

**Life Cycle Assessment of Municipal Waste Management Options in Scotland
Waste Summit October 2007**

1.	INTRODUCTION.....	2
2.	LIFE CYCLE IMPACT ASSESSMENT OF MUNICIPAL WASTE MANAGEMENT OPTIONS	2
2.1.	GOAL AND SCOPE.....	2
2.2.	ENVIRONMENTAL IMPACTS	3
2.3.	FUNCTIONAL UNIT.....	3
3.	RESULTS.....	4
3.1.	COMPARISON AGAINST CURRENT MSW MANAGEMENT ARRANGEMENTS IN 2005/06 (THE BASELINE).....	4
3.2.	GLOBAL WARMING POTENTIAL (GWP).....	4
3.3.	NON-RENEWABLE RESOURCE DEPLETION.....	5
4.	SENSITIVITY TESTING	9
4.1.	COLLECTION MILEAGE.	9
4.2.	RESULTS OF SENSITIVITY TESTING	9
APPENDIX 1 ASSUMPTIONS OF SIGNIFICANT EFFECT:.....		11
APPENDIX 2 ASSUMPTIONS OF LESSER EFFECT:		12
APPENDIX 3 PERCENTAGES OF INDIVIDUAL MATERIALS RECYCLED		14
APPENDIX 4. THE SHADOW PRICE OF CARBON.....		15

FIGURES AND TABLES

Table 1. Breakdown of options modelled in WRATE	3
Figure 1. Global Warming Potential	6
Figure 2. Non-Renewable Resource Depletion	7
Figure 3. Detailed Breakdown of Global Warming Potential	8

1. INTRODUCTION

SEPA was asked by the Scottish Government to identify and compare the environmental impacts of four proposed options for the management of municipal waste (MW) in Scotland in the year 2020. The output of this report is designed to inform the formulation of future waste policy by Scottish Government on the management of municipal waste.

The four options modelled (Options 2-5) are based on two broad categories of residual waste management; landfill and energy from waste with different recycling levels (45%, 50% and 70%). The default technology for energy from waste is combined heat and power incineration. The four options are compared to a baseline of existing practice as at 2005/06 (Option 1). Further detail on these options are set out in Table 1.

The environmental impacts of the options have been identified and compared using the results of Life Cycle Assessment (LCA) modelling using the WRATE software. This is a technique that allows the comparison of the environmental impacts of products or services across their entire life cycle. A short guide to life cycle assessment, what it is and what it does is available as a separate document for reference¹.

This report focuses on the environmental impacts of municipal waste management. An analysis of the financial costs and practicability of reaching the targets for each of the waste management routes contained within each option modelled is beyond the scope of this report. This report is a simplified study which, due to the number of assumptions and uncertainties required to model options for managing wastes arising 12 years in advance (2020) should be treated as an indicative comparison of the likely environmental impacts. The DEFRA Shadow Price of Carbon methodology has been used to place a monetary value on the carbon burden associated with each option. This has been calculated for the single year modelled and a Net Present Value figure estimated for each option over the lifetime of the National Waste Plan. This is set out in Appendix 4.

The conclusions of this report are presented in Section 5 below.

2. LIFE CYCLE IMPACT ASSESSMENT OF MUNICIPAL WASTE MANAGEMENT OPTIONS

2.1. Goal and Scope

The models were restricted to municipal waste (MW) arising within Scotland, and modelled waste management performance in Scotland only. No waste minimisation or home composting was modelled; neither was any recycling that is undertaken by organisations other than local authorities, or organisations collecting on behalf of local authorities, other than that incorporated in the total recycling figures reported by local authorities.

WRATE requires the definition of an electricity generation mix to calculate the offset energy production by energy generated from the waste such as from landfill gas engines or incineration. This represents the mix of fuels used to generate electricity for the year in question for the country under investigation. A number of 'mixes' are preloaded in WRATE, and for this exercise, the preloaded mix for Scotland in 2020 was used.

The total quantity of waste modelled was based on data from the Local Authorities Waste Arisings Survey, 2005/06² and scaled up to 2020 assuming a 1% annual growth rate. With some adjustments required for modelling, this is equivalent to 4,039,293 tonnes of MW per year in 2020.

¹ A Short Guide to Life Cycle Assessment, available upon request from SEPA.

² Local Authority Waste Arisings Survey 2005/06. Available from <http://www.sepa.org.uk/nws/data/lawas.htm>

It is important to note that this is a comparative study and the total waste arisings are less important than the relative performance of the options. So, while it is possible to model the effects of achieving the National Waste Plan target of 0% growth in waste arisings by 2010 this will not have any significant impact on the relative performance of the options. It would simply show smaller impacts due to the reduced quantities of waste managed.

Table 1. Breakdown of options modelled in WRATE

	Option 1 Baseline from 2005/06	Option 2 High Recovery* with landfill	Option 3 High Recovery* with EfW** and landfill	Option 4 Low Recovery* with EfW** and Landfill	Option 5 Medium Recovery* with EfW** and Landfill
Source segregated recycling and composting	23%	70%	70%	45%	50%
Recovery of residual waste including energy recovery and additional recycling and composting	2%	0%	25%	50%	25%
Total municipal waste to landfill	75%	30%	5%	5%	25%

*Recovery – recycling and composting

**EfW – Energy from waste, assumed to be combined heat and power (CHP) with standard incineration technology.

2.2. Environmental Impacts

The assessment was carried out using the Environment Agency's life cycle assessment for waste management tool, WRATE, software version 1.0.1.0.

Six default environmental impacts were available in the software:

- global warming;
- non-renewable resource use;
- acidification;
- eutrophication;
- human toxicity; and
- aquatic eco-toxicity.

The impacts used for the purposes of this report have been restricted to global warming and non-renewable resource use. These are global impacts which will have equal impact across Scotland. The other impacts are more localised in their effects and in the absence of specific locations for the waste management infrastructure the results are not considered meaningful for the consideration of strategic options for Scotland.

A more detailed explanation of environmental impacts is given in section 1 of the Short Guide to Life Cycle Assessment.

2.3. Functional Unit

The functional unit is the municipal waste managed in Scotland in one year, 2020.

3. RESULTS

The environmental impacts used for this report (global warming and non-renewable resource use) are standard indicators used in most life cycle assessments. They are potential impacts, and take no account of any further mitigation measures, and include offsets against standard electricity production and raw material production which may change from the forecasts included in the model depending on international markets and changes in technology.

When considering the results it should be remembered that a positive figure is a potential environmental impact whilst a negative figure represents an offset against a baseline impact. The baseline in this instance is the burdens associated with electricity production in 2020 and current raw material production, so low and negative numbers are desirable. A more detailed explanation of avoided impacts is given in section 1 of the Short Guide to Life Cycle Assessment³.

Global Warming Potential figures (GWP) are reported as carbon dioxide (CO₂) equivalents calculated using the global warming potential 100-year time horizon. The figures for CO₂ equivalence are contained within the model. WRATE has an equivalence for methane, the primary global warming emission from landfill, 23 times that of carbon dioxide. Non-renewable resource depletion results have been converted to show the resource depletion impact of an Average European Inhabitant e.g. how many average Europeans would use those material quantities on an annual basis.

The results are summarised in the graphs shown in figures 1 and 2 below. Due to the uncertainties involved in modelling options 12 years in advance, an error of plus or minus 10% has been assumed and plotted on the charts.

The key points in the comparative analysis are:

3.1. Comparison against current MSW Management arrangements in 2005/06 (the baseline)

For both global warming and non-renewable resource depletion the baseline performs significantly worse than all four options.

There are two predominant reasons for this. First, the very high proportion of waste sent to landfill. Methane from landfilled waste accounts for the GWP burden from this option.

Second, the small avoided impact for non-renewable resource use is accounted for by the relatively low levels of recycling and composting in the baseline

3.2. Global Warming Potential (GWP)

Figure 1 shows the totals for GWP. The immediate and obvious point to note is that the two options (excluding the baseline Option 1) with the greatest reliance on landfill are the worst performing Option 2 (30% landfill) and Option 5 (25% landfill).

Particular points to note are:

(a) Option 2, 70% recycling/composting, 30% residual waste to landfill

While having a significant avoided impact, this option does not perform as well as Option 3, which has the same level of recycling and composting (70%), but where the residual waste is treated via EfW.

³ A Short Guide to Life Cycle Assessment, available upon request from SEPA.

The difference is due to the disposal of the residual waste to landfill in Option 2, rather than EfW as in option 3, and the consequent methane emissions in Option 2. In this case treating the residual waste by EfW is a better option in relation to GWP than disposing of residual waste to landfill. It should be noted that the landfill option in WRATE assumes some methane avoided from either flaring, or where sufficient quantity is available, for energy generation. Even so EfW is still the better option in terms of climate change.

(b) Option 3, 70% recycling/composting with 25% to EfW and 5% to landfill

In terms of global warming potential this is the best option, being significantly better than the Option 4, the option which performs next best in climate change terms.

The primary reason for this is the combination of high recycling/composting, with over 80% of the residual waste remaining after recycling going to thermal treatment. Option 4, while having lower recycling/composting than Option 2, still has greater avoided emissions due to low landfill use. Figure 3 shows the breakdown of the global warming emissions in more detail by showing the emissions from the constituent parts of each scenario. What is obvious from this is that while energy from waste still shows an environmental impact for GWP, it is significantly reduced when compared to the emissions from landfill. The avoided landfill impacts combined with the avoided impacts from recycling/composting account for the better results from options 3 and 4 compared with options 2 and 5 which continue to use landfill to a significant extent.

The reason that energy from waste has a direct impact in global warming terms is that a proportion of the 'fuel' or waste is composed of non-renewable materials such as plastics. Materials such as organic waste are considered carbon neutral, but plastics and other non-renewable materials in particular are not carbon neutral and as such create a direct impact. However this is arguably still a better option for such materials which have missed the recycling systems or are of too poor a quality for recycling. The energy in plastics has a resource value whilst plastics disposed of to landfill confer no benefit. A detailed demonstration of the source of the various global warming impacts for each of the options 1-5 is provided in Figure 3.

(c) Finally, it should be noted that the landfill option in WRATE assumes electricity generation from extracted methane. At the current time it is assumed that this would exaggerate the benefits from gas extraction in Scotland as many landfills are too small for economic electricity generation. The reality could therefore be assumed that disposing of waste to landfill has higher environmental burden, particularly in terms of global warming potential than WRATE currently models. This however is the one option within WRATE where it is not currently possible to modify the process to represent the actual situation in Scottish landfills.

3.3. Non-Renewable Resource Depletion

The impacts for non-renewable resource depletion show a very similar pattern to those for global warming. Those options with high recycling combined with energy recovery are the best performing, whilst those with more than a very small percentage of landfill are the worst performing.

Figure 1 Total Global Warming Potential

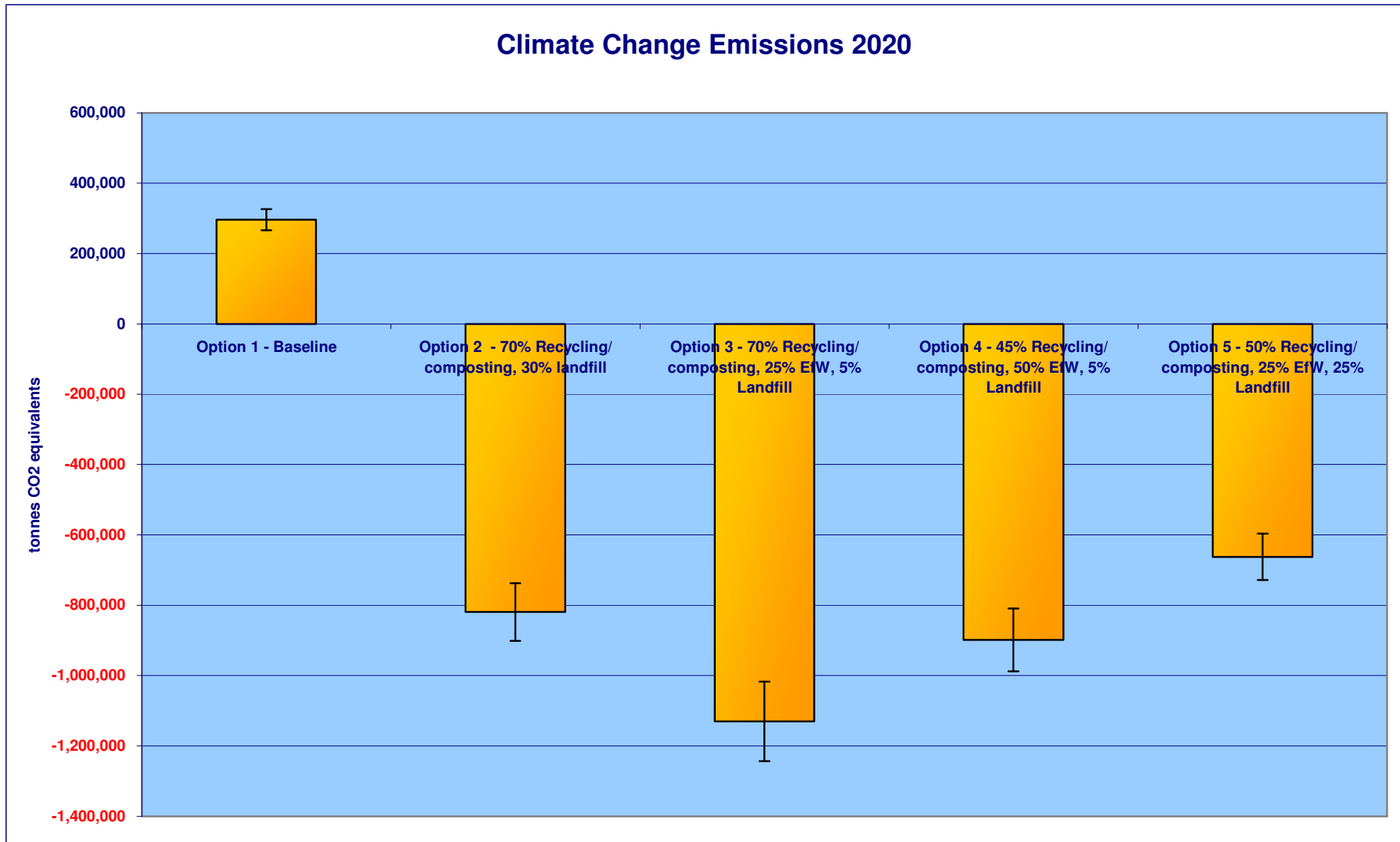


Figure 2. Non-Renewable Resource Depletion

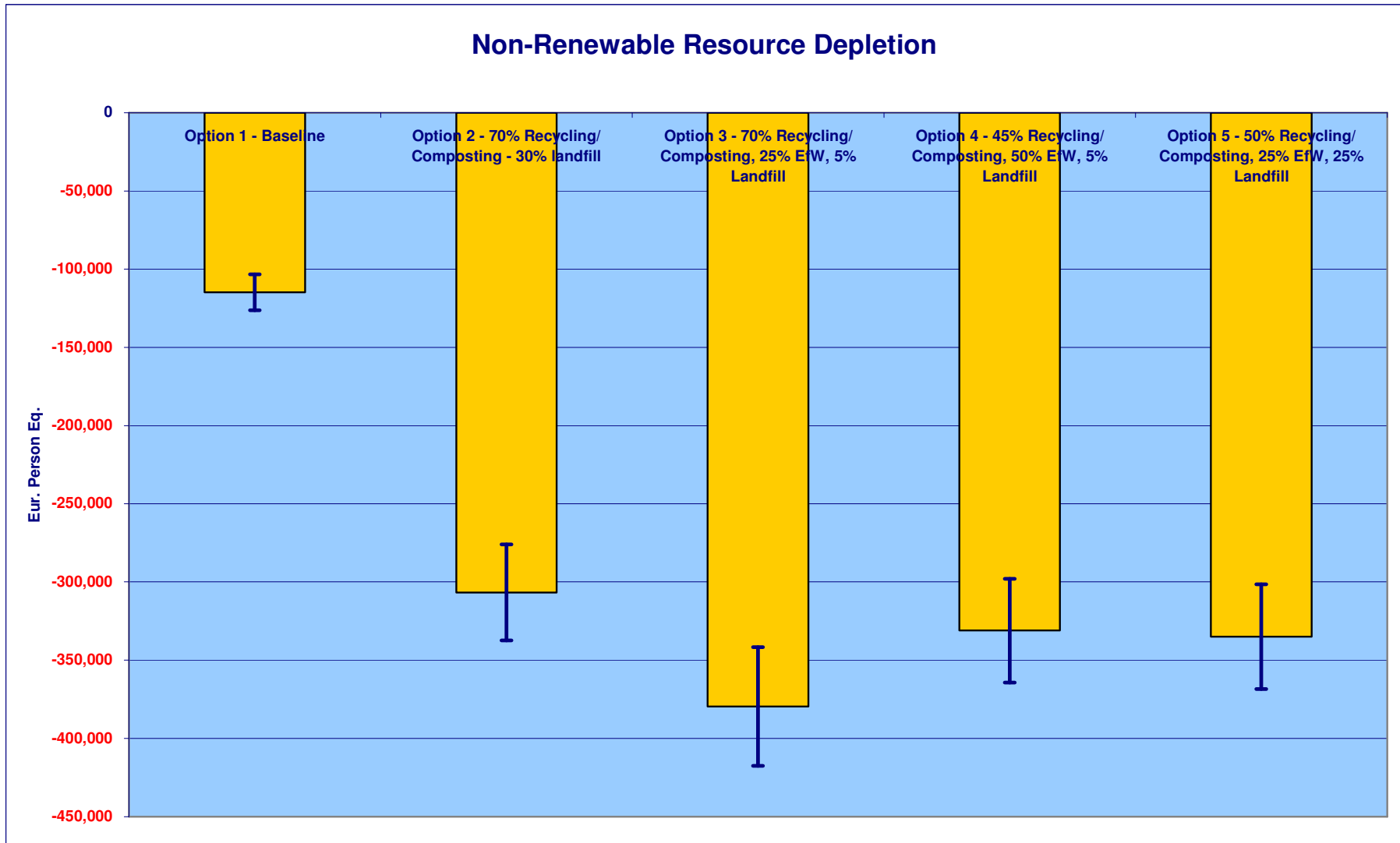
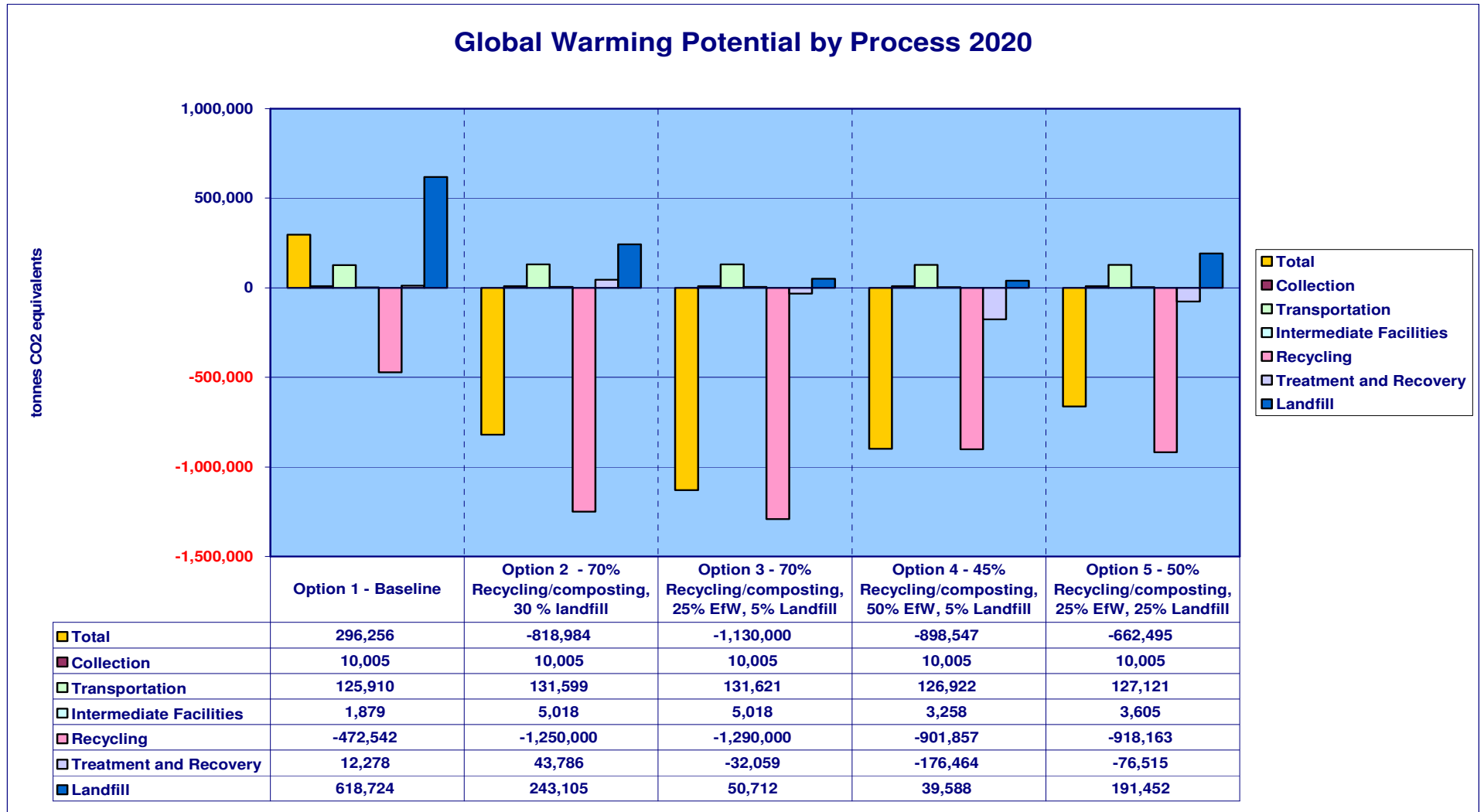


Figure 3. Detailed Breakdown of Global Warming Potential



4. SENSITIVITY TESTING

4.1. Collection Mileage.

Vehicle mileage associated with waste collection has the potential to have a significant effect on results. Accordingly this was varied in order to test the robustness of the assumptions used (A full list of assumptions is available in Appendix 1).

Increased source segregated recycling will inevitably mean increased collection mileage. At the current time there are no reliable estimates of exactly how much increased mileage this would result in. The initial profile of options used the same mileage assumptions for the current (baseline) level of recycling and composting. Therefore to ascertain the effect of an increase in transport on the overall results the mileages have been varied by plus 25%, 50% and 100%.

These tests were carried out on Option 3 (70% recycling/composting with 25% energy from waste and 5% landfill), and Option 4 (45% recycling and composting with 50% energy from waste and 5% landfill). These options were chosen to represent both high and low segregated collection percentages and thus provide an estimation of the potential effect of mileage which can also be applied to the other 2 options.

4.2. Results of Sensitivity Testing

Increasing the collection mileage by up to 100% does increase the impacts of options 3 and 4, but it does not significantly affect the overall difference in impacts between these options in terms of both global warming and non-renewable resource impacts. The difference is proportionately reduced at 25% and 50% increases in mileages. The reason for the reduced impacts is simply that increased mileage means burning more fossil fuels, depleting a non-renewable resource, and emitting carbon.

It is a common assumption that mileage will have a major role on the environmental impacts of waste management systems. It is true that when applying LCA to products transportation is generally a major factor. However when applied to waste management systems the potential effects of mileage is generally low. This is simply because the overall potential impacts of the waste itself are massive in comparison to the potential impacts from transport.

5. CONCLUSIONS

- 5.1. Of the profiled options (2 to 5), the two options which combine recycling with energy from waste and minimal landfill (options 3 and 4) are the best environmental options for both global warming potential and non-renewable resource depletion. It must however be noted that LCA only provides data on potential environmental performance and there are other factors that have to be taken into account when making the final decision on waste management systems.
- 5.2. The treatment of residual waste via Energy from Waste (assuming combined heat and power) clearly improves the performance of the options when compared to landfill; however it is the combination of energy from waste with high levels of segregated recycling/composting that accounts for the majority of the avoided impacts.
- 5.3. The 70% recycling with energy from waste therefore performs best against both indicators in purely environmental terms. An analysis of the financial costs and practicability of reaching this target is beyond the scope of this report.
- 5.4. According to this modelling, the increase in the collection mileage to facilitate additional recycling collection does not have a significant effect on the relative performance of the different options. However, it should be noted that this modelling was done without reference to actual logistic data, and in the absence of an informed assessment of the implications of additional recycling collection on overall vehicle mileage. Collection mileage still carries a significant environmental burden and this should be borne in mind when designing collection systems.

6. Further Work by SEPA

- 6.1. Further LCA work will be required as waste management options are developed. SEPA will discuss this further with the Scottish Government and the Convention of Scottish Local Authorities (CoSLA), before deciding what LCA work should be done at a regional or local authority level within Scotland.
- 6.2. SEPA will discuss further with the Scottish Government and CoSLA how an accurate and up to date analysis of the composition of MW in Scotland can be taken forward, to underpin a more accurate assessment of the environmental performance of future local authority recycling developments.

Appendix 1 Assumptions of Significant Effect:

Municipal Waste Growth Rate

The annual growth rate of MW up to 2020 will be 1%.

Logistics

In the absence of specific mileage data assumptions had to be made on the collections mileages from transfer stations. These were 75km for transport from bring sites to transfer stations, and 120 km for kerbside collection rounds. As the purpose of the study was a comparison of different waste management systems the accuracy of these figures is not of great significance for the final results. In addition sensitivity analysis of the mileage figures establishes the impact of these assumptions.

Currently there are a wide range of collection systems used to collect segregated recyclates and organics at the kerbside. For simplicity a single system has been used, a standard kerbside box for recyclates, a 240 litre wheeled bin for organics, and a 240 litre wheeled bin for residual waste.

All options require a mixture of green waste and food waste collection to achieve the required quantity of material for composting. A consequence of this is the requirement for in-vessel composting in order to comply with the Animal By Products (Scotland) Regulations 2003.

Technologies

The standard energy from waste technology is the Sheffield combined heat and power incineration plant.

Appendix 2 Assumptions of lesser effect:

Numbers are the WRATE reference numbers found in the drop down lists in WRATE
Collection
All dry recyclate collection assumed to be using kerbside box with lid (12018)
Green waste collection assumed to be using 240 litre wheeled bin (12240)
Food waste collection assumes collection via 150 litre bin
Residual waste and mixed waste collected in 240 litre wheeled bins (12240)
Glass and plastics assumed to be collected by a steel, plastic lined bring bank (12096)
Paper and can bring recycling uses the large bring bank (for cans and paper) (12101)
Textiles collected by textile bank (12100)
Wood, scrap metal and rubble assumed to be using open 19.1m ³ skips (12021)
Logistics
Standard refuse collection vehicle for residual waste, mixed waste and organic collections is the 6 x 4 - ULS Diesel (12278)
Standard vehicle for bring banks is the split body RCV (12103)
Standard vehicle for large skip collections is the roll-on, roll-off vehicle (12279)
Collection vehicle mileage data is that provided by local authorities. No adjustment is made for increased kerbside collection.
All vehicles assume the default split between rural/urban and motorway driving according to the collection type.
All kerbside collected dry recyclate is assumed to pass through a transfer facility or simple MRF prior to onward transportation
Onward transportation for dry recyclate is the default distance which varies according to the material.
Recycling
The following materials are recycled through the model: glass, paper, plastic film and dense plastic, ferrous and non-ferrous cans, ferrous and non-ferrous scrap, textiles, wood, and rubble.
Recycling routes are assumed to be:
Wood to wood chip recycling
Textiles to textile recycling
Paper and card to paper and card recycling
Plastic film to LLDPE and agricultural film recycling
Dense plastic to mixed dense plastics recycling
Ferrous metals to ferrous metal recycling
Non-ferrous metals to non-ferrous scrap recycling
Rubble to building rubble recycling.

All WEEE and hazardous household wastes are collected for disposal. Where recycling was specified by the local authorities the quantity to be recycled has been removed from the overall MW total (no data available yet to model these).

Composting

Input to composting plant is direct from collection - no transfer phase.

Mixed green and food waste, or food waste only, assumed to be processed by the enclosed Biodegma process.

Mixed green and food waste, or food waste only, use, assumed to be to the PAS 100 standard.

Appendix 3 Percentages of Individual Materials Recycled

Segregated Recycling/Composting Collections		70%	45%
Paper and Card			
	Newspaper	89%	64%
	Magazines	89%	73%
	Recyclable Paper	86%	58%
	Other Paper	47%	30%
	Packaging Card	79%	50%
	Other Card	69%	43%
Plastic Film			
	Bags	83%	14%
	Packaging	85%	2%
	Other Plastic Film	72%	8%
Plastic - Dense			
	Drinks Bottles	88%	55%
	Other Bottles	80%	50%
	Packaging	72%	45%
	Other Dense Plastic	81%	14%
Textiles			
	Unspecified Textiles	90%	63%
Wood			
	Unspecified Wood	96%	53%
Non-Combustibles			
	Bricks/Blocks/Plaster	42%	34%
Glass			
	Packaging	88%	73%
	Non-Packaging	90%	0%
Organics			
	Garden Waste	93%	84%
	Food Waste	88%	49%
Ferrous Metals			
	Food and Drink Cans	88%	68%
	Other	93%	86%
Non-Ferrous Metals			
	Food and Drink Cans	85%	71%
	Other	76%	70%

Appendix 4. The Shadow Price of Carbon

Shadow Price of Carbon for Municipal Waste Management Options

- 1.1 This addendum to the paper produced by SEPA for the Scottish Government entitled 'Life Cycle Assessment of Municipal Waste Management Options' attempts to apply DEFRA's methodology for the valuing greenhouse gas emissions to the results of the Life Cycle Assessment as produced by WRATE.
- 1.2 The methodology for determining this valuation was the Shadow Price of Carbon (SPC) which replaced the Social Cost of Carbon, the methodology previously used to determine a valuation of greenhouse gas emissions for governmental policy purposes.
- 1.3 The SPC methodology as laid out on DEFRA's web pages was followed as closely as possible with the following proviso. The methodology states that the global warming potential figures used to determine carbon dioxide equivalence for non CO₂ greenhouse gases should be those detailed in the IPCC Second Assessment Report (1995). However, in determining global warming potential WRATE (the software used for determining the Life Cycle Impacts of the Waste Management options) uses more up to date global warming potential figures.
- 1.4 In presenting the results, WRATE gives life cycle impacts time averaged over a single year, in this case 2020. In calculating the value of emissions, the impact can only be accurately calculated for this single year rather than the lifespan of the policy. In order to calculate the value of emissions over the years leading up to 2020, the model would be needed to be altered for every year taking into account differences in waste arisings and waste management methods. The value of the emissions for 2020 is shown in Table 1 below for all the models presented in the paper.

Waste Management Model	CO2 eq. (tonnes) (from LCA)	SPC 2020	Cost £M
Baseline	296256	£32.8	£10
70% recovery - landfill	-818984	£32.8	-£27
70% recovery - 25% CHP, 5% Landfill	-1130000	£32.8	-£37
45% Recovery - 50% CHP 5% Landfill	--898547	£32.8	-£29
50% Recovery - 25% EfW 25% Landfill	-662495	£32.8	-£22

Table 1: Cost of emissions using SPC for 2020 only at 2007 prices

- 1.5 An approximate Net Present Value figure for the lifetime of the policy can be derived by simplifying making the following assumptions / simplifications regarding the implementation of the policy:
- 1.6 Waste Arisings are assumed to be 2020 arisings for the life of the policy (2007-2020).
- 1.7 The waste management system for all models continues as for 2007 (baseline) until 2013 when it reverts to the system modelled for 2020.
- 1.8 The mix of the electricity generated (used for calculating emissions offset by the software) remains at the current 2007 mix until 2012, the projected mix for 2013 until 2018 and the projected mix for 2020 thereafter.
- 1.9 Using these simplifications a Net Present Value figure (again determined in line with DEFRA guidance) has been calculated for four of the models over the lifetime of the policy (2007 -2020). The results are presented in Table 2 below. The results normalised against the baseline are shown in table 3.

Waste Management Model	Cost of CO ₂ eq. emissions Net Present Value (2007-2020) £M
Baseline	£104
70% Recovery - 30% Landfill	-£185
70% Recovery - 25% EfW, 5% Landfill	-£246
45% Recovery - 50% EfW, 5% Landfill	-£236
50% Recovery - 25% EfW, 25% Landfill	-£153

Table 2: Cost of CO₂ emissions using Shadow Price of Carbon, NPV (2007-2020)

Waste Management Model	Cost of CO ₂ eq. emissions Net Present Value (2007-2020) £M
70% Recovery - 30% Landfill	-£290
70% Recovery - 25% EfW, 5% Landfill	-£350
45% Recovery - 50% EfW, 5% Landfill	-£340
50% Recovery - 25% EfW, 25% Landfill	-£257

Table 3: Table 2: Cost of CO₂ emissions using Shadow Price of Carbon, NPV (2007-2020) normalised against baseline