The climate change impacts of burning municipal waste in Scotland

Summary Report

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1 Introduction

This report describes the climate change impacts of burning residual municipal waste in Scotland. The **carbon intensity** and **greenhouse gas emissions** of all six Energy from Waste (EfW) plants burning residual municipal waste in Scotland in 2018 have been calculated. Measuring carbon intensity allows a comparison with other energy production 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 chosen as 2018 as this was the most complete and up to date dataset available. Four of the plants only started operating in this year. A sensitivity analysis was conducted to explore the impact of two critical variables in the model: the composition of waste and the potential of technological solutions.

1.1 EfW plants in Scotland

As of 2019, there are fourteen operational EfW plants in Scotland. Of these, six are 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 2019 which are permitted to take residual municipal waste

Name of plant	Incinerator type	Incineration capacity (tonne/year)	Municipal waste incinerated in 2018 (tonnes)	Status and energy generation type
Dunbar Energy Recovery Facility, Oxwellmains, East Lothians	Moving grate incinerator	300,000	41,284[3]	Fully operational as of 2019[2], CHP potential but currently operating as electricity-only
MVV, Baldovie Industrial Estate, Dundee	Fluidised bed incinerator	110,000	94,624	Operational[1], CHP potential but currently operating as electricity-only
Millerhill Energy Recovery Centre, Edinburgh	Moving grate incinerator	195,000	16,459[3]	Fully operational as of 2019[2], CHP potential but currently 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 but currently 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 but currently 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 2.14 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 are being scaled up over time, which is why inputs in 2018 were well below capacity. They are 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 ZWS (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. The carbon intensity of each EfW plants was calculated and compared to the UK marginal grid average.

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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 the waste burnt;
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, 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 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. The NCV of fuel is a key consideration of EfW operators because it affects the energy (electricity and/or heat) output of their plants.

To assess the sensitivity of the model to changes in NCV, the amount of plastic in residual municipal waste composition was altered. Plastic waste contains high amounts of fossil carbon, so increasing the proportion of plastic waste will increase the carbon content and NCV of waste.

Climate change impacts of 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 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 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

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

as CHP plants. 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 34%.

Scotland is introducing a ban on Biodegradable Municipal Waste (BMW) sent to landfill in 2025. The purpose of this ban is to decrease greenhouse gas emissions from landfill by removing biodegradable content[10]. The model was adjusted to show the greenhouse gas impacts of three scenarios which could meet the BMW landfill ban:

- Default landfill ban scenario (1): all of the 1Mt of residual municipal waste landfilled in 2018 is sent to incineration instead. In this scenario, the incinerators reflect 2018 average practice.
- Landfill ban scenario (2): as in the default scenario, all residual municipal waste is sent to incineration. However, in this scenario, the incinerators are modelled on CHP systems.
- Hypothetical landfill ban scenario (3): all waste currently incinerated is sent to incinerators which are upgraded to CHPs. The remaining residual municipal waste is sent to landfill with pre-treatment, such as MBT, to reduce biodegradability. This is modelled with an assumption that biogenic carbon content is reduced from 15% to 5% of municipal residual waste content[11].

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 carbon intensity of the UK marginal electricity grid average, which was 270 gCO_2/kWh in 2018 [12] (Figure 1).

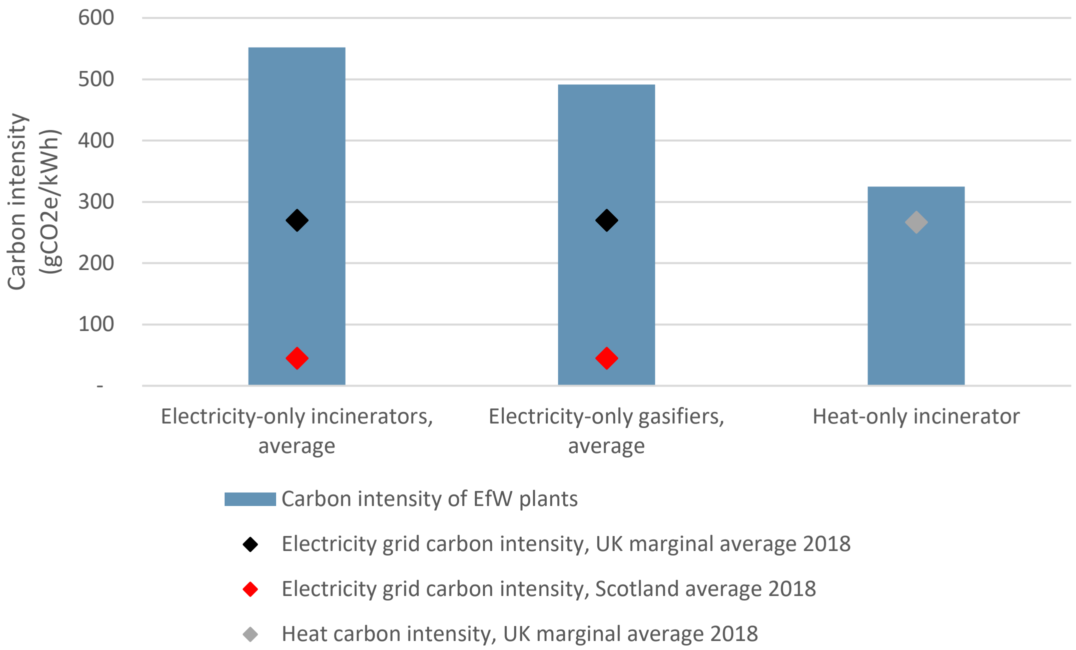
The carbon intensity of the only heat-only incinerator operating in Scotland in 2018 was 325 gCO_2/kWh, reflecting its higher plant efficiency, although this was still higher than the UK marginal heat average (267 gCO_2/kWh).

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

[11] Effective MBT pre-treatment can significantly reduce the biodegradable content of landfilled waste in compliance with the Landfill Ban regulations, resulting in significant emissions savings. While a growing number of studies have shown the emissions savings potential of MBT pre-treatment, the figures here are indicative and are not based on a thorough lifecycle analysis of MBT technology.

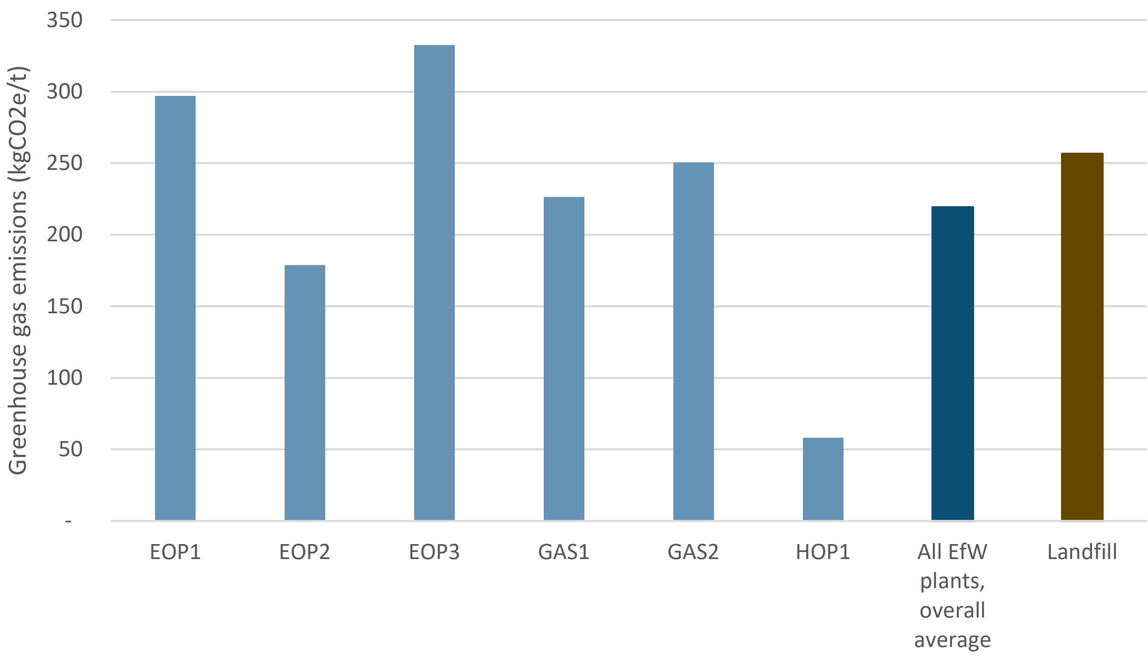
[12] The Scottish grid factor in 2018 was 44 gCO2e/kwh. Taken from Scottish Government (2020) Scottish Energy Statistics Hub, Average greenhouse gas emissions per kilowatt hour of electricity.

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 219 $kgCO_2e/t$, which is 15% less than sending it to landfill (Figure 2). The results for greenhouse gas emissions per tonne of waste differ considerably for each plant.

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

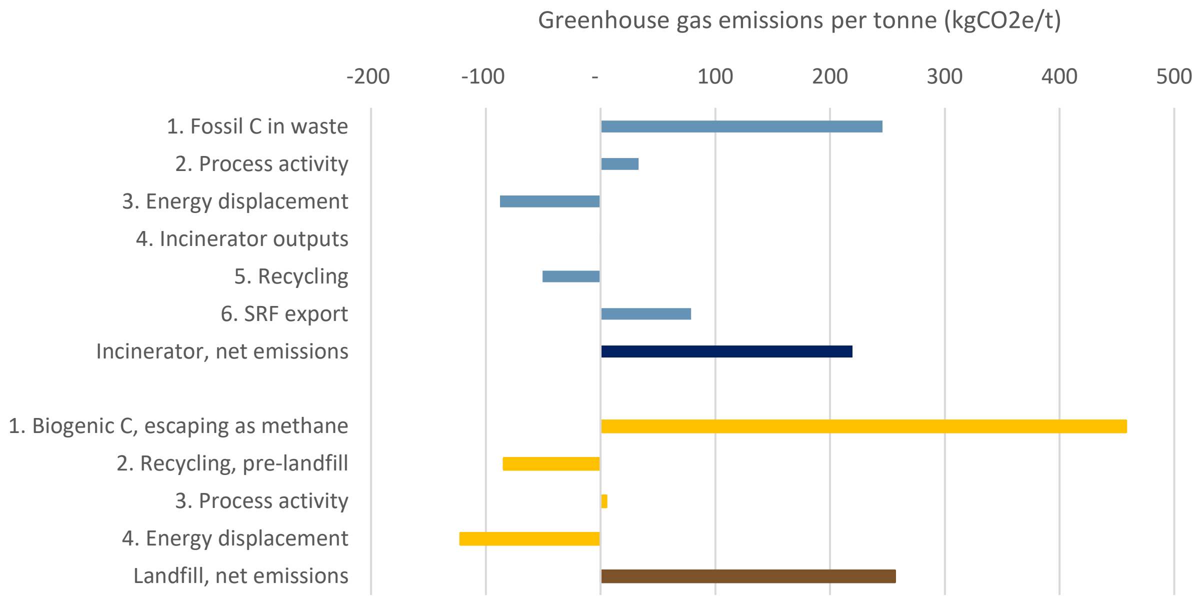


HOP1, the heat-only EfW plant, has lower greenhouse gas emissions per tonne than the other EfW plants because heat-only plants run at a higher efficiency (usually around 50%, compared to 25%). This means much more energy generation can be displaced – reducing the net greenhouse gas emissions per tonne.

Two of the plants in this study, EOP1 and EOP3, have considerably higher GHG emissions per tonne than the other plants (and landfill). These were the only plants not to record any pre-treatment recycling in 2018. 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 show 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 67 ktCO_2e. In addition, 1,031 kt of municipal waste was landfilled resulting 265 ktCO_2e[13].

4 Sensitivity Analysis Results

The sensitivity analysis explored the impact of two variables: the net calorific value (NCV) of waste and the conversion of EfW plants from electricity-only systems to Combined Heat and Power (CHP) systems. The results show that changes in waste composition and technology can considerably alter the climate change impacts of waste management. This has implications for how this study informs long-term infrastructure and policy decisions: such decisions should be based on the most current and accurate data possible, regularly reviewed to ensure climate change impacts are minimised.

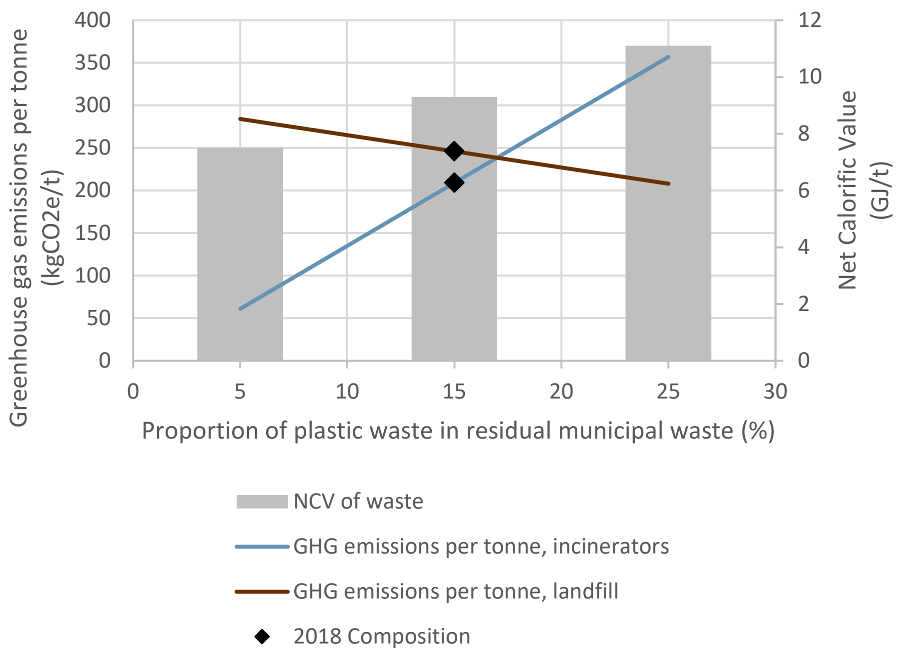
[13] Emissions from EfW are immediate as a result of combustion, whereas emissions from landfill can occur over multiple years as organic matter breaks down.

4.1 Changing the Net Calorific Value of waste

Increasing the proportion of plastic waste in residual municipal waste increased the NCV and GHG emissions per tonne for EfW plants. In the main study, plastic wastes composed 15% of residual municipal waste which has an NCV of 9.3 GJ/t.

As shown in Figure 4, if the proportion of plastic in municipal waste is increased by 10 percentage points to 25% of residual municipal waste (and all else remains equal), NCV rises to 11.1 GJ/t and the GHG emissions from EfW also rises by 70% to 357 kgCO_2e/t. This change in composition would have the opposite effect on landfill emissions (as more carbon would be to be stored rather than converted to methane), reducing the impacts of landfill to 208 kgCO_2e/t. EfW and landfill impacts cross when the proportion of plastic in residual municipal waste is increased by 2 percentage points to 17% of overall waste composition.

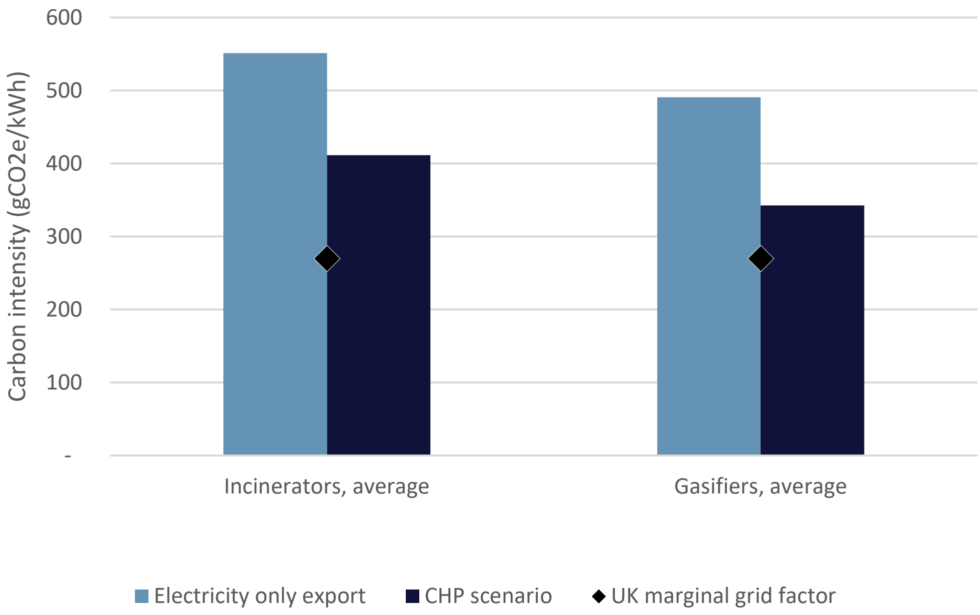
Figure 4. Varying the proportion of plastic in residual municipal waste composition changes the NCV and GHG emissions of EfW and landfill



4.2 Technical 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. The carbon intensity of both types of plants is reduced but not below the UK marginal electricity grid average (Figure 6).

Figure 5. Change in carbon intensity when EfW plants are converted to CHP systems

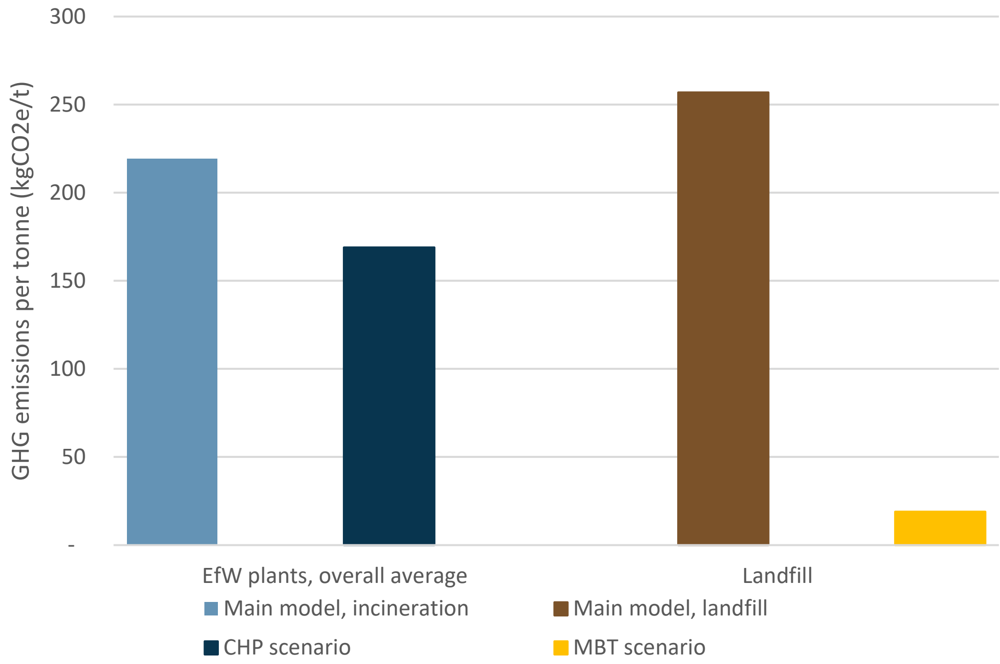


HOP1, the only heat-only incinerator taking municipal waste in Scotland, is not considered in this sensitivity analysis. The carbon intensity of HOP1 is 325 gCO_2/kWh. This is higher than the marginal heat factor for the UK, which is 267 gCO_2/kWh[14].

Converting to CHP systems reduces the net greenhouse gas emissions of EfW plants, as well as it's carbon intensity. The net emissions of the plants fall as more energy displaces marginal energy generation. This is shown in Figure 7. This figure also shows a comparison to the potential savings from removing biodegradable material from landfill. This could be achieved using a Mechanical Biological Pre-treatment (MBT) technology. If levels of biogenic carbon can be reduced from 15% to 5%, landfill impacts would fall from 257 $kgCO_2e/t$ to 19 $kgCO_2e/t$.

[14] 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

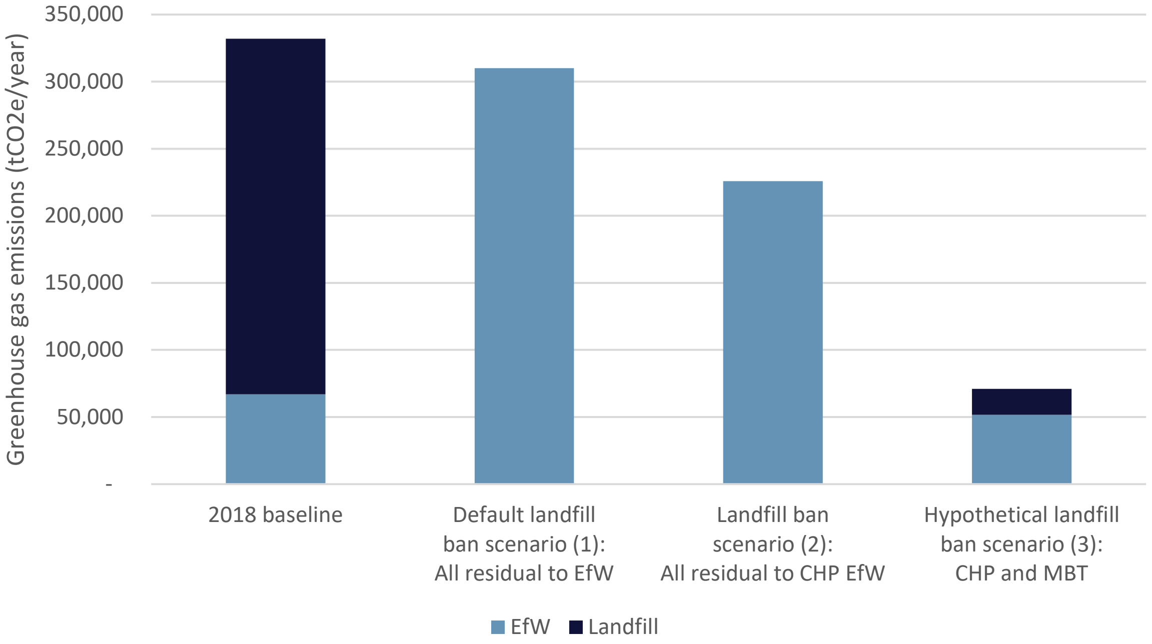
Figure 6. Impact on greenhouse gas emission per tonne of converting to CHP or MBT systems lowers the GHG emissions of waste management facilities



The Scottish biodegradable municipal waste (BMW) ban is due to come into force in 2025. Figure 8 below shows the greenhouse gas impacts of three ways in which this ban could be met:

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

Figure 8. The greenhouse gas impacts of two scenarios for meeting the BMW ban



In 2018, management of residual municipal waste had a greenhouse gas impact of 332,016 tCO_2e. If all waste was sent to electricity-only incineration plants (the default scenario), the impact would be lowered slightly by 7% to 310,125 tCO_2e. If all waste was sent to CHP plants instead, the impact would fall further (27% below the 2018 baseline) to 225,910 tCO_2e. If incinerators were upgraded to CHPs and pre-treatment added to landfill (CHP and MBT scenario), much greater savings are possible. The annual impact would be reduced by 79% to 71,104 tCO_2e.

The savings from landfill pre-treatment are illustrative only and further, more detailed, research is required to understand the exact savings required.

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:

- 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** are based on the plants published Heat and Power Plans rather than annualised energy data.

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.

Whilst there are several areas of uncertainty, the existing model is generally robust. It has been reviewed by the Waste Data Strategy Group, which includes waste data experts from the Scottish Government, SEPA and Zero Waste Scotland. 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. The results show that the carbon intensity of burning waste in EfW plants is 509 gCO_2e/kWh, which is nearly twice the carbon intensity of marginal UK electricity generation. Converting existing electricity-only plants to CHP systems would result in lowering 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 the marginal average. Therefore, EfW can no longer be considered a low carbon technology.

EfW greenhouse gas emissions per tonne of waste averaged 219 $kgCO_2e/t$, which is 15% lower than landfill. The only heat-only plant in Scotland has considerably lower impacts than the other EfW plants because it operates at a higher energy efficiency. Pre-treatment removal of recyclate has a significant carbon saving, where it is conducted.

The sensitivity analysis suggests that these results are dependent on the exact composition of residual municipal waste. As the composition of residual municipal waste changes over time, there is a risk that the greenhouse gas emissions per tonne of waste of EfWs will increase above those of landfill, leading to unnecessary climate change impacts.

The CHP and MBT pre-treatment scenario for meeting the BMW landfill ban suggests that technological solutions could be used to minimise climate change impacts from waste. To ensure this opportunity is realised, strategic decisions about residual waste treatment and infrastructure are required.

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 on which decisions are made. Whilst there are uncertainties in the approach taken in this study, it is robust enough to guide policy development. Long-term infrastructure and policy decisions must be based on the most current and accurate data possible to ensure climate change impacts are minimised. Waste policy should be adapted in the future to take advantage of significant opportunities to reduce the climate change impacts of waste further.

Climate change is not the only considerations 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 we face, 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 guide Scottish waste policy in the future to take advantage of significant opportunities to reduce the climate change impacts of waste further.

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