The climate change impacts of burning municipal waste in Scotland

Summary Report

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Report Documentation

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 in the Technical 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 in the Technical Report for more details.

1 Introduction

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 of the EfW plants and allows a comparison with 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.

This report summarises findings from a study which calculated the climate change impacts of burning residual municipal waste in Energy from Waste (EfW) plants in Scotland in 2018. The technical report describing the methodology and results in detail are available on the Zero Waste Scotland website. This report summarises the methodology, main results and the sensitivity analysis.

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 only started operating in this year. 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.

Climate change is not the only consideration when assessing the impacts of waste management. 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 findings of this study can be used to take advantage of significant opportunities to reduce the climate change impacts of waste.

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. Waste from non-municipal sources is subject to separate regulations and 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[2], CHP potential, operating as electricity-only
MVV, Baldovie Industrial Estate, Dundee	Fluidised bed incinerator	110,000	94,624	Operational[1], CHP potential, operating as electricity-only
Millerhill Energy Recovery Centre, Edinburgh	Moving grate incinerator	195,000	16,459[3]	begun operations in 2018[2], CHP potential, operating as electricity-only
Glasgow Recycling and Renewable Energy Centre (GRREC), Glasgow	MRF[3], AD[4] 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**	

The remaining eight operational EfW plants in Scotland in 2018 processed commercial and industrial waste.

Three additional EfW plants which plan to take municipal waste are currently in construction. These are all expected to be operational by 2022. They will add 708,000 tonnes per year capacity to create a total potential capacity of 1.7 million tonnes per year of municipal residual waste by 2025.

[1] Fires at the Dundee plant in 2018 meant that it was not able to operate for part of the year.
[2] The Dunbar, Millerhill, GRREC and Levenseat facilities all begun operating in 2018 and their operations were scaled up over time, which is why inputs in 2018 were well below capacity. They were mostly expected to be running close to capacity from 2019.
[3] 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.
[4] Anaerobic Digestion (AD) is the treatment of organic feedstock for energy or heat recovery.

2 Methodology

The full methodology used to calculate the carbon intensity and greenhouse gas emissions of the six municipal waste burning EfW facilities operating in Scotland in 2018 is described in the technical report. An overview of the methodology is given below.

2.1 The carbon content of waste

A tonne of residual municipal waste will contain waste which is derived from either fossil carbon (such as plastic), biogenic carbon (such as food waste), inert material (such as metal) or a combination of materials (such as textiles). Biogenic and fossil carbon are counted differently in international climate change reporting guidance. When waste is burnt in an EfW plant, all the carbon is released into the atmosphere immediately: 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 some of which will escape into the atmosphere as methane and contribute to climate change. 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. So, the carbon content of residual municipal waste is a critical parameter in this study.

The composition of waste used in this study is based on the most recent national (2017)[5] waste composition analysis. The biogenic and fossil content of each waste material was based on the assumptions used in a DEFRA (2014) EfW and landfill comparison study[6]. Using these datasets, this study has estimated that one tonne of residual municipal waste in Scotland in 2018 contained 11% fossil carbon and 15% biogenic carbon.

2.2 The carbon intensity of EfW plants

Carbon intensity measures the greenhouse gas (GHG) emissions generated per unit of power generated. 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 (i.e. their ability to convert potential energy into productive energy).

The fossil carbon content of waste is based on the datasets described in Section 2.1 above. The NCV and plant efficiency figures for each plant were taken from their respective Heat and Power Plans[7]. The average NCV was 9.5 GJ/t for the electricity-only incinerators included in this study, and 12.1 GJ/t for the two gasifiers. The average NCV for UK municipal waste in 2018 was 8.9 GJ/t[8]. Plant efficiency averaged 25% for the electric-only plants and 50% for the heat-only plant. These efficiency figures are based on those provided by plant operators in their pre-commissioning Heat and Power plans assuming optimal conditions; they may not reflect actual operational efficiency. The carbon intensity of each EfW plant was calculated and compared to the marginal electricity grid in the UK.

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[5] Zero Waste Scotland (2017) The composition of household waste at the kerbside in 2014-15
[6] DEFRA (2014) Energy recovery for residual waste
[7] 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
[8] Tolvik (2019) UK Energy from Waste Statistics for 2018

2.3 Greenhouse gas emissions of EfW plants and landfill

The methodology for estimating the net carbon emissions generated per tonne of waste burnt for each facility is based on Life Cycle Analysis. This is an internationally recognised approach for measuring and comparing environmental impacts by calculating the emissions and savings of each stages of a process. All emissions and savings from activities from the incinerator gate to final disposal or recycling of materials are included in the assessment.

The EfW process was divided into six life cycle stages:

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

The landfill process was divided into four stages:

1. Emissions from biogenic carbon embedded in waste which escapes as methane;
2. Emissions from sorting and recycling of waste, based on a representative landfill site, including avoided production;
3. Process emissions (transport, sorting and auxiliary inputs to landfill); and
4. Emissions avoided from energy displacement.

The impacts of these stages were calculated and combined to give the net greenhouse gas emissions of each waste management process.

The results of both the carbon intensity and greenhouse gas emissions were anonymised to maintain a focus on the national level, rather than that of individual plants. The methodology is described in more detail in the technical report.

2.4 Sensitivity Analysis methodology

Changing the waste composition

The model in this study is built on assumptions about the 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. The composition of waste is variable and changes over time. So, this sensitivity analysis explored the effect that changes in composition of materials with high fossil and biogenic carbon content would have on the net emissions from waste management options.

The composition of plastic (which has a high fossil carbon content) and food and paper and cardboard waste (which has a high biogenic content) were varied by +/- 10%.

2.5 Scenario Analysis

Technological solutions to residual waste management

Combined Heat and Power (CHP) systems are power plants which convert energy into 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"[9]. All the incinerators and gasifier plants burning residual municipal waste in Scotland in

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

2018 operate as electricity-only plants, except HOP1 which was built and operates as a heat-only plant. The electricity-only plants were all designed as CHP plants[10]. The main model was adjusted to show how converting to CHP systems may change their carbon intensity. Plant efficiency increased from an average of 25% in the main model, to 36%.

Scotland is introducing a ban on landfilling Biodegradable Municipal Waste (BMW) in 2025. The primary purpose of this ban is to decrease greenhouse gas emissions from landfill by removing biodegradable content[11]. Three scenarios for meeting the BMW landfill ban were developed and their greenhouse gas emissions compared:

- 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 GHG emissions.
- 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 biodegradability prior to landfill. The biostabilisation stage is assumed to reduce the biogenic carbon in waste entering landfill from 15% to 5%[12].

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 and improved recycling, for example.

3 Main Results

Burning residual municipal waste in EfW plants in Scotland in 2018, had an average carbon intensity of 509 gCO_2/kWh. The average carbon intensity for electricity-only incinerators and gasifiers burning was 524 gCO_2/kWh. This is nearly twice as high as the average carbon intensity of the marginal electricity grid in the UK, which was 270 gCO_2/kWh in 2018[13] (Figure 1).

The carbon intensity of the only heat-only incinerator operating in Scotland in 2018 was 325 gCO_2/kWh, reflecting its higher plant efficiency, although this was still higher the heat carbon intensity for central or small-scale natural gas plant operating in the UK in 2018 (267 gCO_2/kWh).

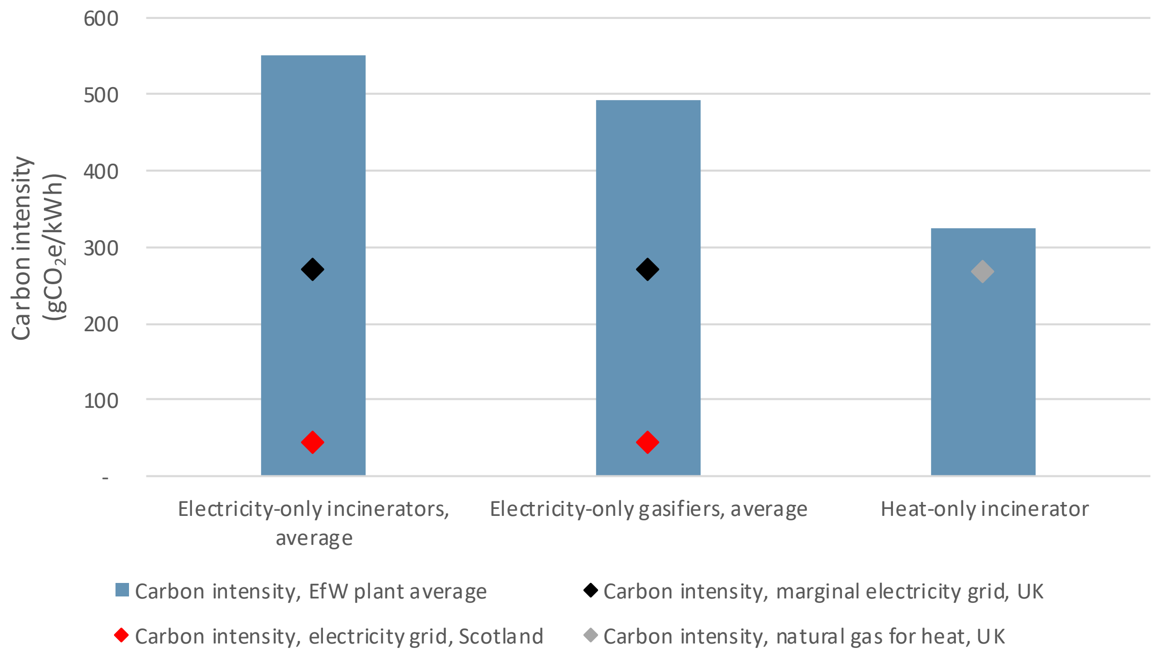
[10] Plans to realise CHP potential are underway at some Scottish electricity-only plants.

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

[12] This is in line with scientifically peer reviewed estimates of the potential savings from biostabilisation. 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.

[13] The Scottish grid factor in 2018 was 44 gCO2e/kwh. Taken from Scottish Government (2020) Scottish Energy Statistics Hub, Average greenhouse gas emissions per kilowatt hour of electricity.

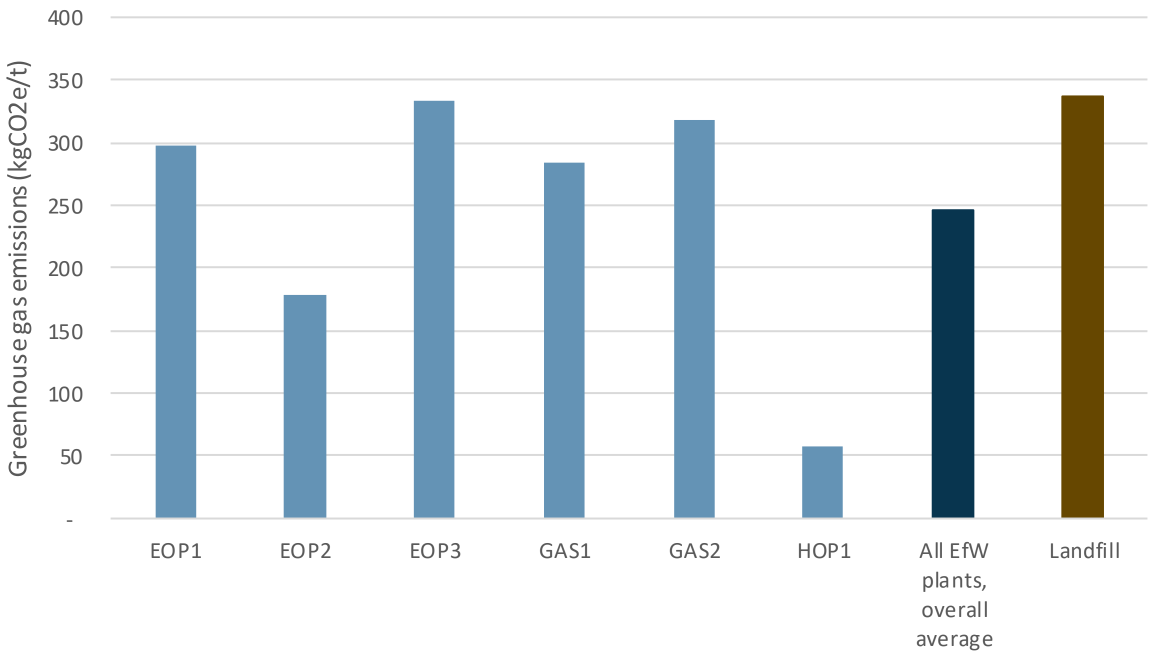
Figure 1. The carbon intensity of EfW plants taking municipal waste in Scotland in 2018



On average, sending one tonne of municipal waste to EfW in Scotland in 2018 emitted 246 kgCO2e/t, which is 27% less than sending it to landfill (

Figure 2). The results for greenhouse gas emissions per tonne of waste differ considerably for each plant. This is largely due to variability in plant performance and NCV figures provided in their heat and power plans, which are key data sources in this study, and which may be different from actual operational performance.

Figure 2. The greenhouse gas emissions of sending one tonne of municipal waste to waste management facilities in Scotland in 2018

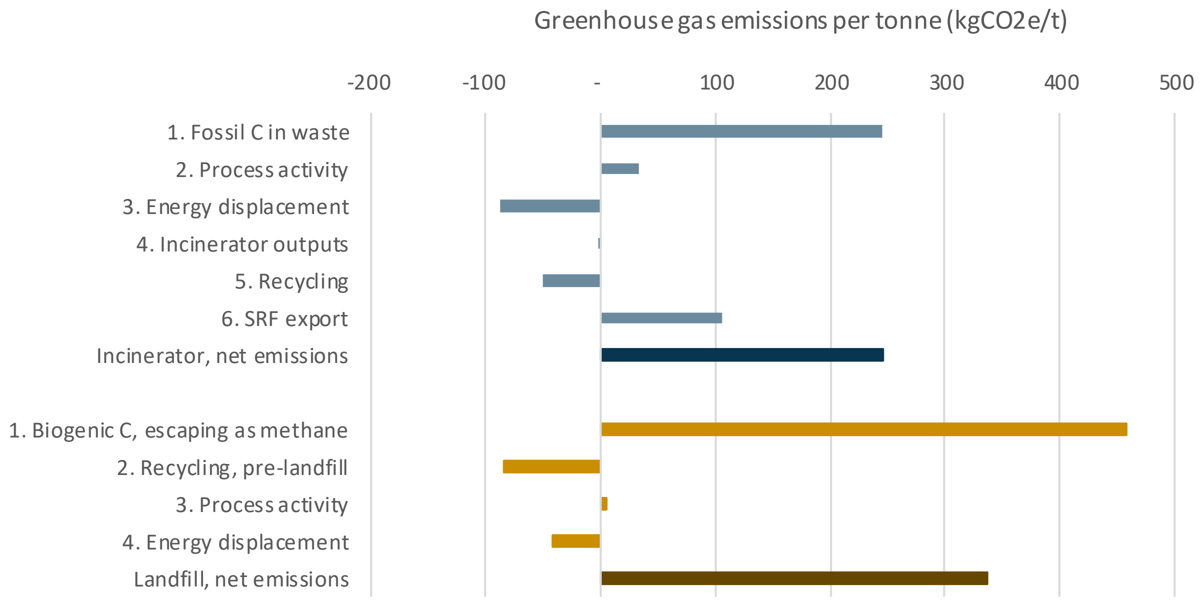


HOP1, the heat-only EfW plant, has lower greenhouse gas emissions per tonne than the other EfW plants because heat-only plants run at a higher efficiency (usually around 50%, compared to 25%). This means more energy generation can be displaced – reducing the net greenhouse gas emissions per tonne.

Two of the plants in this study, EOP1 and EOP3, have considerably higher GHG emissions per tonne than the other plants. These were the only plants not to record any on-site pre-treatment recycling in 2018. Pre-treatment may have occurred offsite, 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.

Figure 3 shows the average greenhouse gas emissions for each stage of the EfW and landfill processes.

Figure 3. Greenhouse gas emissions of sending one tonne of waste to EfW or landfill in Scotland in 2018, by life cycle stage



The greenhouse gas emissions per tonne can be combined with the total residual municipal tonnages sent to each waste management facility to estimate the total greenhouse gas emissions for a given year. 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 347 ktCO_2e[14].

4 Sensitivity Analysis Results

The sensitivity analysis explored two variables: the composition of waste and the potential of technological solutions to lower greenhouse gas emissions of residual municipal waste. The results show that changes in waste composition and technology can considerably alter the climate change impacts of waste management. The results imply that long-term infrastructure and policy decisions should be based on the most current and accurate data possible, regularly reviewed to ensure climate change impacts are minimised.

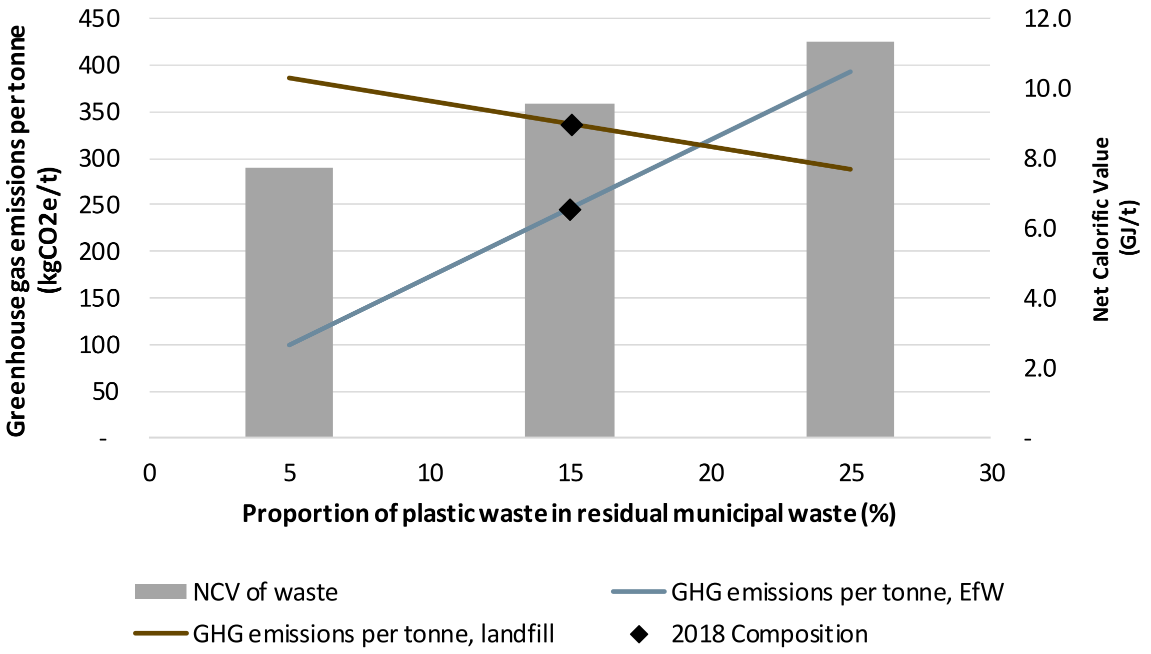
4.1 Changing the composition of waste

The greenhouse gas 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 is the most significant factor affecting greenhouse gas emissions of waste burnt in EfW plants. For landfill, the most significant factor is the biogenic content of waste. In this sensitivity analysis, the fossil and biogenic content of waste was varied by changing the composition of residual municipal waste, assuming concentrations of all other waste increase proportionately. Waste categories with high fossil carbon content (plastic waste) and biogenic carbon content (food and paper waste) were varied.

[14] Emissions from EfW are immediate and occur as a result of combustion, whereas emissions from landfill can occur over multiple years as organic matter breaks down.

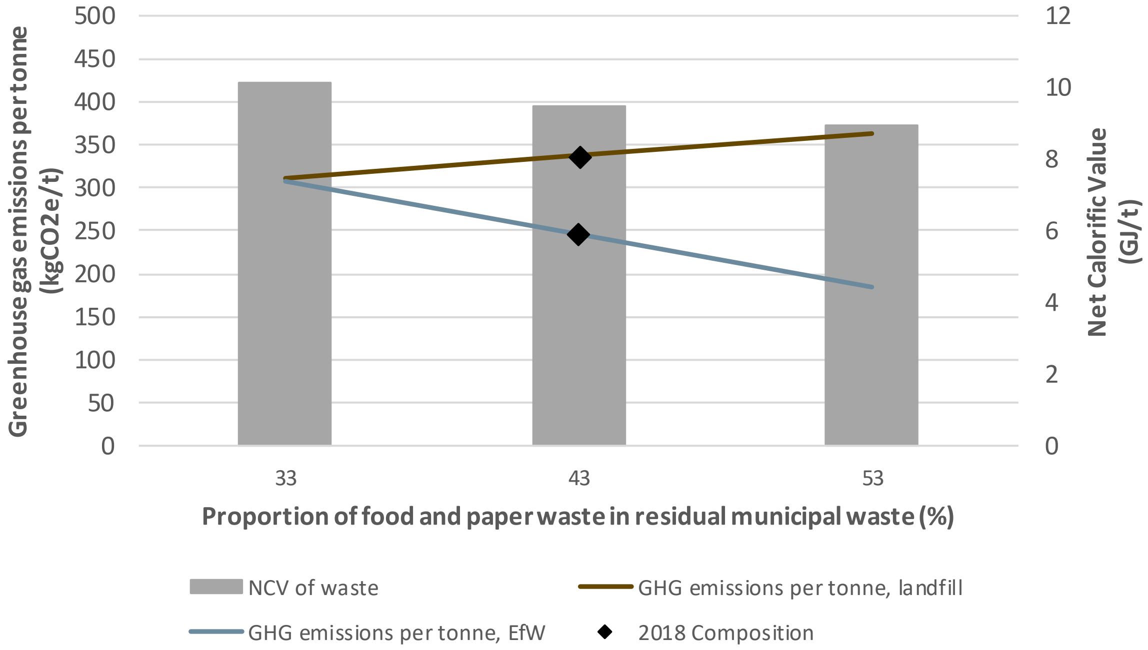
As shown in Figure 4, if the proportion of plastic in residual municipal waste increases, the greenhouse gas emissions of EfW increases. This is because more fossil carbon would be burnt and released into the atmosphere, contributing to climate change. NCV also increases as there is more carbon to burn and release energy from. Landfill emissions fall as plastic content increases (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 4. Varying the proportion of plastic in residual municipal waste composition changes the Net Calorific Value (NCV) and GHG emissions of EfW and landfill



As shown in Figure 5, 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. 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%.

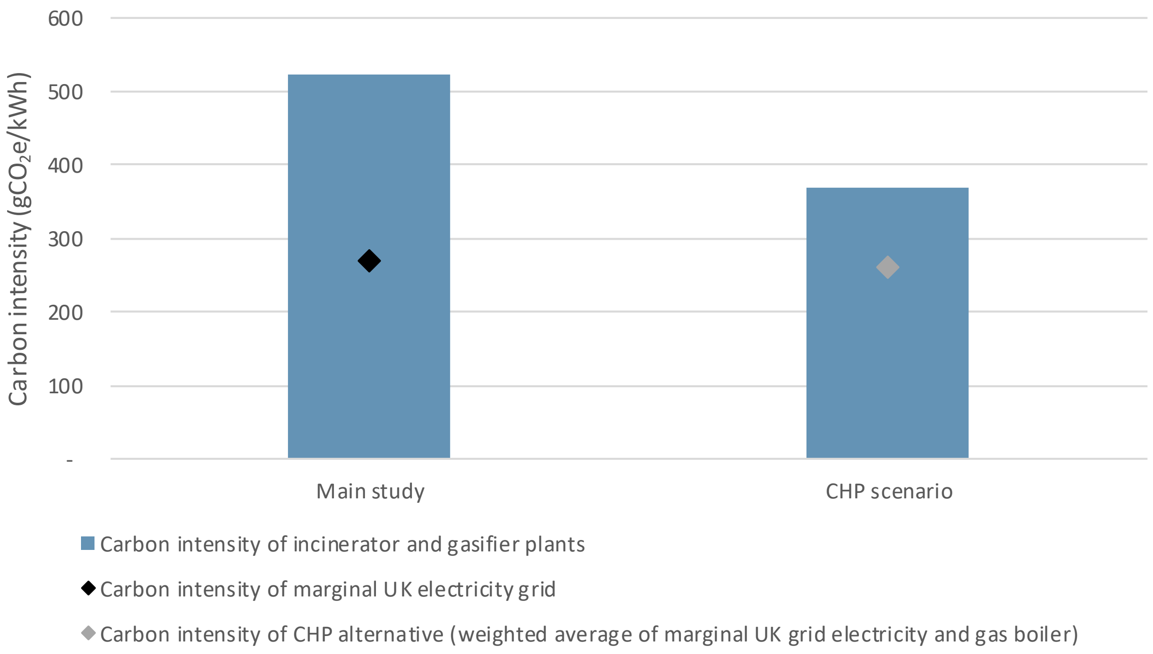
Figure 5. Varying the proportion of food and paper waste in residual municipal waste composition changes the greenhouse gas (GHG) emissions of landfill and EfW



4.2 Scenario analysis of residual waste management solutions

The carbon intensity of electricity-only incinerators and gasifiers was modified to understand how conversion to CHP plants would affect their climate change impacts. The average carbon intensity of EfW plants was reduced by 30% but not below the carbon intensity of alternatives energy generation sources (Figure 6).

Figure 6. Change in carbon intensity when EfW plants are converted to CHP systems



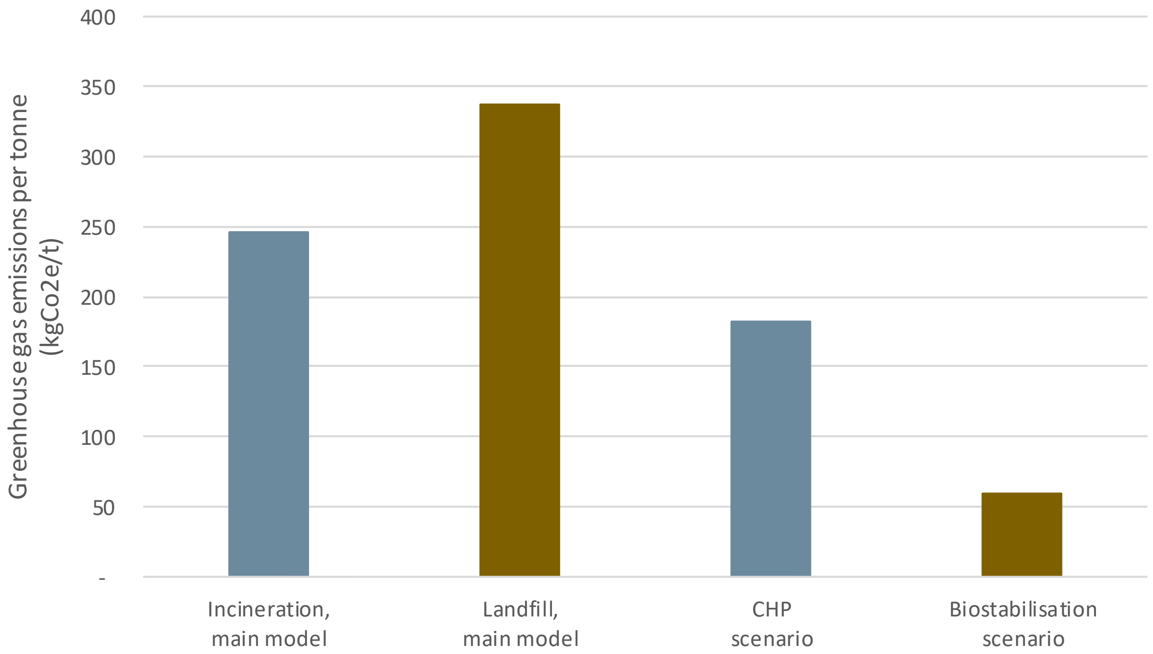
HOP1, the only heat-only incinerator taking municipal waste in Scotland, is not considered in this sensitivity analysis. The carbon intensity of HOP1 is 325 gCO_2/kWh. This is higher the heat factor for central or small-scale natural gas plant operating in the UK in 2018, which is 267 gCO_2/kWh[15].

Changing to a CHP scenario reduces the net greenhouse gas emissions of EfW plants, as well as it's carbon intensity. Net emissions per unit of energy generated, and per unit of waste input, fall as more energy displaces alternative energy generation (Figure 7).

Figure 7 also shows a comparison to greenhouse gas emissions from reducing biodegradable material to landfill. Biostabilisation, in accordance with the Waste (Scotland) Regulations, is a potential option. 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. This report recognises that biostabilisation faces technical, legal and financial barriers[16] which would need to be addressed to make the technology viable within the Scottish context. More detailed analysis is required to understand the full potential of this technology considering its potential to reduce the carbon impacts of residual waste.

[15] 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
[16] Biostabilised waste is currently subject to the full active landfill tax rate, and as such, plants are not currently financially viable in Scotland

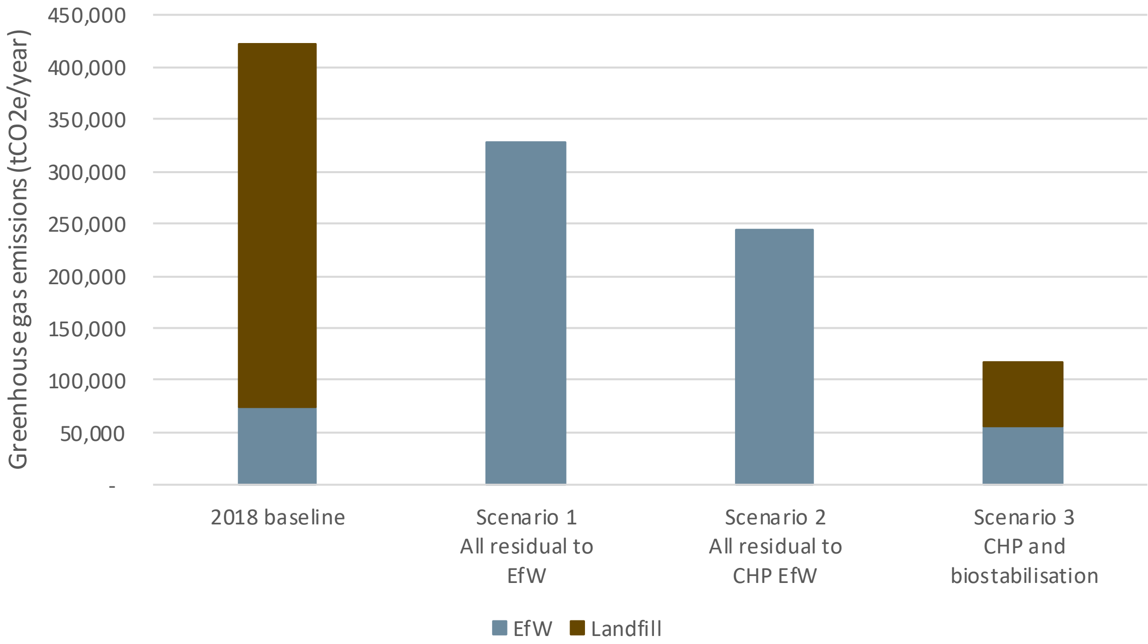
Figure 7. Impact on greenhouse gas emission per tonne of waste of converting EfW plants to CHP or adding a biostabilisation pre-treatment step to landfill



The ban on landfilling biodegradable municipal waste (BMW) in Scotland is due to come into force in 2025. Figure 8 below shows the greenhouse gas impacts of three potential scenarios for how 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 8. 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 8). 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 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 biostabilisation scenario in this study is illustrative only and further, more detailed research is required to understand the environmental impacts of this scenario more fully. The study notes the financial and legal barriers to investing in this technology in Scotland and that there are no reference plants to compare against. This scenario is included here as recognition that there are other potential technological choices for residual waste that have been shown to be a lower carbon option for residual waste disposal.

5 Data gaps

There are several gaps in the data and analysis for this study which should be highlighted. There are planned improvements to the underlying datasets, which will be acknowledged and addressed in any future versions of this study. Despite these limitations, the current study results and conclusions are a valuable new evidence base for decision making today.

The areas of greatest uncertainty are listed below:

- The **composition of residual municipal waste** is variable and changes with the origins of municipal waste and waste collection services;

- The **onward destination of the waste** entering the EfW site is not documented in enough detail to be modelled currently; and

- Data on the **energy outputs of EfW plants, and thus energy displacement,** are based on the plants published Heat and Power Plans rather than annualised energy data or NCV.

- Data on **the operation of biostabilisation plants in the UK context** is poorly understood.

There are some simplifications in the model. For example, landfill emits methane over a much longer period than EfW releases carbon dioxide. This means the model is likely to overestimate the relative impact of landfill.

There are planned improvements to the underlying datasets, which will be acknowledged in any future versions of this study. Despite these limitations, the current study results and conclusions are a valuable new evidence base for decision making today.

6 Conclusion

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

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. Policy measures such as increased separate collection of organic wastes, Deposit Return Scheme, Extended Producer Responsibility, Single-Use Plastics Directive as well as improved sorting to remove plastics will change the waste stream over time but more drastic action is needed to reduce the fossil carbon in the residual waste stream if the emissions from EfW are to be reduced.

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 lower their carbon intensity but not to the level of the UK grid. As a result, EfW in Scotland can no longer be considered a source of low carbon energy within a UK and Scottish context.

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.