CHAPTER 3: ENVIRONMENTAL IMPACTS OF MANAGING RESIDUAL MUNICIPAL SOLID WASTE

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Introduction

This chapter compares the environmental impacts of a range of options for managing residual municipal solid waste (MSW), i.e. the waste that remains after source separation of recyclable fractions. The options are compared to see whether particular types of waste management treatments offer any particular environmental benefits and whether it is possible to discern a hierarchy of environmentally preferred options.

Waste management options modeled

A wide range of options are available for treating the residual component of MSW, ranging from combustion based techniques to biological processes such as anaerobic digestion and composting. There are also systems which combine elements of both, using sorting techniques to recover recyclable materials such as metals, and splitting the waste into an organically based component which can be biologically treated and another fraction - a refuse derived fuel (RDF) which can be combusted. Six examples spanning this range of options were examined.

1. Energy from Waste (EfW) plant exporting electricity.
2. EfW plant exporting heat and power (combined heat and power - CHP).
3. Mechanical Biological Treatment (MBT) plant where recyclable materials such as metals are first separated out and the remaining waste is:
    a. biodried to produce a refuse derived fuel which is burnt in an EfW plant;
    b. sorted into an organic component which is anaerobically digested and a fraction which is burnt in an EfW plant;
    c. sorted into an organic component which is composted and a fraction which is burnt in an EfW plant.

For comparison, the option at the bottom of the waste hierarchy, landfill, was also examined. The characteristics of the plant were chosen to be typical of what can be achieved today with modern plant. A description of the plant and key characteristics are given in Table 1. While the list of examples examined is not exhaustive, it covers the main types of treatment options in use across IEA countries.

Table 1: Characteristics of waste treatment options

Scenario	Abbreviation	Details
Energy from Waste - electricity production	EfW	Facility has an inclined reverse-acting grate capable of burning a broad range of waste calorific values without the need for any auxiliary fuel. Dry urea is injected into the furnace for NOx abatement. Bottom ash is sent for recycling. *Energy recovery: electrical generating efficiency (based on electricity exported and NCV of waste) 23.4%.* *Metal recovery: 80% of ferrous metals and 30% of non-ferrous metals in waste.* *Landfill: for every 1,000 t of waste treated, 26 t of fly ash and flue gas treatment residues are landfilled.*
Energy from Waste - CHP	EfW - CHP	As EfW plant except for energy recovery *Energy recovery: electrical generating efficiency (based on electricity exported and NCV of waste) 21%* *heat efficiency (based on heat exported and NCV of waste) 22%.*
MBT – bio-drying	MBT – bio-drying	Initially, materials are screened and separated. Metals are recovered for recycling, rejects are disposed of to landfill and the remainder of the material is dried to produce RDF. The RDF is then combusted in an EfW plant. *Metals recovery: 82% of ferrous metals and 86% of non-ferrous metals in waste.* *Landfill: for every 1,000 t of waste treated, 164 t of waste are rejected by the MBT process and landfilled and 15 t of fly ash and flue gas treatment residues are landfilled.*
MBT - anaerobic digestion	MBT - AD	Incoming waste is divided into separate substance flows by a number of screening and separating procedures. Subsequent separation of light-density material and medium solids produces a substance suitable for anaerobic digestion. After the AD and oxidation process, the suspension is separated into solid and liquid matter. The liquid is forwarded to the mixer; the solids will first be dried, then landfilled. The initial separation process also produces an RDF, which is combusted in an EfW plant. *Metals recovery: 82% of ferrous metals and 86% of non-ferrous metals in waste.*
MBT - in vessel composting	MBT - IVC	Incoming waste is shredded and then sieved into three fractions. The ‘fines’ fraction is composted in a closed hall for six weeks, and the stabilite produced is then landfilled. The intermediate fraction produced is separated into materials for recycling and RDF. The oversize fraction is fed back into stabilite for disposal to landfill and some into the bunker for re-shredding. The RDF is combusted in an EfW plant. *Metals recovery: 82% of ferrous metals and 86% of non-ferrous metals in waste.* *Landfill: for every 1000 t of waste treated, 13 t of waste are rejected by the MBT process and landfilled, 662 t of stabilite from the AD process are landfilled, and 1 t of fly ash and flue gas treatment residues are landfilled.*
Landfill	-	The landfill has a clay/HDPE composite liner and landfill gas is recovered and used in a gas engine to generate electricity wherever possible; when this is not possible it is flared. Biological oxidation of methane in the cap is assumed to be 10%. Landfill gas emissions are considered over a 150-year period. Over the lifetime of the landfill, about 50% of the methane is recovered and combusted.

Assessing environmental impacts

The environmental impacts of the different waste management options were assessed using the WRATE software tool. WRATE (Waste and Resources Assessment Tool for the Environment) is an integrated waste management life cycle analysis tool developed for the Environment Agency in the UK[1]. It was developed in conjunction with ISO standards (ISO 14041) on Life Cycle Assessment, and both the data on waste management processes contained in the tool and the tool itself have been peer reviewed. It calculates the potential impacts of all stages in the collection, management and processing of municipal waste. The calculation takes account of the infrastructure and its operation, as well as any benefits associated with materials recycling and energy recovery. The calculation produces an inventory of emissions to air, soil and water and of the use of abiotic (non-renewable) resources, which can be analysed within the tool using a variety of impact assessment methodologies. These methodologies characterise the scenario studied in terms of impact categories, such as global warming, acidification potential, eutrophication, abiotic resource use etc. The tool does not evaluate some of the very local, site-specific impacts which can be associated with waste management options, such as noise and odour.

As the aim is to compare treatment options rather than estimate the impacts associated with managing waste, elements which are common to each treatment route - the collection of waste, management of recyclables collected at the kerbside and transport of the waste to a transfer station - were not included in the modelling. Onward transport of the waste, transport of all recyclables and other products from the waste management process, such as RDF and compost, was included as was transport and final disposal of all rejects and waste products. Assumptions about transport distances are shown in Table 2.

The waste composition which was assumed for the modelling (shown in Table 3) was derived by looking at waste compositions reported for a number of IEA countries, and is intended to be representative of the residual waste which would be left after separate, kerbside collection of recyclables. Table 4 shows assumptions made about the electricity mix. Two aspects to the electricity mix are defined, the generating technologies which make up the average electricity mix - this is used to calculate the environmental impacts associated with electricity used, e.g. to operate equipment at MBT plant, and the ‘marginal mix’ - the type of generation which is displaced or avoided when electricity is produced by the waste management option. As discussed below, the benefits of avoiding conventional electricity generation are quite significant in determining the overall environmental benefits of the waste management options, and the modelling thus also considered the environmental impacts of the options under a variety of marginal mixes.

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[1] http://www.environment-agency.gov.uk/research/commercial/102922.aspx

Table 2: Transport distances assumed for modelling

Material	Transport stage	km
MSW	Transfer station to first treatment point (EfW plant, MBT plant, landfill)	80
RDF	MBT to EFW	100
Stabilite	MBT to landfill	100
Recylables (metal and plastic)	EfW or MBT to recyclables processor	100
'Rejects'	MBT to landfill	100
Bottom ash	EfW to landfill	100
APC residues	EfW to hazardous landfill	200

Table 3: Waste composition assumed for modelling (NCV = 8.8 MJ/kg)

Waste fraction	%
Paper/card	18%
Plastic film	8%
Dense plastics	7%
Textiles	3%
Absorbent hygiene products	5%
Wood	2%
Combustibles	5%
Non-combustibles	3%
Glass	3%
Organic -food waste	25%
Organic -garden waste	8%
Ferrous metals	3%
Non-ferrous metals	1%
Fines (<10mm)	8%
WEEE	1%

Table 4: Energy mix assumed for modelling

Energy source	'Average' generation mix	'Marginal' generation mix			
		'Typical' (coal/gas)	Coal based	Gas based	'Low carbon'
Coal	25.4%	50%	100%		
Oil	2.9%				
Gas CCGT	23.9%	50%		100%	15%
Nuclear	22.5%				
Waste	3.6%				
Hydro	14.6%				85%
Other renewables	7%				

Climate change impacts

Greenhouse gas emissions

Landfilling of solid waste produces just over 2% of the total greenhouse gas (GHG) emissions in Europe and in the US[2], and reducing these emissions is an important contribution that waste management can make to tackling climate change. Figure 1 compares the greenhouse gas emissions associated with treating 100,000 tonnes of waste in each of the treatment options described earlier. As shown in Figure 2, the net overall greenhouse gas balance represents the balance between GHG emissions from the waste management process itself, and emissions savings (shown as negative in the graph) due to the materials which are recycled or energy which is produced. These give emissions savings as they avoid the production of energy and materials elsewhere. A net negative emission indicates that overall the treatment option has led to a net reduction in GHG emissions. This does not necessarily mean that managing waste via this treatment option would lead to a reduction in GHG emissions as, described earlier, common elements of the waste management process, such as collection of the waste, have been excluded,

The main sources of GHG emissions are methane (CH_4) contained in fugitive landfill gas emissions, i.e. landfill gas which is not recovered from the landfill and therefore seeps out into the atmosphere, and carbon dioxide (CO_2) released when materials containing carbon from fossil fuel sources (e.g. plastics) are combusted. CO_2 which is of biogenic origin, e.g. from combustion of food and garden waste and of the paper and card in the waste, is not considered to contribute towards global warming, as it is ‘short cycle’ carbon, i.e. it has been sequestered from the atmosphere relatively recently[3].

The key emissions savings that the waste treatment options offer are from the energy produced, which avoids production of electricity from fossil fuels, and recovery of metals for recycling, which avoids production of metals, particularly for aluminium which is a very energy intensive process.

It is clear from Figure 1 that all of the options considered offer significant benefits over landfill in climate change terms, reducing GHG emissions from managing the waste by at least 35% compared to landfill (i.e. from 19 kt CO_2 eq for landfill to 12.5 kt CO_2 eq for the worst performing option, MBT with in-vessel composting and RDF going to EfW). The benefits are largest for routes where all the waste is combusted in an EfW plant, with the bio-drying route also offering significant benefits. In both of these cases there is an overall reduction in GHG emissions. This is due to the large amount of energy recovered in these cases which leads to a large ‘credit’ due to the CO_2 emissions from conventional electricity generation which are avoided. The amount of energy recovered in each waste management option, which is shown in Table 5, has a strong influence on the climate change impact.

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[2] Based on data from national greenhouse inventories for 2007 for the US and European Community as submitted to the UNFCCC, available from http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/4771.php

[3] This assumption is also made e.g. in the preparation of national estimates of greenhouse gas emissions.

Table 5: Energy recovered from the waste

	Net electricity exported kWh/t*	% of energy content of waste
EfW	574	23%
MBT - bio-drying; RDF to EfW	462	19%
MBT - AD + RDF to EfW	349	14%
MBT - IVC + RDF to EfW	176	7%
Landfill	138	6%

* i.e. electricity generated minus any electricity used on plant

Recovering and using both heat and power from the EfW plant improves the environmental performance of all the waste management options which use EfW, emphasising the importance of considering the use of CHP where it is feasible.

Figure 1: Comparison of climate change impacts (for managing 100 kt of MSW)

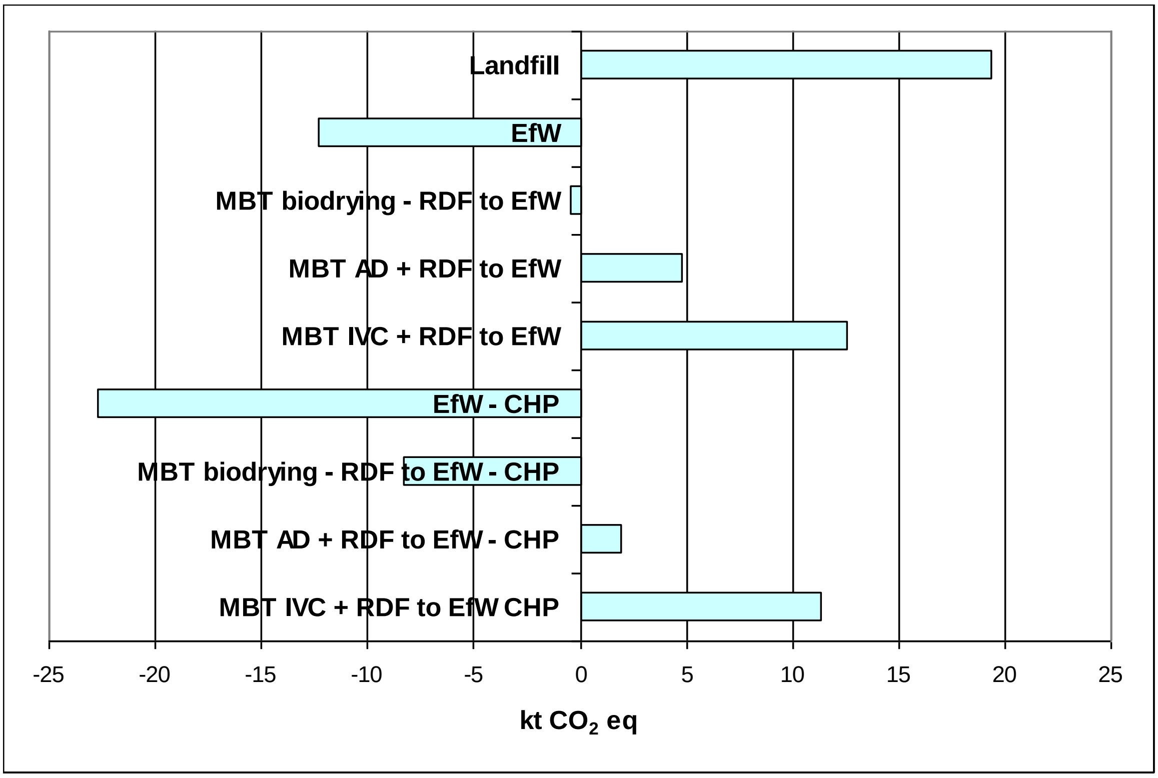
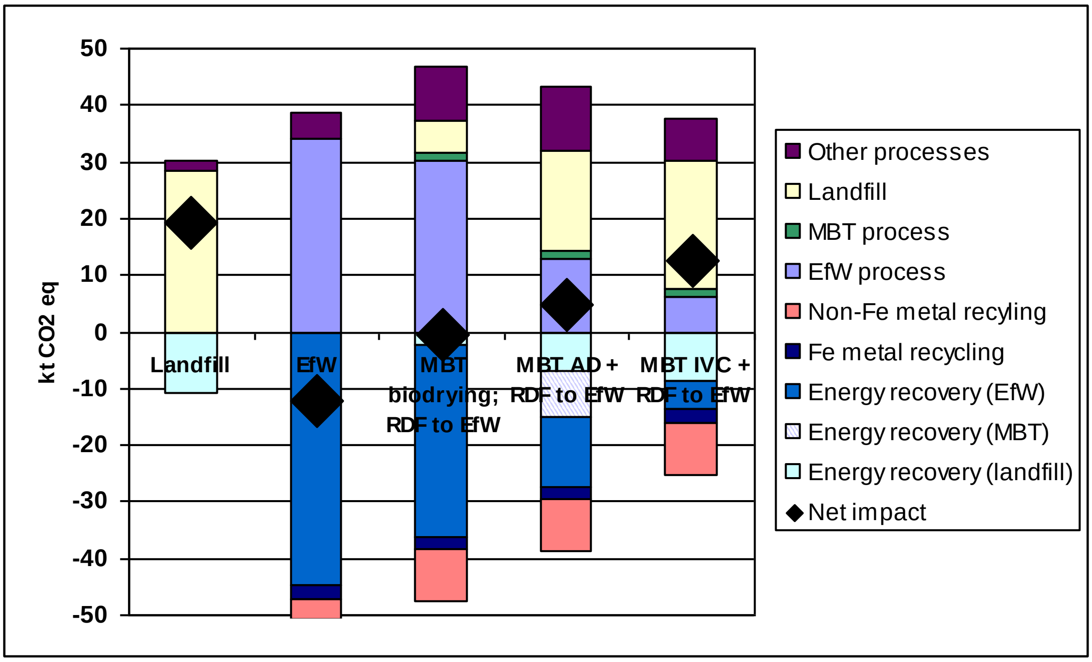


Figure 2: Contribution of processes and material and energy recovery to climate change impacts



Impact of increased material and energy recovery

Given the importance of both energy recovery and materials recovery, the sensitivity of environmental impacts to increased energy recovery and improved materials recovery were examined. The efficiency of the EfW plant was increased to 25%, and that of the EfW - CHP plant to 20% for electricity and 70% for heat. The materials recovery rate for non-ferrous meals in the EfW plant was increased to 50% and in the MBT options, recovery of dense plastics (by e.g. near infra-red (NIR) separation) was implemented (with 50% of dense plastics recovered). It is assumed that all of the materials recovered, go on to substitute for the use of virgin products. Figure 3 shows how increased energy and materials recovery improves the climate change impact of all the waste treatment options, although the relative performance of the options is unaffected, i.e. the EfW plant still offers the lowest climate change impact. In particular, there are substantial benefits from recovering and recycling plastics in the MBT options, and from fully utilising all of the heat which an EfW - CHP plant can produce.

Impact of different electricity mixes

As much of the GHG ‘savings’ for the waste treatment options, particularly for the EfW plant, comes from the energy they produce, the sensitivity of the climate change impact to the type of electricity generation which is replaced was examined. Figure 4 shows the performance of each of the options if coal fired electricity, gas CCGT, a coal/gas mix or a low carbon based electricity source (e.g. predominantly hydro backed up with gas) were the avoided electricity source.

Whenever the electricity generation which is avoided would have come from fossil fuel generation, then all of the waste treatment options have a lower climate change impact than landfill. The relative impacts of the different waste treatment options is unchanged, with the EfW based options having the lowest climate change impact whether generation from coal, gas or a mixture of the two is avoided.

Figure 3: Influence of improved energy and materials recovery on climate change impacts

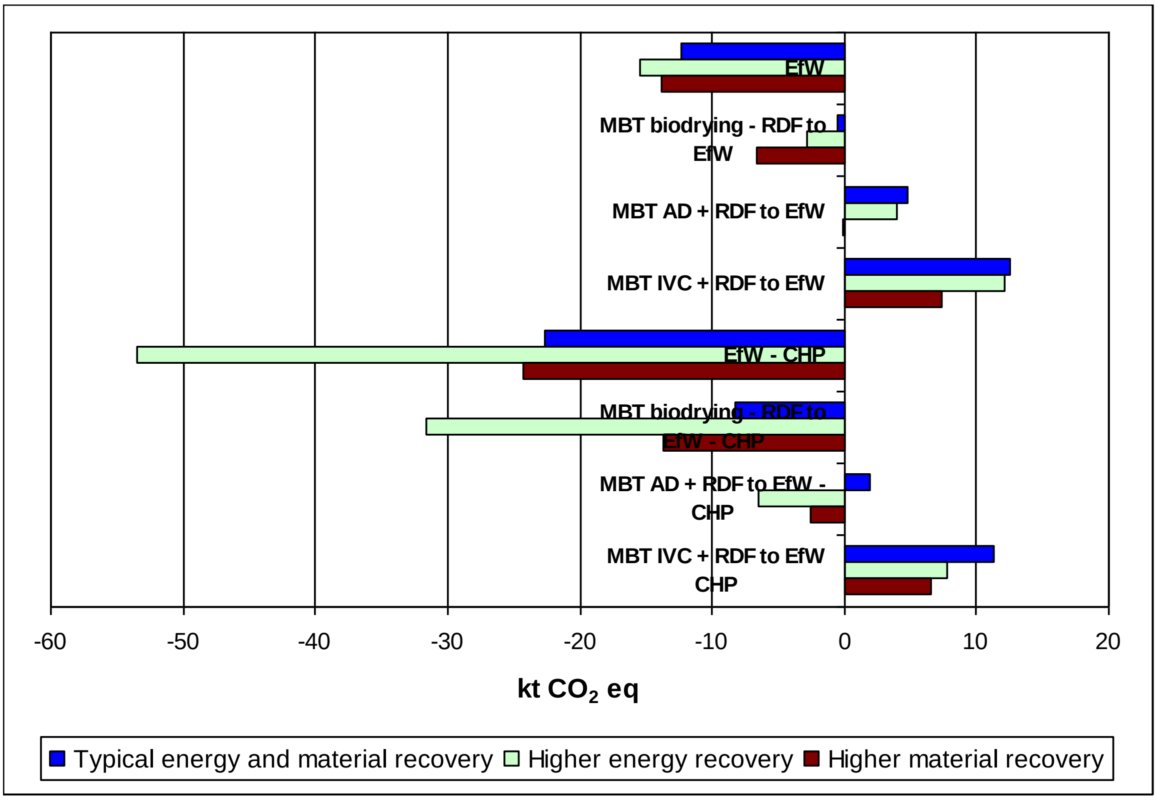
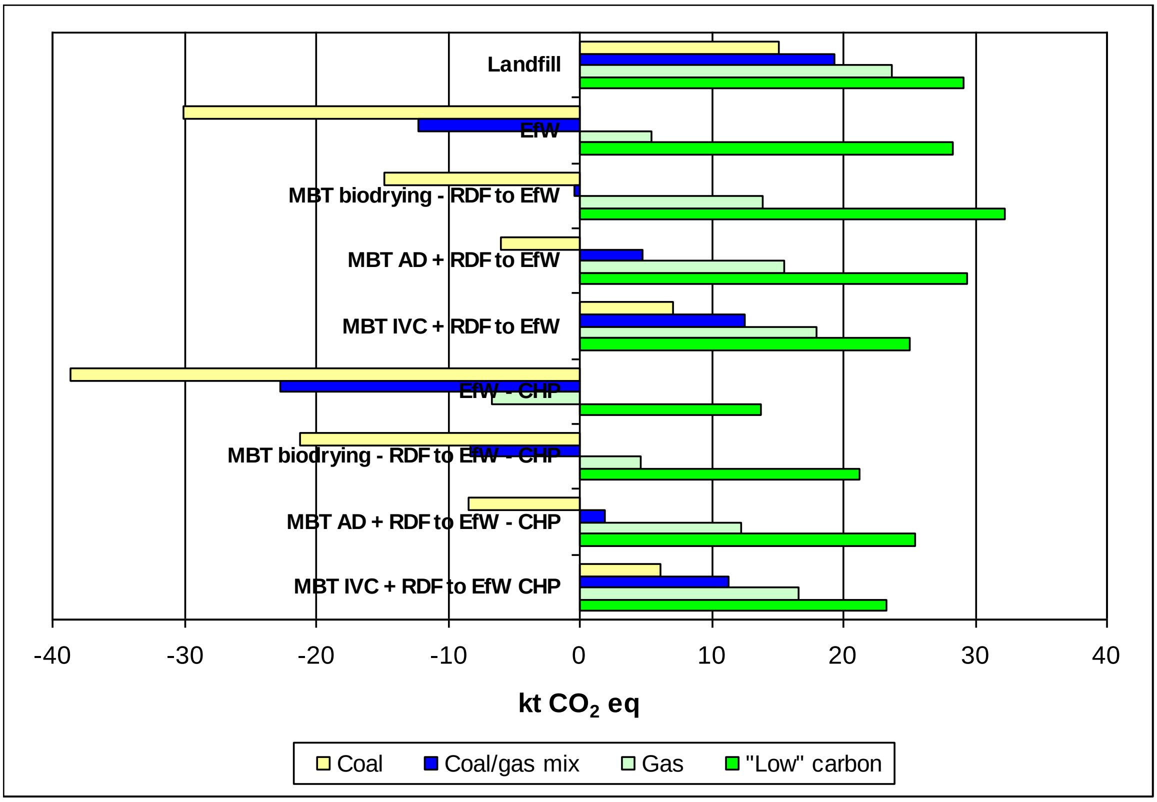


Figure 4: Influence of electricity generation type on climate change impacts



Climate change impacts are obviously lowest where coal fired generation is displaced and highest when a low carbon electricity generation source is displaced. Where a low carbon source is displaced, all the treatment options which recover heat as well as electricity (by burning the residual waste or RDF in an EfW - CHP plant) have a lower climate change impact than landfill. However, where only electricity is produced then not all options perform better than landfill. The EfW and MBT - AD options have a climate change impact broadly equivalent to landfill, the MBT - bio-drying process has a climate change impact about 10% worse, and the MBT - IVC process about 15% less. In countries, where low carbon sources such as hydro or nuclear form the majority of electricity generation, it is thus important to carefully consider the electricity source which may be displaced, if an accurate assessment of climate change and other impacts is to be made.

Other environmental impacts

Waste treatment processes have a number of other potential environmental impacts resulting from emissions of pollutants to air and water, and the use of non-renewable resources

Methodologies have been developed to allow the aggregation of emissions which cause a similar type impact by looking at the relative impact of different emissions and assigning an ‘equivalency factor’ to allow emissions to be summed on the basis of their ‘potency’ in terms of the environmental impact. So in the example above of climate change, the global warming potential of different GHG is used to convert all emissions into equivalent emissions of CO_2, allowing the emissions to be summed and the overall impact assessed. Relatively robust methodologies are available to look at the impact of abiotic (non-renewable) resource depletion, acidification and eutrophication in this way. Methodologies also exist for a number of other impacts (e.g. human toxicity and aquatic toxicity) but these are less robust, and so are not discussed here.

Abiotic resource depletion

In the case of abiotic depletion, i.e. depletion of non-renewable resources, all of the waste management methods examined showed overall savings of resources (Figure 5). This is mainly due to the savings in fossil fuels from the electricity which is produced when managing the waste[4], with smaller savings from use of metal ores and fossil fuels due to metal recycling. Those treatment options where the most energy is recovered, i.e. those based on EfW plant, therefore have the largest benefits in avoided use of resources.

Where the electricity produced would otherwise have come from a ‘low carbon’ mix, which is less heavily based on fossil fuels, then there are less resource savings for all the waste management options, and while options based on EfW still deliver the largest saving, the differences are less pronounced, particularly as the metal recovery, which is achieved at a higher rate in other waste management options, starts to become a more dominant contribution to resource savings.

Improved material recovery rates in the facilities improves the resource savings further - typically by about 60 t antimony eq when plastics recycling is incorporated in the MBT processes and about 9 t antimony eq when recovery of metals is improved at the EfW plant. The ranking of the options is unaffected however, with the EfW options still giving the greatest benefit.

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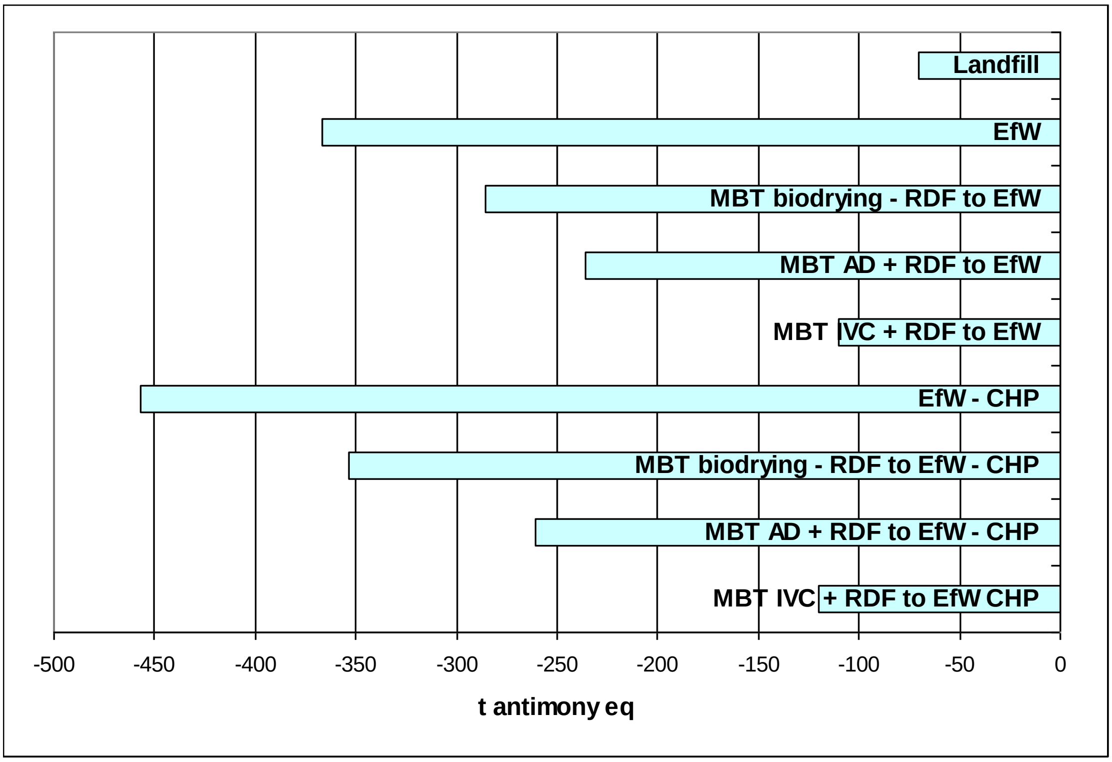
[4] As the common element of collection was excluded from the comparison, this should not be taken to mean that waste management can always reduce the use of resources. Similarly, in a global sense, as the boundaries of the comparison excludes the resources which were consumed to produce the waste, it cannot be concluded that waste management avoids resource depletion.

Figure 5: Comparison of resource depletion (for managing 100 kt of MSW)

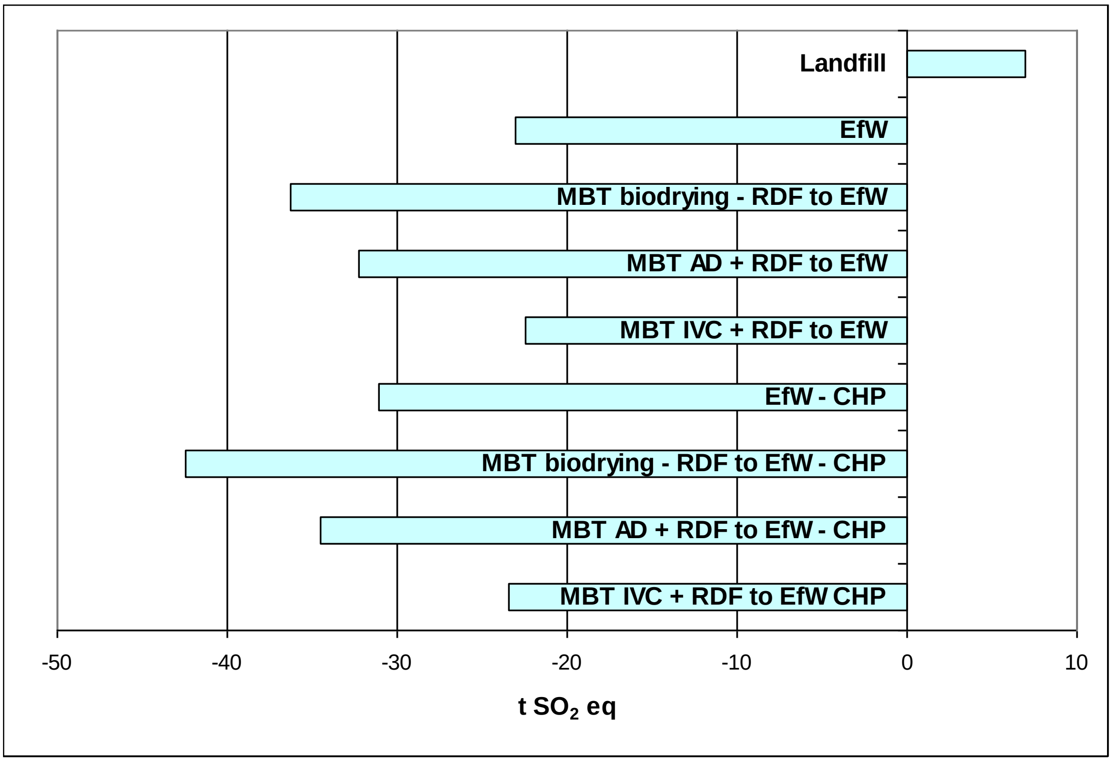


Acidification

In the case of acidification (Figure 6), the net impact is a balance between emissions of acidifying pollutants (such as SO_2 and NO_x) which are avoided due to energy recovered and metal recycling, and the emissions of these pollutants from the waste management plant and from vehicle emissions in transporting the wastes. The largest reduction in acidification options are offered by the MBT - bio-drying system and the MBT - AD based system (due to the large benefit offered by metal recycling); with the EfW plant being broadly equivalent to the MBT based IVC system. Including plastics recovery in the MBT processes more than doubles the reduction in acidifying pollutants as shown in Figure 6, so that even with improved metals recovery at the EfW plant, all the MBT based options have a lower acidifying impact than the EfW plant.

When the electricity offset is produced by gas or a low carbon fuel mix, which have low emissions of the acidifying pollutants, then the pattern becomes even more pronounced, with the EfW option having net overall emissions of acidifying pollutants and performing worse than all of the MBT based options.

Figure 6: Comparison of acidification impacts (for managing 100 kt of MSW)



Eutrophication

Eutrophication impacts (which are evaluated on the basis of emissions of phosphorus, ammonia and nitrogen compounds to air, water and soil) are highest for MBT processes (

Figure 7) which landfill stabilite, due to release of these pollutants from the landfill. The EfW plant has the lowest impact, as emissions from the plant are largely offset by emissions avoided due to the recovery of energy, and to a lesser extent, the recovery of metals.

Improved material and energy recovery do reduce eutrophication impacts, but those for the MBT - AD and MBT - IVC options remain relatively high, as they are dominated by the contribution from landfilling of rejects and stabilite, and the ranking of the options is unaffected. Similarly, changes in the type of electricity mix displaced do not alter the ranking of the treatment options, and even when a low carbon energy mix is displaced, the EfW plant and the MBT - bio-drying options still have a significantly lower impact than the other MBT options and landfill.

Figure 7: Comparison of eutrophication impacts

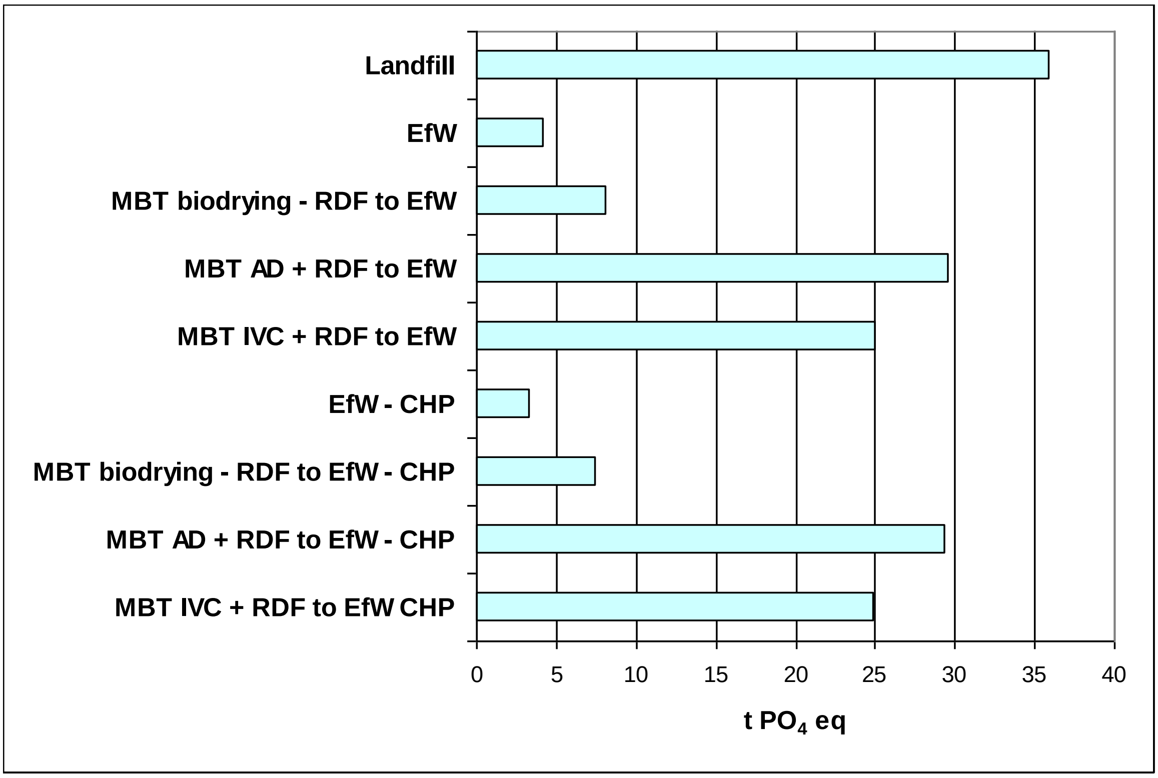
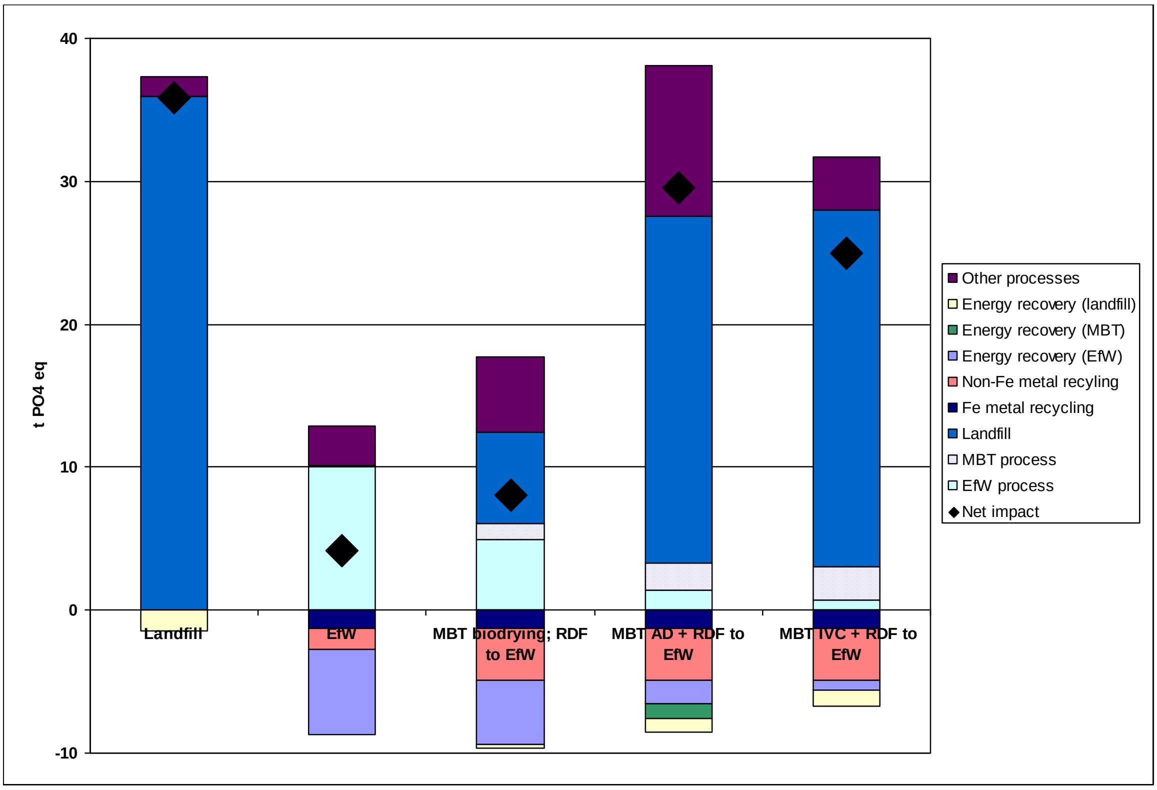


Figure 8: Contribution of processes and materials and energy recovery to eutrophication impacts



Uncertainties in modelling

The modelling aimed to take typical processes and waste compositions, to allow a generic comparison of treatment options. Each treatment option was based on an example of plant which is currently available that could be considered an example of good practice. A sensitivity analysis was used to look at the effect of assumptions, such as electricity mix, that are known to have a significant impact on results to try and ensure that any conclusions drawn are valid over a range of circumstances.

Two areas where there is thought to be a degree of uncertainty, are the modelling of landfill gas emissions from landfilling of stabilite, and the benefits of non-ferrous metal recovery. The former is because it is difficult to estimate the degree of stabilisation which has occurred during the MBT process and to relate this to the generation of landfill gas at a later date. The impact of non-ferrous metals recovery may be overestimated as the only option for modelling this recycling is of aluminium recycling. In reality, there may be a mixture of non-ferrous metals - e.g. in an EfW plant, the non-ferrous metals which are recovered by eddy current separation while predominantly comprised of aluminium, may also contain other metals such as copper and zinc. The benefits of recycling these metals, while still likely to be significant, are however (particularly in the case of climate change impacts) likely to be lower than for aluminium.

The sensitivity of the results to changes in the waste composition, have also not yet been evaluated.

Overall conclusions

All the treatment options considered had, for a typical coal/gas electricity mix, lower environmental impacts than landfill. The ranking of the non-landfill options depends on the environmental impact considered and, for some options, was also affected by the electricity mix that is displaced when energy is recovered from the waste. While no treatment option performed best under all the cases and impacts evaluated, overall, the EfW plant had the best environmental performance, where there is no opportunity to utilise heat, and the EfW - CHP plant where there is an opportunity to supply heat.

Energy recovery and materials recovery of energy intensive materials such as metals and plastics, have significant benefits for all the environmental impacts evaluated, and should be maximised in any waste management option that is implemented. If EfW is part of the option, whether burning MSW directly or RDF, then making the plant a CHP one reduces environmental impacts, particularly if heat utilisation is high.

Climate change impacts are often a key concern and for this impact, an EfW plant (or EfW - CHP plant if heat can be utilised) has the lowest impact, whenever the electricity displaced is based on coal or gas or a mixture of them. However, if the energy recovered is displacing very low carbon electricity, then there is much less differentiation between the options, and the MBT - IVC option performs best, having a slightly lower impact than the EfW plant. An EfW - CHP plant, however, has a lower impact than an MBT - IVC option. For countries with a low carbon electricity mix, it is thus important to consider when assessing options, the structure of electricity supply, and whether one of the low carbon sources, or a marginal, higher carbon source is likely to be displaced.

In the case of depletion of resources, the EfW and EfW - CHP plant have the lowest impact, although the difference between these and other options is less pronounced for a very low carbon electricity mix.

EfW also has the lowest impact when eutrophication is considered, and (together with the MBT - bio-drying option) performs significantly better in this impact area, even when the effects of improved material recovery at MBTs and a low carbon energy mix are evaluated.

The one impact evaluated where EfW does not perform as well is acidification, where emissions of acidifying pollutants from the process are higher than from the MBT treatment options, and the higher metal recovery rates in the MBT processes deliver substantial savings in emissions of acidifying pollutants. The MBT - bio-drying process generally has the lowest acidification impact, although if gas or a low carbon electricity mix is being displaced, then the MBT - IVC process, which involves the lowest amount of combustion of waste, has the lowest impact.