The climate change impacts of burning municipal waste in Scotland

Technical Report

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Report Update

This study was originally published in October 2020. It was reissued in June 2021 with some changes to the methodology and results. These changes are fully documented in Annex 1 of this report. The two most significant changes concern a correction to the original methodology on engine efficiency at landfill facilities, and clarity around the description of the hypothetical biostabilisation scenario (referred to in the original report as Mechanical Biological Treatment scenario). The magnitude and direction of the original results remain largely unchanged.

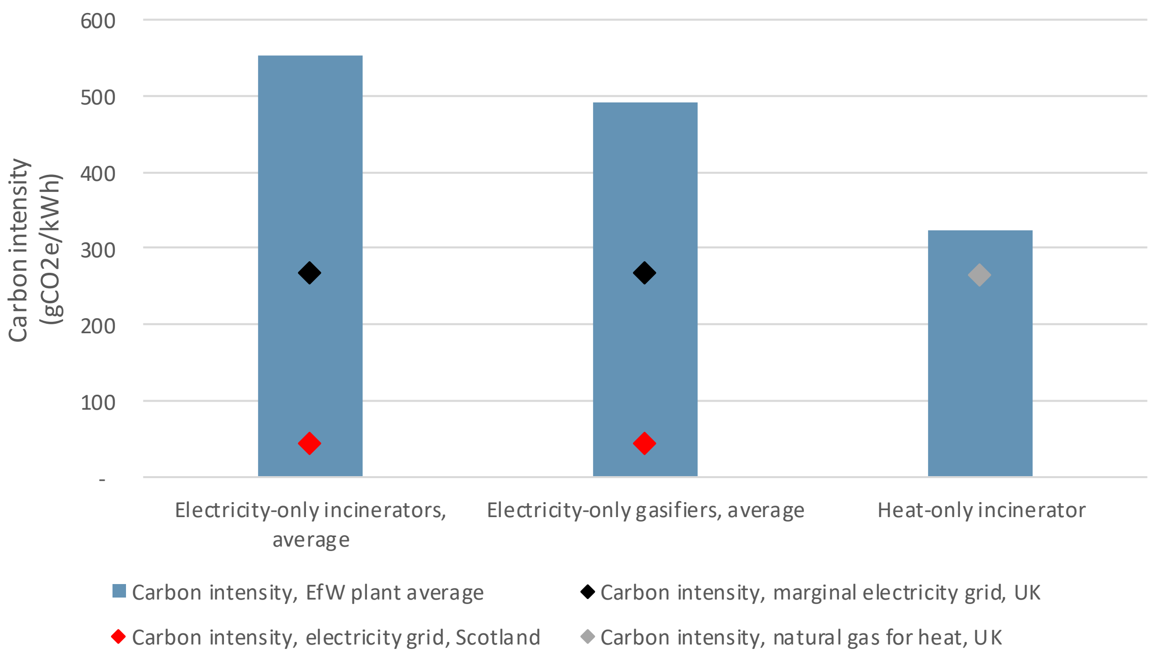
A new sensitivity analysis on the effects of changing the biogenic carbon of waste composition was added. Minor changes have been made regarding methodological updates or clarifications. See Table A1 below for more details.

Executive Summary

This report describes the climate change impacts of burning residual municipal waste in Scotland in 2018. The **carbon intensity** and **greenhouse gas emissions** of the six Energy from Waste (EfW) plants burning residual municipal waste have been calculated. Measuring carbon intensity allows a comparison with other energy generating technologies. Life Cycle Analysis has been used to calculate the net greenhouse gas emissions per tonne of waste input for EfW against landfill as an alternative waste management option. Incineration and landfill are reserved for residual waste once all other, less environmentally damaging options, such as prevention, reuse and recycling, have been exhausted.

Burning residual municipal waste in EfW plants in Scotland in 2018, had an average carbon intensity of 509 gCO_2/kWh. Figure 1 shows the average carbon intensity by EfW plant type. Electricity-only incinerators and gasifiers had an average carbon intensity of 524 gCO_2/kWh. This was nearly twice as high as the carbon intensity of the marginal electricity grid, which was 270 gCO_2/kWh in the UK in 2018[1]. The carbon intensity of the only heat-only incinerator operating in Scotland in 2018 was lower, at 325 gCO_2/kWh, although this was still higher than the carbon intensity for a central or small-scale natural gas plant for heat operating in the UK in 2018 (267 gCO_2/kWh).

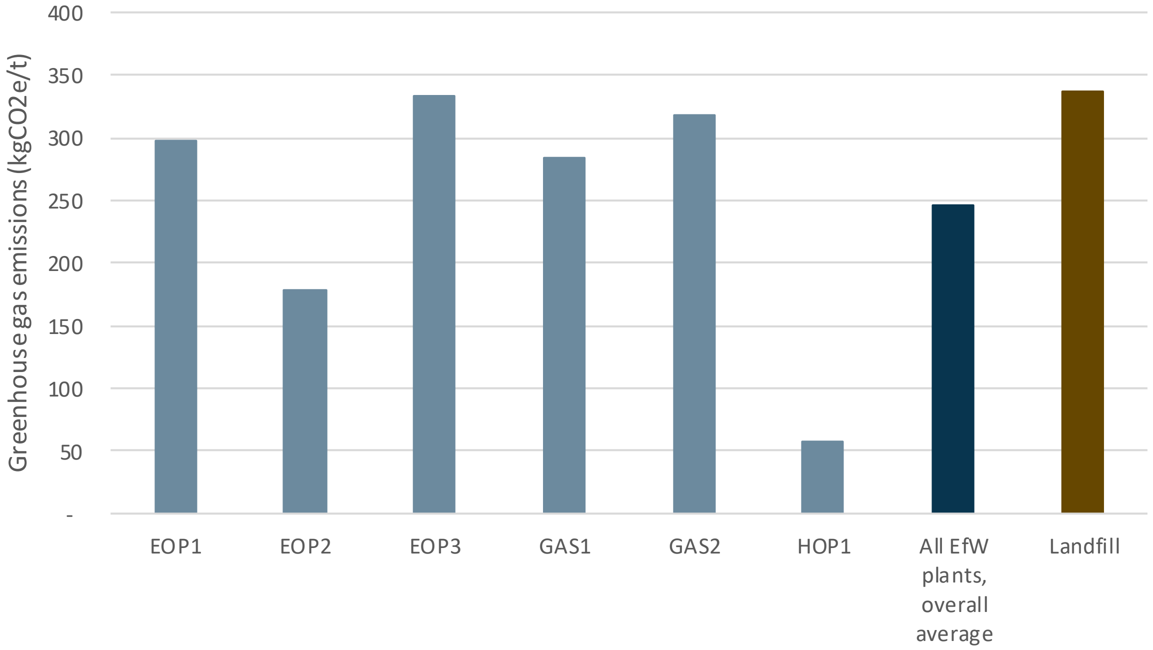
Figure 1. Average carbon intensity of EfW plant types in Scotland in 2018



[1] The average carbon intensity of the Scottish electricity grid average in 2018 was 44 gCO_2e/kWh.

Sending one tonne of residual municipal waste to EfW in Scotland in 2018 emitted 246 kgCO_2e, 27% less than sending the waste to landfill (Figure 2).

Figure 2. Greenhouse gas emissions per tonne from burning and landfilling residual municipal waste in Scotland in 2018



Sensitivity and scenario analyses were conducted to explore the impact of critical variables in the model: the composition of waste and the potential of technological solutions to reduce the climate change impacts from residual waste. The results show that changes in waste composition and technology can considerably alter the climate change impacts of management of residual municipal waste.

Changing the composition of waste

The net emissions of residual municipal waste sent to both EfW and landfill is highly dependent on the composition of that waste. The fossil content of waste is the most significant factor affecting greenhouse gas emissions per tonne of waste burnt in EfW plants. For landfill, the most significant factor is the biogenic content of waste entering landfill. In this sensitivity analysis, the fossil and biogenic content of waste was varied by changing the composition of residual municipal waste. Waste categories with high fossil carbon content (plastic waste) and biogenic carbon content (food and paper waste) were varied.

When fossil carbon increases (e.g. if the proportion of plastic waste in municipal residual waste rises), EfW greenhouse gas emissions rise as more fossil carbon is released into the atmosphere. The net calorific value of waste also rises – burning more carbon releases more energy. EfW and landfill impacts are equal when the proportion of plastic in residual municipal waste is increased from the main model assumptions by 4.6% from 15.0% to 19.6%.

When biogenic carbon decreases (e.g. if the proportion of food and paper waste in municipal residual waste falls), landfill greenhouse gas emissions fall. Assuming that all fossil carbon is sequestered, the removal of biogenic carbon reduces the amount of methane which eventually escapes from landfill as a greenhouse gas. Landfill and EfW impacts are equal when the proportion of food and paper waste in residual municipal waste falls from the main model assumptions by 10.4% from 43.1% to 32.7%.

Potential of technological solutions

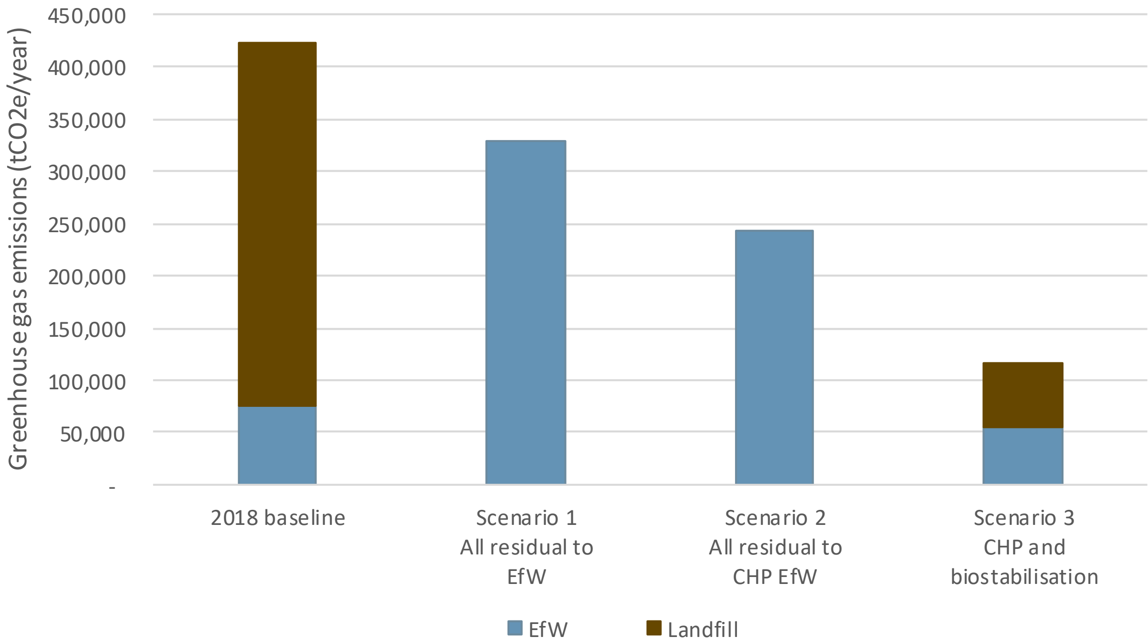
Converting electricity-only EfW plants to Combined Heat and Power (CHP) systems reduces their carbon intensity by 30% but not below the carbon intensity of alternative energy sources.

The Scottish biodegradable municipal waste (BMW) ban is due to come into force in 2025. The aim of this ban it to reduce greenhouse gas emissions from biodegradable material sent to landfill. This study includes an assessment of the greenhouse gas emissions from meeting the ban in three different ways.

Figure 3 shows the estimated impacts of these scenarios, which are:

- Scenario 1: incinerate all waste in facilities which operate at 2018 efficiency levels;
- Scenario 2: incinerate all waste in facilities which operate as CHPs; or
- Scenario 3: upgrade all existing incinerators to CHPs, and pre-treat waste sent to landfill using biostabilisation technology (the tonnage split between incineration and landfill remains at 2018 levels).

Figure 3. The estimated annual greenhouse gas emissions of three scenarios for meeting the BMW ban by managing residual municipal waste in 2018



In 2018, the estimated greenhouse gas emissions from managing residual municipal waste in Scotland were 422,892 tCO_2e (2018 baseline scenario in Figure 3). If all waste was sent to electricity-only incineration plants (Scenario 1), the emissions would be lowered by 22% to 328,865 tCO_2e. If all waste was sent to CHP plants instead (Scenario 2), the emissions would fall further (42% below the

2018 baseline) to 243,573 tCO_2e. If incinerators were upgraded to CHPs and biostabilisation[2] pre-treatment added to landfill (Scenario 3), further emission reductions are possible. The annual greenhouse gas emissions from managing residual waste could be reduced by 72% to 116,926 tCO_2e.

The estimated greenhouse gas emissions from biostabilisation in this study are in line with estimates from such plants operating in Europe[3]. The biostabilisation scenario in this study is illustrative only and further, more detailed research is required to understand the environmental impacts of this scenario in a Scottish context more fully. The study notes that practical, legal and financial barriers to investing in this technology currently exist in Scotland. This scenario is included here as recognition that there are other technological choices for residual waste that have been shown to be a lower carbon option for residual waste disposal. On that basis, such a technological solution has been included and could merit further study on how lower-carbon treatment of residual waste can be pursued.

Conclusions

This study considers the climate change impacts of burning residual municipal waste and compares this to alternative energy generating and waste management options.

The carbon intensity of EfW plants operating in Scotland in 2018 was higher than alternative energy sources. Electricity-only plants emitted nearly twice as many greenhouse gas emissions for each unit of power generated compared to the average of energy technologies supplying the marginal electricity grid in the UK in 2018. Converting these plants to combined heat and power systems would reduce their carbon intensity but not to the level of the UK grid. As a result, EfW can no longer be considered a source of low carbon energy within a UK and Scottish context.

Sending one tonne of waste to EfW emitted 246 $kgCO_2e/t$ on average, which is 27% lower than the emissions from sending the same waste to landfill in Scotland in 2018. The emissions from both EfW and landfill are highly dependent on the composition of waste, which is variable and changing over time. If the fossil carbon in waste increases, EfW emissions rise. If the biogenic carbon in waste increases, landfill impacts rise.

Three scenarios for meeting the BWM ban to landfill indicate that the ban will reduce Scotland's greenhouse gas emissions from waste compared to 2018 levels. The technologies which could be deployed to meet this ban offer different levels of carbon savings. The large potential savings from biostabilisation indicate this option warrants further consideration to explore the practical, legal and financial barriers to be overcome.

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[2]. Biostabilisation as described in this report, refers to a specific type of technology where waste is pre-treated before landfill to reduces its biodegradable content, in accordance with the respiratory test criteria described in the section 4.2.b.i of the Waste (Scotland) Regulations 2012. Biostabilisation is a proven technology with plants operating across Europe, although there are no such plants in Scotland or the rest of the UK.

[3] For example, J. de Araújo Morais et al. (2008) Mass balance to assess the efficiency of a mechanical–biological treatment, Waste Management, Volume 28, Issue 10 found that biochemical methane potential of residual municipal waste was reduced by over 80% after treatment.

1 Introduction

This technical report is part of a study which calculated the climate change impacts of burning municipal waste in Energy from Waste (EfW) plants in Scotland in 2018. This report explains the methodology and describes the results, including the sensitivity analysis, in detail. A summary report is also available on the Zero Waste Scotland website.

There were six EfW plants which burn municipal solid waste (MSW) in Scotland in 2018:

- three electricity-only plants in Dunbar, Dundee and Edinburgh;
- two gasifiers in Glasgow and West Lothian; and
- one heat-only plant on the Shetland Isles.

Most of these plants have only recently started operating and more are expected to be built ahead of the 2025 landfill ban on biodegradable MSW. By quantifying the climate change impacts of burning Scotland's waste, this study can be used to explore and inform waste management decisions.

Plant specific data was used as much as possible in the model. The baseline year was 2018 as this was the most complete and up to date dataset available during the original research phase of the project. Four of the plants started operating in 2018 and this is reflected in the data, results and interpretation. The study also included a sensitivity analysis, to assess the likely effects of future changes in key variables, such as changes to the composition of municipal waste and converting the electricity-only plants to Combined Heat and Power (CHP) plants. The main results, sensitivity analysis results and key uncertainties and data gaps are presented in this report.

Climate change impacts are measured in two ways in this study; **carbon intensity** and **greenhouse gas emissions**. Carbon intensity is a standard approach for comparing the climate change impacts of different energy generation technologies, such as gas fired power stations. EfW plants are classified as power stations for national emissions reporting purposes. Therefore, a comparison to other energy generating technologies is appropriate. Life Cycle Analysis (LCA) methodology is used to assess the greenhouse gas emissions and savings of sending one tonne of municipal waste to a waste disposal route. It can be used to compare the climate change impact of waste management technologies with similar boundaries. In this study, EfW is compared to landfill.

Climate change is not the only consideration when assessing the environmental impacts of waste management. Land use management and land, air and water pollution other than those contributing to climate change must also be considered when comparing EfW and landfill. However, given the global scale and urgency of the climate emergency, the impact of our waste management choices on climate change are a priority issue. The model and report produced by this study can be used to take advantage of significant opportunities to further reduce the climate change impacts of waste.

Key terms used in this study are defined in the box below.

Definitions of key terms

Climate change impacts

A measure of greenhouse gases (GHG) including carbon dioxide (CO_2) and methane (CH_4), which are produced as a result of human activities, and which influence the climate of our planet through atmospheric warming. These can be grouped and quantified into a single figure (known as a global warming potential or GWP), using estimates of the relative impact of each GHG. This figure, measured in CO_2 equivalent units (CO_2e), can be used to compare processes which emit different types of GHG (such as EfW and landfill).

The boundaries for this study are consumption based, rather than territorial. This reflects the global nature of material consumption and climate change. As nearly all the activities included in the study occur within Scottish geographic boundaries, the results would not change greatly if they were territorial based. The main difference would be an exclusion of emissions and savings associated with the export of materials for recycling and Solid Recovered Fuel exported for burning.

Carbon intensity

A measure of carbon dioxide emissions relative to the energy generation for a fuel or technology, such as a power station. It is usually measured in units of gCO_2/kWh and can be used to compare the environmental efficiency of energy generating technologies. It only considers the impact of energy generation, not wider activities related to these technologies, such as transport, processing and emissions saved from energy offset.

Greenhouse Gas emissions

Life Cycle Analysis (LCA) is used as a methodology for measuring all the greenhouse gas emissions and savings from each stage of a process. The approach used in this study includes the emissions from transporting, on-site processing and burning of municipal waste, as well as the emissions saved from the energy offset and recycling for each EfW plant. This can be compared to other processes with similar boundaries, such as landfill[4]. GHG emissions are measured in $kgCO_2e$ per tonne of waste input.

Displacement of energy or virgin material production

It is assumed that energy generated from a process such as burning waste displaces an alternative form of energy generation. The emissions which would have otherwise occurred from that alternative energy generation are included as part of the savings from the EfW process. The EfW plants in this study are assumed to displace UK marginal electricity grid.

Materials which are recycled are assumed to displace virgin material production. For example, the impacts of metal recovery include the savings from avoided extraction of metal ores, as well as the impacts of transporting and reprocessing the recyclate.

[4] Greenhouse gas emissions from landfill occur over a long period dependent on the decomposition rate of waste in landfill.

1.1 EfW plants in Scotland

In 2018, there were fourteen operational EfW plants in Scotland. Of these, six were permitted to take municipal waste. Details of these plants are listed in Table 1. Municipal waste is defined as "waste from households as well as other waste which because of its nature or composition is similar to waste from households" by the Landfill (Scotland) Regulations 2003 (as amended)[5]. Waste from non-municipal sources is subject to separate regulations and is beyond the scope of this study.

Table 1. Operational EfW plants in Scotland in 2018 which are permitted to take residual municipal waste

Name of plant	Incinerator type	Incineration capacity (tonne/year)	Municipal waste incinerated in 2018 (tonnes)	Status in 2018 and energy generation type
Dunbar Energy Recovery Facility, Oxwellmains, East Lothians	Moving grate incinerator	300,000	41,284[3]	Begun operations in 2018[6], CHP potential, operating as electricity-only
MVV, Baldovie Industrial Estate, Dundee	Fluidised bed incinerator	110,000	94,624	Operational[6], CHP potential, operating as electricity-only
Millerhill Energy Recovery Centre, Edinburgh	Moving grate incinerator	195,000	16,459[3]	Begun operations in 2018[7], CHP potential, operating as electricity-only
Glasgow Recycling and Renewable Energy Centre (GRREC), Glasgow	MRF[8], AD[9] and gasifier	154,000	66,504[3]	Begun operations in 2018, producing SRF[6] and electricity CHP potential, operating as electricity-only
Levenseat Thermal Waste Treatment Plant, West Lothian	MRF[4], AD[5] and gasifier	200,000	63,355[3]	Begun operations in 2018, producing SRF[6] and electricity CHP potential, operating as electricity-only
Lerwick Energy Recovery Plant, Lerwick, Shetland Islands	Moving grate incinerator	24,000	23,053	Operational, built and operating as heat-only
Total (tonnes)		**983,000**	**305,280**	

[5] SEPA Guidance (2018) Biodegradable Municipal Waste Landfill Ban
https://www.sepa.org.uk/media/352595/sepa_bmw_landfill_ban_guidance_note.pdf
[6] Fires at the Dundee plant in 2018 meant that it was not able to operate for part of the year.
[7] The Dunbar, Millerhill, GRREC and Levenseat facilities all begun operating in 2018 and their operations were scaled up over this year, which is why inputs in 2018 were well below capacity. They were mostly expected to be running close to capacity from 2019.
[8] Materials Recovery Facility (MRF) are partially mechanised approaches to removing materials with recycling value from municipal waste before the remained is burnt for energy generation.
[9] Anaerobic Digestion (AD) is the treatment of organic feedstock for energy or heat recovery.

There is one heat-only plant on this list. The other plants, including the gasifiers, have been planned as Combined Heat and Power (CHP) plants. However, they operated as electricity-only plants in 2018.

Of the remaining eight operational EfW plants in Scotland in 2018:

- Five were small scale commercial or industrial incinerators with a combined capacity of 66,000 tonnes per year;
- Three were large scale co-incinerators which mainly take biomass as a fuel but are supplemented with waste from commercial and/or industrial sources. They have a combined capacity of 1.4 million tonnes per year and waste makes up about 19% of their total inputs (275,000 tonnes per year).

A further two small scale commercial incinerators were not operational in 2018.

Future developments include:

- Three EfW plants, which plan to take municipal waste are currently in construction. These are all expected to be operational by 2022, assuming they pass their commissioning stages as planned, and will add 708,000 tonnes per year capacity to create a total potential capacity of 1.7 million tonnes per year of municipal waste by 2025.
- Plans for a further eighteen incinerators are held by SEPA. Half of these plants have been given planning permission, but none have permits or begun construction as of June 2020 when this study was originally conducted.

2 Methodology

This section details the methodology used to calculate the carbon intensity and greenhouse gas emissions of the six municipal waste burning EfW facilities operating in Scotland in 2018. The methodology is split into five sections:

1. Estimate the biogenic and fossil carbon content of municipal waste in Scotland in 2018;
2. Calculate the carbon intensity of the EfW plants;
3. Calculate the greenhouse gas emissions of EfW plants using LCA;
4. Calculate the greenhouse gas emissions of landfill using LCA; and
5. Description of how the sensitivity analysis was conducted.

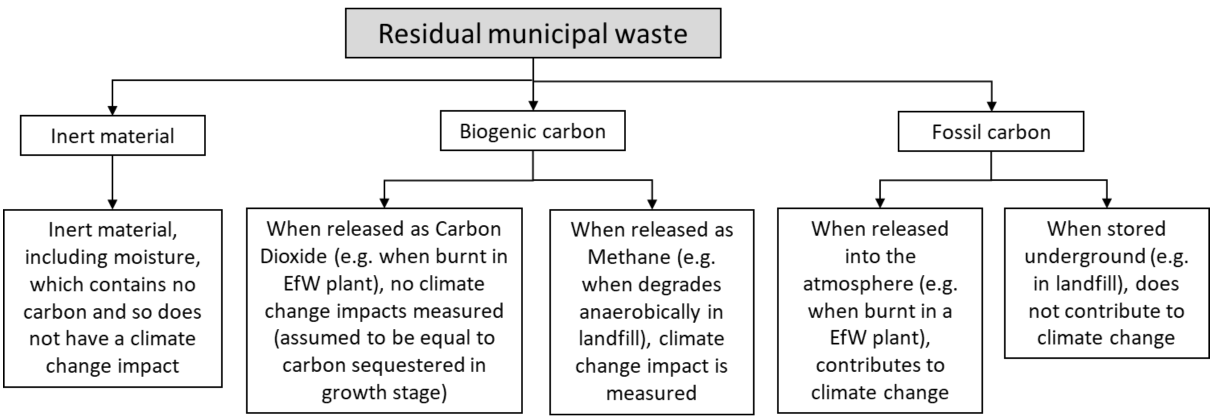
2.1 The carbon content of waste

A typical tonne of residual municipal waste will contain many different waste materials, some of which will contain carbon. This carbon can be divided into two categories: **biogenic carbon,** which is derived from biological sources such as plants; and **fossil carbon** which is derived from fossil fuels. Carbon in waste can be either completely biogenic (such as food waste) completely fossil-based (such as plastic) or a mix of biogenic and fossil (such as cotton and polyester mixed clothing). Some wastes do not contain any carbon (such as sand) are said to be inert or non-combustible.

From a climate change accounting perspective, biogenic and fossil carbon are counted differently. The Intergovernmental Panel on Climate Change (IPCC) methodology for reporting national greenhouse gas emissions from waste only includes biogenic carbon when it is released into the atmosphere as methane. This can happen when biogenic waste degrades anaerobically in landfill, for example. Biogenic carbon released as carbon dioxide is assumed to be equal to the carbon sequestered when the biogenic material was grown. In contrast, fossil carbon released into the atmosphere by human activities contributes to climate change. If it is placed in long term storage instead, the climate change impacts of fossil carbon can be mitigated.

When waste is burnt in an EfW plant, nearly all[10] the biogenic and fossil carbon is released into the atmosphere immediately as carbon dioxide: the fossil carbon will contribute to climate change. When waste is landfilled, all of the fossil carbon and about half of the biogenic carbon will be stored in the landfill for many years without degrading. The rest of the biogenic carbon will be converted to landfill gas (a mixture of ~50% carbon dioxide and 50% methane) some of which will escape into the atmosphere and contribute to climate change. The different possible fates of biogenic and fossil carbon in waste and their contributions to climate change have been summarised in Figure 4.

Figure 4. The climate change impacts of inert, biogenic and fossil carbon material in waste



[10] Less than 3% of carbon remains in the ash (DEFRA, 2014 Energy recovery for residual waste).

Therefore, the climate change impacts of EfW are largely determined by the amount of fossil carbon in residual municipal waste, whilst the impacts of landfill are largely determined by the proportion of biogenic carbon in waste which is released into the atmosphere as methane. So, the carbon content of residual municipal waste is a critical parameter in this study.

To calculate the biogenic and fossil carbon content of waste, two pieces of information were required:

1. An up to date composition of residual municipal waste sent to landfill and EfW in Scotland; and
2. An estimation of the biogenic and fossil carbon content of each waste material type in residual municipal waste.

The composition of waste used in this study is based on the ZWS (2017)[11] waste composition analysis. This study estimated a national composition of residual municipal waste collected at kerbside in Scotland in 2014-15. An annual update is made to this composition analysis by SEPA to reflect expected changes in the proportion of food waste in residual municipal waste as food waste collection schemes are introduced across the country. The 2018 composition, as calculated by SEPA, was used in this study.

The biogenic and fossil content of each waste material was based on the assumptions used in a DEFRA (2014) EfW and landfill comparison study[12]. The composition and carbon content of waste estimates used in this study is shown in Table 2.

[11] Zero Waste Scotland (2017) The composition of household waste at the kerbside in 2014-15

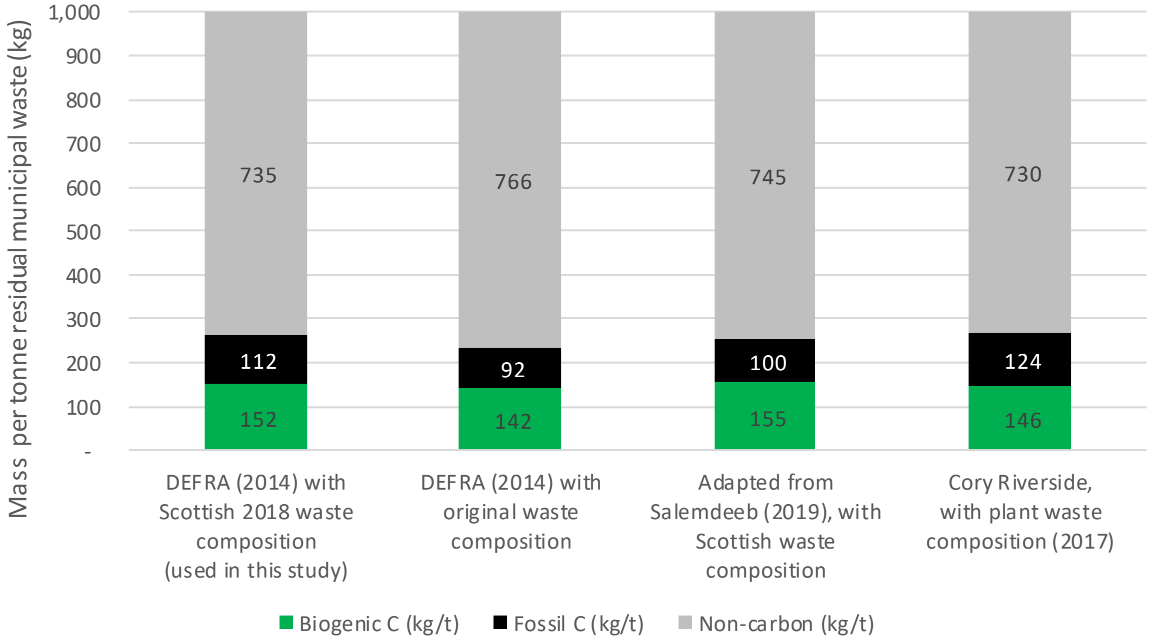
[12] DEFRA (2014) Energy recovery for residual waste

Table 2. The estimated composition and carbon content of residual municipal waste in Scotland in 2018

Waste material type	Proportion of waste	Proportion of waste which contains carbon (%)	Proportion of carbon which is biogenic (%)	Proportion of carbon which is fossil (%)
Animal and mixed food waste	27%	14%	100%	0%
Discarded equipment (excluding discarded vehicles, batteries and accumulators wastes)	2%	0%	0%	0%
Glass wastes	3%	0%	0%	0%
Health care and biological wastes	10%	19%	79%	21%
Household and similar wastes (refuse and furniture)	7%	45%	50%	50%
Metallic wastes, mixed ferrous and non-ferrous	3%	0%	0%	0%
Mineral waste from construction and demolition	4%	7%	50%	50%
Paper and cardboard wastes	16%	32%	100%	0%
Plastic wastes	15%	52%	0%	100%
Rubber wastes	0%	0%	0%	100%
Textile wastes	6%	40%	50%	50%
Vegetal wastes	6%	24%	100%	0%
Wood wastes	1%	44%	100%	0%
Total	**100%**	**26.5%**	**15.2%**	**11.2%**

The lack of published information on composition and carbon content of waste, along with the natural variability of waste itself means that there is a high degree of uncertainty surround these parameters. Figure 5 compares the carbon content of waste used in this study with three alternative sources: the original DEFRA (2014) study; the results of a 2017 UK metastudy of waste composition[13]; and a review by the Carbon Trust of the Cory Riverside EfW plant in England which estimated the carbon content of its waste in 2015[14].

Figure 5. A comparison of the carbon content of one tonne of residual municipal waste



Whilst Figure 5 indicates the parameters used in this study are consistent with alternative sources, the further analysis indicates that the model is highly sensitive to the composition of waste. This issue is explored further in the sensitivity analysis.

2.2 The carbon intensity of EfW plants

Carbon intensity measures the greenhouse gas (GHG) emissions generated per unit of power generated. It is often reported in units of "grams of carbon dioxide emissions per kilowatt hour" or (gCO_2/kWh). It is possible to estimate the carbon intensity of individual EfW plants using three key pieces of information:

- the emissions from the fossil carbon content of waste;
- the net calorific value (NCV) of the waste input and;
- the plant efficiency.

The carbon intensity of each of the EfW plants taking residual municipal waste was calculated using the information above and

Equation 1 and Equation 2.

[13] Salemdeeb R (2019) Beyond the food waste hierarchy: a quantitative assessment of embodied environmental impacts using a hybrid approach. PhD thesis. University of Cambridge (UK).
[14] Carbon Trust (2017) Cory Riverside Energy: A Carbon Case

Equation 1. Efficiency of fuel

$$\frac{\text{GHG emissions from fossil carbon content of waste (kg } CO_2\text{/t)}}{\text{(Net calorific value of waste (GJ/t) / 0.0036)}} = \text{Efficiency of fuel (kg } CO_2\text{/kWh)}$$

Where:

GHG emissions from the fossil carbon content of waste is based on the fossil carbon content of waste (Table 2

Table 2) converted into carbon dioxide emissions using the molecular mass for carbon and oxygen. This was calculated for each plant based on the municipal waste inputs for 2018;

The **net calorific value (NCV) of waste** is based on estimates stated in the Heat and Power Plans for individual plants[15]. The average NCV was 9.5 GJ/t for electricity-only incinerators and 12.1 GJ/t for the gasifiers. The average NCV for UK municipal waste in 2018 was 8.9 GJ/t[16];

Energy (GJ/t) was converted to power (kWh/t) using a standard conversion of dividing GJ by 0.0036 to give kWh.

Equation 2. Carbon intensity of EfW plants

$$\frac{\text{Efficiency of fuel (kg } CO_2\text{/kWh)}}{\text{Plant efficiency (\%)}} \times 1000 = \text{Carbon intensity of EfW plant (g } CO_2\text{/kWh)}$$

Where:

The efficiency of the fuel is calculated from Equation 1.

Plant efficiency is based on the best available data for the plant[15]. Plant efficiency averaged 25% for the electricity-only plants and 50%[17] for the heat-only plant. In 2018, produced either electricity or heat, no plants produced both.

This allowed the carbon intensity of each EfW plants burning residual municipal waste in Scotland in 2018 to be calculated. This could then be compared to other energy generating technologies.

2.3 Greenhouse gas emissions of EfW plants

The methodology for estimating the net carbon emissions generated per tonne of waste burnt for each facility is based on a Life Cycle Analysis (LCA). LCA is an internationally recognised approach to measuring and comparing environmental impacts by calculating the emissions and savings of each stages of a process.

In this study, a disposal to cradle boundary is used. All emissions and savings from activities from transport to the incinerator gate to final disposal or recycling of materials are included in the assessment. Where there are emissions savings from avoided production due to recycling, these have been included. The system boundaries for the incinerators, gasifiers (which have more complex pre-treatment stages) and landfill (as an alternative disposal route for municipal waste) are shown in Figure 6, Figure 7 and Figure 8.

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[15] Dunbar: Viridor (2008) Heat Plan, Facility: Oxwellmains, Viridor Waste Management Ltd
Dundee: ARUP (2017) Pollution Prevention and Control Permit – Non-Technical Summary
Millerhill: FCC Environment (2015) Heat and Power Plan
GRREC: Viridor (2017) Heat and Power Plan
Levenseat: Fichtner Consulting Engineers Limited (2014) Heat and Power plan and supporting information
Lerwick: Shetland Islands Council Environmental Service (2009) PCC Permit
[16] Tolvik (2019) UK Energy from Waste Statistics for 2018
[17] In line with external references, for example EEA (2018) Efficiency of conventional thermal electricity and heat production in Europe

Figure 6. System boundaries for sending one tonne of waste to an incinerator

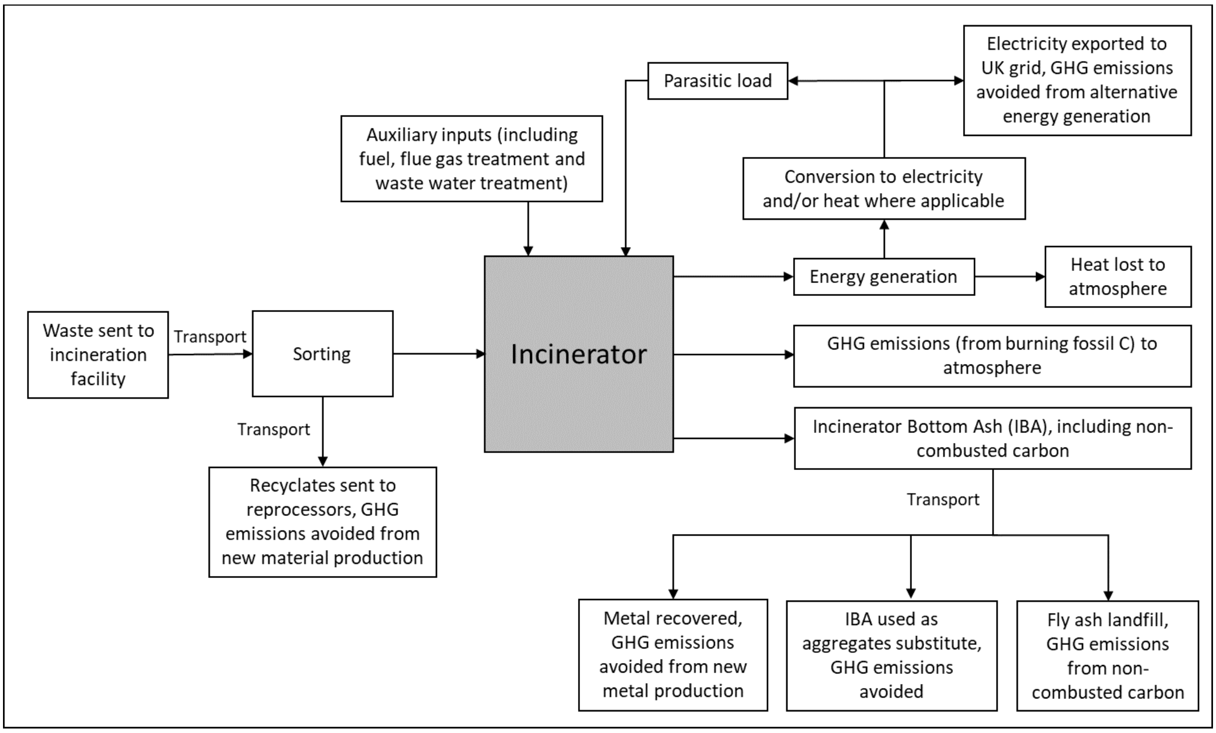


Figure 7. System boundaries for sending one tonne of waste to a gasifier

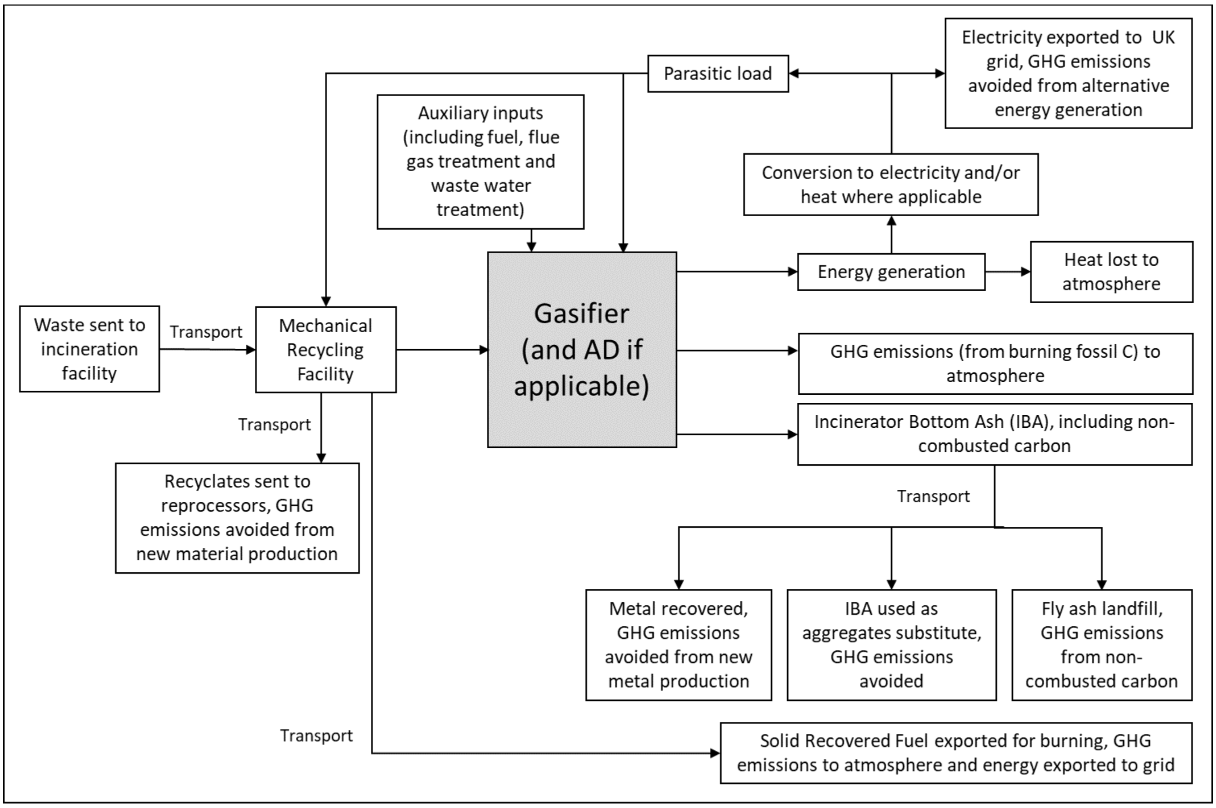
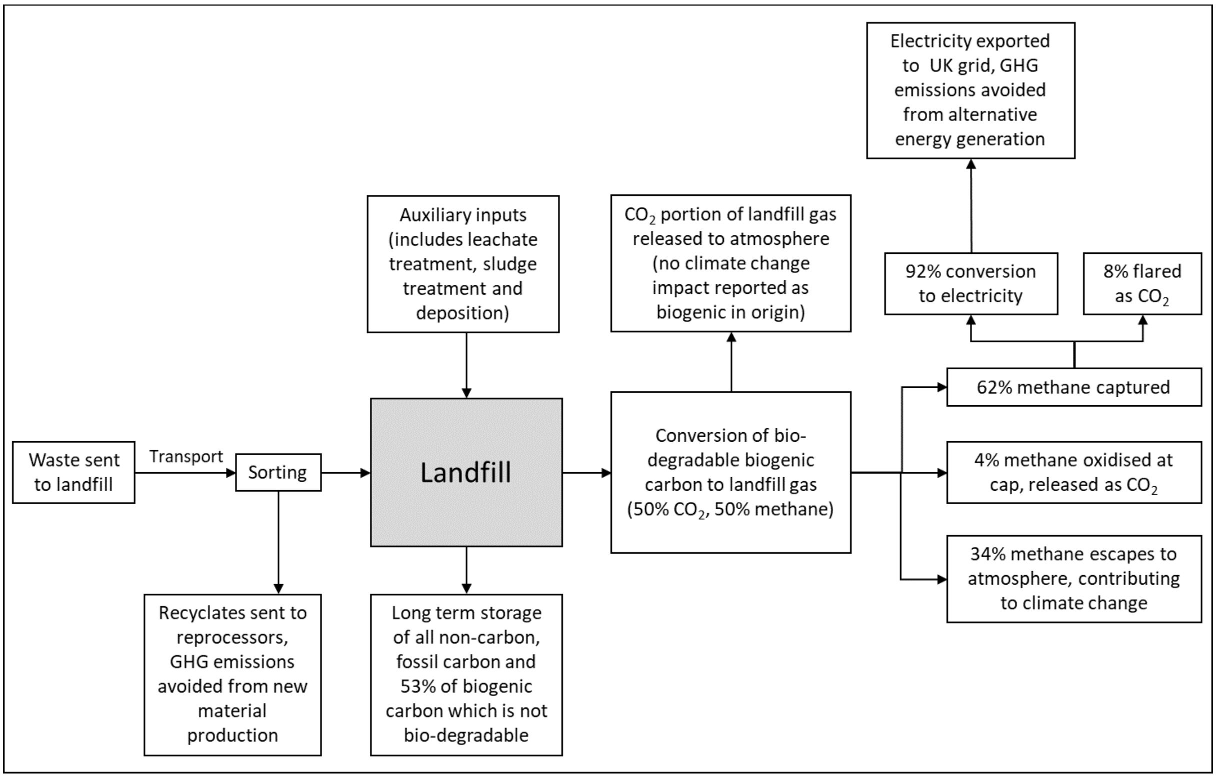


Figure 8. System boundaries for sending one tonne of waste to landfill



The EfW plant model has been divided into six life cycle stages:

1. Emissions from the fossil carbon embedded in the waste burnt;
2. Process emissions (transport, sorting and auxiliary inputs to the incinerator);
3. Emissions avoided from energy displacement;
4. Emissions from incinerator wastes;
5. Emissions avoided from pre-treatment recycling and metal recovery; and
6. Emissions from SRF export (gasifiers only).

The rest of Section 2.3 details the method used to calculate the emissions and savings for each of these stages.

The **emissions from fossil carbon embedded in waste burnt** is based on the fossil carbon content of waste (Table 2) converted into carbon dioxide emissions using the atomic mass for carbon and oxygen. The tonnages and type of waste sent to each EfW plant are published by SEPA annually[18]. The amount of waste burnt is calculated from this data, minus any recyclate removed during pre-treatment. For the gasifiers, the tonnages converted to SRF are also excluded from the tonnages burnt.

The **process emission** stage includes:

- Transport of waste to facility (based on BEIS carbon conversion factors for 2018[19] and Zero Waste Scotland Carbon Metric distances for transporting municipal waste[20]);
- Sorting of waste (Zero Waste Scotland Carbon Metric assumption); and

[18] SEPA (2019) Site Returns Data
[19] BEIS (2019) Greenhouse gas reporting: conversion factors 2019
[20] Zero Waste Scotland (2020) Carbon Metric 2018

- Auxiliary inputs to the incinerator (adapted from Ecoinvent[21]).

The **emissions avoided from energy displacement** was estimated using the annual electrical and heat power output estimates for the plant; the load factor for the plant (used to account for the difference between peak expected performance and actual performance, and assumed to be 80% unless plant specific data is available) and the running hours (assumed to be 8,000 hours per year unless plant specific data is available); and the parasitic load (from the Heat and Power Plans of individual plants). These parameters can be used to estimate the power generated from burning one tonne of waste for each EfW plant. This figure is multiplied by the UK carbon factors for marginal electricity[22]and heat[23] generation to calculate the emissions avoided from alternative energy generation.

The **emissions from incinerator wastes** included: transportation of Incinerator Bottom Ash (IBA); displacement of aggregates; transport of fly ash to landfill; and the release of uncombusted carbon from fly ash in landfill.

The **emissions avoided from recycling and metals recovery** is based on the tonnages reported as outputs by each EfW plant and the Zero Waste Scotland Carbon Metric factors for substitution and recycling for each material.

Both gasifier plants began operations in 2018. Their operations and tonnage throughput for this year are not representative of their future expected performance. In 2018, both gasifiers mainly processed their waste by producing Solid Recovered Fuel (SRF) for export, rather than burning it. In GAS1, 70% of waste sent to the plant was converted to SRF, at GAS2 this figure was 82%. The model boundaries include the **emissions from the transport and burning of SRF**. Transport distances were based on the proportion of RDF tonnages sent to Scottish, UK and European locations, as recorded by SEPA. The SRF was assumed to be burnt in EfW plants in the UK (based on SEPA data regarding destination of SRF) and with a plant efficiency of 35%[24], reflecting the high number (67%) of R1[25] plants across the UK[26].

The results for both the carbon intensity and greenhouse gas emissions for EfW plants were anonymised to ensure the focus of the results remains on the national picture, rather than at the level of individual plants.

2.4 Greenhouse gas emissions for landfill

The greenhouse gas emissions of sending one tonne of residual municipal waste to landfill in Scotland in 2018 was estimated using LCA. There were four stages to this:

1. Calculating the proportion of biogenic carbon embedded in waste which escapes as methane;
2. Sorting and recycling of waste, including avoided production;
3. Process emissions (transport and auxiliary inputs to landfill); and
4. Emissions avoided from energy displacement.

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[21] Ecoinvent Version 3, "Municipal solid waste {GB}|treatment of, incineration | Cut-off, U" adapted to include only impacts from auxiliary processes including materials for DE NOx stage, cement required for solidification of landfill material, auxiliary inputs for the waste water treatment stage and flue gas treatment.

[22] BEIS (2019) Green Book supplementary appraisal guidance on valuing energy use and greenhouse gas (GHG) emissions

[23] Ecoinvent Version 3, "Heat, central or small-scale, natural gas {Europe without Switzerland}| market for heat, central or small-scale, natural gas | Cut-off, U", year of calculation is 2018, method is IPCC GWP 2013 100a

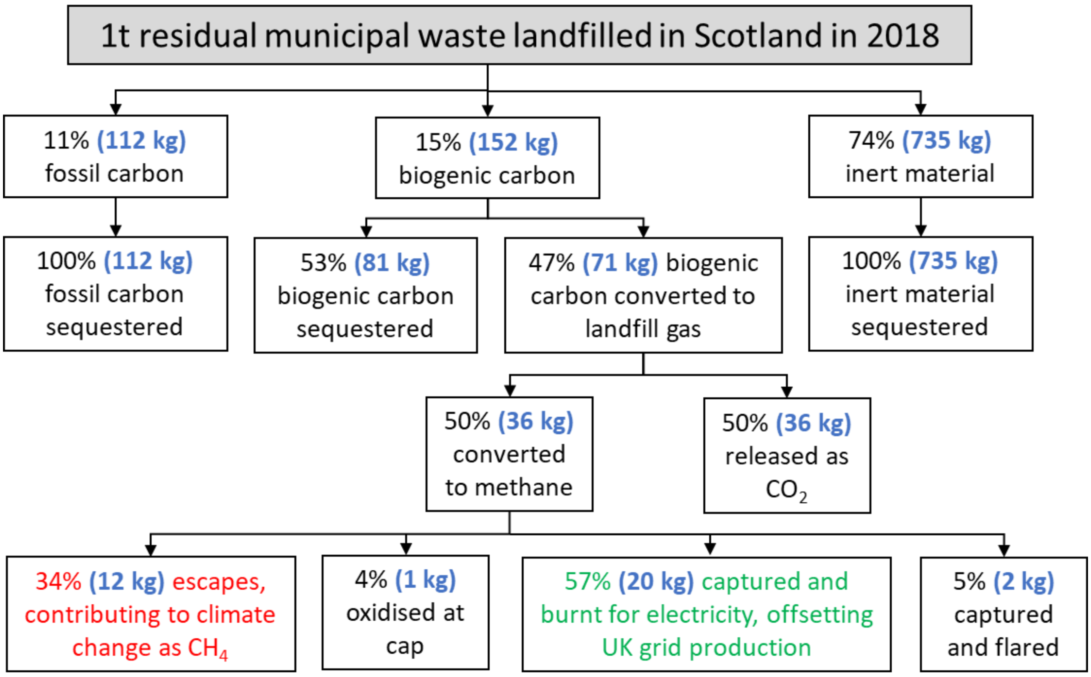
[24] SEPA (2014) Thermal Treatment of Waste Guidelines 2014

[25] R1 is a formula used across the UK to assess the efficiency of EfW plants generating energy from burning waste. Plants operating at or above R1 levels are classed as recovery plants. Below this level, plants are classed as disposal.

[26] Tolvik (2019) UK Energy from Waste Statistics for 2018, page 8

The fate of carbon sent to landfill is shown in Figure 9. Estimates for the amount of **carbon escaping as methane** is shown in red and the amount of carbon burnt for energy is shown in green. The composition of waste figures is the same as those used for the EfW model and set out in Table 2. The proportion of biogenic carbon which bio-degrades (47%) is based on material specific estimates used in the DEFRA (2014) study and MelMod (a UK and Scottish Government model created to measure the impacts of landfill for the purposes of national carbon reporting[27]).

Figure 9. The fate of carbon in one tonne of residual municipal waste landfilled in Scotland in 2018



The amount of biogenic carbon escaping as methane is calculated from the mass of the carbon given above (12 kg/t) and using the molecular mass of methane. This is then multiplied by the global warming potential of methane[28] to give the greenhouse gas emissions.

About 10% of waste sent to landfill is **sorted for recycling** (mainly glass, metals, plastics and wood). The amount and type of materials recycled are estimated from 2018 site returns data from a representative landfill site. The carbon factors for recycled materials in the Scottish Carbon Metric were used to calculate the carbon savings from recycled materials and the remaining waste was assumed to be sent to landfill.

To ensure the EfW and landfill models are comparable, the boundaries of the system must be the same. So, the relevant **process emissions** for activities including transport and leachate treatment are also included in the landfill calculations.

The power generated from methane captured and **burnt for energy generation** can be estimated by calculating Equation 3.

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[27] Ricardo (2018) MelMod 2018 Inventory Scotland (model version V01-10) and Ricardo (2018) National Atmospheric Emissions Inventory

[28] For methane, this is 28, excluding feedback mechanisms based on the IPPC 4th Assessment Report. This is consistent with Scottish Government climate change reporting.

Equation 3. Energy generated per tonne of waste landfilled

$$\text{Volume of methane captured and burnt for energy generation per tonne waste } (m^3/t) \times \text{NCV of gas } (MJ/m^3) \times \text{Plant efficiency } (\%) = \text{Energy generated per tonne waste } (MJ/t)$$

Where:

The volume of methane is based on mass of methane captured and burnt for energy generation (kg/t) divided by the standard density of methane (0.66 kg/m^3);

The engine efficiency is assumed to be 36%[29].

Energy (MJ/t) was converted to power (kWh/t) using a standard conversion of dividing MJ by 3.6. The power generated from landfill gas is assumed to displace marginal grid electricity in the UK.

It is assumed that this methane goes on to be released into the atmosphere as biogenic CO_2, and so is not counted as climate change impacts in this model.

2.5 Sensitivity Analysis methodology

Sensitivity analyses were conducted to explore the importance of key parameters in the model: the composition of residual municipal waste; and the climate change impacts of potential technological solutions to residual waste management. The methods used for these sensitivity analyses are described in this section.

Changing the composition of waste

The model in this study is built on assumptions about the fossil and biogenic carbon content of residual municipal waste. The emissions from EfW depend on the fossil carbon content of waste and the emissions from landfill depend of the biogenic carbon content of waste. As the composition of waste is variable and changes over time, this sensitivity analysis explored the effect changes in waste composition would have on the net emissions from waste management options. The proportion of high carbon waste types was altered, which in turn changed the amount of fossil and biogenic carbon in waste and the resulting emissions from waste management options.

Plastic content of waste was varied to show the effects of changing fossil carbon content of waste. In the main model, plastic waste is assumed to make up 15% of the weight of residual municipal waste and 69% of its fossil carbon content. This composition is varied by +/- 10% in the sensitivity analysis. The composition of other materials were adjusted proportionately.

Food and paper content was varied to show the effect of changing biogenic carbon content of waste. In the main model, these two waste categories make up 43% of the weight of residual municipal waste and 59% of its biogenic carbon content. This composition is varied by +/- 10%. The composition of other materials were adjusted proportionately.

The results of this sensitivity analysis show the effect of changing composition on net calorific value of waste, as well as the greenhouse gas emissions. The carbon content of waste can be expressed in terms of net calorific value (NCV), as it is carbon which is burnt to produce energy: the more carbon present in a fuel, the higher it's NCV. NCV is a key consideration of EfW operators because it affects

[29] The inclusion of this figure is the main update to the landfill model compared to the original published study in October 2020. See Annex 1 for further details on this change. The figure is based on discussions with SEPA and Ricardo landfill experts and is in line with MelMod 2018 Inventory Scotland (model version V01-10)

the efficiency of waste used as a fuel. The higher the NCV, the more energy can be generated per tonne of waste input.

Potential technological solutions to residual waste management

Combined Heat and Power (CHP) systems are power plants which convert and supply energy in the form of both electricity and heat. They are more efficient than electricity-only power plants. In alignment with Pollution Prevention and Control (PPC) Regulations, incineration of waste can only be permitted when "conditions necessary to ensure the recovery of energy takes place with a high level of energy efficiency"[30].

All the plants burning residual municipal waste in Scotland in 2018, except the heat-only plant in Lerwick, operate as electricity-only plants. They were all designed as CHP plants, as required by planning regulations, to maximise their efficiency. The main model was adjusted to show how converting to CHP systems may change their carbon intensity. This was done using electricity and heat efficiency scenarios for each plant, published as part of their Heat and Power Plans. These plans calculated the electricity and heat efficiencies required to meet the standards of high performing CHPs. Plant efficiency increased, from an average of 25% in the main model, to 36%. The electricity and heat outputs for each plant were also changed to reflect the increase in energy displacement, using the figures suggested in the Heat and Power Plan calculations. The CHP EfW plant scenarios were compared to a scenario based on a mix of 55% electricity and 45% heat[31]. The weighting was based on the average electricity and heat outputs estimated by the EfW plant operators for the CHP scenarios in their Heat and Power Plans.

The CHP EfW plant scenario is compared to an alternative scenario for meeting the Biodegradable Municipal Waste (BMW) ban to landfill which removes biodegradable carbon in a pre-treatment step. Such pre-treatment steps mean that carbon is released aerobically as carbon dioxide in pre-treatment, rather than anaerobically, and as methane (a much more potent greenhouse gas) in landfill. This could be done using technology already operating in Europe[32] known as biostabilisation. The technology uses mechanical and biological processes to degrade the biodegradable content of residual waste prior to landfilling. This pre-treatment results in a biostabilised output which, when landfilled, produces lower greenhouse gas emissions than untreated residual waste. Such technologies offer an alternative means of meeting the BMW ban to incineration. Whilst such plants exist in Europe, there are no such reference plants in Scotland. However, the greenhouse gas emissions which are the focus of this report, can be estimated for a scenario based on this technology. The biostabilisation scenario modelled in this report reduces the biogenic carbon in waste entering landfill from 15% to 5%. This is in line with scientifically peer reviewed estimates of the potential savings from biostabilisation[33]. The study recognises that, as the biostabilised waste output of such operations would still be required to pay the active landfill tax rate, such plants are not currently financially viable in Scotland. More detailed analysis is required to understand the full potential of this technology in light of its potential to reduce the carbon impacts of residual waste.

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[30] SEPA (2014) Thermal treatment of waste guidelines

[31] The alternative scenario was based on marginal electricity supplied by the grid and heat supplied through a household gas boiler. The heat factor used was 0.250 kgCO2e/kWh. This was taken from Ecoinvent 3 "Heat, central or small-scale, natural gas heat production, natural gas, at boiler condensing modulation <100kW), IPCC 2013 GWP 100.

[32] See Figure 9 in Juniper (2005) Mechanical Biological Treatment: A guide for decision makers

[33] For example F, J. de Araújo Morais et al. (2008) Mass balance to assess the efficiency of a mechanical–biological treatment, Waste Management, Volume 28, Issue 10 and Zhang et al. (2011) Environmental and economic assessment of combined biostabilization and landfill for municipal solid waste , Journal of Environmental Management, Volume 92, Issue 10.

Scotland is introducing a ban on Biodegradable Municipal Waste (BMW) sent to landfill in 2025. The primary purpose of this ban is to reduce greenhouse emissions from landfill by removing biodegradable content[34].

The greenhouse gas emissions of three scenarios for meeting the BMW landfill ban were modelled. The baseline greenhouse gas impacts of residual municipal waste management were calculated for 2018 based on the model outputs. This was compared to the three scenarios for the meeting the ban:

- Scenario 1: the 77% of residual municipal waste landfilled in 2018 is sent to incineration instead. In this scenario, the incinerators reflect 2018 average operating practice and carbon impacts.
- Scenario 2: as in the scenario 1, all residual municipal waste is sent to incineration however, the incinerators are modelled on upgrading the current plants to Combined Heat and Power (CHP) systems.
- Scenario 3: Waste that is currently incinerated continues to be sent to incinerators which are upgraded to CHPs. The remaining mass of waste that is being landfilled is sent to biostabilisation plants, to reduce biodegradable content prior to landfill.

These scenarios consider 2018 levels of waste only. It is acknowledged that absolute emissions could reduce in a more circular based economy through waste prevention, improved recycling and other means.

[34] SEPA (2018) Biodegradable Municipal Waste landfill ban, legislative context

3 Main Results

3.1 The carbon intensity of burning residual municipal waste

The weighted average[35] carbon intensity of EfW plants burning residual municipal waste in Scotland in 2018 was 509 gCO_2/kWh. Table 3 shows the carbon intensity for each EfW plant and the average for each plant type.

Electricity-only incinerators and gasifiers have an average carbon intensity of 524 gCO_2/kWh. This is nearly twice as high as the carbon intensity of the marginal electricity grid, which was 270 gCO_2/kWh in the UK in 2018[36]. The carbon intensity of the only heat-only incinerator operating in Scotland in 2018 was 325 gCO_2/kWh. The carbon intensity is lower because heat-only plants operate at higher plant efficiencies (around 50%) compared to electricity-only (25%). However, even this plant operated at a higher carbon intensity than a central or small-scale natural gas plant for heat operating in the UK (267 gCO_2/kWh).

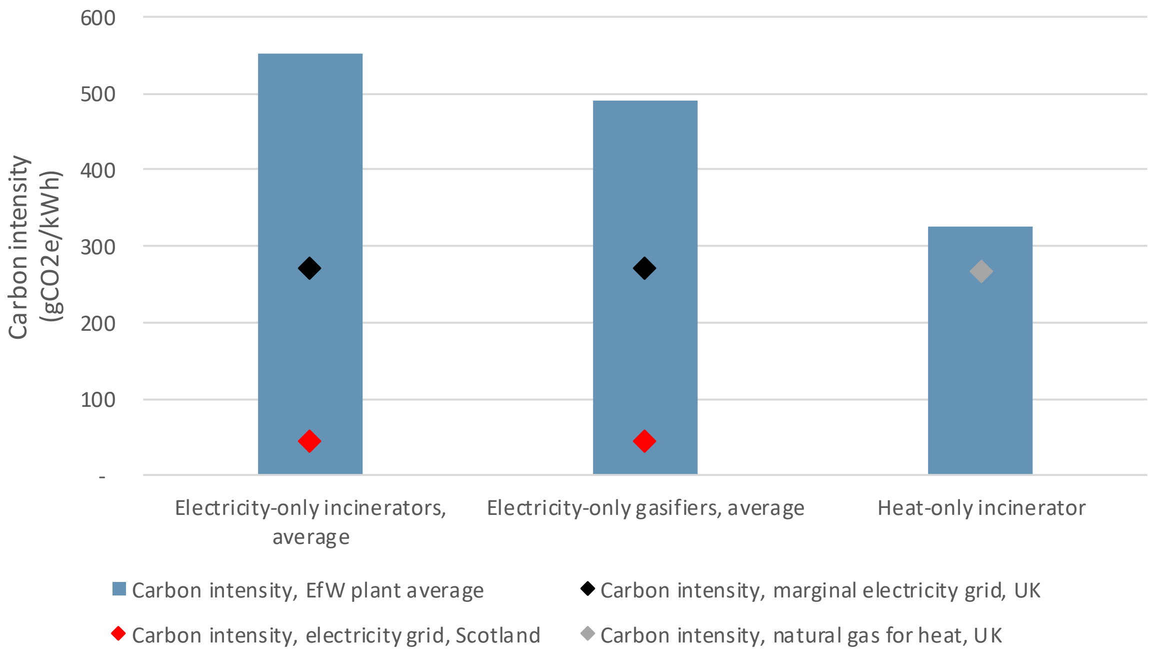
Table 3. Carbon intensity of EfW plants burning municipal waste in Scotland in 2018

Plant	Carbon intensity (gCO_2/kWh)
Electricity-only plant 1 (EOP1)	565
Electricity-only plant 2 (EOP2)	513
Electricity-only plant 3 (EOP3)	744
Gasifier plant 1 (GAS1)	563
Gasifier plant 2 (GAS2)	417
Heat-only plant 1 (HOP1)	325
Electricity only incinerators, weighted average	**552**
Electricity-only gasifiers, weighted average	**492**
All EfW plants, overall weighted average	**509**

[35] A weighted average was used for this calculation based on the waste tonnage input into each plant.
[36] The average carbon intensity of the Scottish electricity grid in 2018 was 44 gCO2e/kwh. Taken from Scottish Government (2020) Scottish Energy Statistics Hub, Average greenhouse gas emissions per kilowatt hour of electricity.

Figure 10 shows the average carbon intensity of the plants compared to the carbon intensity of marginal electricity for the UK grid and the carbon intensity for heat generated from a central or small-scale natural gas plant operating in the UK. All plant types have a higher carbon intensity than their alternatives, which means more greenhouse gas emissions per unit of power produced are emitted from EfW plants compared to alternative energy sources.

Figure 10. The carbon intensity of EfW plants taking residual municipal waste in Scotland in 2018



3.2 Greenhouse gas emissions from burning and landfilling residual municipal waste

The average greenhouse gas emissions resulting from sending one tonne of municipal waste to incineration in Scotland in 2018 was 246 $kgCO_2e/t$. This is 27% less than sending the same tonne of waste to landfill. Table 4

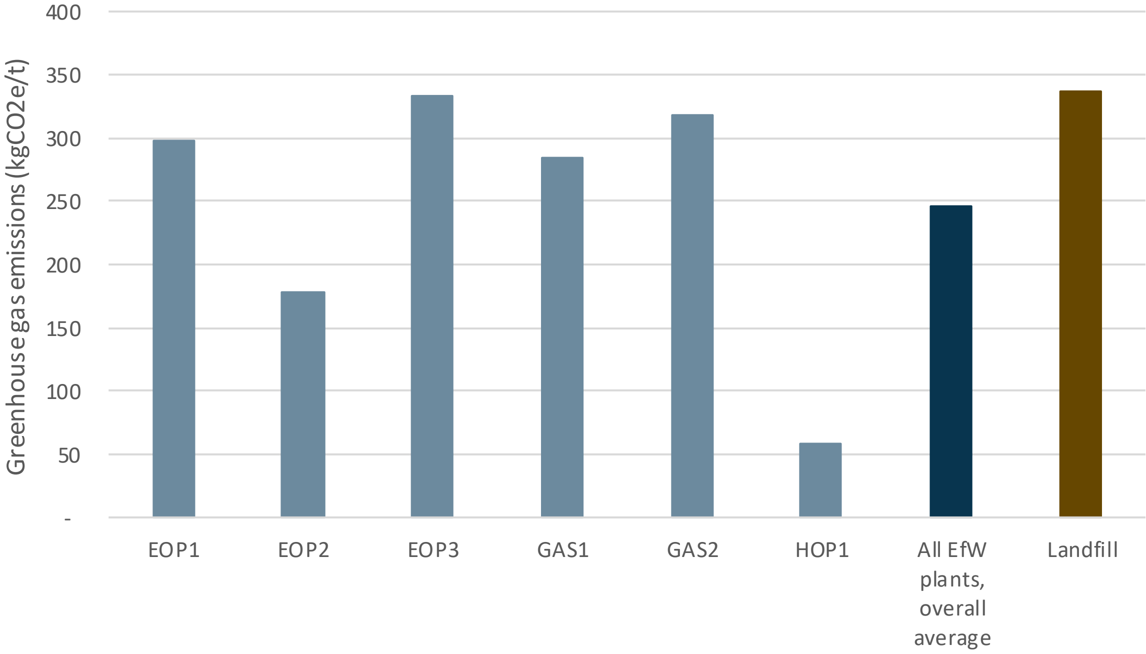
Table 4 and Figure 11 show the greenhouse gas emissions of sending one tonne of waste to waste management facilities (EfW plants and landfill) in Scotland in 2018.

Table 4. The greenhouse gas emissions of sending one tonne of residual municipal waste to waste management facilities in Scotland in 2018

Plant	Greenhouse gas emissions per tonne ($kgCO_2e/t$)
Electricity-only plant 1 (EOP1)	297
Electricity-only plant 2 (EOP2)	179
Electricity-only plant 3 (EOP3)	333
Gasifier plant 1 (GAS1)	284
Gasifier plant 2 (GAS2)	319
Heat-only plant 1 (HOP1)	58
Electricity only incinerators, weighted average	**227**
Electricity-only gasifiers, weighted average	**301**
All EfW plants, weighted average	**246** [37]
Landfill	**337**

[37] This rises to 310 kgCO2e/t if the Scottish average electricity grid factor is used instead of the UK factor.

Figure 11. The greenhouse gas emissions of sending one tonne of municipal waste to waste management facilities in Scotland in 2018



The heat-only plant has lower greenhouse gas emissions per tonne than the other plants because heat-only plants run at a higher efficiency. This means much more energy generation can be displaced by this plant – reducing the greenhouse gas emissions overall.

Two of the plants in this study, EOP1 and EOP3, have considerably higher GHG emissions per tonne than the other plants (and landfill). These were the only plants not to record any on-site pre-treatment recycling in 2018. Off-site pre-treatment may have occurred however, data on this is unavailable. At EOP2, 11% of waste brought on site was sorted for pre-treatment recycling. If pre-treatment recycling had been conducted at EOP1 and EOP3, at similar levels to this, their net greenhouse gas emissions per tonne would have been more in line with the other electricity only incinerators and gasifiers.

Table 5, Table 6 and Figure 12 show the more detailed results for the carbon factors for each waste facility, broken down by life cycle stage.

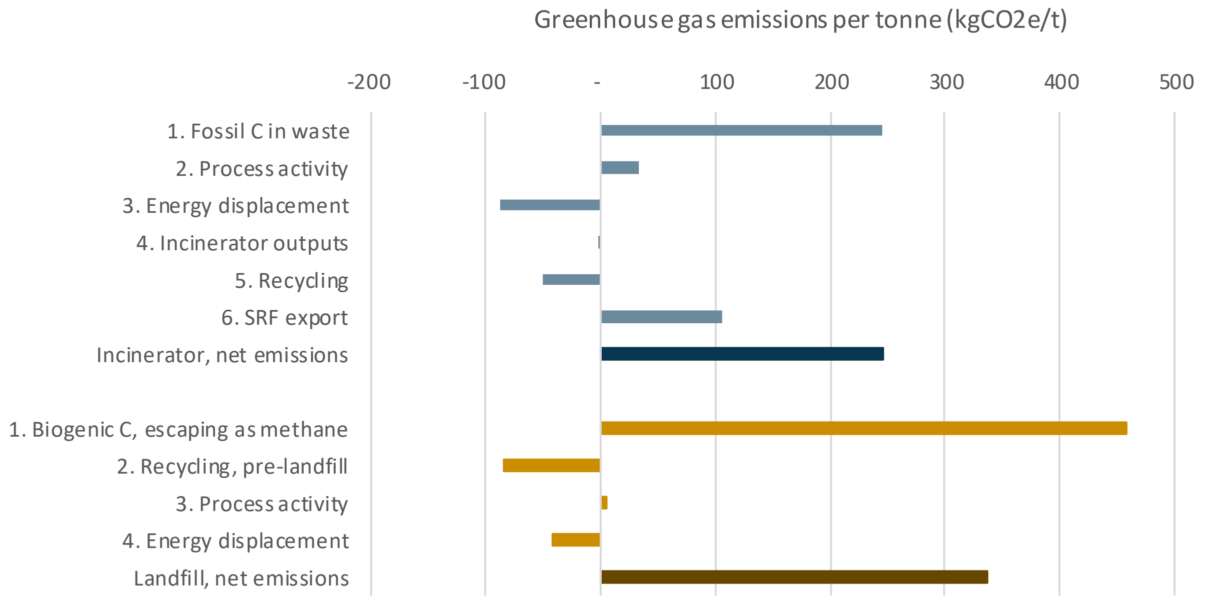
Table 5. Greenhouse gas emissions of sending one tonne of residual municipal waste to EfW plants in Scotland in 2018, by life cycle stage

Life cycle stage	Greenhouse Gas Emissions per tonne ($kgCO_2$/tonne of waste input)					
	EOP1	EOP2	EOP3	GAS1	GAS2	HOP1
1. Fossil carbon embedded in waste	412	322	412	109	67	401
2. Process activities	35	35	35	30	30	35
3. Energy displacement	-127	-101	-97	-28	-11	-334
4. Disposal of incinerator wastes	-3	0	-4	-0	0	-3
5. Recycling, including metal recovery	-20	-78	-14	-37	-57	-41
6. SRF export and burning	-	-	-	210	289	-
Net GHG emissions per tonne	**297**	**179**	**333**	**284**	**319**	**58**

Table 6. Greenhouse gas emissions of sending one tonne of residual municipal **waste to landfill in Scotland in 2018, by life cycle stage**

Life cycle stage	GHG Emissions per tonne ($kgCO_2e$/tonne)
1. Biogenic carbon embedded in waste, which escapes as methane	458
2. Materials removed for recycling, pre-landfill	- 84
3. Process Activity	5
4. Energy displacement	- 42
Net GHG emissions per tonne	**337**

Figure 12. GHG emissions of sending one tonne of residual municipal waste to incineration and landfill in Scotland in 2018



These results, along with the total tonnages sent to each waste management facility in 2018, can be used to estimate the total greenhouse gas emissions in 2018 for each facility. This is shown in Table 7. An estimated 305 kt of municipal waste was burnt in Scotland in 2018, resulting in 75 $ktCO_2e$. In addition, 1,031 kt of municipal waste was landfilled resulting in 347 $ktCO_2e$.

Table 7. The impact of disposal of residual municipal waste in Scotland in 2018

Facility	Tonnes sent to waste management facility (t)	Greenhouse gas emissions per tonne ($kgCO_2e/t$)	Total greenhouse gas emissions in 2018 (tCO_2e)
EOP1	41,284	297	12,263
EOP2	94,624	179	16,915
EOP3	16,459	333	5,473
GAS1	66,504	284	18,917
GAS2	63,355	319	20,194
HOP1	23,053	58	1,342
All EfW plants	**305,280**	**246**	**75,105**
Landfill	**1,031,467**	**337**	**347,787**

4 Sensitivity Analysis Results

4.1 Changing waste composition

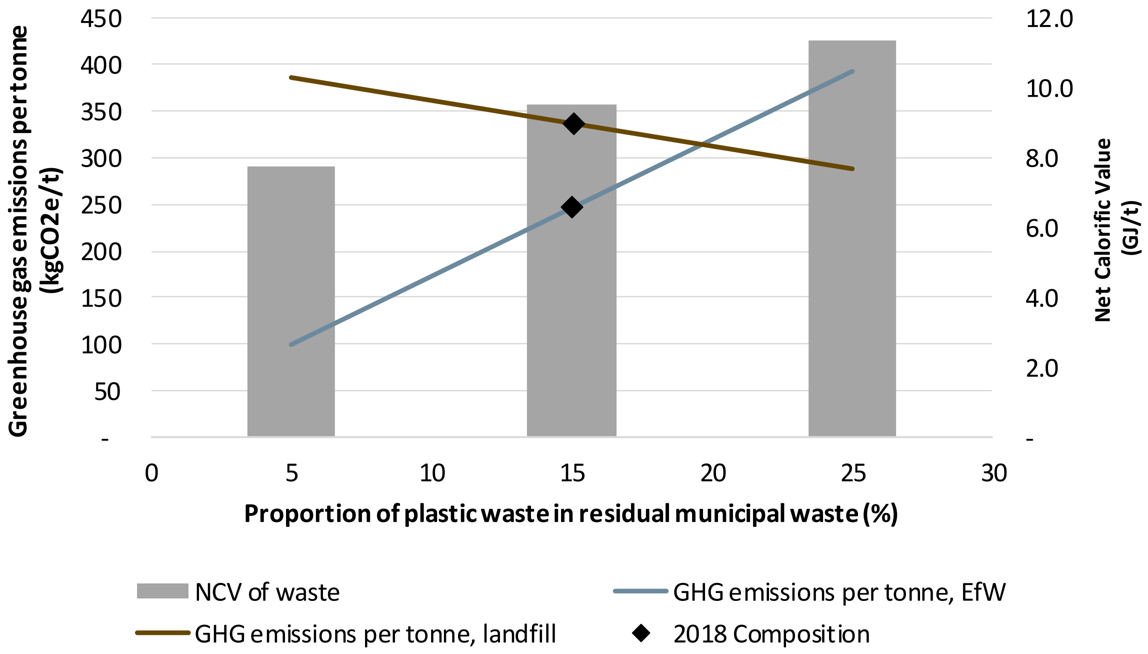
The emissions of residual municipal waste sent to both EfW and landfill is highly dependent on the composition of that waste. Waste composition is varied and changes over time. The fossil content of waste burnt is the most significant factor affecting greenhouse gas emissions per tonne of EfW plants. For landfill, the most significant factor is the biogenic content of waste entering landfill. In this sensitivity analysis, the fossil and biogenic content of waste was varied by changing the composition of waste materials with high fossil and biogenic carbon content. The results are shown in the change in greenhouse gas emissions and net calorific value (NCV) of waste. The NCV of waste is of interest to EfW plant operators as this is a key measure of the efficiency of burning waste as a fuel – the higher the NCV, the more energy can be generated.

In the main study, plastic wastes, which comprised 15% of residual municipal waste, has a NCV of 9.5 GJ/t and makes up 69% of its fossil carbon content.

As shown in

Figure 13, if the proportion of plastic in residual municipal waste increases, the greenhouse gas emissions of EfW rise. This is because more fossil carbon would be burnt and released into the atmosphere, contributing to climate change. NCV also rises because there is more carbon to burn and release energy from. Landfill emissions fall as plastic content rises, as all fossil carbon is stored in landfill. EfW and landfill impacts are equal when the proportion of plastic in residual municipal waste is increased from the main model assumptions by 4.6% from 15.0% to 19.6%.

Figure 13. Varying the proportion of plastic waste in residual municipal waste composition changes the net calorific value (NCV) and greenhouse gas (GHG) emissions of EfW and landfill

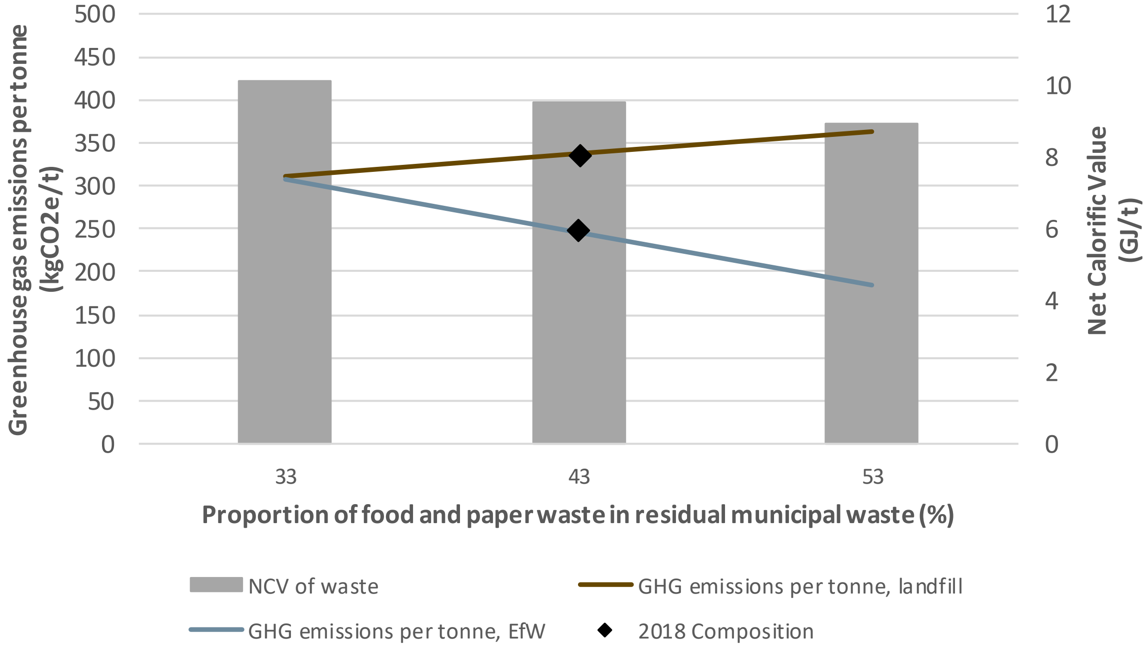


In the main study, most of the biogenic carbon is found in two waste categories: food waste and paper and cardboard waste. Together these categories compromised 43% of the mass and 59% of the biogenic carbon of residual municipal waste.

As shown in Figure 1

Figure 134, if the proportion of food and paper waste in residual municipal waste decreases, the greenhouse gas emissions of landfill falls. This is because removing biogenic carbon from landfilled waste reduces the amount which anaerobically degrades and escapes as methane, contributing to climate change. The figure shows EfW greenhouse gas emissions increase with the removal of biogenic content as each tonne of waste contains proportionally more fossil content. Landfill and EfW impacts are equal when the proportion of food and paper waste in residual municipal waste falls from the main model assumptions by 10.4% from 43.1% to 32.7%.

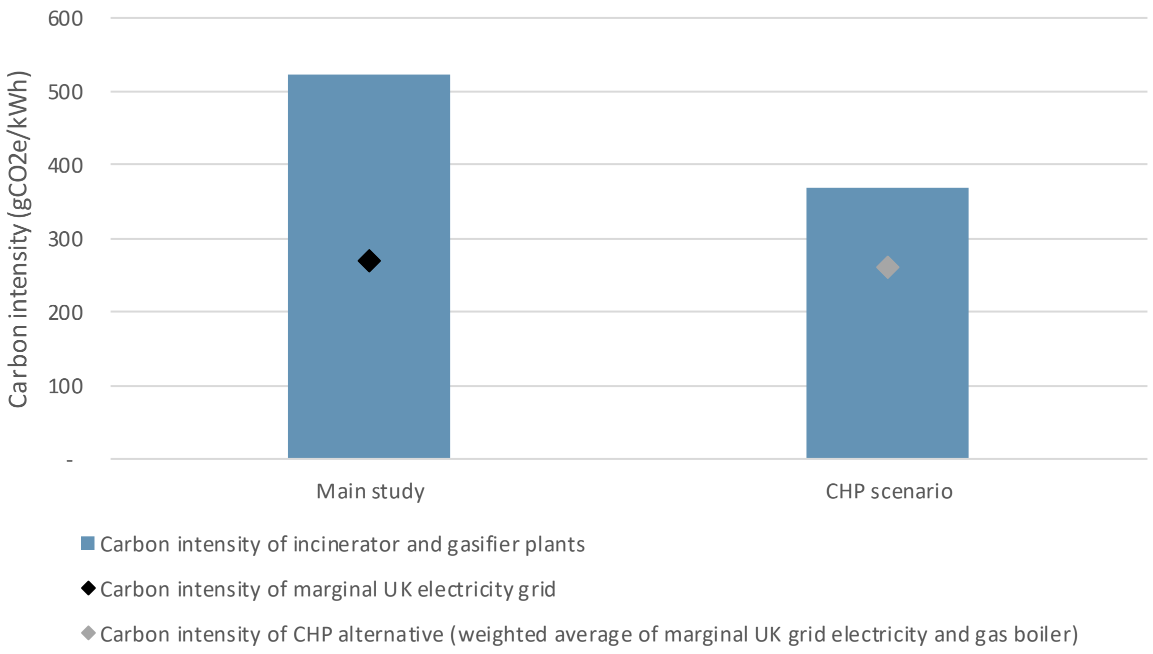
Figure 14. Varying the proportion of food and paper waste in residual municipal waste composition changes the greenhouse gas (GHG) emissions of landfill and EfW



4.2 Technological solutions to residual waste management

The carbon intensity of electricity-only incinerators and gasifiers was modified to understand how conversion to CHP plants would affect their climate change impacts. Figure 15 shows the results of this analysis. The average carbon intensity of EfW plants was reduced by 30% but not below the carbon intensity of alternatives.

Figure 15. Converting to CHP systems lowers the carbon intensity of EfW plants



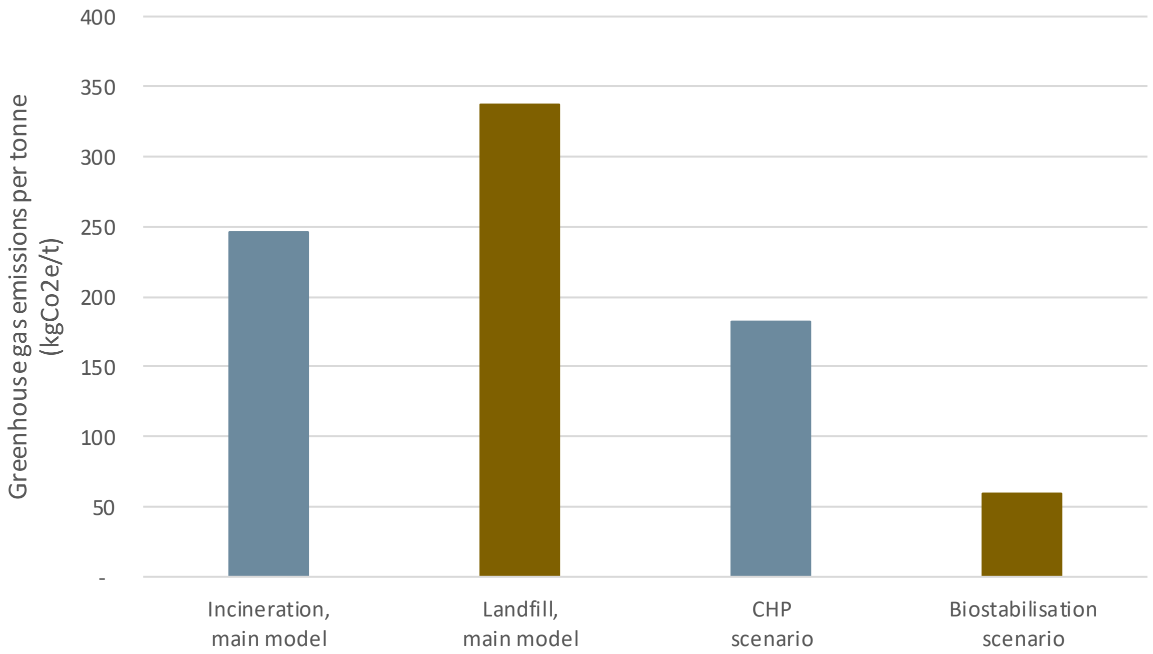
HOP1, the only heat-only incinerator taking municipal waste in Scotland, is not considered in this sensitivity analysis. The carbon intensity of HOP1 is 325 gCO_2/kWh. This is higher than the carbon intensity for heat generated from a central or small-scale natural gas plant for heat operating in the UK in 2018, which is 267 gCO_2/kWh[38].

Changing to a CHP scenario reduces the net greenhouse gas emissions of EfW plants, as well as the carbon intensity. The net carbon impact of the plants fall as more energy displaces energy generation. This is shown in Figure 16.

Figure 16 also shows a comparison to the potential savings from reducing biodegradable material to landfill. This could be achieved using biostabilisation. If levels of biogenic carbon can be reduced from 15% to 5% of residual municipal waste, landfill impacts would fall from 337 kgCO_2e/t to 59 kgCO_2e/t. As discussed above, this report recognises that, as the biostabilised waste output of such operations would still be required to pay the active landfill tax rate, such plants are not currently financially viable in Scotland. More detailed analysis is required to understand the full potential of this technology considering its potential to reduce the carbon impacts of residual waste.

[38] From Ecoinvent V3, "Heat, central or small-scale, natural gas {Europe without Switzerland}| market for heat, central or small-scale, natural gas | Cut-off, U", year of calculation is 2018, method is IPCC GWP 2013 100a

Figure 16. Converting to CHP or biostabilisation technologies lowers the GHG emissions of waste management facilities

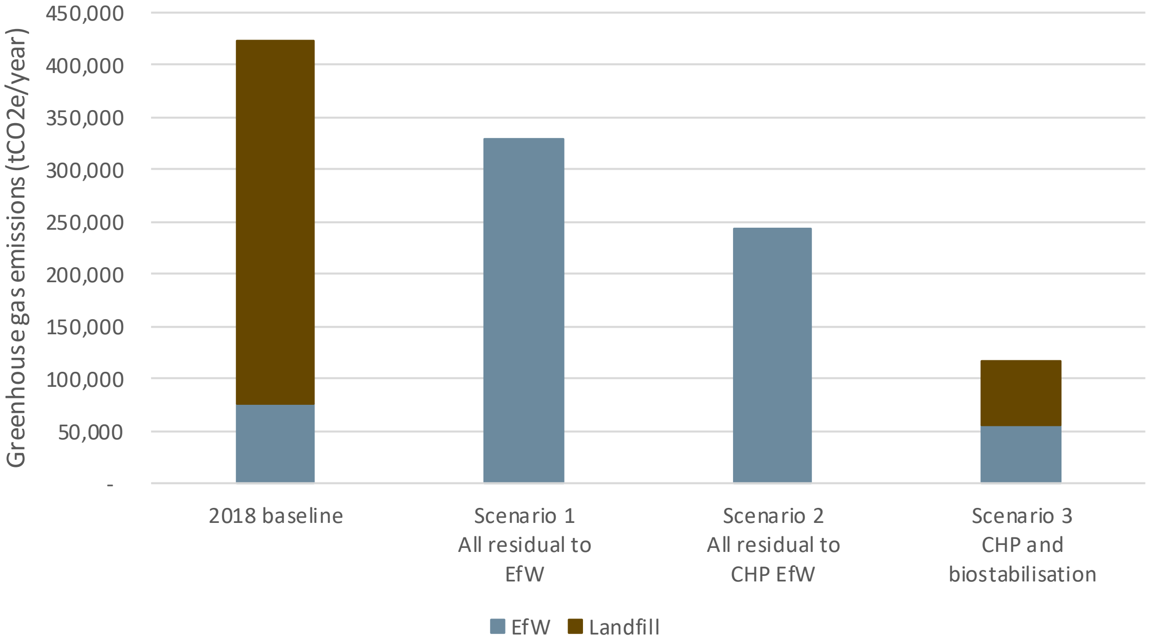


4.3 Meeting the BMW landfill ban

The Scottish biodegradable municipal waste (BMW) ban is due to come into force in 2025. Figure 17 below shows the greenhouse gas emissions of three ways in which this ban could be met:

- Scenario 1: incinerate all waste in facilities which operate 2018 efficiency levels;
- Scenario 2: incinerate all waste in facilities which operate as CHPs; or
- Scenario 3: upgrade all incinerators to CHPs and pre-treat waste sent to landfill with biostabilisation (the tonnage split between incineration and landfill remains at 2018 levels).

Figure 17. The estimated annual greenhouse gas impacts of three scenarios for meeting the BMW ban for 2018



In 2018, the estimated greenhouse gas emissions from managing residual municipal waste in Scotland were 422,892 tCO_2e (2018 baseline scenario in Figure 17). If all waste was sent to electricity-only incineration plants (Scenario 1), the emissions would be lowered by 22% to 328,865 tCO_2e. If all waste was sent to CHP plants instead (Scenario 2), the emissions would fall further (42% below the 2018 baseline) to 243,573 tCO_2e. If existing operational incinerators were upgraded to CHPs and biostabilisation pre-treatment added to landfill (Scenario 3), much lower emissions are possible. The annual greenhouse gas emissions from managing residual waste could be reduced by 72% to 116,926 tCO_2e.

The greenhouse gas emissions from biostabilisation are illustrative only and further, more detailed research is required to understand this scenario more fully.

5 Data gaps

There are several gaps in the data and analysis for this study which should be highlighted. The areas of greatest uncertainty are listed below:

1. The **composition of residual municipal waste** is variable and changing. Scottish residual municipal waste composition is estimated annually based on a composition analysis by Zero Waste Scotland of household waste at the kerbside, last conducted in 2014-15[39] and annual figures on waste generated published by SEPA. The composition of waste will change year to year as consumption habits, waste policies and waste management practices evolve. All these factors contribute to gaps in our understanding of the composition of waste. The significance of this has been partly explored in the sensitivity analysis above. An update to the waste composition analysis study, tailored to the requirements of this study, would reduce uncertainty.

2. The **destination of the waste** entering the EfW site is also a source of uncertainty. Waste that enters an EfW site may arrive pre-sorted (public data on off-site pre-treatment is currently unavailable), or be sorted on-site for recycling, incineration or rejected from both sorting and incineration, in which case it is landfilled. Most of the waste is burnt but exact volumes are not known. The fate of waste items which are difficult to recycle or incinerate, such as mattresses, is unknown. Using a basic industry assumption[40] and site return data on material entering the site, the model calculates that most material (about 90%) entering sites is burnt (excluding gasifiers which also produce SRF). SEPA is in discussions with plant operators about collecting more detailed data in the future. This uncertainty around sorting means there is also a lack of transparency on the exact composition of waste being incinerated.

3. Data on the **energy outputs of EfW plants, and thus energy displacement,** are based on PPC permits, rather than annualised energy data or NCV. These permits state the theoretical maximum energy outputs the plants would achieve, operating at maximum capacity. These energy outputs have been scaled down to the waste input levels given for 2018. However, this assumes maximum energy outputs are achievable, and a linear relationship between waste inputs and energy outputs. Measurements of actual energy outputs would give a more accurate understanding of the inputs and outputs of EfWs in Scotland. It is possible to calculate energy displaced from NCV. However, plant reported energy outputs were considered a more certain starting point energy displacement calculations than waste composition estimates. Finally, annual outputs for 2018 may not be representative of future outputs. As such, this report provides the carbon performance comparison at one point in time.

4. Data on **the operation of biostabilisation plants in the UK context** is poorly understood. Zero Waste Scotland have commissioned a research project to understand the role biostabilisation in Scotland in greater detail.

The amount and type of material recycled from residual municipal waste sent to landfill is estimated from site returns data from a representative landfill site. This is the best resource currently available. SEPA are planning updates to their waste publications in 2021 which could be used to improve this.

There are some simplifications in the model. For example, nitrous oxide (N_2O) is a powerful greenhouse gas but emissions from modern EfW plants have been reduced to almost nothing, so this was also excluded from the analysis.

[39] Zero Waste Scotland (2017) The composition of household waste at the kerbside in 2014-15
[40] Tolvik (2019) UK Energy from Waste Statistics for 2018

The model and results of the sensitivity analysis allows users to assess the importance of the main variables. There are planned improvements to the underlying datasets. It is therefore concluded that this study is a strong evidence base for considering the position of EfW in the waste hierarchy.

6 Conclusion

This study quantifies the climate change impacts of burning residual municipal waste in EfW plants in Scotland in 2018. It focuses on two measures: carbon intensity and greenhouse gas emissions using a lifecycle approach. The results show that the carbon intensity of burning waste in EfW plants was 509 gCO_2e/kWh in 2018. This is nearly twice the carbon intensity of UK marginal electricity generation in 2018, which has fallen considerably in recent years due to successful decarbonisation practices. Converting existing electricity-only plants to CHP systems would lower the carbon intensity and greenhouse gas emissions of electricity-only incinerators and gasifiers. However, even if these plants were operating as CHP systems, their carbon intensities would still be higher than that of the heat and electricity they displace. As a result, EfW can no longer be considered a source of low carbon energy.

EfW greenhouse gas emissions per tonne of waste averaged 246 kgCO_2e/t, which was 27% less than landfill. The single heat-only plant in Scotland had considerably lower impacts than the other EfW plants because it operated at a higher energy efficiency. EfW pre-treatment removal of recyclate had a significant carbon saving, where it is conducted.

The greenhouse gas emissions from both EfW and landfill are highly dependent on the composition of waste, which is variable and changing over time. If the fossil carbon in waste increases, the net calorific value of waste as a fuel rises but so too do the EfW greenhouse gas emissions. If the biogenic carbon in waste increases, landfill impacts rise.

Three scenarios for meeting the BWM ban to landfill have shown that this ban will reduce Scotland's greenhouse gas emissions from waste compared to 2018 levels. The technologies which could be deployed to meet this ban offer different levels of carbon savings. The large potential savings from biostabilisation indicate this option warrants further consideration.

The significance and variability of key parameters such as the composition of waste and the decarbonisation of the grid, illustrate the importance of regularly updating the evidence base for this subject area. Whilst there are uncertainties in the approach taken in this study, it is robust enough to draw evidence-based conclusions. The findings of this report can be used to explore and inform future waste management choices to ensure climate change impacts from waste are minimised.

Annex 1: Record of Changes

No.	Description	Explanation	Impact of change on main results
1.1	Added landfill engine efficiency to energy displacement calculations in GHG emissions analysis. After consultation with SEPA and Ricardo landfill experts, the engine efficiency of 36% was used. This is the same as the figure used in the MelMod 2018 Inventory Scotland. The methodology and figures in the results section have been updated to reflect this change.	This parameter was erroneously excluded from the original analysis.	The addition of engine efficiency has reduced total energy produced by landfill gas engines. As a result, the landfill GHG emissions factor has increased from 259 kgCO2e/t to 337 $kgCO_2e/t$.
1.2	Engine efficiency was also added to the energy displacement of SRF exported by the gasifier plants. The methodology and results sections of the report have been updated to reflect this change.	This parameter was erroneously excluded from the original GHG emissions per tonne of waste analysis (although not from the carbon intensity calculation). The factors used are the plant efficiency factors quoted by individual plants in their heat and power plans. The calculations for the impact of burning SRF were also updated with an engine efficiency. 35%[41] was used, reflecting the high number of R1 EfW plants in UK (the main export location).	The average EfW GHG emissions factor per tonne of waste increased from 219 $kgCO_2e/t$ to 246 $kgCO_2e/t$ when engine efficiency is added to gasifiers. Individual plant factors changed for both gasifier plants too.
1.3	Added biogenic carbon analysis to the sensitivity analysis.	Illustrates the effects of changing biogenic content of waste on waste management emissions.	None. Additional information.
1.4	Added units to equations.	Aids understanding of methodology.	None.
1.5	Updated Table 2, Figure 9 and some related figures in text.	Waste composition figures presented were from an old source, not used in the model. These have been replaced with the correct figures.	None.

[41] SEPA (2014) Thermal Treatment of Waste Guidelines 2014