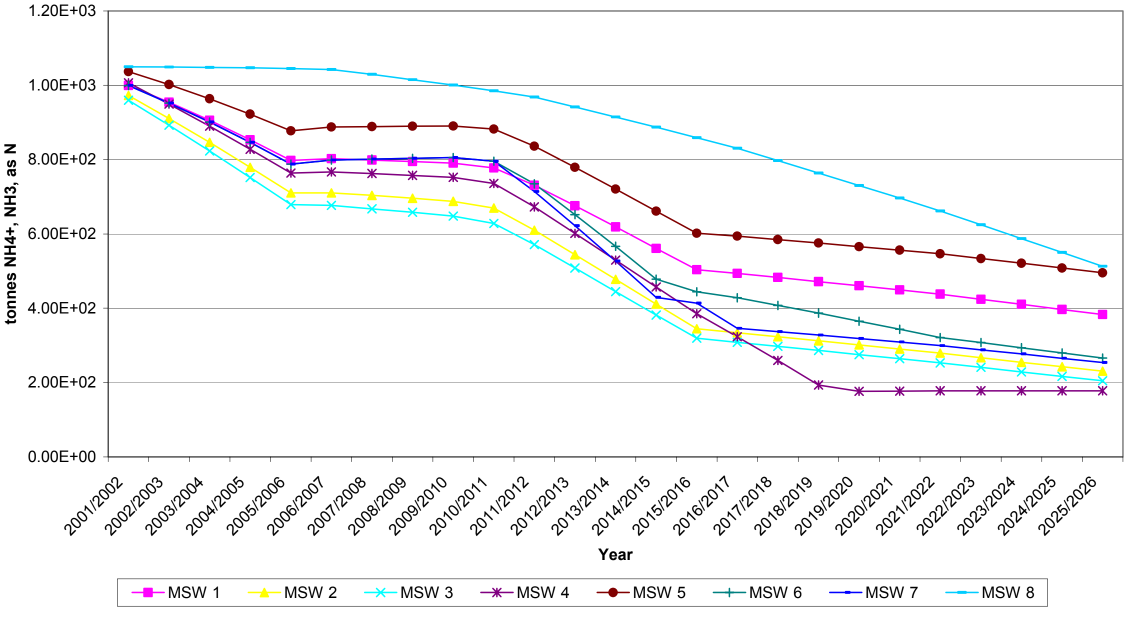


Figure H2.3 CIO Ammonia Emissions to Air for Scotland

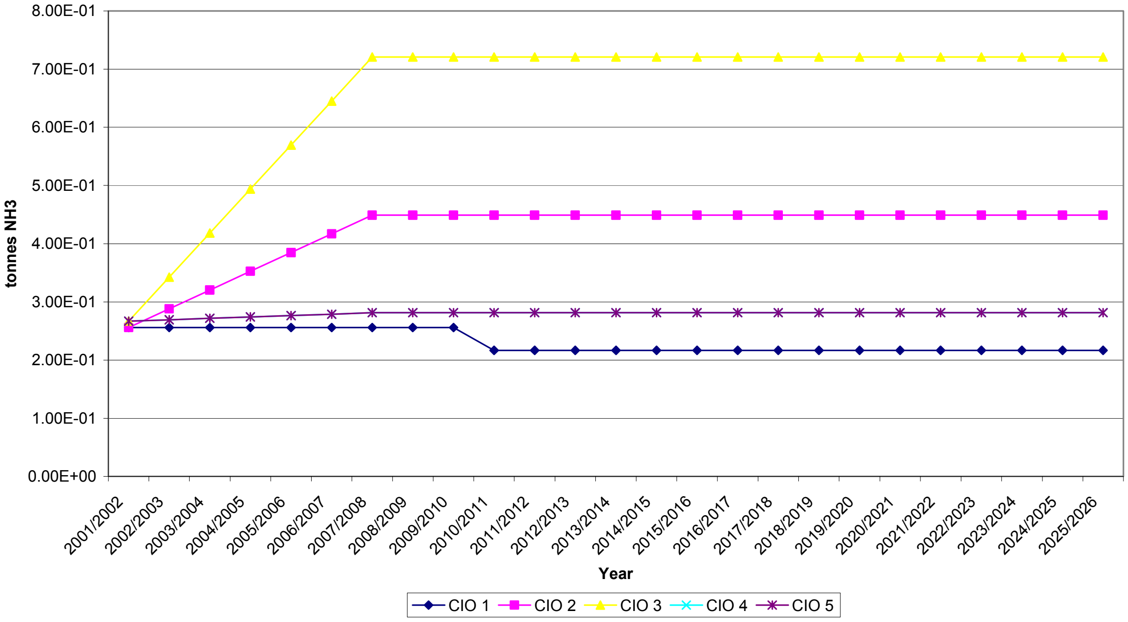
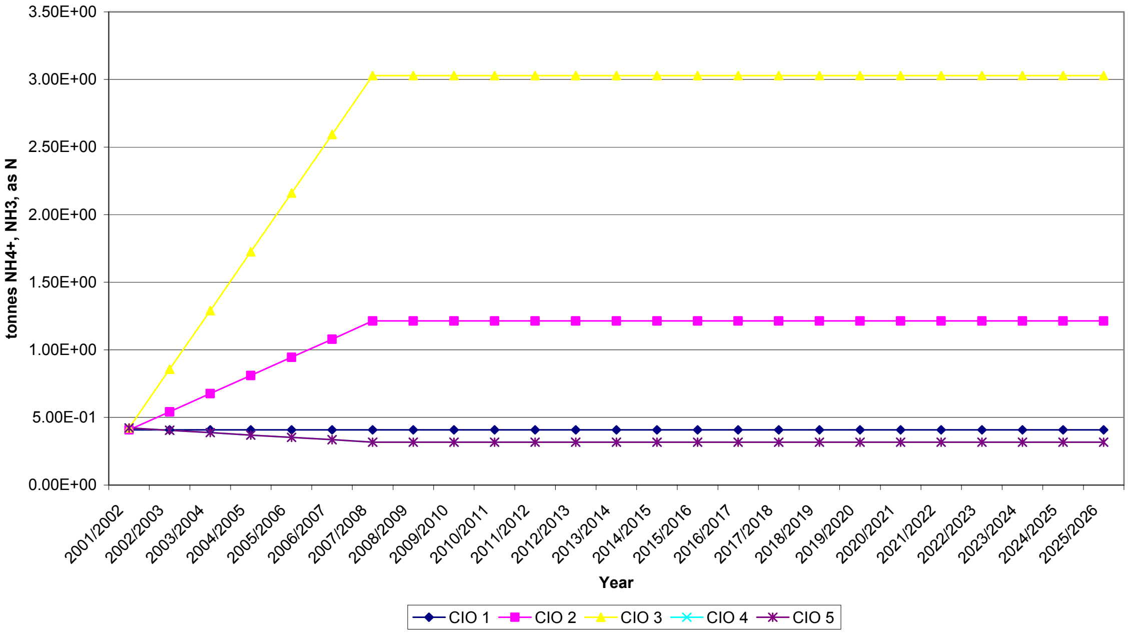
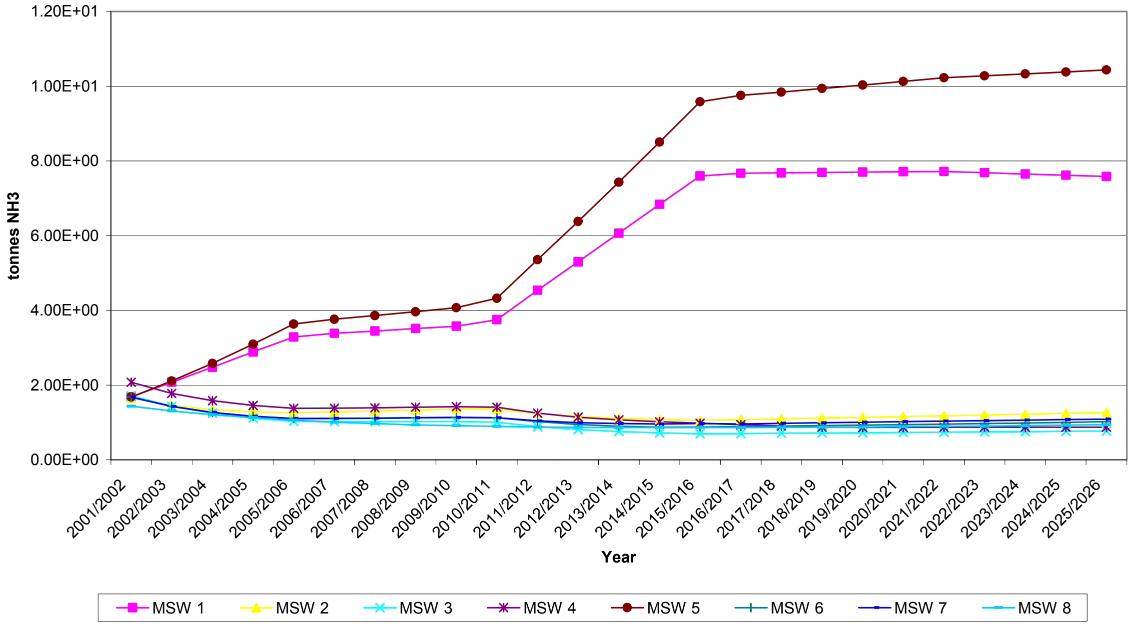


Figure H2.4 CIO Ammonia Emissions to Water for Scotland



H3 AMMONIA EMISSIONS FOR NORTHERN IRELAND

H3.1 MSW Ammonia Emissions to Air for Northern Ireland



H3.2 MSW Ammonia Emissions to Water for Northern Ireland

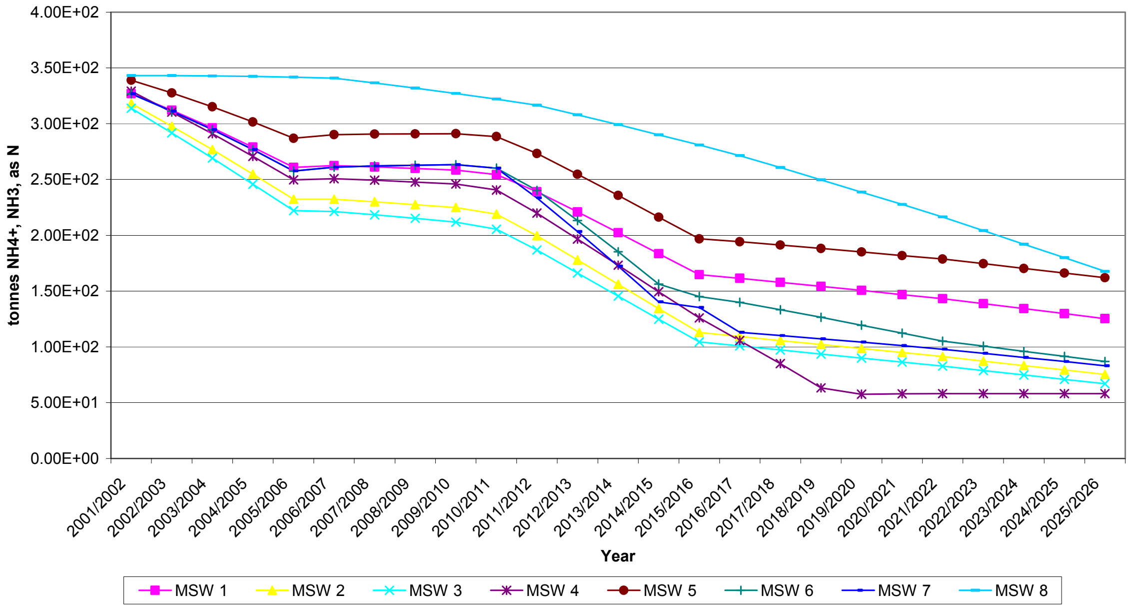
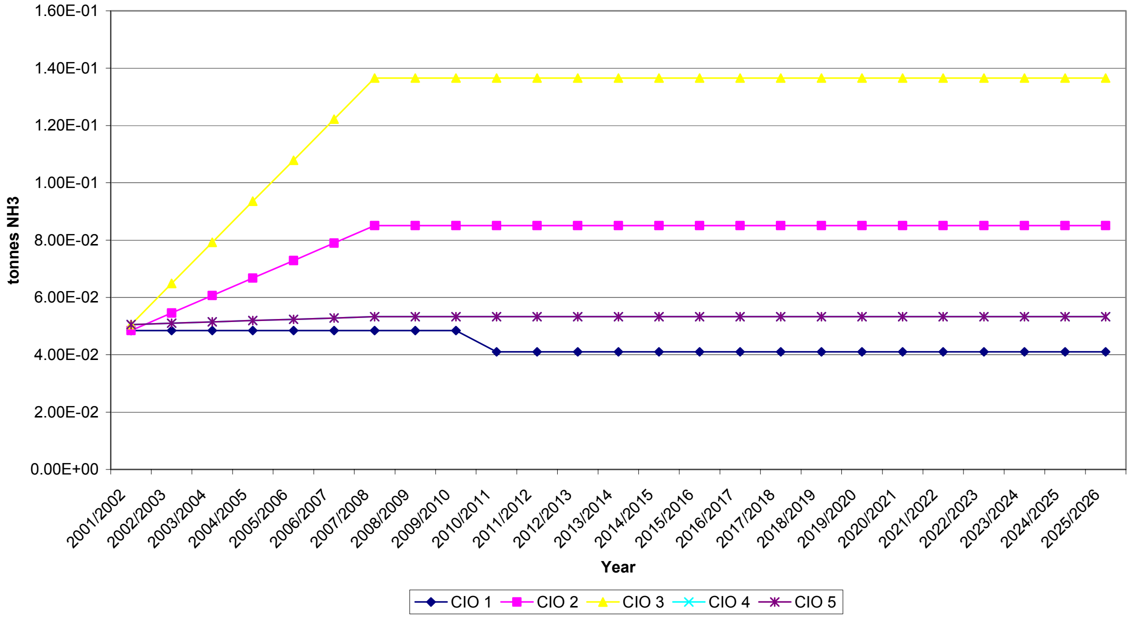


Figure H3.3 CIO Ammonia Emissions to Air for Northern Ireland



H3.4 CIO Ammonia Emissions to Water for Northern Ireland

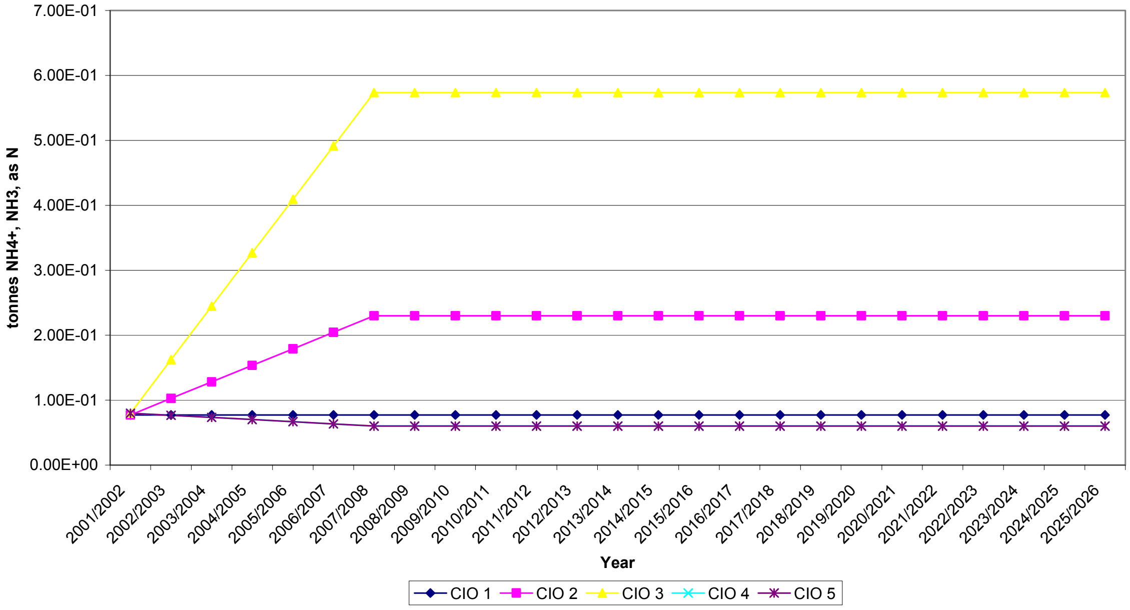


Figure H4.1 MSW Ammonia Emissions to Air for the Channel Islands

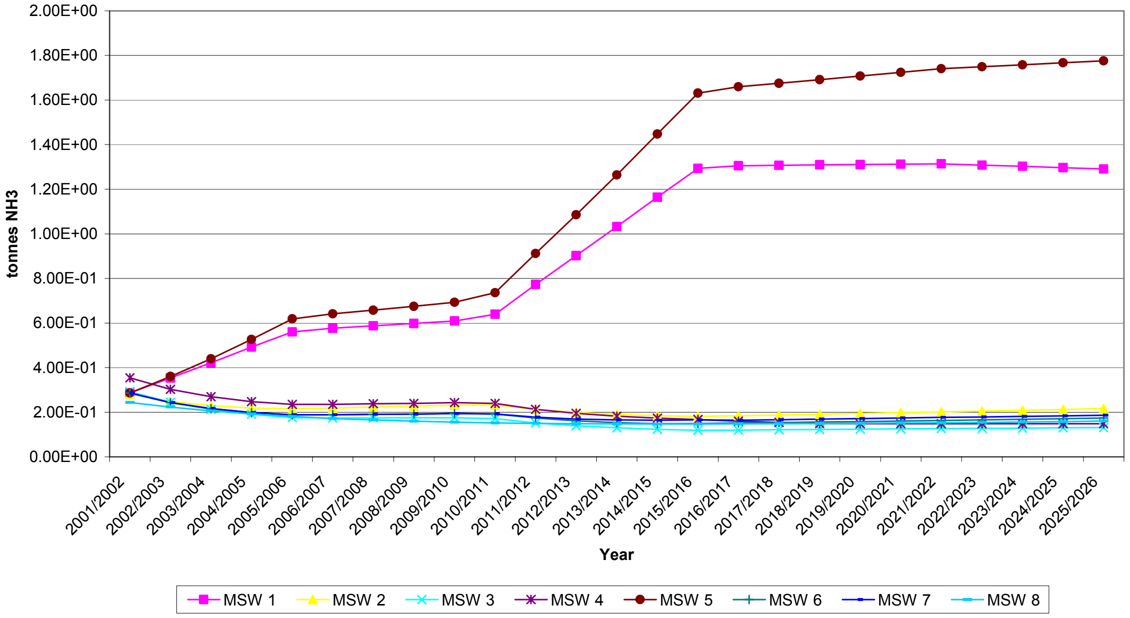


Figure H4.2 MSW Ammonia Emissions to Water for the Channel Islands

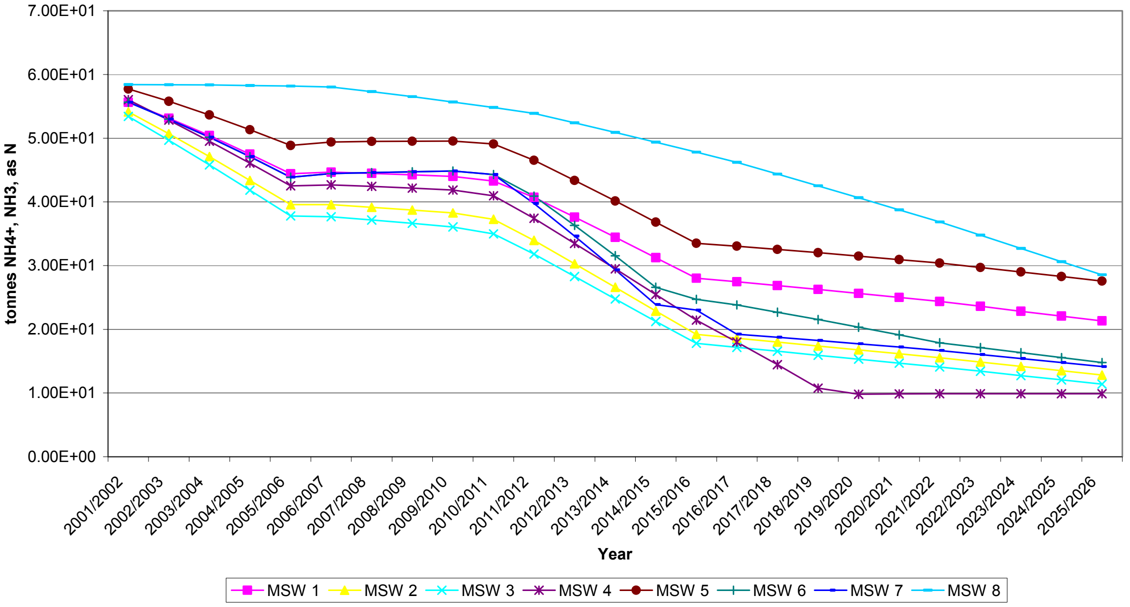


Figure H4.3 CIO Ammonia Emissions to Air for the Channel Islands

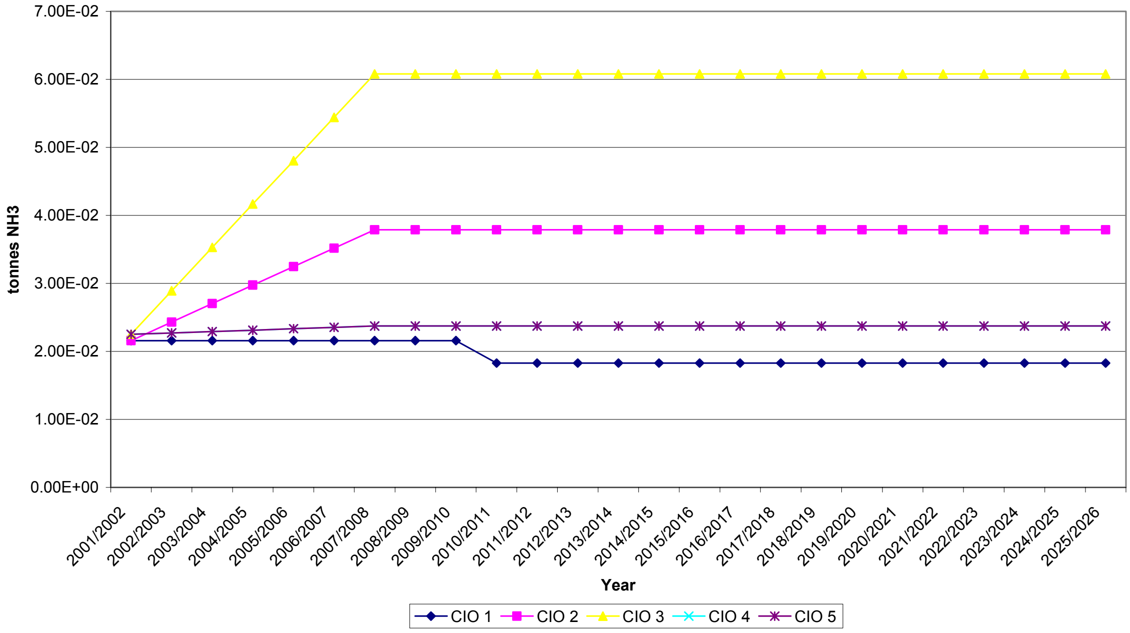
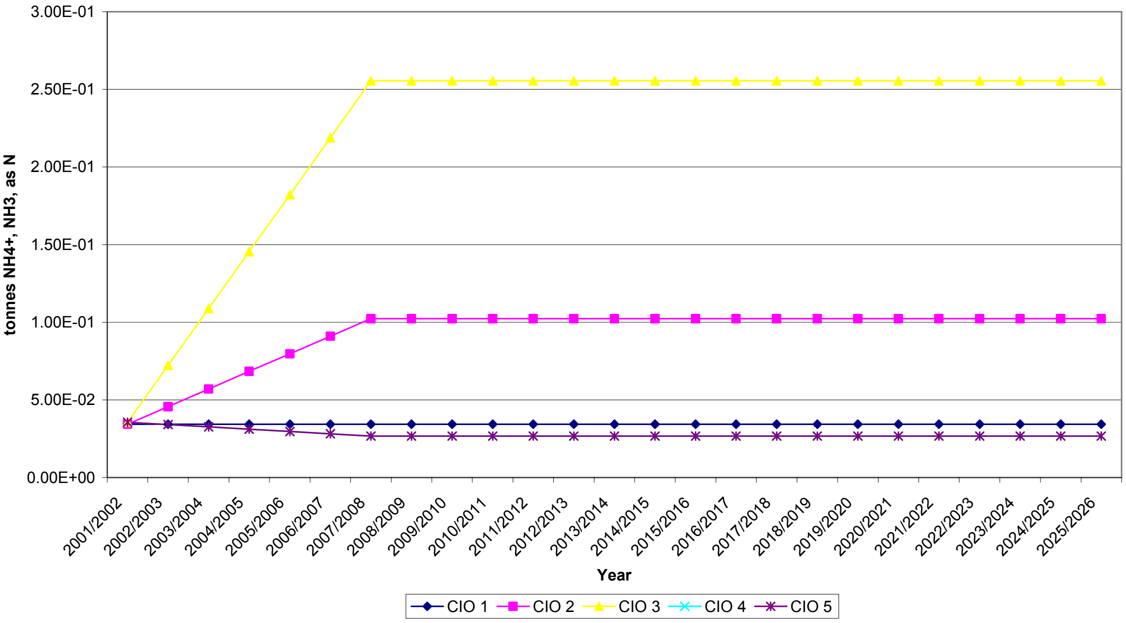


Figure H4.4 CIO Ammonia Emissions to Water for the Channel Islands



Annex I

Landfill Assumptions Sourced from ***WISARD*** and used in the Ammonia Emissions Modelling

I1 LANDFILL ASSUMPTIONS SOURCED FROM WISARD AND USED IN THE AMMONIA EMISSIONS MODELLING

I1.1 AUTHOR

Bob Gregory (Land Quality Management Ltd, SChEME, University of Nottingham), September 1999.

I1.2 SOURCE

"Wisard Landfill data calculation sheets", B. Gregory for AEATechnology, LQM Ref. 157, 7 September 1999.

I1.3 REPRESENTATIVITY

Data is collated from both modelled and bibliographic sources.

I1.4 COMMENT

Robinson (1995) defined these types to include a high proportion of current (and future) landfill sites. The key elements of a WISARD site with these characteristics are:

- A high waste filling rate (>400 t/day or >88000 t/yr).
- They are operated to minimise water ingress by cellular tipping, grading, capping and progressive restoration.
- They are lined and capped with either a natural clay or a composite liner system.

Examples of sites which fall into these categories, though not necessarily with comparable liner systems to that incorporated in WISARD, include Stangate East, Compton Bassett, Coney Hill, Greengairs, Calvert, Brogborough and Offham.

I1.5 DATA GAPS

I1.5.1 Operations

Major impact (diesel consumption of the machinery assumed to be 1 l/t by Ecobilan)

I1.5.2 Pumped leachate quantities

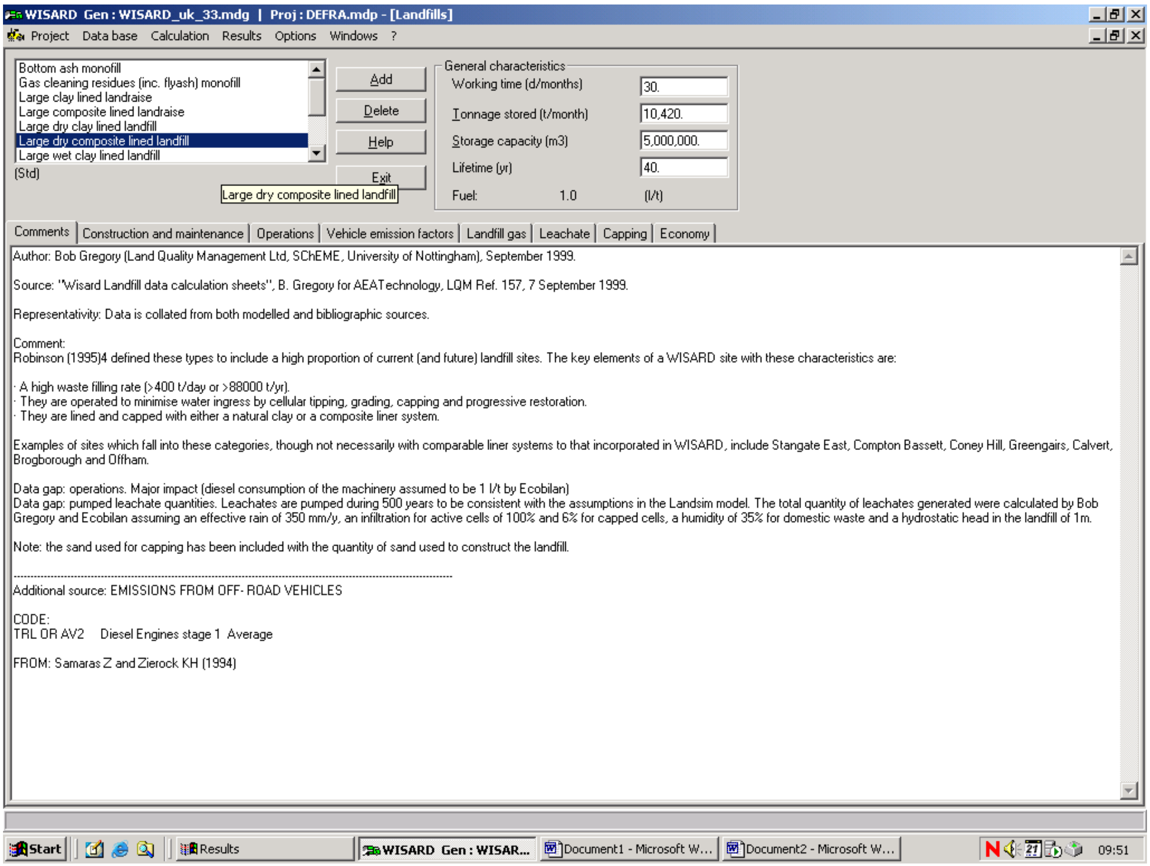
Leachates are pumped during 500 years to be consistent with the assumptions in the Landsim V2 model (1) . The total quantity of leachates generated were calculated by Bob Gregory and Ecobilan assuming an effective rain of 350 mm/y, an infiltration for active cells of 100% and 6% for capped cells, a humidity of 35% for domestic waste and a hydrostatic head in the landfill of 1m.

Note: the sand used for capping has been included with the quantity of sand used to construct the landfill.

I1.6 ADDITIONAL SOURCE: EMISSIONS FROM OFF- ROAD VEHICLES

CODE: TRL OR AV2 Diesel Engines stage 1 Average

FROM: Samaras Z and Zierock KH (1994)



Working time (d/months) 30.

Tonnage stored (t/month) 10,420.

Storage capacity (m3) 5,000,000.

Lifetime (yr) 40.

Fuel: 1.0 (l/t)

Author: Bob Gregory (Land Quality Management Ltd, SChEME, University of Nottingham), September 1999.

Source: "Wisard Landfill data calculation sheets", B. Gregory for AEATechnology, LQM Ref. 157, 7 September 1999.

Representativity: Data is collated from both modelled and bibliographic sources.

Comment:
Robinson (1995)4 defined these types to include a high proportion of current (and future) landfill sites. The key elements of a WISARD site with these characteristics are:

· A high waste filling rate (>400 t/day or >88000 t/yr).
· They are operated to minimise water ingress by cellular tipping, grading, capping and progressive restoration.
· They are lined and capped with either a natural clay or a composite liner system.

Examples of sites which fall into these categories, though not necessarily with comparable liner systems to that incorporated in WISARD, include Stangate East, Compton Bassett, Coney Hill, Greengairs, Calvert, Brogborough and Offham.

Data gap: operations. Major impact (diesel consumption of the machinery assumed to be 1 l/t by Ecobilan)
Data gap: pumped leachate quantities. Leachates are pumped during 500 years to be consistent with the assumptions in the Landsim model. The total quantity of leachates generated were calculated by Bob Gregory and Ecobilan assuming an effective rain of 350 mm/y, an infiltration for active cells of 100% and 6% for capped cells, a humidity of 35% for domestic waste and a hydrostatic head in the landfill of 1m.

Note: the sand used for capping has been included with the quantity of sand used to construct the landfill.

Additional source: EMISSIONS FROM OFF- ROAD VEHICLES

CODE:
TRL OR AV2 Diesel Engines stage 1 Average

FROM: Samaras Z and Zierock KH (1994)

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(1) LandSim was developed for the Environment Agency by Golder Associates (UK) Ltd., the model can be purchased at http://www.landsim.com/

Annex J

Scenario Descriptions

J1 WASTE MANAGEMENT ROUTES

Table 1.1 provides the combined recycling and composting rate assumed for each scenario in each year. *Table 1.3* and *Table 1.4* show the proportion of municipal waste that is landfilled and incinerated for each scenario in each year. *Table 1.2* shows how the combined recycling and composting rate is broken down by material recycled and organic waste composted.

Table 1.1 Proportion of MSW Arisings Recycled and Composted for Each Option in Each Year

	Scenario 1	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*	*Scenario 8*
2002	22%	22%	22%	22%	22%	22%	22%	15%
2003	26%	26%	26%	26%	26%	26%	26%	16%
2004	30%	30%	30%	30%	30%	30%	30%	18%
2005	31%	31%	31%	31%	31%	31%	31%	19%
2006	32%	32%	32%	32%	32%	32%	32%	20%
2007	34%	34%	34%	34%	34%	34%	34%	22%
2008	35%	35%	35%	35%	35%	35%	35%	23%
2009	36%	36%	36%	36%	36%	36%	36%	24%
2010	37%	37%	37%	37%	37%	37%	38%	26%
2011	37%	37%	37%	37%	37%	37%	40%	27%
2012	38%	38%	38%	38%	38%	38%	41%	28%
2013	39%	39%	39%	39%	39%	39%	43%	30%
2014	39%	39%	39%	39%	39%	39%	44%	31%
2015	40%	40%	40%	39%	40%	40%	44%	32%
2016	41%	41%	41%	39%	41%	41%	45%	34%
2017	42%	42%	42%	39%	42%	41%	45%	35%
2018	42%	42%	42%	39%	42%	42%	46%	36%
2019	43%	43%	43%	39%	43%	43%	47%	37%
2020	44%	44%	44%	39%	44%	44%	47%	39%
2021	44%	44%	44%	39%	44%	44%	48%	40%
2022	45%	45%	45%	39%	45%	45%	48%	41%
2023	46%	46%	46%	39%	46%	46%	49%	43%
2024	47%	47%	47%	39%	47%	46%	49%	44%
2025	47%	47%	47%	39%	47%	47%	50%	45%

Table 1.2 Breakdown of MSW Recycling and Composting by Material for Each Scenario

	Composting	**Recycling**						
	Putrescible	Paper	Glass	Ferrous Metal	Textiles	Non Ferrous Metal	Plastics	Others
Scenario 1	25%	34%	15%	10%	1%	1%	0%	12%
Scenario 2	31%	40%	12%	8%	1%	1%	0%	8%
Scenario 3	20%	50%	12%	8%	1%	1%	1%	8%
Scenario 4	25%	34%	15%	10%	1%	1%	0%	12%
Scenario 5	16%	26%	17%	12%	1%	3%	13%	13%
Scenario 6	25%	34%	15%	10%	1%	1%	0%	12%
Scenario 7	25%	34%	15%	10%	1%	1%	0%	12%
Scenario 8	25%	34%	15%	10%	1%	1%	0%	12%

Table 1.3 Proportion of MSW Arisings Incinerated for Each Option in Each Year

	Scenario 1	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*	*Scenario 8*
2002	14%	14%	14%	14%	14%	14%	14%	10%
2003	16%	16%	16%	16%	16%	16%	16%	11%
2004	18%	18%	18%	18%	18%	18%	18%	12%
2005	18%	18%	18%	18%	18%	18%	18%	12%
2006	18%	18%	18%	18%	18%	18%	18%	13%
2007	18%	18%	18%	18%	18%	18%	18%	14%
2008	18%	18%	18%	18%	18%	18%	18%	15%
2009	19%	19%	19%	19%	19%	19%	19%	15%
2010	23%	23%	23%	23%	23%	23%	23%	16%
2011	27%	27%	27%	27%	27%	27%	27%	17%
2012	31%	31%	31%	31%	31%	32%	31%	18%
2013	34%	34%	34%	34%	34%	36%	34%	18%
2014	38%	38%	38%	38%	38%	38%	35%	19%
2015	38%	38%	38%	42%	38%	38%	38%	20%
2016	38%	38%	38%	46%	38%	39%	38%	21%
2017	38%	38%	38%	50%	38%	39%	38%	21%
2018	38%	38%	38%	51%	38%	40%	38%	22%
2019	38%	38%	38%	51%	38%	40%	38%	23%
2020	38%	38%	38%	51%	38%	41%	38%	24%
2021	38%	38%	38%	51%	38%	41%	38%	24%
2022	38%	38%	38%	51%	38%	41%	38%	25%
2023	38%	38%	38%	51%	38%	41%	38%	26%
2024	38%	38%	38%	51%	38%	41%	38%	27%
2025	38%	38%	38%	51%	38%	41%	38%	27%

Table 1.4 Proportion of MSW Arisings Landfilled for Each Option in Each Year

	Scenario 1	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*	*Scenario 8*
2002	63%	63%	63%	63%	63%	63%	63%	75%
2003	58%	58%	58%	58%	58%	58%	58%	73%
2004	52%	52%	52%	52%	52%	52%	52%	71%
2005	51%	51%	51%	51%	51%	51%	51%	69%
2006	49%	49%	49%	49%	49%	49%	49%	67%
2007	48%	48%	48%	48%	48%	48%	48%	65%
2008	47%	47%	47%	47%	47%	47%	47%	62%
2009	45%	45%	45%	45%	45%	45%	45%	60%
2010	41%	41%	41%	41%	41%	41%	40%	58%
2011	36%	36%	36%	36%	36%	35%	34%	56%
2012	31%	31%	31%	31%	31%	30%	28%	54%
2013	27%	27%	27%	27%	27%	25%	22%	52%
2014	22%	22%	22%	22%	22%	23%	21%	50%
2015	22%	22%	22%	19%	22%	21%	17%	48%
2016	21%	21%	21%	15%	21%	20%	17%	46%
2017	20%	20%	20%	11%	20%	19%	16%	44%
2018	19%	19%	19%	10%	19%	18%	16%	42%
2019	19%	19%	19%	10%	19%	17%	15%	40%
2020	18%	18%	18%	10%	18%	15%	14%	38%
2021	17%	17%	17%	10%	17%	15%	14%	35%
2022	17%	17%	17%	10%	17%	14%	13%	33%
2023	16%	16%	16%	10%	16%	13%	13%	31%
2024	15%	15%	15%	10%	15%	13%	12%	29%
2025	14%	14%	14%	10%	14%	12%	12%	27%

Figures 1.1 to 1.3 are graphical representations of *Table 1.1, 1.3 and 1.4*. *Figure 1.4* shows how the scenarios perform with regards to the landfill diversion targets.

Figure 1.1 *Percentage of MSW Waste Arisings Recycled and Composted*

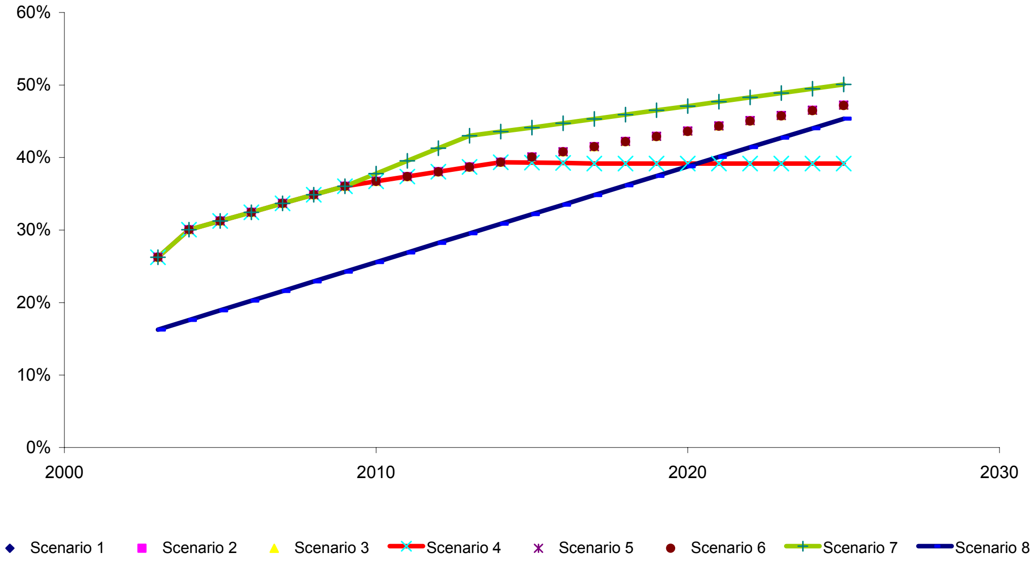

Figure 1.2 *Percentage of MSW Waste Arisings Incinerated*

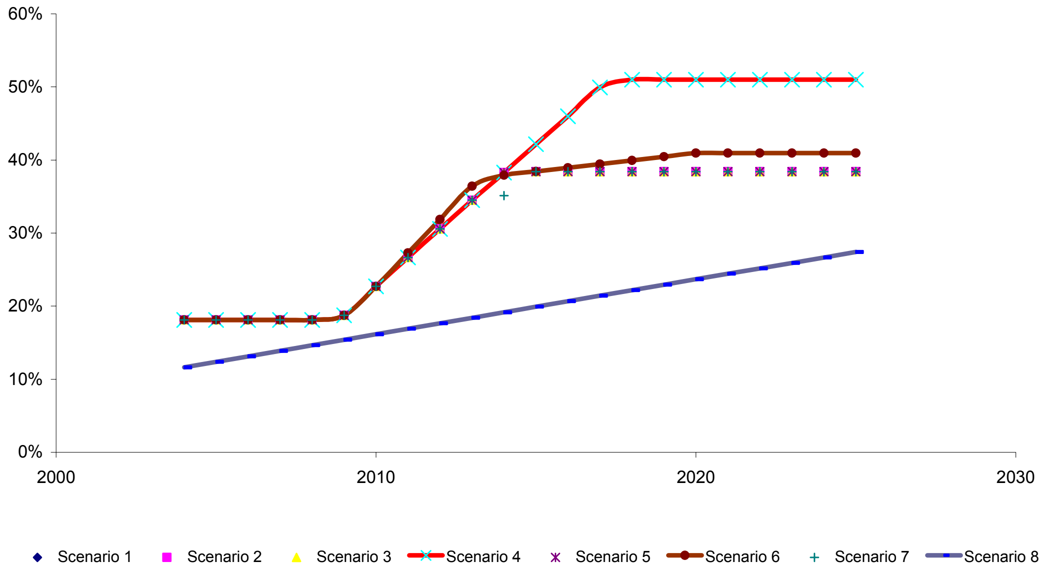

Figure 1.3 Percentage of MSW Waste Arisings Landfilled

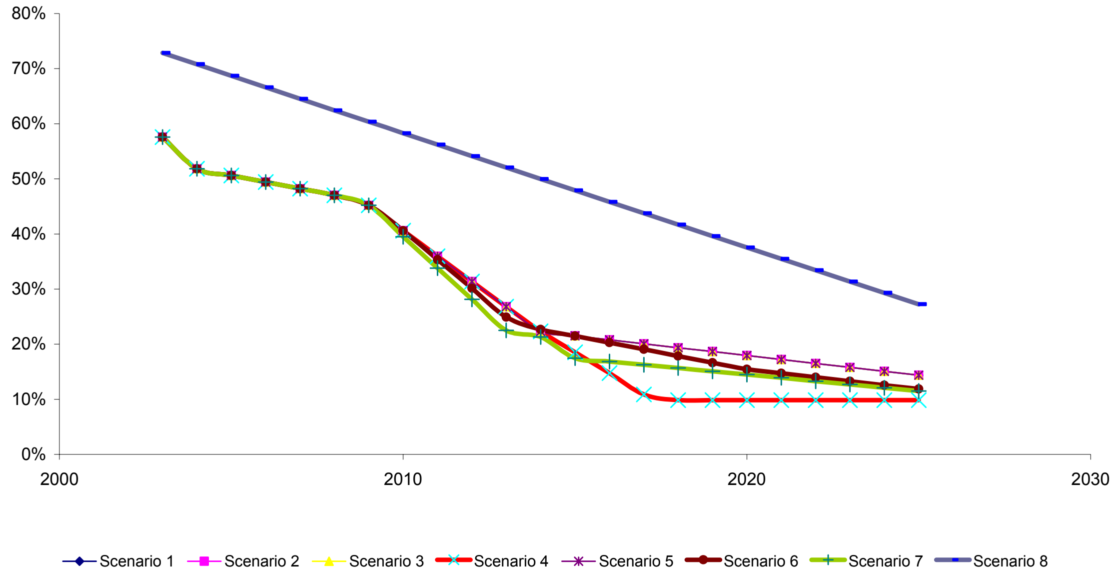

Figure 1.4 Compliance with Landfill Directive Diversion Targets