

Waste Management Criteria

The Climate Bonds Standard & Certification Scheme's
Waste Management Criteria

Background Paper

December 2019

The Climate Bonds Initiative gratefully acknowledges the Technical and Industry Working Group members who supported the development of these Criteria. Members are listed in Appendix 1. Special thanks are given to Resource and Waste Solution's Terry Coleman, the lead specialist coordinating the development of the Criteria through the Technical Working Group and to Golder Associates for the use of their WRATE software (www.wrate.co.uk).

List of Acronyms and Abbreviations

C&I waste - commercial & industrial waste
CD&E waste - construction, demolition and excavation waste
CH₄ - methane
CI - carbon intensity
CO₂ - carbon dioxide
CO₂e - carbon dioxide equivalent
CV - calorific value
EfW – energy from waste
E-waste - electronic waste
EPR - Extended Producer Responsibility
GIB - Green Investment Bank
GWMO - The Global Waste Management Outlook
GWP - global warming potential
HDPE - high density polyethylene
ICT - information and communications technology
IEA - International Energy Agency
IPCC - The Intergovernmental Panel on Climate Change
LCA - life cycle assessment
MBT – mechanical biological treatment
MRFs - material recovery facilities
MSW - municipal (solid) waste
PAS - Publicly Available Specification
PET - polyethylene terephthalate
PP – polypropylene
SLCP - short-lived climate pollutant
TCFD - Task Force on Climate-related Financial Disclosures
WEEE - waste electrical and electronic equipment

List of Tables and Figures

Figure 1: Criteria development timeline

Figure 2: The waste hierarchy

Figure 3: Proportion of global waste managed by different methods

Figure 4: Municipal waste and resource management assets/activities

Figure 5: Schematic representation of qualifying carbon intensity threshold for EfW plants

Figure 2-1: Pathway to Certification

Figure 4-1: Net GWP for different waste management options

Figure 4-2: Greenhouse gas emissions from the management of 1000 tonnes of food waste

Figure 4-3: Greenhouse gas emissions from the management of 1000 tonnes of garden waste

Figure 4-4: Greenhouse gas emissions from the management of 1000 tonnes of waste paper

Figure 4-5: Greenhouse gas emissions from the management of 1000 tonnes of waste card

Figure 4-6: Greenhouse gas emissions from the management of 1000 tonnes of waste plastics

Figure 4-7: Decarbonisation of the UK electricity grid (Dept. for Business, Energy and Industrial Strategy)

Figure 4-8: Effect of electricity grid decarbonisation on landfill and EfW

Figure 4-9: Effect of different efficiencies of EFW

Figure 4-10: Effect of landfill gas capture and electricity generation

Figure 4-11: Annual net greenhouse gas emissions

Table 1: Examples of issued labelled green bonds funding waste assets and projects

Table 2: Examples of issuers of unlabelled green bonds

Table 3: Key principles for the design of the Waste Management Criteria

Table 4: scope of eligible projects and assets for Climate Bonds Certification under the Waste Management Criteria

Table 5: clarification of which Sector Criteria assets or activities are eligible for Climate Bonds Certification under the Waste Management Criteria.

Table 6: Quantitative and qualitative ranking of waste management options (Life cycle emissions kgCO_{2e}/tonne of waste)

Table 7: Criteria for Waste Collection

Table 8: Criteria for Waste Storage

Table 9: Criteria for Waste Sorting

Table 10: Criteria for Recycling and Reuse

Table 11: Criteria for Composting

Table 12: Criteria for Anaerobic Digestion

Table 13: Increases in recycling in Europe

Table 14: Criteria for Energy from Waste

Table 15: Criteria for landfill gas recovery

Table 16: Checklist for evaluating the Issuer's Adaptation & Resilience performance in respect of a waste management facility

Table 5-1 Calculation of average electricity grid carbon intensity

Box 1: Waste Type

Box 2: Key observations and statistics on waste management

Box 3. Publicly Available Specification 100: Specifications for Compost Material

Box 4. Publicly Available Specification 110: Specification for bio-based waste digestate

Box 5. EfW and the draft EU Taxonomy

Box 6. Step by Step Approach to assessing Energy from Waste

Definitions

Certified Climate Bond: A Climate Bond that is certified by the Climate Bonds Standard Board as meeting the requirements of the Climate Bonds Standard, as attested through independent verification.

Climate Bond Certification: allows the issuer to use the Climate Bond Certification Mark in relation to that bond. Climate Bond Certification is provided once the independent Climate Bonds Standard Board is satisfied the bond conforms with the Climate Bonds Standard.

Climate Bond: A climate bond is a bond used to finance – or refinance - projects needed to address climate change. They range from wind farms and solar and hydropower plants, to rail transport and building sea walls in cities threatened by rising sea levels. Only a small portion of these bonds have been labelled as green or climate bonds by their issuers.

Climate Bonds Initiative (CBI): An investor-focused not-for-profit organisation, promoting large-scale investments that will deliver a global low carbon and climate resilient economy. The Initiative seeks to develop mechanisms to better align the interests of investors, industry and government so as to catalyse investments at a speed and scale sufficient to avoid dangerous climate change.

Climate Bonds Standard (CBS): A screening tool for investors and governments that allows them to identify green bonds where they can be confident that the funds are being used to deliver climate change solutions. This may be through climate mitigation impact and/ or climate adaptation or resilience. The CBS is made up of two parts: the parent standard (Climate Bonds Standard v3) and a suite of sector specific eligibility Criteria. The parent standard covers the certification process and pre- and post-issuance requirements for all certified bonds, regardless of the nature of the capital projects. The Sector Criteria detail specific requirements for assets identified as falling under that specific sector. The latest version of the CBS is published on the Climate Bonds Initiative website.

Climate Bonds Standard Board (CBSB): A board of independent members that collectively represents \$34 trillion of assets under management. The CBSB is responsible for approving i) Revisions to the Climate Bonds Standard, including the adoption of additional sector Criteria, ii) Approved verifiers, and iii) Applications for certification of a bond under the Climate Bonds Standard. The CBSB is constituted, appointed and supported in line with the governance arrangements and processes as published on the Climate Bonds Initiative website.

Green Bond: A Green Bond is where proceeds are allocated to environmental projects. The term generally refers to bonds that have been marketed as “Green”. In theory, Green Bonds proceeds could be used for a wide variety of environmental projects, but in practice they have mostly been the same as Climate Bonds, with proceeds going to climate change projects.

Industry Working Group (IWG): A group of key organisations that are potential issuers, verifiers and investors convened by the Climate Bonds Initiative. The IWG provides feedback on the draft sector Criteria developed by the TWG before they are released for public consultation.

Technical Working Group (TWG): A group of key experts from academia, international agencies, industry and NGOs convened by the Climate Bonds Initiative. The TWG develops the Sector Criteria - detailed technical criteria for the eligibility of projects and assets as well as guidance on the tracking of eligibility status during the term of the bond. Their draft recommendations are refined through engagement with finance industry experts in convened Industry Working Groups and through public consultation. Final approval of Sector Criteria is given by the CBSB.

Waste Management Assets and Projects: Assets and projects relating to the management of waste, and/or the development or acquisition of associated infrastructure. These facilities might include: energy from waste, anaerobic digestion, recycling and other technologies such as the installation of effective gas collection and recovery systems on landfill sites.

Table of Contents

List of Acronyms and Abbreviations	2
List of Tables and Figures	3
Definitions	4
1 Introduction	6
1.1 Overview	6
1.2 Funding needs of a low-carbon and climate resilient economy	6
1.3 Role of bonds	7
1.4 Introduction to Climate Bonds Initiative and the Climate Bonds Standard	8
1.5 Process for Sector Criteria Development	8
1.6 Revisions to these Criteria	9
2 Sector Overview	10
2.1 What is Waste Management	10
2.2 The Development of Waste Management	13
2.3 Waste Management and climate change	15
2.4 Investment need	18
2.5 Bonds in the sector	18
3 Principles and Boundaries of the Criteria	21
3.1 Guiding Principles	21
3.2 Assets and Activities Covered by these Criteria	22
3.3 Assets out of Scope	25
3.4 Overarching Considerations	26
3.5 Setting Mitigation Thresholds for Waste Management	27
3.6 Main Results from the Life Cycle Assessment for Waste Materials	28
3.7 The Criteria for Waste Management	30
3.8 Adaptation & Resilience Requirements	40
4 Appendices	43
Appendix 1: TWG and IWG members	43
Appendix 2: Pathway to Certification	45
Appendix 3: Summary of public consultation	46
Appendix 4: Using life cycle assessment in the development of the Criteria	51
Appendix 5: Qualifying Criteria for Energy from Waste facilities	76
Appendix 6: Further Reading	79

1 Introduction

1.1 Overview

This Background Document serves as a reference document to the Waste Management Criteria. The focus of those Criteria is municipal waste management and is the first sector-specific criteria for waste management that the Climate Bonds Initiative has released. The purpose of this Background Document is to provide an overview of the key considerations and issues that were raised during the course of development of the Waste Management Criteria.

The Criteria for different sectors of the economy are developed through a consultative process with sector-specific Technical Working Groups (TWGs) and Industry Working Groups (IWGs), and through public consultation. The TWGs comprise academic and research institutions, civil society organisations, multilateral banks and specialist consultancies whereas IWGs are represented by sector-specific and financial industry experts including potential bond issuers, investors and underwriters. This document aims to capture these various dialogues and inputs and substantiate the reasoning behind the Waste Management Criteria. A period of public consultation offers the opportunity for any member of the public to comment on the Criteria.

This Background Document begins with an introduction to the challenges in financing a low carbon and climate resilient world and the role that bonds can play in meeting these challenges, particularly through the standardisation of green definitions. Section 2 provides an introduction to the waste management sector and the implications of climate change on the sector in terms of both emissions and climate risks. Section 3 explains the principles and boundaries of the development of the Waste Management Criteria, what is included and excluded and synthesises the discussions arising from the Waste Management TWG and IWG and presents the resulting Criteria.

Supplementary information is available in addition to this document including:

1. [Climate Bonds Standard V3](#): the umbrella document laying out the common requirements that all Certified Climate Bonds need to meet, in addition to the sector-specific Criteria (V3 is the most recent update version). ^[1]_[SEP]
2. [Climate Bonds Standard & Certification Scheme Brochure](#): an overview of the purpose, context and requirements of the Climate Bonds Standard & Certification Scheme. ^[1]_[SEP]

For the documents listed above, see <https://www.climatebonds.net/standard/waste>. For more information on the Climate Bonds Initiative and the Climate Bond Standard & Certification Scheme, see <https://www.climatebonds.net/standard>.

1.2 Funding needs of a low-carbon and climate resilient economy

The current trajectory of climate change is expected to lead to a global warming of 3.1-3.7°C above pre-industrial levels by 2100¹, posing an enormous threat to the future of the world's nations and economies. The effects of climate change and the risks associated with a greater than 2°C rise in global temperatures by the end of the century are significant: rising sea levels, increased frequency and severity of hurricanes, droughts, wildfires and typhoons, and changes in agricultural patterns and yields. Avoiding such catastrophic climate change requires a dramatic reduction in global greenhouse gas emissions.

¹ According to Climate Tracker, under current policies we could expect 3.1-3.7°C: 2018. Temperatures: Addressing global warming. Accessed on 17.05.2018. Available from: <http://climateactiontracker.org/global.html>

Meanwhile, the world is entering an age of unprecedented urbanisation and related infrastructure development. Global infrastructure investment is expected to amount to USD 90 trillion over the next 15 years, which is more than the entire current infrastructure stock.²

To ensure sustainable development and slow climate change, this infrastructure needs to be low-carbon and resilient to climate change, without compromising the kind of economic growth needed to improve the livelihoods and wellbeing of the world's most vulnerable citizens. Ensuring that the infrastructure built is low-carbon is estimated to raise annual investment needs by 3–4% to USD 6.2 trillion.³ Climate adaptation needs add another significant amount of investment, which is estimated at USD 280–500 billion per annum by 2050 for a 2°C scenario.⁴

According to the Task Force on Climate-related Financial Disclosures (TCFD), there are two broad channels through which climate change can present risks to business activities and assets⁵:

1. Physical risk: the risk of impacts from climate- and weather-related events, such as floods and storms that damage property or disrupt supply chains and trade;
2. Transition risk: the financial risks that could result from the process of adjustment towards a lower-carbon economy. These include sudden shifts in demand; legal risk due to parties who have suffered loss or damage seeking compensation; and changes in policy favouring lower carbon technologies.

These could prompt a reassessment of the value of a large range of assets as costs and opportunities become apparent, and widespread inadequate information on these risks could even threaten the stability of the financial system. Risks to financial stability will be minimised if the transition begins early and follows a predictable path, thereby helping the market anticipate the transition to a 2°C world.

1.3 Role of bonds

Traditional sources of capital for infrastructure investment (governments and commercial banks) are insufficient to meet capital requirement needs to 2030; institutional investors, particularly pension and sovereign wealth funds, are increasingly seen as viable actors to fill these financing gaps.

Capital markets enable issuers to tap into large pools of private capital from institutional investors. Bonds are appropriate investment vehicles for these investors as they are low-risk investments with long-term maturities, making them a good fit with institutional investors' liabilities (e.g. pensions to be paid out in several decades).

Across investors and financial markets, different entities face different types and severities of risks related to climate change, depending on many factors including degree of long-term exposure, likelihood of negative climate impacts, and ability to mitigate impacts or shift positions.

Bonds offer relatively stable and predictable returns, and long-term maturities. This makes them a good fit with institutional investors' investment needs. Labelled green bonds are bonds with proceeds used for green projects, mostly climate change mitigation and/or adaptation projects, and labelled accordingly. The rapid growth of the labelled green bond market has shown in practice that the bond markets provide a promising channel to finance climate investments.

The green bond market can reward bond issuers and investors for sustainable investments that accelerate progress toward a low carbon and climate resilient economy. Commonly used as long-term debt instruments, green bonds are issued by governments, companies, municipalities, commercial

² The Global Commission on the Economy and Climate, (2016a). *The Sustainable Infrastructure Imperative: Financing for Better Growth and Development*. The 2016 New Climate Economy Report. (n.d.). Available [online](#).

³ The Global Commission on the Economy and Climate, (2016b). *The Sustainable Infrastructure Imperative: Financing for Better Growth and Development*. The 2016 New Climate Economy Report. (n.d.). Available [online](#).

⁴ UNEP, (2016). *The Adaptation Finance Gap Report*. [Available online](#).

⁵ TCFD, (2017). *Final Report: Recommendations of the Task Force on Climate-related Financial Disclosures*. Available from: <https://www.fsb-tcfid.org/publications/final-recommendations-report/>. Accessed on 04.06.2018.

and development banks to finance or re-finance assets or activities with environmental benefits. Green bonds are in high demand and can help issuers attract new types of investors.

Green bonds are regular bonds with one distinguishing feature: the proceeds are earmarked for projects with environmental benefits, primarily climate change mitigation and adaptation. A green label is a discovery mechanism for investors. It enables the identification of climate-aligned investments with limited resources for due diligence. By doing so, a green bond label reduces friction in the markets and facilitate growth in climate-aligned investments.

However, currently green bonds only account for less than 0.2% of the global bond market which stands at USD 100 trillion. The potential for scaling up is tremendous. The market now needs to grow much bigger quickly.

1.4 Introduction to Climate Bonds Initiative and the Climate Bonds Standard

The Climate Bonds Initiative is an investor-focused not-for-profit organisation whose goal is to promote large-scale investments through green bonds and other debt instruments to accelerate a global transition to a low-carbon and climate-resilient economy.

Activating the mainstream debt capital markets to finance and refinance climate-aligned projects and assets is critical to achieving international climate goals, and robust labelling of green bonds is a key requirement for that mainstream participation. Confidence in the climate objectives and the use of funds intended to address climate change is fundamental to the credibility of the role that green bonds play in a low carbon and climate resilient economy. Trust in the green label and transparency to the underlying assets are essential for this market to reach scale but investor capacity to assess green credentials is limited, especially in the fast-paced bond market. Therefore, the Climate Bonds Initiative created Climate Bonds Standard & Certification Scheme, which aims to provide the green bond market with the trust and assurance that it needs to achieve scale.

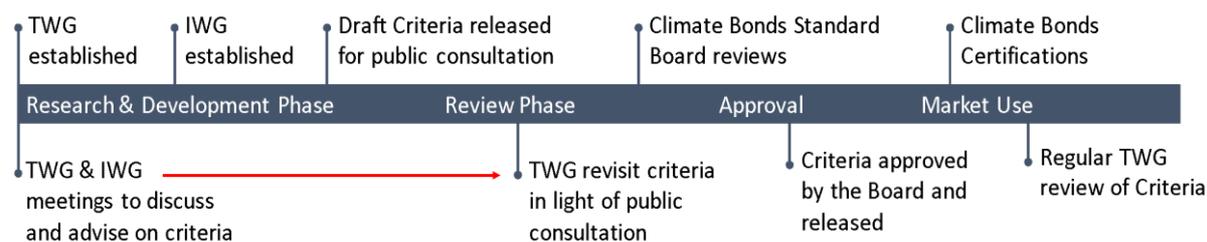
The Climate Bonds Standard & Certification Scheme is an easy-to-use tool for investors and issuers to assist them in prioritising investments that truly contribute to addressing climate change, both from a resilience and a mitigation point of view. It is made up of the overarching Climate Bonds Standard detailing management and reporting processes, and a set of Sector Criteria detailing the requirements assets must meet to be eligible for certification.

The Sector Criteria cover a range of sectors including solar energy, wind energy, marine renewable energy, geothermal power, low carbon buildings, low carbon transport, forestry, bioenergy and water. The Certification Scheme requires issuers to obtain independent verification, pre- and post-issuance, to ensure the bond meets the requirements of the Climate Bonds Standard.

1.5 Process for Sector Criteria Development

The Climate Bonds Standard has been developed based on public consultation, road testing, review by the assurance roundtable and expert support from experienced green bond market actors. The Standard is revisited and amended on an annual basis in response to the growing green bond market. Sector-specific Criteria, or definitions of green, are developed by Technical Working Groups (TWGs), made up of scientists, engineers and technical specialists. Draft Criteria are presented to Industry Working Groups before being released for public comment. Finally, Criteria are presented to the Climate Bonds Standard Board for approval as seen in Figure 1.

Figure 1: Criteria development timeline



1.6 Revisions to these Criteria

As part of the Climate Bonds Initiative’s goal to accelerate a global transition to a low-carbon, climate resilient economy, the Waste Management Criteria seek to maximise viable bond issuances with verifiable climate outcomes. All groups and individuals involved recognise the unique nature of this sector and its inherent lack of data. The Criteria should be a foundation and starting point from which to encourage increased transparency and consistency in application of scientific best practices and data in the context of bond issuances.

The Criteria will be reviewed three years after launch, or potentially earlier if the need arises, at which point the TWG will take stock of issuances that arise in the early stages and any developments in improved methods and data that can increase the climate integrity of future bond issuances. After the first review, the Criteria will be reviewed again periodically on a needs basis as technologies and the market evolve. As a result, the Criteria are likely to be refined over time, as more information becomes available. However, certification will not be withdrawn retroactively from bonds certified under earlier versions of the Criteria.

2 Sector Overview

2.1 What is Waste Management

One of the first legal definitions of waste on record was in the US Solid Waste Disposal Act 1965, where the term 'solid waste' was defined as meaning 'garbage, refuse, and other discarded materials'. In Europe, the first Framework Directive on Waste (75/442/EEC) gave the following definition: 'waste' means any substance or object which the holder disposes of or is required to dispose of pursuant to the provisions of national law in force' and similar definitions have been adopted in other countries and internationally: the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal defines "wastes" as "substances or objects which are disposed of or are intended to be disposed of or are required to be disposed of by the provisions of national law".

Waste tends to be categorised as: municipal (solid) waste ("MSW"), commercial & industrial waste ("C&I waste"), construction, demolition and excavation waste ("CD&E waste"), hazardous waste, agricultural & forestry waste, and mining & quarrying waste. While the definition of MSW varies between countries, it is widely understood to include waste from households, and similar C&I waste. There are also specific waste categories such as hazardous waste, food waste, electronic waste ("e-waste") and packaging waste that cut across multiple domains (e.g. e-waste will appear in MSW as well as C&I waste). Wastewaters are usually excluded from definitions of waste. Box 1 provides details on the different waste types. The focus of this Background Document is municipal solid waste.

Box 1: Types of waste.

Municipal waste (MSW) consists of waste from households and similar commercial and industrial waste. Household waste typically consists of newspapers, food and other product packaging, food, clothing, electronic appliances, batteries, etc. In composition terms, MSW tends to be broken down into those materials that can be usefully recycled: paper and card, plastics, glass, metals, textiles, food and garden (yard) waste, and other. MSW contains relatively small amounts of hazardous waste.

Commercial and industrial waste (C&I waste) comes from premises operating a trade or business. Industrial waste is generated from manufacturing and other industrial processes, including sectors such as food & drink, textiles, wood, paper, power & utilities, chemicals manufacturing, metals manufacturing, machinery & equipment. Commercial waste comes from sectors such as retail, hotels, catering, education, transport, storage, etc. By material type, C&I waste typically consists of paper and card, food waste, plastics (film and dense plastics), chemical waste, metals, clinical and healthcare waste, non-metallic wastes, animal and vegetable waste, sludges and mineral waste.

Construction, demolition and excavation waste (CD&E waste) is generated during excavation, and the construction, renovation, or demolition of buildings and civil infrastructure (e.g. roads, bridges, flyovers, subways, etc.). It contains a high percentage of relatively inert materials (e.g. concrete, masonry, asphalt) but also wood, metal, glass, gypsum, plastic, cardboard and hazardous substances such as treated wood and asbestos.

Hazardous waste: Waste that can pose substantial, potential threats to public health or the environment. It includes infectious clinical waste from hospitals etc.; waste from the production of pharmaceutical products; waste from the production of inks, dyes, pigments, paints, lacquers and varnish, acids and alkalis and chemical substances arising from research and development.

Agricultural & forestry waste: Includes crop residues, animal faeces and urine, wood residues and waste. Traditionally managed as part of the agricultural value chain, with the majority of waste either returned to the soil or used as biofuel.

Mining & quarrying waste: The majority of mining and quarrying waste is surplus soil or rock, termed over-burden. This is primarily managed by mining companies as near as possible to the point of generation. Overburden tends to sit outside national waste environmental control regimes, although will be subject to development controls. In Europe, liquid and slurry waste from mining is subject to the Mining Waste Directive.

Food waste: Any food and parts of food that are removed from the food supply chain. It results from many things, including inefficiencies in food supply chains, food becoming spoilt or out of date, oversupply, and consumer shopping and eating habits.

E-waste: Also commonly referred to as waste electrical and electronic equipment (“WEEE”). This includes a wide range of electronic products such as computers and televisions, as well as electrical equipment such as hairdryers, washing machines, and air-conditioners. This is the fastest-growing waste stream around the world due to increased consumer demand, obsolescence (real and perceived), and rapid developments in technology and innovation⁶.

Packaging waste: Packaging is any material used to hold, protect, handle, deliver and present goods. By material type, packaging waste typically consists of cardboard, glass, plastic, wood, steel and aluminium. Plastics, including some packaging waste, make up the largest proportion of marine litter.

⁶ Ellen MacArthur Foundation (EMF), (2013). *Towards the Circular Economy: Economic and business rationale for an accelerated transition*. Isle of Wight, UK: EMF. Available [online](#).

The Global Waste Management Outlook⁷ (“GWMO”) reviews waste management around the world. Global waste generation⁸ is estimated at between 7 to 10 billion tonnes per annum. For OECD countries this estimated to comprise 24% MSW, 32% C&I waste, and 36% CD&E waste^{9,10}. The World Bank¹¹ estimates global MSW generation from the 40% of the world’s population living in cities (3 billion people) to be 1.3 billion tonnes per year, increasing to 2.2 million tonnes per year by 2025. Box 2 summarises some of the key observations and statistics in both reports to help inform priority areas within the waste management sector.

Box 2: Key observations and statistics on waste management [1,4]1. MSW generation and national income: Whilst generation rates vary widely within and between countries, MSW generation per capita is highly correlated with national income. Waste generation per capita is expected to increase for low- and middle-income countries as their economies grow. Stabilisation or even a slight decrease has been seen in high-income countries but only when undergoing some form of economic downturn or stagnation.

2. MSW composition: Organic materials form the bulk of MSW, ranging from 34% in high-income countries to 53% by weight in both low and lower-middle income countries. The remaining components of MSW (in order of percentage contribution by weight) are paper and card, plastics, glass, and metals.

3. MSW collection coverage: The average collection coverage in low-income countries is 36%, increasing to 82-100% in upper-high income countries. Africa (25-70%) and Asia (50-90%) are the continents with the lowest average coverage.

4. MSW waste treatment: Landfilling and incineration of waste are the most common management methods in high-income countries. While quantitative data is not readily available, it is understood that most low and lower-middle income countries dispose of their waste in open dumps¹¹.

5. MSW recycling: Recycling rates are highest in high-income countries (averaging 35% and up to 70%), although some low and lower-middle income countries achieve reasonable recycling rates (averaging 15 to 30%).

6. Global investment in waste processing technologies¹²: By waste type, the largest investment areas were: MSW (28%), Agricultural & forestry (26%), Organic (12%). By country (for MSW only), the largest investment areas were the UK (24%) and the US (11%) for developed countries, and China (10%) and India (5%) for developing countries. By facility type (for MSW only), the largest investment areas were: combustion (with energy recovery) (44%), waste processing (15%), gasification (11%), integrated/mixed facilities (9%), and recycling (8%).

It is widely recognised that the quality and availability of waste data is low^{13 14 15}. This presents a challenge in producing historical and current waste statistics as well as future projections. The World Bank estimates global municipal waste production at 2.01 billion tonnes but also cautions about waste

⁷ Wilson, D.C. et al., (2015). *Global Waste Management Outlook Summary for Decision-Makers*. UN Environment and ISWA. Available online: https://www.iswa.org/fileadmin/galleries/Publications/ISWA_Reports/GWMO_summary_web.pdf

⁸ This figure covers MSW, C&I waste and CD&E waste.

⁹ Data for OECD countries is used as a proxy due to limitations on data availability for the rest of the world. Data does not include agricultural & forestry waste and mining & quarrying waste.

¹⁰ Ellen MacArthur Foundation (EMF), (2013). *Towards the Circular Economy: Economic and business rationale for an accelerated transition*. Isle of Wight, UK: EMF. Available [online](#).

¹¹ Hoornweg, D. and Bhada-Tata, P. 2012. *What a Waste: A Global Review of Solid Waste Management*. Washington D.C., US: World Bank. No.15.

¹² Based on analysis of global data on the development of new waste treatment and recovery facilities over the 2-year period 2013-2014.

¹³ Ellen MacArthur Foundation (EMF), (2013). *Towards the Circular Economy: Economic and business rationale for an accelerated transition*. Isle of Wight, UK: EMF. Available [online](#).

¹⁴ United Nations Environment, (2015). *Global Waste Management Outlook*. Osaka, Japan: UNEP Division of Technology, Industry and Economics (DTIE) International Environmental Technology Centre (IETC).

¹⁵ Hoornweg, D. and Bhada-Tata, P. 2012. *What a Waste: A Global Review of Solid Waste Management*. Washington D.C., US: World Bank.

data generally¹⁶. However, although data on MSW are far from complete, they are much better than the data on CD&E waste and C&I waste. Estimates suggest CD&E waste generation of 821 million tonnes in the EU (in 2012), 250 million tonnes in the US (in 2006), 77 million tonnes in Japan, 33 million tonnes in China and 17 million tonnes in India (all in 2010)¹⁷.

Best estimates on hazardous waste generation indicate 34 million tonnes in the US (in 2011) and 101 million tonnes in the EU (increasing by 3.3% from 2010 to 2012)¹⁸. Similar estimates are not available for C&I waste, with the exception of the UK, which generated an estimated 48 million tonnes in 2012¹⁹. These figures bear little or no relation to the respective populations and the likely scale of waste generation.

2.2 The Development of Waste Management

Over the last 40 to 50 years, waste quantities have continued to grow with improvements in living standards and, with increasing urbanisation, the amount of waste that has to be collected and managed has increased in parallel. However, standards for waste management and hence the environmental impacts of waste vary widely. In much of the developing world waste is disposed of in open dumps, some of which are on fire and none of which has systems to collect and utilise landfill gas produced from decomposition of the waste which contains methane, a powerful greenhouse gas. Across Europe standards of waste management are some of the highest globally and there has been a growing emphasis on recycling, reuse and recovery and on substantially reducing the landfill of untreated biodegradable waste, supported by legislation.

The waste hierarchy (Figure 2) is a well-known framework that illustrates the different waste management options in the general order of their relative environmental impacts. Prevention is prioritised followed by reuse, recycling, other recovery with disposal as the last resort. Generally, all countries have experienced problems dealing with the quantities of waste produced by their increasing, and increasingly affluent, populations and, over the past three decades, many developed economies have sought to move away from landfill and deal with waste higher up the waste hierarchy, mainly by recycling and composting with the recovery of energy from waste replacing landfill for residual waste.

There has been an increase in recycling rates in high-income countries over the last 30 years, with average MSW recycling rates in EU countries increasing by 13 percentage points between 2004 to 2014 from 30.6% to 43.6%²⁰, while there has been a decrease in the amount of MSW sent to landfill in the majority of OECD countries from 2000 to 2013^{21 22}.

¹⁶ Kaza, S., Lisa, Y., Bhada-Tata, P. and Van Der Woerden, F., (2018). *What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050*. Overview booklet. World Bank, Washington, DC.

¹⁷ Ellen MacArthur Foundation (EMF), (2013). *Towards the Circular Economy: Economic and business rationale for an accelerated transition*. Isle of Wight, UK: EMF. Available [online](#).

¹⁸ Ibid.

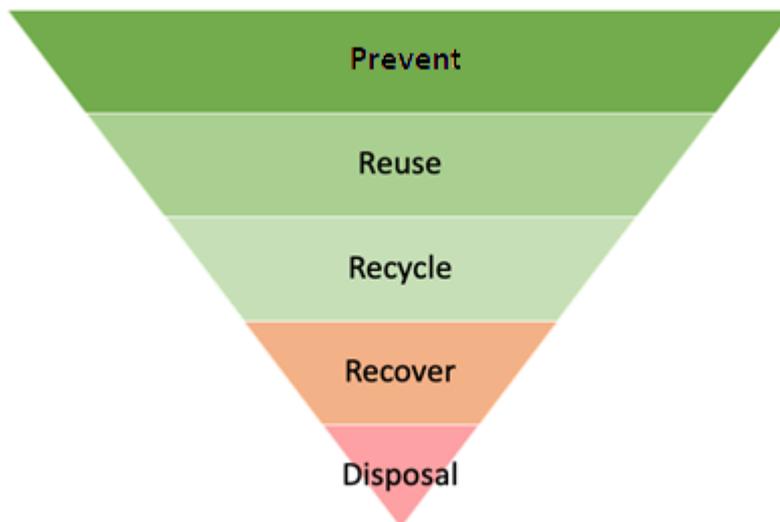
¹⁹ Department for Environment, Food & Rural Affairs (DEFRA), (2015). *Digest of Waste and Resources Statistics – 2015 Edition*. [Online] London, UK: DEFRA. Available [online](#). [Accessed 12 September 2016].

²⁰ European Environment Agency, (2016). *Waste Recycling*. Available [online](#).

²¹ Ellen MacArthur Foundation (EMF), (2013). *Towards the Circular Economy: Economic and business rationale for an accelerated transition*. Isle of Wight, UK: EMF. Available [online](#).

²² Organisation for Economic Co-operation and Development (OECD), (2015). *Environment at a Glance 2015: OECD Indicators*. [Online] Paris, France: OECD Publishing. Available [online](#). [Accessed 12 September 2016].

Figure 2: The waste hierarchy



Government Interventions

Many governments have used fiscal intervention as a means to move the management of waste up the hierarchy. In the EU, the majority of countries apply landfill taxes (averaging €80 per tonne of waste) that have increased with time. Other examples of fiscal interventions include New York's tax credit in favour of remanufacturing firms and China's reduced or eliminated Value Added Tax on products manufactured using recycled/secondary materials²³.

The EU bans certain waste types from landfill (e.g. tyres and liquids) and imposes mandatory limits on the amount of biodegradable MSW landfilled²⁴. Some member states have gone further: in the Netherlands, for example, landfill bans and a very high landfill tax has led to the closing of 60 landfill sites and landfill operations running at a financial loss due to low quantities of incoming waste²⁵.

Countries around the world have also adopted Extended Producer Responsibility ("EPR"). This requires producers to take responsibility for the costs of managing their products when they reach end of life. In the EU, EPR legislation exists for batteries, packaging waste, end-of-life vehicles, and waste electrical and electronic equipment ("WEEE").

Private Sector Interventions

Many global businesses now have environmental strategies and targets to increase recycling rates and decrease the percentage of waste sent to landfill, some businesses even targeting zero waste to landfill²⁶. In the UK, the Courtauld Commitment 2025 is a voluntary commitment by businesses in the food & drink sector to reduce UK food & drink waste by 20% over 10 years; signatories including Birds Eye, Coca Cola, KFC, Marks & Spencer, Pizza Hut, and Tesco²⁷. And Procter & Gamble has developed a partnership with its waste management provider Veolia, to repackage and repurpose waste detergent into new cleaning solutions²⁸.

²³ Ellen MacArthur Foundation (EMF), (2015). *Delivering the Circular Economy: A Toolkit for Policymakers*. Isle of Wight, UK: EMF.

²⁴ Confederation of European Waste-to-Energy Plants (CEWEP), (2015). *Landfill taxes & bans*. [Online] Düsseldorf, Germany: CEWEP. Available [online](#). [Accessed 12 September 2016].

²⁵ Ellen MacArthur Foundation (EMF), (2013). *Towards the Circular Economy: Economic and business rationale for an accelerated transition*. Isle of Wight, UK: EMF. Available [online](#).

²⁶ Examples include Ford, Mars, and Unilever.

²⁷ Waste & Resources Action Programme (WRAP). [No date]. *The Courtauld Commitment 2025*. [Online]. Available at: <http://www.wrap.org.uk/content/courtauld-commitment-2025>. [Accessed 12 September 2016].

²⁸ Veolia. [No date]. *Circular Economy Case Studies: Cleaning up in partnership with Procter & Gamble*. [Online] Available at: <http://www.veolia.co.uk/Procter-Gamble>. [Accessed 12 September 2016].

Future Waste Management

Innovation in science and technology offers more opportunities to reduce resource use and convert waste into resources. 3D printing, for example, can reduce material use significantly and has enabled a 90% reduction in titanium waste from the manufacture of Airbus aircraft titanium parts²⁹. Moreover, innovation in business models and ways of delivering goods and services will further transform how resources and waste are managed. The proliferation of collaborative consumption platforms (e.g. AirBnB, Uber, and Zipcar) and businesses offering performance models (e.g. Ricoh leasing printers, Interface leasing carpets, Philips leasing lighting) suggest that the shift in consumer preferences and asset utilisation is already underway.

For the future, in 2015, the United Nations Division for Sustainable Development set out 17 Sustainable Development Goals in its 2030 Agenda for Sustainable Development, including “sustainable consumption and production” that specifies targets on waste and resource use. The European Union’s 2018 adoption of a new “Circular Economy Package” demonstrates a shift in government ambitions, moving away from just dealing with waste towards resource efficiency and a circular economy approach³⁰.

However, the improving living standards of large populations in developing countries is likely to increase the overall amounts of waste. In developed economies, the focus is likely to be on reducing waste, e.g. through greater resource efficiency and longer useful lives, the circular economy, increasing reparability and remanufacturing, recycling and using energy recovery to deal with what remains with minimal landfill; whereas in much of the developing world the next steps will probably be providing more and better waste collection services and managing waste in controlled landfills rather than open dumps.

2.3 Waste Management and climate change

Current state of waste management and future projections

The Intergovernmental Panel on Climate Change (IPCC) estimates that waste management accounted for 2.9% of global GHG emissions³¹ in 2010 (1446MtCO_{2e}), the main sources being landfilling (43%), wastewater handling (54%) and waste incineration (<3%). Wastewater is excluded from these Criteria. Landfill (including open dumping) is the main source of methane, which makes up 90% of total GHG emissions from waste³². Globally, landfilling is the third largest source of anthropogenic methane³³. Methane is classified as a short-lived climate pollutant (SLCP), a class of climate pollutants increasingly under international scrutiny. Addressing SLCPs alongside CO₂ is the only way of limiting global temperature increases to below 2 degrees Celsius³⁴.

More recently, the World Bank has estimated GHG emissions from waste management alone as 5% of global GHG emissions or 1.6 billion tonnes CO_{2e}, primarily from open dumping and disposal in landfills without landfill gas capture systems³⁵. Even this underestimates the sector’s potential for climate change mitigation, when the overall effects of better waste and resource management are taken into account. Prevention, reuse, recycling, and energy recovery can all reduce methane emissions from landfill, avoid emissions linked to resource extraction and production using virgin materials, and offer an alternative energy source to fossil fuels. Accounting the whole lifecycle,

²⁹ Winne, S., et al., (2012). *Increasing the climate resilience of waste infrastructure*. London, UK: Department for Environment, Food and Rural Affairs (DEFRA).

³⁰ A circular economy is an alternative to a traditional linear economy (make, use, dispose) in which we keep resources in use for as long as possible, extract the maximum value from them whilst in use, then recover and regenerate products and materials at the end of each service life.

³¹ The IPCC estimate does not take into account benefits from material recycling, organic recycling and energy from waste.

³² Ellen MacArthur Foundation (EMF), (2015). *Growth Within: A Circular Economy Vision for a Competitive Europe*. Isle of Wight, UK: EMF.

³³ Global Methane Initiative. Global Methane Emissions and Mitigation Opportunities. https://www.globalmethane.org/documents/analysis_fs_en.pdf

³⁴ Climate and Clean Air Coalition, (2018). Why act on short-lived climate pollutants (infosheet) <http://ccacoalition.org/en/resources/why-act-short-lived-climate-pollutants-infosheet>

³⁵ Kaza, S., Lisa, Y., Bhada-Tata, P. and Van Der Woerden, F., (2018). *What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050*. Overview booklet. World Bank, Washington, DC.

incorporating the benefits of recycling and energy recovery, the sector has the potential to contribute a 10 to 15% reduction in global GHG emissions³⁶.

Figure 3: Proportion of global waste managed by different methods³⁷



Figure 3 from the World Bank³⁷ shows the proportion of the world's waste recovered or disposed of in different ways. 70% of waste is landfilled or just dumped.

The IPCC has not forecast what changes need to be made globally in waste management to achieve a 2°C global warming target. However, the following data give an indication of future investment needs:

- An estimated 57% to 64% of the population in low income countries do not have access to a waste collection service. Globally more than 2 billion people have no waste collection³⁸ meaning waste is probably tipped nearby or burned.
- Even where waste is collected, a large proportion of the collected waste is taken to dumps or uncontrolled landfills,³⁹
- By 2050 the world's population is forecast to grow by 2.2 billion to 9.8 billion: 90% of this increase will be in Africa and Asia.⁴⁰
- 66% of this population is projected to be urban.⁴¹
- Population in the group of 47 least developed countries is expected to almost double to 1.9 billion by 2050⁴².
- By 2050, the share of world income in low and middle-income countries will double to 40%⁴³.
- The amount of waste generated world-wide is projected to increase from 2.02 billion tonnes in 2016 to 3.4 billion tonnes by 2050⁴⁴.
- The IPCC estimated GHG emissions from waste management (excluding wastewater)⁴⁵ in 2010 as 665MtCO₂e.: 93% of these were from landfill or dumping.

³⁶ Ellen MacArthur Foundation (EMF). 2013. *Towards the Circular Economy: Economic and business rationale for an accelerated transition*. Isle of Wight, UK: EMF.

³⁷ Kaza, S., Lisa, Y., Bhada-Tata, P. and Van Der Woerden, F., (2018). *What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050*. Overview booklet. World Bank, Washington, DC.

³⁸ Wilson, D.C. et al., (2015). *Global Waste Management Outlook Summary for Decision-Makers*. UN Environment and ISWA. Available online: https://www.iswa.org/fileadmin/galleries/Publications/ISWA_Reports/GWMO_summary_web.pdf

³⁹ Ibid.

⁴⁰ UN, (2014). *World Urbanization Trends*.

⁴¹ Ibid.

⁴² <https://www.un.org/development/desa/en/news/population/world-population-prospects-2017.html>

⁴³ <http://siteresources.worldbank.org/INTSDNETWORK/Resources/Roadto2050Part1.pdf>

⁴⁴ Kaza, S., Lisa, Y., Bhada-Tata, P. and Van Der Woerden, F., (2018). *What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050*. Overview booklet. World Bank, Washington, DC.

⁴⁵ The IPCC estimate does not take into account material recycling, organic recycling and energy from waste.

Thus, the future picture is of many more people each generating more waste than today, resulting in global waste that, without investment in prevention, collection and management, will produce increased greenhouse gas emissions, estimated at 2.5 billion tonnes of CO₂e. by 2050⁴⁶.

Greenhouse Gas Emissions from Waste Management

Like all human activity, waste management processes produce greenhouse gases. The two principal greenhouse gases produced by waste management activities are methane and carbon dioxide. Other greenhouse gases, such as nitrous oxide, are produced by different waste management processes but their quantities are much smaller and consequently they are much less important in relation to the impact of waste management on climate change.

Carbon dioxide is produced from:

- burning waste, where the carbon in materials, such as plastics, paper and food, is oxidised by combustion;
- the biological, aerobic decomposition of waste plant and animal matter, for example, food, garden or yard waste and paper and card in composting or in shallow open dumps;
- the operation of collection and waste management systems:
- fuel for vehicles and heavy plant to move waste; and
- (indirectly) the electricity required to operate waste management equipment.

Where organic waste is decomposed in the absence of air (anaerobically)⁴⁷, the bacteria responsible produce a mix of gases, typically consisting of more than 98% carbon dioxide and methane, containing 50% to 60% methane. Such decomposition occurs in anaerobic digestion processes, in landfills and in open dumping⁴⁸.

The carbon dioxide released from the decomposition of biogenic wastes (food, paper and card etc.) from landfills, composting, anaerobic digestion and from waste combustion is regarded by international convention as not contributing to climate change, having been absorbed from the atmosphere by plants etc. in the first place. Emissions of biogenic carbon dioxide are accounted for by the IPCC under the 'land use / land use change and forestry' sector by calculating the net loss (or gain) in global biomass⁴⁹.

Methane from landfills and fossil carbon dioxide from the combustion of, e.g. plastics are key GHGs from waste management⁵⁰. Methane is a powerful greenhouse gas, 28-34 times more potent than carbon dioxide over a 100-year timeframe and 84-86 times more powerful over 20-years⁵¹. As well as being a powerful greenhouse gas, methane is a source of energy. The methane-rich gas from landfills and from anaerobic digestion can be captured and burned to generate electricity and/or heat or purified and turned into fuel. Combustion of waste, either from open burning or by modern incineration produces carbon dioxide from both biogenic and fossil carbon-based waste materials. In a modern energy from waste plant, the heat produced from this combustion is recovered to produce electricity and/or heating or cooling.

Given the 1.4 billion tonnes of waste that is currently landfilled or dumped without known landfill gas controls, recovering the methane produced from landfill is likely to be the most important contribution of waste management to climate change mitigation.

⁴⁶ Kaza, S., Lisa, Y., Bhada-Tata, P. and Van Der Woerden, F., (2018). *What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050*. Overview booklet. World Bank, Washington, DC.

⁴⁷ In the absence of oxygen.

⁴⁸ Some shallow open dumps will degrade aerobically.

⁴⁹ Ellen MacArthur Foundation (EMF). 2015. *The New Plastics Economy: Rethinking the Future of Plastics*. Isle of Wight, UK: EMF.

⁵⁰ Ibid.

⁵¹ IPCC 5th Assessment Report

2.4 Investment need

The sector already has \$300 billion of active projects⁵², of which \$85 billion relates to MSW⁵³. The investment required to deal with future waste management within a 2°C scenario is difficult to quantify, particularly as it is the capital cost that is of interest, that cost depends on the type of management system and a lot of the investment will be in developing countries. The World Energy Council has estimated the global waste to energy market will reach \$40 billion by 2023⁵⁴. Moreover, the capital expenditure for waste management in developing Asian countries has been estimated at between \$23.7 and \$90.3/tonne for composting and energy from waste respectively⁵⁵. The overall investment required, taking an average of the global waste forecast to be generated between 2016 and 2050, is between \$2.1 trillion and \$7.8 trillion.

With regard to MSW, recovery of energy from residual waste is likely to form the largest funding area based on the proportion of MSW that is not currently recycled or composted; but recycling facilities, composting and AD and waste collection will also require substantial investment, for example, to meet new targets. Whilst statistics on MSW growth and collection coverage suggest that low-income countries are in more urgent need of funding, higher income countries must not be ignored as they seek to upgrade their infrastructure and increase recycling and recovery.

Historically, both the public sector: national or local governments, international and financing institutions, and the private sector have financed investments in the sector⁵⁶. The majority of public sector funding has been from local or regional government, making service delivery vulnerable to political factors and national economic problems⁵⁷. Although private operators have more flexibility because their income can be related to the cost of service delivery, they also require external funding to upgrade or develop new, capital intensive facilities.

In its Fourth Assessment Report, the IPCC states, “The major impediment in developing countries is the lack of capital, which jeopardises improvements in waste and wastewater management. Developing countries may also lack access to advanced technologies. However, technologies must be sustainable in the long term, and there are many examples of advanced, but unsustainable, technologies for waste management that have been implemented in developing countries. Therefore, the selection of truly sustainable waste and wastewater strategies is very important for both the mitigation of GHG emissions and for improved urban infrastructure.”⁵⁸

2.5 Bonds in the sector

Given the funding needs of the sector, there is a role for the \$100 trillion bond market to play alongside governments and international organisations who have been the dominant funders. The USD 93 trillion global bond market has a huge potential to provide capital for waste management investment.

Green bonds have proven to be a useful tool to mobilise debt capital market for climate change solutions. The green bond market has been growing rapidly over the last three years with the global issuance totalling USD155bn in 2017. However, the rapid growth in the green bond market has been met with questions around the environmental claims of these bonds. In the absence of clear and widely accepted definitions and standards around what is green, many investors have raised concerns about ‘greenwashing’, where bond proceeds are allocated to assets that have little or uncertain environmental value. This can both shake confidence in the market and hamper efforts to finance a transition to a low carbon economy. The Climate Bonds Standard Waste Management Criteria define what is low carbon and climate resilient waste management assets and projects by

⁵² Over a two-year period January 2013 to December 2014.

⁵³ Ellen MacArthur Foundation (EMF). 2013. *Towards the Circular Economy: Economic and business rationale for an accelerated transition*. Isle of Wight, UK: EMF.

⁵⁴ Waste to Energy 2016, World Energy Council.

⁵⁵ João Aleluia, Paulo Ferrão, Assessing the costs of municipal solid waste treatment technologies in developing Asian countries, Instituto Superior Técnico, University of Lisbon, Waste Management

⁵⁶ Ellen MacArthur Foundation (EMF). 2013. *Towards the Circular Economy: Economic and business rationale for an accelerated transition*. Isle of Wight, UK: EMF.

⁵⁷ Ibid.

⁵⁸ https://www.ipcc.ch/publications_and_data/ar4/wq3/en/ch10s10-6-3.html

setting requirements of climate change mitigation and adaptation impacts in the waste sector. The Criteria provide guidance to the market on what types of waste management projects should be included in the green bonds to ensure the robust growth of the market.

There are two types of green bond: labelled and unlabelled green bonds⁵⁹. Labelled green bonds issued to date tend to be mixed use of proceeds bonds⁶⁰, including assets and projects of other sectors. Most assets and projects that are funded are waste treatment facilities, waste-to-energy facilities and waste collection vehicles⁶¹. Bond issuers include municipalities, waste management companies, general corporates (e.g. Apple), commercial banks (e.g. HSBC), and development banks. Table 1 provides some examples of issued labelled green bonds funding waste assets and projects.

Table 1: Examples of issued labelled green bonds funding waste assets and projects

Entity	Description	Use of bond proceeds	Issuance size	Issuance date	Maturity	Coupon	Label
Apple*	US technology business	Waste and pollution management projects to improve recycling and reduce landfill waste	\$1.5bn	Feb 2016	7 years	2.85%	Sustainability
Bank of Qingdao*	Chinese bank	Recycling projects	\$616m	Mar 2016	3-5 years	3.25-3.4%	EY
City of Napa*	US municipality	Composting facility and roof extension of an existing recycling facility	\$12.5m	Oct 2016	2-10 years	1.09-2.44%	Self label
Kommuninvest*	Sweden municipal bank	Waste-to-energy projects	\$600m	Apr 2016	3 years	1.5%	CICERO
Link REIT*	Hong Kong Real Estate Investment Trust (REIT)	Projects to reduce waste to landfill by 40% by 2022	\$500m	Jul 2016	10 years	2.87%	Sustainability
Nordic Investment Bank	International financial institution	Waste management facilities	\$565.5m	Sep 2015	7 years	0.375%	CICERO
Ramsey County (Minnesota)	US municipality	Acquisition of an existing waste management facility – waste-to-energy and recycling	\$17.9m	Feb 2016	1-25 years	3-3.125%	Self label

⁵⁹ Labelled green bonds are bonds with use of proceeds earmarked to finance new and existing projects with environmental benefits. A green bond label is a signalling or discovery mechanism for investors.

⁶⁰ A mixed use of proceeds bond here means a bond where a proportion of the proceeds will fund waste assets but the remainder will fund assets in other sectors.

⁶¹ Waste collection vehicles are subject to the Transport Criteria.

* This is a mixed use of proceeds bond where a proportion of the proceeds will fund assets in the waste sector but the remainder is used to fund assets in other sectors.

Unlabelled green bonds⁶² have generally been issued by organisations whose primary activity is waste management. That is, who might be deemed ‘pure play’ operators. These organisations have tended to be corporates or municipalities, the majority of which are based or headquartered in the US. While developed markets have dominated bond issuance, there has also been issuance from emerging markets such as China and Mexico. The main activities of bond issuers either fall into recycling or waste-to-energy. Table 2 provides a sample of issuers in the unlabelled green bond market.

Table 2: Examples of issuers of unlabelled green bonds

Organisation	Description of activity	Country of origin	Type
Cascades Inc.	Produces packaging and tissue products composed mainly of recycled fibres	Canada	Corporate
Covanta Energy Corporation	Operates waste-to-energy facilities	US	Corporate
GMR Materials Co. Ltd	Engages in waste automobile and waste appliance recycling business, and plant destruction activities	South Korea	Corporate
Jefferson County (Alabama)	Provides solid waste management services	US	Municipality
Scott County (Minnesota)	Provides services in hazardous waste disposal, recycling, and solid waste management	US	Municipality
Super Dragon	Engages in industrial waste removal and disposal as well as recycling of previous metals and electronic industrial waste	Taiwan	Corporate

⁶² Unlabelled green bonds do not carry a green label and are issued by ‘pure play’ companies that operate in climate-aligned sectors e.g. renewable energy.

3 Principles and Boundaries of the Criteria

This section sets out the key principles governing the Criteria for qualifying waste management assets and activities under the Climate Bonds Standard and describes the assets and activities covered by those Criteria.

3.1 Guiding Principles

The Climate Bonds Standard needs to ensure that the waste management assets and projects included in Certified Climate Bonds deliver GHG mitigation potential and climate resilience benefits in line with best available scientific knowledge and compatible with the goals of the Paris Agreement. At the same time, the Waste Management Criteria need to be pragmatic and readily usable by stakeholders in the market to maximise engagement and use. High transaction costs run the risk of reducing uptake of a standard in the green bond market. Keeping the costs of assessment down while maintaining robust implementation of the criteria is important. Table 3 sets out the principles guiding the development of the Waste Management Criteria to meet and balance these two goals.

Table 3: Key principles for the design of the Waste Management Criteria

Principle	Requirement for the Criteria
Level of ambition	Compatible with meeting the objective of 2°C or less temperature rise above pre-industrial levels set by the Paris Agreement, and with a rapid transition to a low carbon and climate resilient economy.
Robust system	Scientifically robust to maintain the credibility of the Climate Bond Standard.
“Do not reinvent the wheel”	Harness existing robust, credible tools, methodologies, standards and data to assess the low carbon and climate resilient credentials of any technology, endorsed by multiple stakeholders where possible.
Level playing field	No discrimination against certain groups of producers (such as smallholders) or geographies or technologies.
Multi-stakeholder support	Supported by key stakeholders; those within the relevant industry, the financial community and broader civil society.
Continuous improvement	Subject to an evolving development process with the aim of driving continuous improvement and credibility in the green bond market.

To grow the market meaningfully, bonds in the waste management sector should fit the needs of both investors and issuers.

Bonds used to finance the waste management sector are fairly common and share similarities with other large-scale infrastructure bonds. Waste Management has traditionally been handled by municipalities through public investments. As the sector grows and privatisation continues to play an increasing role in public investments through public-private partnerships and the like, it is important at this stage to ensure both traditional asset investment strategies and novel asset/waste investment strategies are covered in the Criteria.

To date, the green bond market has primarily been used to finance general waste management, recycling facilities, fleet upgrades, landfill gas capture, and strategies to reduce waste to landfill. While financing these investments has several benefits, the role of the Climate Bonds Standard and Waste Management Criteria is to develop technology-agnostic, climate mitigation and resilience thresholds

for the sector. These metrics and thresholds help asset owners, issuers, and investors determine the most climate compatible types of activities to finance.

By determining the types of activities to finance through bonds, issuers will be key drivers for growth in the waste management climate/green bond market. However potential bond investors can also drive the market's growth by signaling the types of investments they are eager to make.

For bond investors, this means eligibility Criteria should promote bond issuances that are:

- Relatively straightforward, predictable, and easy to understand (e.g., in terms of the source and credibility of expected cash flows);
- Transparent regarding use of bond proceeds and intended impacts, facilitating independent third-party scrutiny;
- Sizeable, liquid and preferably rated; and
- A comparable investment opportunity relative to non-green-labelled bonds. This may mean, for example, involving concessional funding or government incentives to improve the risk/return profile, particularly at this nascent stage.

For bond issuers, this means eligibility Criteria should:

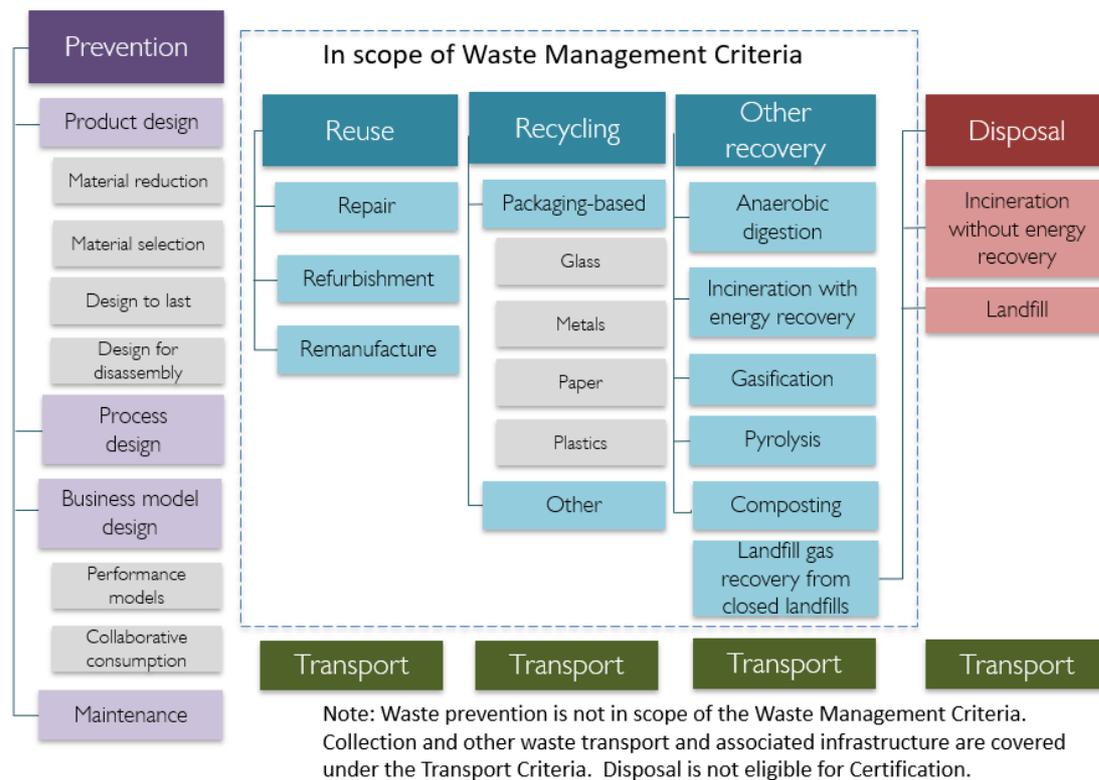
- Allow a relatively wide scope for eligible activities;
- Indicate scientifically robust references and approaches for calculating climate benefits (e.g., guidelines for selecting among existing methodologies and tools);
- Cater to a range of potential issuers (and users of the guidance), including: (a) relatively large companies, including banks, who aggregate across sectors and industries, (b) smaller companies and organisations, where there may need to be some aggregation and, or, concessional support, and (c) government agencies; and
- Leave room for issuances that are short-term inter alia trade / input finance, insurance, uptake of relevant, proven technology.

3.2 Assets and Activities Covered by these Criteria

These Criteria cover assets and activities that deal with municipal waste (MSW) which consists of waste from households and similar wastes from industry and commerce. They therefore exclude other wastes from industry and commerce, all hazardous wastes and CD&E wastes. Assets and activities dealing with waste prevention are also out of scope of these Criteria, as are all assets and activities dealing with wastes other than MSW or similar wastes (Section 3.4).

Figure 4 shows the different types of waste management assets and activities in the waste hierarchy to illustrate those that are covered by these Criteria.

Figure 4: Municipal waste and resource management assets/activities



Preventing or reducing the generation of waste is at the top of the waste hierarchy because it offers the largest environmental benefits through reducing the extraction, refining and processing of raw materials in addition to not producing waste and therefore no greenhouse gas emissions associated with waste management. However, waste prevention takes place in industry sectors other than waste management and may not involve tangible assets.

Therefore, these Criteria are restricted to the eligibility of assets that deal with waste and focus on equipment, facilities and vehicles in the following activities:

- Collection (including collection infrastructure, containers)⁶³
- Transportation (covered by the CBI Transport Criteria)
- Sorting to separate recyclables
- Reuse and recycling (including processing into secondary raw materials and repair)
- Composting & anaerobic digestion of green/garden/yard and food waste
- Thermal treatment with energy recovery of residual waste (outside the EU)
- The installation of gas recovery systems for landfill sites (for non-operational landfill sites only)

The key mitigation opportunities within the above activities are raw material substitution (through material recycling), fossil energy substitution (through energy recovery and from recycling), and the collection and utilisation of landfill gas. Material recovery includes the sorting and processing of waste to produce materials that substitute virgin materials.

The resulting scope of eligible assets and activities is presented in Table 4 using a traffic light system for ease of use as follows:

- Green: almost certain to be compatible with a low carbon or climate-resilient economy in all circumstances and therefore automatically eligible for certification;

⁶³ Collection vehicles and other transport infrastructure are covered under CBI's Transport Criteria documents.

- Red: not eligible for certification under any circumstances either because they are incompatible with a low carbon or climate-resilient economy;
- Amber: potentially eligible for certification subject to meeting the specified criteria for that asset or activity.

The first column in Table 4, 'Eligible activity types', gives a list of all the activity types that are within scope of the Waste Management Criteria. The second column, 'Example use of proceeds', is an illustrative list of the type of projects that may be included in a Certified Climate Bond. It is not possible to include an exhaustive list of all potential uses of proceeds due to the breadth of possibilities, but all uses of proceeds must fall within one of the specified eligible activity types.

Table 4: Summary scope of eligible projects and assets for Climate Bonds Certification under the Waste Management Criteria

Eligible activity types	Example use of proceeds	Mitigation	Adaptation & resilience
Material Reuse	Facility repairing and/or reusing products or components for same purpose for which they were conceived.	●	●
Material Recycling	Facilities producing recycled glass, metal, paper, and plastic from post-consumer waste.	●	●
	Facilities using recycled glass to produce glass aggregate.	●	●
Collection Infrastructure	Containers provided for waste.	●	●
Composting	Facility producing compost via green waste such as food, garden or yard wastes.	●	●
Anaerobic Digestion	Facility processing food, garden or yard, or other organic materials to produce biogas and digestate for e.g. electricity generation	●	●
Pre-sorting	Facilities for segregating mixed recyclables into separate, saleable streams, e.g. material recovery facilities (MRFs).	●	●
Waste Incineration or Gasification & Energy Recovery	Facility producing electric and/or heat via the combustion of municipal solid waste OR mixed residual waste.	●	●
	Facility producing electric and/or heat via gasification of residual municipal solid waste.	●	●

Decommissioned Landfill only, with Gas Capture & Energy Generation	<i>Project</i> to capture biogas from non-operational landfill (ceased receiving waste except inert restoration materials).		
--	---	---	---

3.3 Assets out of Scope

It is essential that clear guidance on which Sector Criteria assets and projects are eligible for Climate Bonds Certification is given. This saves confusion and means that it is clear to the verifier, issuer and investor which requirements a given asset or project is expected to meet. Table 5 identifies possible overlaps and explains which Sector Criteria should be referred to in which cases. The following sections give further explanation.

Table 5: Potential assets which have overlaps with other Climate Bonds Certification Criteria.

Assets or Activity	Comments on Applicable Sector Criteria
Municipal Solid Waste Prevention	Manufacturing facilities reducing their waste generation both pre and post-consumer are not within the scope of the Waste Management Criteria. They will be considered when Manufacturing Criteria are developed.
Remanufacturing Facility	Manufacturing facilities using reclaimed or recycled materials to manufacture goods and services are not within the scope of the Waste Management Criteria. They will be considered when Manufacturing Criteria are developed.
Land Transport	Vehicles used within the waste facilities are eligible for certification if they meet the Transport Criteria. Other mobile plant assets within the facility itself are eligible for certification under the Waste Management Criteria when part of a wider eligible project. All collection vehicles and those used for transfer of waste are also eligible but must comply with the Transport Criteria.

As outlined above, although waste prevention offers the largest environmental benefit, waste reduction and prevention are factors that will be taken into account in future iterations of other industry sector Criteria. The scope of these Criteria is to deal with materials when they have become waste and up until they cease to be waste.

The TWG initially considered other categories of waste: hazardous, construction, demolition and excavation (CD&E) waste, WEEE and other wastes from industry and commerce that were not similar to municipal waste. However, although data on municipal waste were sparse, they were substantially better than those for any of the other categories of waste. There were insufficient data on amounts, composition and on the emissions of greenhouse gases over the life cycle of their treatment. For these reasons, the Waste Management Criteria cover only municipal waste.

Table 4 also shows that recycling glass as glass aggregate is not eligible under these Criteria, because it offered only marginal climate change mitigation benefits which were negated by the transport of the glass during collection and to the recycling facility. However, recycling glass generally where it involves remelting, such as packaging glass into new packaging glass is automatically eligible.

3.4 Overarching Considerations

Geographic coverage

The Waste Management Criteria are designed to be universally applicable and, unless stated otherwise, can be applied to the waste management assets and activities listed regardless of the location of those assets or activities. Where these more generic Criteria are insufficient to indicate the climate compatibility of the asset, additional, context-specific requirements are stipulated. This context-specificity is necessary to account for the differing pace of development of the waste management sector and technology deployment across different geographies moving the management of waste up the waste hierarchy to better greenhouse gas mitigation options.

Bond term vs. asset lifetime

The term of a bond may be equivalent or less than the planned life of the asset or activity that it finances. The Criteria must define the boundaries within which the benefits of an asset or activity will be evaluated and quantified – i.e. over the period of the term of the bond or over the operational life of the asset. Assets and projects funded by Climate Bonds should provide GHG mitigation benefits over the entire operational life of the asset as this more accurately reflects the overall climate benefits from the asset. Asset life has therefore been set as the temporal boundary of the Waste Management Criteria. This will ensure that only investments that have net positive impacts on climate change over the life of the asset are certified.

Objective Assessment of Climate Change Impacts

It was decided early in the development of these Criteria that while the waste hierarchy provided a good guide for the relative attractiveness of different approaches to waste management, as it is only a general guide, where possible, the climate change impacts of different waste management assets should be compared using life cycle assessment (LCA) but applied to global climate change impacts, given the Climate Bonds Initiative's climate focus. This was particularly important in taking into account the benefits related to the recycling of different materials and also the effects that the decarbonisation of the electricity grid would have on the climate change benefits of energy from waste.

LCA is an environmental accounting technique used to study and improve the impacts of a product or service. It involves considering everything in the economy that is affected by the study, drawing a boundary around this and quantifying all the material and energy flows across this boundary (to and from the environment). It is a holistic approach, considering all the environmental effects of a proposed change from the change in the extraction of raw materials through to their final disposal. It is also objective, in that it uses independent data and it should be transparent, with all assumptions clearly stated. It therefore avoids shifting environmental burdens from one place or one time to another and ensures all the environmental burdens and benefits that relate to a product or service are taken into account.

However, due to its holistic nature, an LCA can be time-consuming and expensive. Criteria for certification of Climate Bonds need to maximise simplicity and minimise transaction costs for issuers. In part this means ensuring that issuers can get a reasonably clear steer as to whether their asset/bond is or is not likely to be eligible for certification in advance of starting the process of certification, including contracting a verifier to give assurance over compliance.

A simplified LCA approach that avoids the need for issuers to carry out either an LCA or extensive and expensive data collection was adopted for the development of these Criteria. This is described in more detail in Appendix 4.

Choices affecting an LCA

For an LCA of a given waste management system there are several issues that can significantly affect the results:

- The global warming potential (GWP) of methane;
- The GWP of biogenic carbon dioxide;
- The value assigned to stored carbon dioxide, for example, by storing carbon dioxide deep underground in geological formations, or by converting biomass to carbon and storing this;
- The limits of what is included and excluded from the assessment, known as the system boundary; and
- The assumptions that are made.

Each of these was considered in some detail (see Appendix 4). It was decided that:

- The GWP of 28 for methane (relative to carbon dioxide's value of 1) used in the latest IPCC Assessment report⁶⁴ would be used, except where this was fixed within life cycle data sets or software at the AR4 value of 25, when the latter would be used.
- For any carbon dioxide produced from living matter: plants and/or animals, a GWP of 0 would be used, compared with a value of 1 for carbon dioxide from fossil sources, such as coal combustion.
- A specific allowance of 3.67 kgCO₂e⁶⁵ per kg of carbon would only be made for carbon storage or sequestration where this was the principal function of the asset.

The assumptions made for the LCAs and how the systems were defined are also discussed in Appendix 4.

3.5 Setting Mitigation Thresholds for Waste Management

The Criteria have been based on the characteristics of the waste and the waste management process, and are designed so that they are met by the processes that perform best or are below the threshold for each waste type or material.

Numerous life cycle assessments of different waste management systems were modelled to build a picture of the GHG impacts from different wastes managed in different ways and under different circumstances. The modelling is described below and in more detail in Appendix 4.

The intended purpose of the modelling was two-fold:

- To produce a sufficiently clear picture of the nature and level of the thresholds required for each type of waste; and
- To provide sufficient information to preclude the need for issuers to carry out their own life cycle assessment.

More than 100 different waste management scenarios were modelled covering: different waste materials and residual waste compositions, different management options and different carbon intensities for the electricity grid. The LCA modelling was carried out using the WRATE software, a life cycle tool developed by the Environment Agency and approved by the England and Wales Governments. The software was also used by the UK's Green Investment Bank (GIB)⁶⁶.

Although LCA is used to calculate various impacts, such as ozone depletion potential, human toxicity etc., only the emissions related to climate change were of interest. There was no evidence from any of the modelling or from elsewhere that:

- a. there were significant other impacts from the waste management system studied; or
- b. the same standards as applied in developed countries should not and could not be applied globally.

⁶⁴ Intergovernmental Panel on Climate Change (IPCC). 2007. Waste Management. In: *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Bogner, J., M. Abdelrafie Ahmed, C. Diaz, A. Faaij, Q. Gao, S. Hashimoto, K. Mareckova, R. Pipatti, T. Zhang]. Cambridge, UK and New York, US: Cambridge University Press.

⁶⁵ This is calculated from the atomic mass of carbon (12.01) and the molecular mass of carbon dioxide (44.01): 12.01 kg of carbon will produce 44.01/12.01 = 3.67 kg CO₂.

⁶⁶ Now the Green Investment Group (GIG) following its acquisition by Macquarie.

Initially ten different systems for managing all MSW were modelled. This was:

- in part to address concerns that promoting the removal of some waste fractions could make the overall impact from the system worse;
- to look at the effects of different energy conversion efficiencies;
- to understand if and how the results reflected the waste hierarchy.

The ten systems which were initially modelled were:

1. Landfill without gas capture;
2. Landfill with efficient (75%) gas capture;
3. EfW with 15% thermal efficiency⁶⁷;
4. EfW with 25% thermal efficiency plus 40% green and food waste to composting;
5. Gasification, with residual to landfill (as 2);
6. EfW with 25% thermal efficiency plus 40% green and food waste to AD;
7. EfW with 25% thermal efficiency;
8. EfW with 25% thermal efficiency, plus 10% dry recycling;
9. EfW with 25% thermal efficiency, plus 20% dry recycling; and
10. 20% recycling, with residual to landfill (as 2).

Each of these was modelled for two waste compositions, typical of both developed and developing countries and initially used three different carbon intensities of electricity grid (coal, coal and gas – 50:50 and natural gas), producing sixty sets of results. Later sensitivities examined the effects of lower carbon intensity grids (see Appendix 4).

3.6 Main Results from the Life Cycle Assessment for Waste Materials

The results of the initial modelling showed that:

- the LCA work generally supported the waste hierarchy, with the possible exception of food and garden (yard/green) waste where composting and anaerobic digestion resulted in slightly higher greenhouse gas emissions than combustion in a modern, high-efficiency (29% net overall) EfW plant producing electricity that displaced a mixed coal and gas electricity grid⁶⁸;
- the biggest single change in GHG emissions from a change in waste management resulted from installing efficient gas collection and recovery systems on landfill sites; and
- although the waste compositions used made a difference to the results, alterations to the hypothetical electricity grids produced considerably more change in the overall results.

More details of the modelling, the compositions and grids used can be found in Appendix 4.

Managing Different Waste Materials

Further LCAs were conducted on the constituent materials in waste, examining the impacts from managing them separately in every way that was practicable for that material. The results of this analysis are reproduced in an overall grid (Table 6), showing the GHG impacts of managing the different waste materials by different methods.

Table 6 shows eight different materials that are most commonly separated for recycling or biological treatment plus the two hypothetical residual compositions for the developing and the developed world, combined with six different methods of management, including landfill, divided into an additional four categories with different gas recovery rates, three additional categories for energy from waste for

⁶⁷ Thermal efficiency is a simpler way to measure performance of a plant than that used by the EU to define the difference between recovery and disposal. It is equal to the net useful energy produced (electricity supplied to the grid – electricity taken from the grid)/energy available in waste input). A thermal efficiency of 25% is approximately at the boundary of recovery.

⁶⁸ Subsequent analysis examined the effect of lower carbon electricity grids.

different thermal efficiencies, and up to an additional three recycling routes for each material, for example, packaging glass to packaging glass or glass to aggregate⁶⁹.

Emissions are given as kgCO₂e/tonne of the particular waste fraction assessed, or per tonne of residual waste. Figures in brackets are negative and therefore (by convention) show an overall benefit. The colouring gives a visual indication of the climate change impacts of the waste managed in a particular way: dark green showing the highest benefit (largest negative emissions) through to red which shows those waste options with the highest GHG emissions for a particular waste or waste material.

Table 6: Quantitative and qualitative life cycle emissions of waste management options (kgCO₂e/tonne of waste)

kg CO ₂ e/ per tonne of waste processed	Landfill 50%	Landfill 70%	Landfill 80%	Landfill 90%	Composting	AD	Gasification	EfW 20%	EfW 25%	EfW 29%	Recycling High	Recycling Medium	Recycling Low
Plastics	101			48			1,184	1,233	1,038	883	(1,338)	(824)	
Cardboard	1,100	720	530	340		(265)	(339)	(299)	(393)	(469)	(62)		
Paper	1,485	971	713	456		(232)	(294)	(256)	(338)	(404)	(550)	(376)	(299)
Food	547	360	267	173	(27)	(96)	(94)	(65)	(95)	(118)			
Green	569	375	277	180	(29)	(130)	(118)	(89)	(124)	(153)			
Glass											(407)	(226)	(25)
Steel											(1,829)		
Aluminium											(10,721)		
Residual European ^a		226 ^b					(119)	49	(164)				
Residual Developing ^a		209 ^b					(67)	76	(103)				
GHG Emissions (kgCO ₂ e/tonne)	(>1000)	501-1000	251-500	(101-250)	(51-100)	(<50) → <50	51-100	101-250	251-500	501-1000	>1000	Not modelled	Not valid

Notes:

a. Based on slightly different marginal grid from first five rows

b. Calculated with 75% gas recovery

System boundaries, data and assumptions are described in more detail in Appendix 4

Residual waste can be treated by AD, but the solid products are landfilled and it has not been modelled.

Paper and cardboard cannot be recycled to the same quality product due to the reduction in fibre length.

Plastics can theoretically be recycled to the same use but sometimes mixed plastics cannot be sufficiently separated economically.

It is accepted that aluminium, steel and glass can go to landfill or EfW but essentially there are no significant direct benefits or disbenefits from their landfill or from combustion – they all pass through each ‘process’ essentially unchanged without generating any significant emissions. Although EfW facilities recover both ferrous and non-ferrous metals, this benefit is not taken into account here.

Table 6 can be used to examine the relative environmental costs and benefits of managing different waste fractions and residual waste using different assets. To find the best option of those considered for managing a material simply compare the numbers in the table for the relevant row. The lowest number, including any negative numbers (shown thus (79)), is the best option for managing that waste material from the point of view of climate change mitigation.

For residual waste assets⁷⁰, the calculations behind Table 6 use a high carbon intensity⁷¹ marginal electricity grid⁷² of 50% coal and 50% natural gas. Initial analysis of the life cycle results from WRATE showed that the performance of EfW plants and landfill with gas recovery, are affected by:

- the carbon intensity of the electricity displaced;

⁶⁹ Other methods of management, including pyrolysis and gasification followed by chemical recycling were discussed but were not included at this stage due to the variability and the lack of life cycle data.

⁷⁰ Referring to energy from waste and landfill.

⁷¹ The carbon intensity of electricity is the total emissions (often expressed as kgCO₂e per kWh) of electricity supplied to the grid.

⁷² Marginal grid here means that electricity generation that will be substituted by electricity generated from EfW, AD or from the combustion of landfill gas.

- the efficiency of the EfW plant or landfill gas recovery; and
- the composition of the residual waste, particularly the percentage of fossil carbon.

All of these were examined in detail as the Criteria were developed.

Recycling will also be affected by changes in the electricity grid, both where the recycling is located, because these processes require power; and also where virgin raw material extraction and processing takes place, because both these can consume large amounts of electricity. The climate change benefits derived from recycling being the difference between the emissions avoided from extracting and producing the material that is displaced and the emissions from collecting and processing it into secondary raw material. Therefore, if the grid carbon intensities for extraction and processing are much lower than those for recycling, recycling may become much less beneficial, or even potentially harmful, for climate change mitigation.

However, the countries where virgin materials are extracted and processed and those collected waste is processed into secondary raw materials (and therefore the electricity grids used) are determined by global markets. Therefore, while default (e.g. global or European) values were used in the modelling, it is not possible to predict how recycling of different materials in any one asset will be affected by changes in the electricity grid in different countries.

Generally, only those options shown by the life cycle modelling to be the best for managing the particular waste fraction have been included in the Criteria below. For residual waste, these means that landfill has been excluded and EfW has been included, because landfill of residual waste always produced substantial emissions contributing to climate change. The exception is composting and anaerobic digestion, that have been included although they show lower climate change benefits than high electricity only efficiency EfW plant. This is because none of the modelling used a very low carbon grid, and this could make anaerobic digestion and composting more beneficial than EfW.

3.7 The Criteria for Waste Management

These Criteria cover waste management operations for waste once it has become waste at all levels of the hierarchy. By definition then it excludes waste prevention. Waste Management Criteria are defined for storage infrastructure, sorting and MRFs, reuse and recycling, composting and anaerobic digestion, incineration with energy recovery and landfill gas recovery. All mobile plant used at waste management facilities, such as forklifts, loading shovels etc. are included within the assest covered by these Criteria.

Waste Collection

The development of low carbon waste processing assets requires organised, regular, waste collection services – in effect, it is essential infrastructure for low carbon waste management systems, hence its inclusion in these Criteria. Collection here covers containers and vehicles used to collect and deliver waste to waste facilities.

Table 7 below details the Criteria for assets collecting and handling municipal solid waste, including mixed residuals, recyclables, and green/yard waste. Although collection produces only a minor part of the impacts of most waste management systems, greenhouse gas emissions from waste collection mainly arise from vehicles used to transport that waste. Therefore, all collection and other waste transport vehicles will have to meet CBI's general Transport Criteria for low GHG emission vehicles. Additionally, where containers are provided or used for storing or transporting waste, these should be 100% recycled and recyclable material to be certified.

Table 7: Criteria for Waste Collection

Assets covered	Eligibility Criteria
ISO containers, recycling bins, wheeled bins, green/ garden waste containers	Made from 100% recycled and recyclable materials. Containers for residual waste will not be eligible unless part of an investment that also includes an equivalent number of separate containers for material recycling. Support source segregation of waste.
Collection vehicles	Must meet Transport Criteria

Waste Storage

Bond issuances often include a mix of assets, many of which support the main processing activity. In the case of assets for handling or storing waste, their effect on the mitigation impact of the system is small in comparison to the processing assets. In order to reduce the requirements on the issuer while maintaining the potential for the largest mitigation impact across the system, handling infrastructure, such as waste storage facilities are automatically certifiable, if they are dedicated to supporting waste management facilities that meet any of the other elements of these Criteria, e.g. storage for a metals recycling facility, or storage for an eligible Energy from Waste facility. Transport linked to storage must meet the Transport Criteria. Other mobile plant assets within the facility itself are eligible for certification when part of a wider eligible project. Table 8 below details the criteria for assets storing and bulking municipal solid waste.

For the purposes of clarity, waste storage assets which are not dedicated to eligible waste management facilities are not covered under the Criteria as they have no added indirect mitigation benefit for the waste sector.

Table 8: Criteria for Waste Storage

Assets covered	Eligibility Criteria
Storage and bulking facilities	Dedicated to eligible waste processing asset(s) downstream. Those downstream assets do not need to be certified but do need to meet the criteria for that asset type. All waste stored must be transferred to those assets.
Collection vehicles	Must meet Transport Criteria

Waste Sorting, Separation and MRFs

Waste sorting is an intermediate process which should be followed by recycling. It has relatively little impact on mitigation but is often a necessary step to provide clean, separated materials for recycling. In this circumstance it is eligible for certification. It is also eligible when used in mechanical biological treatment (MBT) prior to processing in EfW facilities to reduce the overall impact on climate change, provided that the EfW would itself be certifiable.

MBT to landfill (in full or in part) is not eligible, because outputs have to go to an eligible facility and landfills are not eligible under these Criteria. Biodegradable waste to landfill from MBT is only partially treated and will still produce methane. The contribution of landfill emissions to climate change, the

highly uncertain nature of methane emissions from landfills; and the uncertainty about the amount of methane generated from residual municipal waste that is only partially degraded by MBT prior to landfilling are all supportive of this exclusion.

It is good practice (and a legal requirement in some countries) that the producer of the waste should know where its waste will be taken and to what type of process it will be subjected. In this instance, a form of evidence such as invoices or weighbridge tickets that the waste is going to a facility that is eligible under these Criteria will be required.

Table 9 below details the criteria for assets sorting municipal solid waste.

Table 9: Criteria for Waste Sorting

Assets covered	Eligibility Criteria
Sorting facilities (Includes material recovery facilities (MRFs) and some MBT plants.	Facilities sorting mixed recyclables into separate glass, metal, plastic, paper, etc. are eligible for certification where the outputs are demonstrated via invoices or weighbridge tickets to go to facilities that are or would be certifiable under CBI's criteria.
	Facilities processing mixed residual waste to produce feedstock for EfW are eligible where they separate waste components for recycling and both the recycling and residual outputs are demonstrated via evidence to go to facilities that are or would be certifiable under CBI's criteria.

Recycling and Reuse

These assets include facilities processing separated, recycled waste materials into secondary raw materials, and facilities reselling, repairing, refurbishing or reconditioning goods, equipment and appliances. These assets all produce materials for the consumer and/or commercial market. Table 10 below details the Criteria for assets processing waste into new materials.

Recycling offers one of the largest net mitigation benefits within the municipal waste management sector. Materials refurbishment, reuse, and recycling/recovery produces both direct mitigation benefits through prevention of materials to landfill and indirectly by offsetting new material extraction, refining, processing.

The conversion of waste material into a different material by chemical reaction (other than combustion) – termed ‘chemical recycling’, is being developed across many countries now to enhance the recycling of plastic and paper waste. Chemical recycling should be seen as a complementary solution to mechanical recycling where the latter proves to be inefficient such as in the case of difficult to recycle plastics, i.e. not properly sorted, multilayered or heavily contaminated waste. Chemical recycling of difficult to recycle plastics is eligible under the Recycling and Reuse part of this Criteria.

Reuse is more complex. Some items could be reused for a purpose that would not have been fulfilled by a new product. For example, if an electric kettle is reused as a garden ornament where none was required previously and a replacement kettle is still required, that reuse offers no tangible benefits. Therefore eligibility is limited to putting products back to their original use.

Table 10 below details the criteria for assets relating to recycling and reuse.

Table 10: Criteria for Recycling and Reuse

Assets covered	Eligibility Criteria
Facilities processing recyclable waste fractions into secondary raw materials	The secondary raw materials (such as steel, aluminum, glass, plastics) cease to be waste and are sold to be used as secondary raw materials.
Facilities collecting, sort, clean, refurbish, recondition and/ or repair products	The products are put back to their original use without any further pre-processing required. For waste electrical and electronic equipment (WEEE) specifically, the product is covered by an ecolabelling scheme and only those products meeting the three lowest energy use categories are eligible.

Composting

These Criteria cover facilities for composting food waste and/or garden/yard (green) waste into compost.

These facilities receive only separated green and/or food waste and use aerobic biological degradation to produce composts. Table 11 below details the criteria for assets composting green and food waste.

The Criteria are based on the UK Publicly Available Specification (PAS 100)⁷³ for waste derived composts (see Box 3 for more details). This was developed by WRAP and the Environment Agency and is overseen by BSI, the UK equivalent of CEN. Other, similar standards⁷⁴ will be acceptable provided they cover the following to an equivalent level:

- Waste inputs,
- Monitoring,
- Sampling and testing, and
- Product quality.

The process also has to have zero measurable methane emissions and these requirements are incorporated in an environmental permit which is independently regulated.

Table 11: Criteria for Composting

Assets covered	Eligibility Criteria
Facilities processing food and/ or green/ garden/ yard waste to produce compost for agricultural, municipal or consumer applications	<ul style="list-style-type: none"> • Zero measurable methane emissions • Monitoring, sampling and control of the following is carried out in accordance with PAS100 guidance or equivalent national or state standard or guidance: <ul style="list-style-type: none"> - Waste inputs (to ensure only source separated, uncontaminated garden/yard and other appropriate waste is received). - The process (for example, to ensure temperature, moisture and emissions are aligned with correct process operation). And

⁷³ http://www.wrap.org.uk/sites/files/wrap/PAS%20100_2011.pdf

⁷⁴ For example, the South Australia guidelines, https://infostore.saiglobal.com/en-gb/standards/as-4454-2012-121773_SAIG_AS_AS_267608/

- Product quality (properly sampled and analysed for parameters that would affect its use: for example, heavy metals and other biocidal substances, particle size, contamination, stability).
- The resulting product is not landfilled and replaces non-waste material in the market.

Box 3. Publicly Available Specification 100: Specifications for Compost Material

The British Standard Institution publicly available specification for compost materials known as BSI PAS 100 applies across the UK and covers the whole of the production cycle from waste input, production methods, sampling, quality control, contaminants and laboratory testing. The material must be sampled and tested to make sure that the product meets the PAS 100 criteria and therefore is fit for use. PAS 100 applies only to source-segregated biodegradable wastes treated at centralised, on-farm and community composting facilities.

PAS 100 was selected as an example because:

- CBI wishes to certify only those assets that genuinely contribute to climate change mitigation.
- There is a need for a standard to ensure compost is produced and used beneficially without environmental detriment.
- It is publicly available, in use and was developed by a group involving all the different parties.
- It covers standards for the waste input, the process, the product, its use and its monitoring.

Anaerobic Digestion

These Criteria cover facilities for digesting food waste and/or green waste anaerobically to produce biogas consisting of carbon dioxide and methane. The gas should be burned to produce electricity and/or heat, or purified to methane for vehicle fuel, injection into the gas grid or chemical conversion. Because the feedstock contains only biogenic carbon, any electricity or heat produced from combustion to form carbon dioxide is essentially free of fossil carbon. The carbon dioxide equivalent (CO₂e) intensity of the electricity is dictated by how much methane escapes from the process.

The Criteria are based on the UK Publicly Available Specification (PAS 110)⁷⁵ for waste digestates (see Box 4 and Appendix 6 for more details). This was developed by WRAP with the Environment Agency and others is overseen by BSI, the UK equivalent of CEN. Other, similar standards will be acceptable provided they cover to an equivalent level the following:

- Waste inputs,
- Monitoring,
- Sampling and testing,
- Product quality.

The process must also have methane emissions less than or equal to 1285g per tonne of waste input. This has been calculated as equivalent to the 100gCO₂e/kWh derived by CBI's Technical Energy Group as the carbon intensity of renewables. These, equivalent or more stringent requirements must be incorporated in an environmental permit which is independently regulated.

⁷⁵ <http://www.wrap.org.uk/content/bsi-pas-110-producing-quality-anaerobic-digestate>

Table 12 below details the criteria for assets processing food and/or green waste using anaerobic digestion and composting technologies.

Table 12: Criteria for Anaerobic Digestion

Assets covered	Eligibility Criteria
Facilities which produce power and/ or heat using food and/ or green/ yard waste	<ul style="list-style-type: none"> • Total methane emissions \leq 1285g CH₄/ tonne of waste input (this is approximately equivalent to 100g CO₂e/ kWh) • Woody waste must be segregated before or after processing and sent to an eligible EfW or composting plant • Monitoring, sampling and control of the following is carried out in accordance with PAS110 guidance or equivalent national or state standard or guidance <ul style="list-style-type: none"> - Waste inputs (to ensure only source separated, uncontaminated food and other appropriate waste is received). - The process (for example, to ensure temperature and emissions are aligned with correct process operation). And <ul style="list-style-type: none"> - Product quality (properly sampled and analysed for parameters that would affect its use: for example, heavy metals and other biocidal substances, nutrients and contamination). • The solid and liquid products are not landfilled and replace non-waste materials in the market.

Box 4. Publicly Available Specification 110: Specification for bio-based waste digestate

The British Standard Institution publicly available specification for whole digestate, separated liquor and separated fibre derived from the anaerobic digestion of source-segregated biodegradable materials covers the whole of the production cycle from waste input, production methods, sampling, quality control, contaminants and laboratory testing. The material must be sampled and tested to make sure that the product meets the PAS 110 criteria and therefore is fit for use. PAS 110 applies only to source-segregated biodegradable wastes treated at centralised, anaerobic digestion facilities.

PAS 110 was selected as an example because:

- CBI wishes to certify only those assets that genuinely contribute to climate change mitigation.
- There is a need for a standard to ensure compost is can be used beneficially without further environmental detriment.
- It is publicly available, in use and was developed by a group involving all the different parties.
- It covers standards for the waste input, the process, the product, its use and its monitoring.

However, any similar state, national or government agency standard that applies similar criteria to achieve similar quality controls on anaerobic digestion is acceptable.

Energy from Waste

In this document, energy from waste means assets producing electricity and/or heat or cooling from thermal decomposition of waste by combustion or assets using another thermal process such as gasification. These assets produce electricity and/or heating or cooling, and also extract some materials from residual waste for recycling, such as ferrous and non-ferrous metals.

As illustrated in the waste management hierarchy, the best ways to deal with waste are to i) avoid creation of it at all, but ii) where it is created, reuse or recycle it. There is, therefore, a rationale for excluding EfW from these Criteria, on the basis that EfW is a ‘once-through’ process that takes out of circulation potentially recyclable materials, and recognizing this activity as Paris Agreement

compatible may undermine the goals of establishing a zero-waste circular economy as quickly as possible, if it diverts green investment away from activities higher up the waste management hierarchy.

Against this though, there is the reality that there is currently no prospect of recycling everything. Even in the European Union, with one of the most environmentally aware legislatures in the world, it is accepted that more than one third of municipal waste will be managed as residual waste even in 2035⁷⁶. It is possible that with developments in the circular economy, waste prevention and in waste technologies that residual waste might effectively be reduced more quickly than either those targets or past trends imply and CBI will continue to monitor this and keep the treatment of residual waste and the eligibility of EfW facilities under review.

In the meantime, we still need to manage residual waste in the way that has least impact on the climate. EfW is the only route that, subject to conditions, is currently able to provide this. However, EfW should be viewed as potentially a transitional technology that offers substantial mitigation compared to landfill, so long as lock-in of such technology (and lock-out or delay of alternative investments higher up the waste management hierarchy) is avoided.

Table 6 illustrates the options considered by the TWG for dealing with residual waste. Of these, landfill has been excluded from eligibility for the treatment even of residual waste due to the high methane emissions produced, even with the most optimal gas recovery systems in place. Pyrolysis was excluded due to the lack of data for a successful, commercially sized plant. For gasification, we were able to access life cycle data for one process but there has, as yet been no widespread take up of the technology. In either case, where the organics from these processes are used to provide energy in the form of electricity, heating and cooling, they are likely to offer similar climate change benefits to EfW.

In the EU, the Technical Expert Group convened by the European Commission to support its proposed draft Regulation on sustainable investment is working on a Sustainability Taxonomy. It is highly likely that the EU Sustainability Taxonomy currently under development will not recognize EfW facilities (see Box 5 below). Therefore, CBI has decided that it will not currently regard EfW facilities within the EU as eligible, because it does not wish to undermine those objectives and guidelines within the EU.

Hence these Criteria allow for the certification of EfW facilities in all jurisdictions except the EU, subject to the following conditions aimed to address concerns over EfW displacing recycling either i) now (by processing more than residual waste available) or ii) in the future via locking in EfW facilities and diverting green finance away from new recycling, re-use or waste prevention activities. The Criteria also set efficiency requirements on EfW facilities to ensure certified facilities provide a climate mitigation benefit. These conditions, the rationale for them, and the steps to assess them are explained in more detail below. In line with the potential positioning of EfW as a transitional activity or technology while circular economy systems are established, these Criteria will be reviewed on a regular basis to align the Criteria with most climate-friendly waste management and investment practices for each waste stream, including any residual waste, as these evolve.

⁷⁶ The EU's Framework Directive on Waste (WFD), as modified to include the Circular Economy Package, prescribes new, higher levels of recycling of 65% and 60% by 2035. Thus, the recycling targets mean there will be 35% or more residual waste in the EU when the targets are achieved.

Box 5: EfW and the draft EU Taxonomy

The TEG published a draft Taxonomy Report in June 2019¹ and is currently reviewing its proposals in light of feedback from a public consultation over the summer and will release an updated Taxonomy Report to the Commission early in 2020. The June 2019 draft report states that experts' opinions differed on whether EfW would be an appropriate environmentally sustainable activity offering a substantial contribution to climate mitigation, but ultimately EfW was excluded from the draft Taxonomy. The arguments for and against its inclusion were based on:

- Against: the large portion of waste currently incinerated that could be recycled;
- For: the reliance of some individual Member States on the incineration;
- Against: the risk that further increasing capacities (in the EU) could result in lock-in preventing more reuse and recycling
- Against: recognition of EfW causes harm to the environmental objectives of a circular economy: waste prevention and recycling.

Thermal efficiency

A minimum thermal efficiency (electrical and heat output to grid divided by the heat content in the waste (net calorific value or lower heating value basis)) has been set for EfW plant of 25% as electricity, representing the approximate boundary between the EU definition of incineration which is recovery and that which is disposal.

Removing fossil carbon inputs

CBI's analysis of the effects of waste composition and decarbonisation of electricity grids shows that both can have substantial effects on the climate change mitigation potential of an EfW plant to the extent that certification would not meet CBI's guiding principles. In order to address these concerns, CBI undertook additional analysis to investigate the effects of fossil carbon content of the waste, efficiency of the EfW plant and the carbon intensity of the electricity grid on the climate change mitigation benefits of EfW.

The results of the analysis show that, where the electricity grid is decarbonised, EfW (without allowing for carbon dioxide 'savings' from metals recovery that takes place) could produce a net burden on climate change. Further, although it could still be a better residual waste management option than landfill, for fossil-based plastics it was worse. To ensure that EfW did meet the CBI's guiding principles, an additional qualification requirement has been introduced: the average net carbon⁷⁹ intensity of the electricity (and/or heat) produced over the planned lifetime of the plant, must be less than the carbon intensity of electricity (and/or heat) produced by a qualifying EfW plant (i.e. 25% electrical efficiency) when both dense and film plastics are removed from the waste input. This qualification requirement is termed the 'waste management allowance'. In order to qualify for certification under the Criteria, EfW plant must therefore demonstrate that the average carbon intensity of the electricity produced is less than the average carbon intensity for delivering management of residual waste when potentially recyclable dense and film plastics have been removed. It does not matter how this carbon intensity is achieved or when, as long as the average over the life of the plant meets the requirement. A plant operator might plan to a gradual decarbonisation trajectory with a related recycling strategy removing increasing amounts of plastics. Alternatively, an operator might be above the average for the first five years but have confirmed plans to deliver heat to a new industrial premises being built next-door. Box 6 gives the steps involved.

⁷⁹ Fossil carbon dioxide only.

Box 6. Step by Step Approach to assessing the qualifying carbon intensity of Energy from Waste

Step 1: Obtain the best available, detailed waste compositional analysis for the waste input.

Step 2: Adjust if necessary for changes in recycling since the analysis.

Step 3: Combine with proximate analysis of the different waste fractions (calorific value, total carbon content, estimated proportion of fossil carbon), calculate the net CV and the fossil carbon content of the projected waste input.

Step 4: Calculate what would be the emissions intensity of the EfW plant gCO_{2e}/kWh produced at the minimum qualifying efficiency when the dense and film plastic has been removed (termed the waste management allowance).

Step 5: This figure is the emissions intensity that must be demonstrated to be met if the plant is to be considered as eligible under this Criterion.

Note that it is not necessary to remove all the dense and film plastics. The qualifying limit can be achieved through other (or a combination of) measures, such as increased plant efficiency due, e.g. to the recovery and supply of heat.

Recycling of outputs

Recycling of metals and bottom ash is also a requirement: incinerator bottom ash (IBA) must be recovered as must at least 90% of the metals from the IBA but no allowance will be made for this additional recycling in relation to the emissions of carbon dioxide it saves.

Avoiding lock-out of recycling

Over the period of 25 years (the typical operational period for an EfW contract), recycling can be expected to increase substantially. There has been concern that municipal waste could become locked into residual waste management contracts and hinder efforts to increase recycling. In the EU, the rate of recycling and composting of municipal waste is planned to increase from an average 46% in 2017 to meet the 65% target in 2035, or approximately 1% per year. CBI analysed data from the European Environment Agency for recycling and composting in 32 European countries over a period of approximately 10 years⁸¹. Table 13 shows the average increase in the rate of recycling and composting rate grouped by the starting rate in 2004⁸².

Table 13: Increases in recycling in Europe

Start range % recycling and composting	Percent points increase over 10 years	Percent increase forecast
50 to 59	5.5	5.5
40 to 49	5.3	5.5
30 to 39	5.7	5.5
20 to 29	12.2	15
10 to 19	16.0	15
0 to 9	16.4	15

The overall average data show that between 2004 and 2014, the rate of recycling and composting increased from 30.6% to 43.6%, an average rate of approximately 1.3% per year. Table 13 shows that the largest increases are where the starting point is lowest and once 30% or more has been achieved, the average rate of increase for the slows markedly from almost 15% to just over 5%. There

⁸¹ <https://www.eea.europa.eu/data-and-maps/indicators/waste-recycling-1/assessment>

⁸² Where 2004 data were unavailable, different years were used.

have been exceptions to this: with higher growth, notably Wales and Taiwan⁸³; and also those with much lower or even negative growth (Austria and Finland). None of these countries has been included in the above averages.

Therefore, in order to ensure that increases in recycling are not prevented by contracts which divert waste components that would have been recycled to EfW as residual waste, an EfW plant will not be eligible for certification where its capacity is greater than the amount of residual waste that would be available, as predicted by the third column of Table 13. For example, where the total amount of municipal waste collected for the area is 400,000 tonnes per year and the recycling/composting and reuse rate is 25%, then over a 25-year life, we assume the rate will increase by 15% in the first ten years, 5.5% in the next ten and 2.75% in the final five years, giving a recycling rate of 48.25% in 25 years' time. Therefore, with no growth in waste amounts, the maximum permitted capacity of EfW would be 51.75% of 400,000 or 207,000 tonnes per year.

Table 14: Criteria for Energy from Waste

Assets covered	Eligibility Criteria
Facilities which produce power and/ or heat/ cooling by the thermal processing of residual waste, including rejects from recycling/ composting/ AD	<p>For EfW facilities outside the EU only:</p> <ul style="list-style-type: none"> • Plant efficiency $\geq 25\%$; AND • Bottom ash recovery; AND • $\geq 90\%$ recovery of metal from ash; AND • Average carbon intensity of electricity and/ or heat over the life of the plant \leq waste management allowance; AND • The capacity of the plant does not exceed the calculated residual waste at any time in the plant's life. <p><i>(EfW facilities within the EU are not eligible for certification.)</i></p>

Landfill Gas Recovery

Landfill, as shown by Table 4-3 in Appendix 4, has the highest impacts on climate change of any waste management method due to the effects of the biogas generated from anaerobic decomposition of the waste and emitted to the atmosphere – biogas is approximately 50% methane, with a 100-year average GWP of 28 times that of carbon dioxide. Controlled landfill has advantages over open-dumping but, unless the methane produced is collected and destroyed, it will contribute significantly to climate change. Landfills globally present a substantial threat to climate change – they are essentially uncontrolled bioreactors; are at the bottom of the waste hierarchy, are not compatible with a 2°C scenario and therefore do not meet the CBI's guiding principles for certification (Section 3.1).

However, installing effective gas collection and recovery at an existing landfill site produces the largest single contribution to climate change mitigation per tonne of waste (see Table 4-4, Appendix 4). Therefore, although operational landfills are excluded from certification, the installation of landfill gas recovery systems at landfills that are closed, or being restored with soil and/or subsoil, is deemed certifiable. A minimum efficiency has been set for certification of landfill gas recovery: 75% of the total landfill gas generated over the gas-generation lifetime. This is considered to be the maximum practicable extraction efficiency over the gas generation lifetime of the landfill (circa 150 years)⁸⁶. Achieving this level requires sacrificial gas wells, stand-by flares, constant expert management and maintenance of the gas control and recovery system for many decades after waste input and with it, the income, have ceased.

⁸³ Recycling – Who really leads the World? Issue 2, Eunomia and the European Environmental Bureau

⁸⁶ For example,

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/321606/LFTGN03.pdf

For a gas capture asset to qualify for certification, it must no longer be taking biodegradable waste or prolonging the lifespan of the landfill asset. This requirement is to ensure no green bond funding goes towards supporting continued development of landfill facilities.

Table 15 below summarises the Criteria for assets processing municipal solid waste to produce electricity, heat or cooling and fuel.

Table 15: Criteria for landfill gas recovery

Projects covered	Eligibility Criteria
Projects to capture biogas from closed landfill facilities	<ul style="list-style-type: none"> • Gas capture $\geq 75\%$; AND • Gas used to generate electricity and input to the natural gas grid or used as vehicle fuel; AND • The landfill is not accepting further waste (with the exception of restoration materials)

3.8 Adaptation & Resilience Requirements

Framework for Criteria addressing Climate Adaptation and Resilience

As discussed in Section 2, municipal waste management has the potential to improve the resilience of ecosystems to climate change by preventing waste, emissions and other pollutants from entering the environment. And conversely, climate change can influence the resilience of assets and facilities via an increased number and intensity of weather events, coastal inundation, and more extreme temperatures.

Therefore, specific requirements about climate change adaptation and resilience are included to ensure that; waste management facilities are resilient to climate change; and waste management assets/projects have no negative impact on climate resilience of areas in, or beyond that in, which they are operated.

The climate risk posed to the waste management sector is more about asset level resilience and hence the siting of facilities. Therefore, those seeking certification for waste management assets and projects will be required to conduct a climate risk assessment and have an adaptation plan where high risks are identified – assessed via the Adaptation and Resilience Checklist.

Adaptation and Resilience Checklist

The Adaptation & Resilience checklist focuses on the processes the issuer should demonstrate they have been through to determine if the issuer is asking and evaluating the right questions regarding climate change resilience at the right stages of development and if the issuer is monitoring and reporting appropriately.

To meet the requirements, issuers must demonstrate that:

- Climate related risks and vulnerabilities to the asset are identified; and
- Impacts in, and beyond, the asset to ecosystems and stakeholders are identified; and
- Strategies to mitigate and adapt to the climate risks and vulnerabilities identified to protect the asset.

The checklist (Table 16) is a tool to verify that the issuer has implemented sufficient processes and plans in the design, planning and decommissioning phases of a project to ensure that the operation and construction of the asset minimises environmental harm; the asset is appropriately adaptive and resilient to climate change; and supports the adaptation and resilience of other stakeholders in the surrounding environment.

All elements of this checklist must be addressed, with appropriate evidence provided that these requirements are being met or are not applicable in respect of the specific assets and projects linked to the bond. It is expected that the evidence will encompass a range of assessment and impact reports and associated data, including, but not limited to, those reports required to meet national and local licensing and approval processes. This might include Development Consent Orders, Environmental Impact Assessments, Vulnerability Assessments and associated Adaptation Plans.

Table 16: Checklist for evaluating the Issuer’s Adaptation & Resilience performance in respect of a waste management facility

Item	Proof given	Overall assessment
Section 1: The issuer identifies the climate related risks and vulnerabilities to the asset/site		
<p>Processes are in place (as part of both the asset design and ongoing management) to assess key risks to the assets from a changing climate.</p> <p>These key risks should include the following, plus any others felt to be of concern for the operation of these assets. The risks should be identified and interpreted in terms of the impact on the asset and the related effects for the business – e.g. impact on operating feasibility and schedules, and potential system outages, impact on maintenance requirements etc.</p> <p>N.B. This list taken from World Banks Climate and Disaster Risk Assessment Tool</p> <ul style="list-style-type: none"> ● Temperature changes, and extremes in temperature ● Extreme precipitation and flooding ● Drought ● Sea level rise and storm surge ● Strong winds <p>How these affect the asset or site in question will be highly variable and will be for the issuer to identify and relate to their operations. These assessments should use climate information, modelling and scenarios from a peer-reviewed source.</p> <p>This assessment should be done regularly. The frequency of the assessment will depend on the nature of the climate related risks and vulnerabilities, and should be specified by the issuer and reported against in subsequent annual reporting.</p>		
Section 2: The issuer identifies the impacts in larger context (spatially and temporally) beyond the asset/site (i.e. the impacts of the underlying assets and projects on the broader ecosystem and stakeholders in that ecosystem)		
<p>Processes should be in place (as part of both the asset design and ongoing management) to assess the impact of the waste management asset on the climate resilience of other stakeholders in the social, economic and environmental system in which it operates and how to mitigate or reduce any negative impacts</p>		

<p>These assessments address:</p> <ul style="list-style-type: none"> ● Any ways in which waste management facilities might affect the climate resilience of other users/stakeholders? ● Any ways in which waste management facilities improve the adaptation capacity of other users/stakeholders? ● For example, they may include: ● Impact on water quality and quantity for other users in the basin ● Waste and pollution emitted ● Fire hazards 		
<p>Section 3: The issuer has designed and implemented strategies to mitigate and adapt to these climate risks and vulnerabilities</p>		
<p>An adaptation plan has been designed and is being implemented to address the risks identified in the assessments above.</p> <p>The issuer has designed or amended asset maintenance plans to ensure that scheduled maintenance is sufficient to cope with the ongoing impacts of climate change; and a plan has been established to govern how to approach emergency maintenance needs arising from sudden climate change impacts (e.g. extreme storms).</p> <p>The issuer has training, capacity and governance arrangements in place for how the organisation will deal with the impacts of exceptional events (e.g. droughts, floods, severe pollution events, extreme storms, winds etc.).</p> <p>The issuer has monitoring and reporting systems and processes to identify high risk scenarios.</p> <p>The issuer has contingency plans to address disruption to operations or loss of the asset and any resulting environmental or social damage.</p> <p>The issuer has processes for feeding risk assessment back into decision-making.</p> <p>The issuer has a budget allocated to implementing the adaptation plan and has a named member of staff responsible for its implementation.</p> <p>The issuer complies with any existing broader or higher-level adaptation plans, such as NAPAs.</p>		

4 Appendices

Appendix 1: TWG and IWG members

Working group members

Waste Management Technical Working Group Members

Adam Read - Ricardo Energy & Environment
Adrian Barnes - Green Investment Bank
Amrita Sinha - C40
Bernie Thomas - Resources Futures
Brendan Edgerton - World Business Council on Sustainable Development
Carla Tagliaferri - University College London
Chris Hoy - Ricardo Energy & Environment
Dominic Hogg - Eunomia
Gary Crawford - Veolia / International Solid Waste Association
Jess Allan - Anaerobic Digestion and Bioresources Association
Keith James - WRAP
Libby Bernick – Trucost
Margaret Bates - University of Northampton
Mariel Vilella - Zero Waste Europe
Mia (Chang) He - CECEP Consulting
Phil Coughlan - Herrera
Professor Richard Murphy - University of Surrey
Samantha Arnold - Golder Associates
Shui-e Yin - Environmental Sanitation Engineering Technology Research Center of Ministry of Housing and Urban-Rural Development
Sourabh Manuja - The Energy and Resources Institute
Stuart Ferguson - London Waste & Recycling Board
Suneel Pandey - The Energy and Resources Institute
Terry Coleman - Resource and Waste Solutions LLP
Thom Koller - Anaerobic Digestion and Bioresources Association
Wenqin Lu - CECEP Consulting

Waste Management Industry Working Group Members

Alexandra Licurse - Debt Capital Markets Origination
Andrew McIntyre - ADB
Atul Sanghal - Emergent Ventures
Charles Gooderham - ERM
Chiael Anderson - ERM
Chiew Lee TAN - NEA
Chindarat Taylor
Damasco Zagaglia - ISS
Desmond Ho – NEA
Doug Farquhar - DNV GL
Dr. Tahsin Choudhury - Tuev Nord
Duncan Russel - ERM
Emilie Hagan - Atelier Ten
Eng Kim TAN - NEA
Grace Sapuay

Waste Management Background Paper

Hailei Zhu (Albert) - CQC
Herman Oterdoom
James Leung - NEA
Janina Lichnofsky - ISS
John Sayer - Carbon Care Asia Limited
John Scanlon - Suez
Joseph BOEY - NEA
Julien Grimaud - 2ei
Larry Grant - Eden Eco Solutions
Margaret Andrews - Suez
Mark Berry - Norton Rose Fulbright
Mark Fisher - EY
Melanie Eddis - ERM
Mike Cao - Shanghai Mu Yi Investment Advisors Ltd.
Michael van Brunt - Covanta
Monica Reid - Kestrel Verifiers
Myles Cohen - Earth Link
Paul Gilman - Covanta
Pip Best - EY
Rainer Winte - Tuev Nord
Robert Rosenberg - ISS
Sarah Fee - ERM
Soo San ONG - NEA
Stacey Mack - NSF
Stan Krpan - Sustainability Victoria
Stuart Hayward Higham - Suez UK
Susan Robinson - WM
Tara Hemmer - WM
Tina Sentner - NSF
Xing Lan - Carbon Care Asia Limited
Yixiang - Coamc
Yongjun Li - Tuev Nord

Appendix 2: Pathway to Certification

Climate Bonds Certification is available to bonds, or other debt instruments, funding assets or projects that meet the requirements of the Climate Bonds Standard. The actual certification process is a five-step process shown in Figure 1.

First, the issuer must prepare the bond by identifying the assets or projects that will make up the use of proceeds. For Climate Bonds Certification to be awarded, the use of proceeds must match assets and projects deemed eligible under the Climate Bonds Standard's Sector Criteria. Eligible assets are listed under the Climate Bonds Standard's Sector Criteria. One bond may contain eligible assets from a mixture of different Sector Criteria.

Next, a prospective issuer must appoint an approved third-party verifier, who will provide a verification statement that the bond meets the Climate Bonds Standard. The Climate Bonds Standard allows certification of a bond prior to its issuance, enabling the issuer to use the Climate Bonds Certification Mark in marketing efforts and investor roadshows. Subject to the recommendation of the third-party verifier and all the relevant reports being submitted, the prospective issuer is awarded Climate Bonds Certification.

Post bond issuance, the issuer and verifier have 12 months to submit a post-issuance report confirming proceeds have been allocated to eligible assets. Thereafter, the issuer must prepare a brief report annually to confirm that the bond is still in compliance with the Climate Bonds Standard.

Climate Bonds Certification is also available to bonds that have already been issued, this is referred to as post-issuance certification. The issuer just needs to appoint a third-party verifier to prepare a report stating that all use of proceeds falls within the Climate Bonds Standard's eligible projects and assets.

Figure 2-1: Pathway to Certification



Appendix 3: Summary of public consultation

Public consultation for the Waste Management Criteria was held June 2019 – August 2019. Public consultation consisted of two webinars and promotion via the Climate Bonds blog and twitter. Technical Working Group and Industry Working Group members also promoted public consultation via their networks.

No.	Category	Feedback Received	Response
1	Overarching principles/ethos	<p>The criteria should adopt a systems perspective to be able to identify the highest priority intervention points including climate data, policy drivers, and interactions between waste infrastructure and systems on the ground. This systems perspective should be guided by the waste hierarchy, which is both an effective guide and policy tool for local waste decisions and serves as a climate decision making tool. The steps at the top of the waste hierarchy (reducing generation of waste, reuse systems, and organics infrastructure - compost and anaerobic digestion) provide the most significant climate benefits in the waste management sector. This perspective is echoed in the European Investment Bank's Circular Economy Guide which identifies energy recovery (EfW) as a leakage from a circular system. Thus, systems and infrastructure at the top of the hierarchy should be prioritized for climate interventions before disposal systems like EfW and landfill gas.</p>	<p>The waste hierarchy is a good general guide but life cycle studies can show reasons for departure from it. We have taken into account the waste hierarchy by recognising that those mid-hierarchy are automatically eligible (e.g. recycling), whereas those lower down are subject to more conditions/ criteria and limit eligible use of proceeds – e.g. landfill where only specific projects for gas capture on closed landfills are eligible. We are aiming to promote assets higher up the hierarchy. Separate collection and treatment of organics is only of marginal climate change benefit in its own right; the major benefit comes from diversion of the waste from landfill but this counter-factual was not considered for any option and only absolute, not comparative benefits were taken into account.</p>
2	Overarching principles/ethos	<p>The text states that “Assets dealing with waste prevention are also out of scope of these Criteria, as are all assets dealing with wastes other than MSW or similar wastes (Section 3.4). This is a critical missed opportunity to support the highest goal of any waste management hierarchy and covers a set of activities that could use extensive investment.</p>	<p>We agree that minimising waste in the first place is the best way forward and that waste prevention is critical to minimising emissions. However, these are not tackled here / at this time as waste prevention measures would fall outside of the waste management criteria, as the Criteria deals with waste once it has become waste. In time, we aim to expand our other sector criteria (e.g. buildings, food supply chains, manufacturing etc.) to ensure waste creation is minimised economy wide. But this is a complex issue, covering design, construction/ manufacturing, transport etc. in many sectors.</p>
3	Overarching principles/ethos	<p>We are concerned that the criteria does not include waste prevention/reduction activities which have the highest GHG savings potential.</p>	<p>As above.</p>

4	Overarching principles/ethos	We have strong reserves about the scope of activities covered under this waste management standard. We are surprised that waste prevention activities are not included. Waste prevention is on the top of the waste hierarchy and should hence be prioritized. On the other hand, we are concerned that activities at the low end of the waste hierarchy, such as waste incineration, have made their way into the standard and can qualify as 'environmentally friendly'.	As above. Activities at the bottom of the waste hierarchy have been excluded. Those at the lower end of the hierarchy are subject to stringent eligibility conditions.
5	Waste to Energy	The criteria should exclude waste-to-energy as an eligible asset as a climate mitigation strategy under the current framework which would not be in line with transition to a net-zero emissions economy by 2050.	We appreciate the concerns around EfW. Unfortunately, there is currently no prospect of recycling everything, even in the EU. Therefore, we still need to manage residual waste in the way that has least impact on the climate. With that in mind, using energy from that waste makes sense, and we have proposed criteria that impose a tighter threshold on emissions intensity by requiring higher performance and also allowing recycling to develop. Our criteria are global, and many places do not have infrastructure in place for extensive recycling etc. yet, and EfW (particularly under these conditions) is a better option than landfill. We see EfW as a transitional activity and will be reviewing the Criteria after 2 years with the view to potentially remove this from the Criteria in alignment with most climate-friendly waste management practices at that moment in time.
6	Waste to Energy	It is particularly difficult to understand why CBI's draft standards are weaker than and, in many cases, contradict EU waste policy.	As above, our criteria are global but they are also aligned with EU waste policy as set out in the Framework Directive on Waste.
7	Waste to Energy	We are concerned that the criteria are not in line with the long-term net-zero emissions strategy. Our major concern is that waste incineration with energy recovery (R1) despite its very high direct CO ₂ emissions (600 g CO ₂ eq per kWh) is still considered as a climate change mitigation strategy.	The Criteria bring the emissions intensity down from the current 500g to 600g CO ₂ eq per kWh by increasing efficiency, recovering heat and decreasing the fossil content of the waste input. Ultimately, if beneficial recycling cannot be achieved, CBI needs to consider the best way of managing residual waste.
8	Waste to Energy	Deem as ineligible all schemes which promote the burning of woody biomass to generate electricity other than combined with heat at small, local scale.	Only energy from waste schemes dealing with residual waste are eligible.

9	Waste to Energy	Explain further how the defossilised carbon intensity of 240gCO ₂ /kWh is computed.	This is now the waste management allowance. The residual waste composition and the properties of each fraction are used to calculate the emissions intensity of useful energy produced in a qualifying plant.
10	Waste to Energy	The lack of use of waste heat is the critical factor here. If EfWs don't use waste heat, then they shouldn't meet the criteria. In fact, they should be incentivised to improve this (maybe get cheaper finance the more they do) through a banding on the level of CHP QA they achieve. This is already an established practice (to get ECAs and banded ROCs), so will work as a platform to expand.	CBI has provided a standard that would normally require the recovery of heat as above. However, the eligibility criteria allow for operators to meet the carbon intensity in one or more different ways, including the provision of heat.
11	Waste to Energy	The criteria for energy-from-waste (pages 35 & 36) take into account only the plastic derived fraction of the energy, the remainder being considered carbon-neutral "renewable" energy. This is a fundamental misunderstanding as the climate impact of a combustion material is not solely depended on the fossil- or non-fossil nature of its carbon atoms, but on the entire impact of the chain of extraction, production, manufacturing and transport up to the arrival at the facility.	This is why waste prevention is at the top of the hierarchy, because these upstream impacts are avoided. However, when considering an LCA for waste, the waste has zero burdens. The same arguments can be applied to recycling but CBI has been consistent throughout.
12	Waste to Energy	The technical standards are quite hard to follow and validate. For example for Energy from Waste facilities (EfW), the last criteria of average carbon intensity of electricity and/or heat from the EfW over the life of plant being less than a certain metric, to be honest that is quite hard for me to follow and given we are financing some of these facilities it is difficult to identify if they fall under this criteria based on the technical spec which we received from the borrower.	We have simplified the structure of the criteria for EfW to avoid the need to look at the current and future electricity grids.
13	Cross cutting	Furthermore, the text should provide support for separation of organics. As noted in the text, organic materials form the bulk of MSW, even more so in the global south, and generate methane when sent to landfills and dumps. The most effective way to prevent these methane emissions - and to avoid CO ₂ emissions from burning those materials - is to separate organics. Yet the climate benefits of compost and the application of compost is	Both AD and composting are included with eligibility criteria because they provide a slight mitigation benefit. CBI is aware of the issue of methane from landfills and also that CO ₂ emissions are produced from both AD and composting but like those from burning biowaste in an EfW are not regarded by the IPCC as contributing to climate change. The main benefits from composting and AD derive from avoiding landfill

		largely overlooked in the criteria. Composting and anaerobic digestion (with composting) have the greatest climate benefits, according to studies by Eunomia and others.	of organic waste, which is a comparative benefit and as outlined in point 1, the avoidance of landfill is not taken into account.
14	Cross cutting	If Climate Bonds don't acknowledge and endorse some form/mechanism of incentivising better CHP efficiency, then its credibility risks degradation. Sustainability needs to include environmental improvements as well as economic (& social). Simply comparing EfW to landfill is a very narrow perspective and bias towards large companies bank rolling the protracted, high development costs of EfW that then end up risk forcing out SMEs and more innovative, higher efficiency process advances for the future.	These Criteria are focussed on climate change mitigation, as is CBI. There is no comparison made between EfW and landfill, the emissions calculated are absolute but there is a recognition that there is residual waste and CBI wants to certify a high standard for dealing with it.
15	Cross cutting	The parameters and assumptions need to be assessed by an independent service provider, so that they can be compared for tangible, transparent scoring and audit trail reporting by investors and stakeholders.	There will be a verification process in place.
19	Cross cutting	The LCA modelling was carried out using the WRATE software, a life cycle tool developed by the Environment Agency and approved by the England and Wales Government. This software has received significant criticism from Eunomia, which should be taken into account. First of all, it seems that the Life Cycle Analysis carried out for the purpose of this standards were limited to GHG emissions – which is a narrow view of LCA. One of LCA's main advantages is to compare the overall environmental performance of a product/activity according to various impact categories, such as air or water quality. The LCA results presented in the CBI standard solely reports on the carbon footprint of some waste management strategy.	It is true that WRATE has been criticised by Eunomia but that criticism was neither significant nor peer reviewed. It remains the only LCA software approved by government and has been used in the environmental justification of more than £1 billion investment in waste management facilities by Defra's Waste Infrastructure Development Programme and the Green Investment Bank. The background document explains that the focus of the LCA would be on GHG emissions, which are those that most concern CBI. Other environmental impacts were also checked to ensure there were no major adverse implications.
20	Cross cutting	The CBI should ultimately encourage and promote waste programmes that can reach 75-80% separate collection and treatment and that maximise further material recovery with Mechanical Recovery and Biological Treatment.	CBI with the TWG examined all waste management methods for MSW. We have allowed for separate collection for recycling to increase over the coming years and have ensured this is not restricted. All genuine recycling is eligible, as are composting and AD, subject to conditions to ensure their climate change benefit.
21	Other/ uncategorised	It would be easier for a non-technical person to understand if we had	We have simplified the criteria for EfW, which were the most complex.

Waste Management Background Paper

		something easily understandable like equivalent criteria for Anaerobic Digestion Facilities (Methane emissions < 450g per tonne of waste input) which is a lot easier to validate.	
22		The criteria do not cover decentralised options for waste management and processing. Further, some of these processes could be carbon accretive (-ve GWP impact).	CBI was advised by the TWG about methods of dealing with MSW and all these were considered. No assets that weren't covered were identified in public consultation,

Appendix 4: Using life cycle assessment in the development of the Criteria

Life cycle assessment (LCA) is an environmental analysis technique used to study and improve the impacts of a product or service on the environment. It involves including in the system studied everything in the economy that is affected by the process or item under consideration, delineating this system, and quantifying all the significant material and energy flows across this boundary (to and from the environment).

LCA is a holistic approach, considering all the environmental flows resulting from a product or service: any emissions to the environment; the materials used, from their extraction as raw materials through to final disposal, any useful energy used or supplied and how it is generated. It is also objective, in that it uses independent data and it should be transparent, with all assumptions clearly stated. It therefore has the potential to avoid shifting environmental burdens from one place or one part of the system to another and ensures all the burdens and benefits from the environmental flows that relate to a product or service are taken into account.

However, even a simplified LCA that avoids the need for issuers to carry out extensive and expensive primary data collection was considered too complex and time-consuming for green bond issuers to use. The approach agreed with the TWG was therefore to carry out numerous, simplified or high-level LCAs of waste management systems to examine the results and the effect of key parameters so as to draw broad conclusions that could be used to develop the Criteria.

Conducting high-level LCAs of the various waste streams involved in the sector using mostly generic data has provided a comprehensive, science-based understanding of impacts of the system studied, while avoiding the higher costs of a full LCA and also avoiding the need to conduct LCAs on a project-by-project basis. The following principles were used to conduct the simplified LCAs to underpin the Criteria.

1. limiting the number of processes for which data are required by including only the processes that generate or avoid significant emissions;
2. ignoring processes that are unchanged in both the baseline and proposed systems, because they won't affect the outcome;
3. using existing data, databases and standardised factors instead of collecting new data;
4. unless there is evidence of other, serious environmental effects, considering only the emissions that contribute to global climate change; and
5. employing one of the many, widely available pieces of software that perform the calculations required.

Software used

There are several life cycle assessment tools available on the market. For this analysis, WRATE⁸⁷ was chosen as it was developed and approved by the UK government, and conformed to the required principles discussed above while not being overly burdensome.

WRATE was developed by and for the Environment Agency for England and Wales, independently of any interests in any particular waste management process. It was developed specifically to enable waste managers to carry out life cycle assessments for waste management. It was recommended by government for use in assessing waste management facilities and is still in use today by local authorities, waste management companies and is recommended for analysis by others such as the National Infrastructure Commission.

The software includes data on the environmental flows (termed burdens - both capital and operational) from all waste management processes within the system boundaries, including the following:

- the collection of wastes from households, including the manufacture, supply and maintenance of any containers used;

⁸⁷ Developed for the Environment Agency for England and Wales by ERM and Golder Associates.

- the transport of that waste, including the manufacture of vehicles, their maintenance and other operational requirements such as fuel and tyres;
- any sorting or storage of the waste, including construction and operation;
- the treatment of the waste, including construction and operation;
- the disposal of any waste, including construction and operation;
- the conversion of any waste materials into secondary raw materials or compost;
- the production of raw materials, including those substituted by secondary raw materials produced from waste; and
- the generation of electricity and heat from conventional means substituted by energy from waste.

The model contains data gathered by the Environment Agency for numerous options for each of these categories. The data give the emissions resulting from the manufacture, construction and use of each of the assets used in managing the MSW. Data on the production/manufacture of different materials come from ecoinvent™, a standard life-cycle inventory database. When all the user-data on the weight of waste, its composition, the number of containers, the weight of waste managed by different methods etc. has been entered, the software calculates the overall emissions from all the system components to give a total weight of each emission produced to air, water and land and the amounts of electricity, heat and raw materials displaced. These inventory data are the weights of all flows to and from the environment and the general economy associated with managing the specified waste for one year.

The software also calculates the environmental impacts from the inventory data by grouping together related emissions: for example, for climate change, all greenhouse gas emissions are grouped and each is given a GWP (equivalence to carbon dioxide). These equivalent figures are then added together to give a total climate change impact of the waste management system being studied as a weight of carbon dioxide equivalent (CO₂e).

WRATE was used to define each waste management system and to calculate the greenhouse gas emissions associated with it and with managing each waste fraction. The studies were conducted both to inform the TWG in its development of the Waste Management Criteria, and to provide evidence as to whether an asset is or is not likely to be eligible for certification. The LCAs allowed the TWG to develop comparisons across waste types and management options. This means that under the Waste Management Criteria, issuers are not required to conduct their own life cycle assessment of GHG emissions associated with their assets but can leverage results to demonstrate that they meet the GHG emissions required for that type of facility).

The System Boundary, Assumptions and Other Factors Affecting the Results

The results for any given LCA of a waste management system will be affected by several overarching issues:

- The global warming potential (GWP) of methane;
- The GWP of biogenic carbon dioxide; and
- The value assigned to stored carbon dioxide, for example, by storing carbon dioxide deep underground in geological formations, or by converting biomass to carbon and storing this.

The Global Warming Potential (GWP) of Methane

GWP is the means by which the effects on climate change of different processes emitting different quantities of different greenhouse gases can be compared. GWP estimates reflect the energy absorbed by different greenhouse gases relative to carbon dioxide and their relative effect is different for different timescales. To ensure that the impacts of waste activities and mitigation actions are fairly assessed, the choice of GWPs should take into consideration how they reflect the relative value of methane's impact.

The table below provides the main options for GWPs for the calculation of CO₂e emissions.

Table 4-1: Global warming potentials for different greenhouse gases⁸⁸

		Lifetime (years)	GWP	
		IPCC AR5	IPCC AR5	
			20y	100y
Carbon dioxide	CO ₂	-	1	1
Methane	CH ₄	12	84	28
Nitrous oxide	N ₂ O	121	264	265
PFC 14	CF ₄	50,000	4,880	6,630

As GWPs are calculated relative to carbon dioxide (CO₂), GWPs based on a shorter timeframe (e.g. 20 years) will be larger for GHGs with lifetimes shorter than CO₂ and lower for longer timeframes. Thus, methane (CH₄) has a lifetime in the atmosphere of 12 years and its 20-year GWP is 84 compared with the 100-year GWP of 28. The 100-year GWP therefore probably understates the relative value of methane's true impacts on waste management and the 20-year GWP might be seen as a more appropriate measure. However, the United Nations Framework Convention on Climate Change and its Kyoto Protocol has adopted the 100-year GWP, which is now widely used as the default metric. Moreover, most life cycle inventory databases use the 100-year GWP.

This question is most significant when comparing the management of residual MSW by landfill or EfW. A carbon balance was conducted to compare the climate change impacts from landfill and EfW for different waste compositions using both GWPs. The results had little practical effect on the relative preference between the two methods, with EfW generally performing better than landfill. However, most LCAs of waste management and most software uses the AR4 100-year average value of 25 or the equivalent AR5 value of 28. Therefore, for consistency, CBI has adopted the 100-year GWPs in the IPCC's AR5 for the calculation of CO₂e emissions. Methane has been assigned a GWP of 28, except where it is incorporated into the software as the AR4 value of 25, when this will be used.

The GWP of biogenic carbon dioxide

Biogenic carbon is the carbon contained in the cells of living matter – plants and animals. By convention, the IPCC (and LCA) do not normally 'count' emissions of carbon dioxide from biogenic carbon. This is because biogenic carbon is in a short carbon cycle – plants absorb carbon dioxide from the atmosphere turn this into cellulosic material and other organic compounds, which then break down and release carbon dioxide when the plant dies and decomposes or is burned. Provided this plant growth is sustainable, e.g. the paper is from forest with constant biomass, there is no net change in the amount of carbon dioxide available and a GWP of zero is assigned.

On the other hand, fossil carbon is typically in a carbon cycle of millions of years and when fossil fuels are used, carbon is taken out of this 'permanent' store and converted to carbon dioxide that adds to the concentration in the atmosphere. Hence fossil carbon dioxide is assigned a GWP of 1.

In reality, this is a simplification. If one considers the effect on the concentration of carbon dioxide in the atmosphere, a GWP of 1 should be assigned to all carbon dioxide emissions, whatever the source and then a value of -1 to carbon dioxide that is absorbed by plants. However, doing this means knowing the net change in biomass resulting from the products we consume and the plants we grow – potentially a huge task. Where there is a major reduction in biomass, e.g., through unsustainable felling of forest or fire, the overall effect of the associated CO₂ emissions is no different from the burning of fossil carbon and should be given a GWP of 1.

If biogenic carbon is assigned a GWP of 1, because all carbon dioxide has the same effect in the atmosphere, this means:

- fossil CO₂, biogenic CO₂ from sustainable forest and biogenic CO₂ from unsustainable forest have the same GWP.

⁸⁸ Intergovernmental Panel on Climate Change, (2013). Fifth Assessment Report.

- The change in global biomass resulting from the system being considered must be known and included in the calculation
- To make the material flows balance mathematically a value of -1 should be assigned to biogenic carbon dioxide absorbed by biomass.

Therefore, CBI certification will record biogenic carbon dioxide emissions where practicable but follow UNFCCC convention and assigns biogenic carbon dioxide a GWP of zero.

Sequestered or stored carbon

A legitimate means of mitigating climate change is to sequester carbon by putting it into some form of relatively permanent store, for example, by converting paper into carbon black or char or capturing fossil carbon dioxide and pumping it into long-term geological storage. The atomic weight of carbon is approximately 12 and the molecular weight of carbon dioxide is approximately 44; therefore every 12 kg of carbon stored as carbon is equivalent to 44 kg of carbon dioxide or the climate change mitigation benefit of every tonne of carbon stored is equivalent to 44/12 or 3.67 tonnes of carbon dioxide.

This approach could also be considered for landfills, and for composting and AD. Although paper and other waste containing biodegradable carbon degrades in landfill, modelling and monitoring has shown that approximately half the biodegradable carbon may remain in the landfill for a period of over 100 years. Compost also increases soil carbon, although the degradation of soil carbon appears to be an order of magnitude faster than that in a landfill, possibly due to the action of organisms in soil, and consequently new compost has to be added to maintain soil carbon levels.

This approach would give any carbon stored a GWP of -3.67 per unit weight of carbon. Effectively this is a similar argument to that around biogenic carbon and, if adopted, one could argue biogenic carbon dioxide should also be assigned a value of 1. As a point of fact, some of the effects of storage of biogenic carbon in a landfill are already taken into effect, in that the emissions from the carbon assumed to be undegraded are not included.

A further complexity is that fossil carbon (mostly in plastic) is locked up in a landfill for much longer than biogenic carbon and therefore any fossil carbon should also be assigned a similar GWP of -3.67.

Subject to two provisos, sequestered carbon is assigned a GWP of zero due to the uncertainties involved and to align with current conventions. The two provisos are:

- That where the main design function of a waste management process is to put biogenic carbon into permanent store, this is allowed for by using a GWP value of -3.67 for the carbon as carbon in store; and
- This matter is kept under regular review by CBI.

The System Boundary

The results of any life cycle study will also be affected by what is included and excluded from the assessment, known as the system boundary; and the assumptions that are made.

The system boundary for these studies was effectively set by the software used, WRATE. The physical system includes all equipment, processes and activities from when municipal waste is set out ready for collection through to its disposal and any environmental emissions resulting from that disposal. The temporal boundary for the generation of gas from landfills is 150 years and that for leachate is 5,000 years; by which times over 99% of degradation and release of any contaminants will be complete.

Although generally regarded as minor and often ignored, the burdens from the construction of all waste management plant and landfill sites are included as are those from the manufacture of any waste vehicles and any containers used for waste. Energy and fuel used, the extraction of raw materials and their conversion into e.g. steel and their use in plant and vehicles are all included. Data for materials used in construction were taken from ecoinvent, an industry standard database covering global markets. The construction of waste management facilities that meet best practice was also

considered by the TWG unlikely to vary significantly globally and would in any case, have only a minor effect on the results.

The extraction and manufacture of any materials that could be recovered from waste, such as plastics, aluminium, paper and compost are also included, as are the materials and energy required to transform recycle into secondary raw materials capable of substituting virgin materials, to allow the relevant savings from recycling materials to be calculated.

The software deals with different geographies, by allowing the user to input the appropriate electricity grid and data for the relevant waste composition.

Assumptions

The main assumptions in the LCA modelling are as follows:

General

- All systems are modelled from the waste at the kerbside through to its recovery as a replacement raw material or its assimilation into the environment. Benefits accrue to the system from electricity exported to the grid, heat supplied or material produced, due to the saving in the emissions that would have been produced by virgin production.
- Waste is assumed to enter the system with zero burdens (no embodied emissions) and all emissions or emissions savings are attributable to the modelled system.
- Two waste compositions were used for the residual waste studies:
 - A typical developed world, determined from a research study of over 40 separate compositional analyses in England. This was then adjusted to account for 70% prior recycling of steel and aluminium.
 - A developing world composition based on the average of several developing countries municipal waste compositions⁸⁹.
- The percentage of carbon etc. in each fraction was derived from the UK National Household Analysis Programme⁹⁰.
- Electricity substituted is future long-run (build marginal) based on UK government projections.
- For these calculations, CH₄ was given a GWP of 25 relative to fossil CO₂ (1) and biogenic CO₂ has GWP of 0.

Landfill

- Landfill gas degradation modelled on biogenic carbon content of waste fractions. % volume methane from site monitoring, then modelled. The assumed end point is 150 years (this accounts for 99.5% of CH₄). Production of landfill gas is modelled according to waste composition following analysis of the biogenic carbon and moisture contents in each fraction.
- Leachate modelled using EA LandSim model over 5,000 years and the total emissions calculated.
- Gas recovery was set as 75% lfg collection over lifetime.
- 99% of gas collected was assumed to be burned in lfg engine.
- A gas engine (burns methane with CO₂) - efficiency approx. 35%.

EfW

- The conversion of fossil carbon to carbon dioxide >97% modelled on actual plant data and scaled.
- Processes modelled:
 - for first comparison - dry scrubbing with selective non-catalytic reduction (SNCR);
 - for second - wet scrubbing with selective catalytic NO_x reduction.
- Heat produced is not used unless stated.

⁸⁹https://www.researchgate.net/profile/Tanmoy_Karak/publication/230806748_Municipal_Solid_Waste_Generation_Composition_and_Management_The_World_Scenario/links/0912f5049d07c2d5b4000000.pdf

⁹⁰ Although these are UK figures, it was accepted by the TWG that whereas the proportion of different waste fractions would vary (e.g. increased food waste and lower glass content in developing world composition, the composition of individual fractions was unlikely to vary substantially between countries.

AD

- Over 99% of methane is captured and combusted to biogenic carbon dioxide.
- Gas engine (burns methane with CO₂) – at an efficiency of approx. 35%.
- Burdens associated with all materials of construction are included as are as e.g. iron ore, limestone, coal and oil in the ground.
- Gas is stored prior to electricity generation.
- Only basic gas clean-up to allow combustion in gas engine assumed, i.e. carbon dioxide not removed to permit input to gas grid.
- Digestate and liquor used as compost / fertiliser to replace non-waste products, including chemical fertiliser based on N:P:K potential.

Composting

- Based on commercial in-vessel process scaled up to meet quantity requirements.
- No significant greenhouse gases are emitted from main processing - predominantly biogenic carbon dioxide. Preparation prior to processing and post-processing assumed to use diesel.
- Compost produced to PAS 100 standard assumed to replace compost made from non-waste materials, e.g. peat.
- A minor amount of ammonia is produced.

Recycling

- Recycled glass, metals and plastics are assumed to have direct equivalence to virgin materials - i.e. more recycled material is not required to perform the same function.
- Substitution is based on average recycled rate in the market, not substituting virgin material.
- 100% recovery from arisings assumed.
- No rejects assumed, because sorting etc. was not included in modelled system.

Modelling municipal waste management systems

Ten waste management systems were initially modelled:

- to provide an overall picture of the potential global warming impacts of a variety of different waste management systems;
- how this potentially varied with composition and electricity grid mix;
- to develop some generic, indicative steps between different waste management options in terms of the GWP difference between them.

Each system was modelled to manage all the municipal waste, rather than a single material stream, such as food waste or glass.

Method

WRATE was used⁹¹ to model the management of 100,000 tonnes per year of municipal waste.

Ten different methods of waste management were modelled. These were:

11. Landfill without gas capture
12. Landfill with efficient (75%) gas capture
13. EfW with 15% thermal efficiency⁹²
14. EfW with 25% thermal efficiency plus 40% green and food waste to composting

⁹¹ CBI and the TWG wish to express their thanks to Golder Associates for making available the WRATE software and for carrying out some of the analysis.

⁹² Thermal efficiency is a simpler way to measure performance of a plant than that used by the EU to define the difference between recovery and disposal. It is equal to the net useful energy produced (electricity supplied to the grid – electricity taken from the grid)/energy available in waste input). A thermal efficiency of 25% is approximately at the boundary of recovery.

15. Gasification, with residual to landfill (as 2)
16. EfW with 25% thermal efficiency plus 40% green and food waste to AD
17. EfW with 25% thermal efficiency
18. As 7 (EfW with 25% thermal efficiency), plus 10% dry recycling
19. As 7 (EfW with 25% thermal efficiency), plus 20% dry recycling
20. 20% recycling, with residual to landfill (as 2)

Each of these was run for the latest England municipal waste composition representing a developed world composition and also for municipal waste composition based on an unweighted average of data from several developing countries in Africa, South Asia, East Asia and the Pacific⁹³. Each composition was also initially modelled using three variations of electricity grid:

- a) Coal
- b) Coal and Gas, 50:50
- c) Natural gas

Assumptions and scenarios

Waste management systems include containers, vehicles and their fuel consumption. However, the contributions of these assets to the system's climate change potential were generally small, except where the overall burden or benefit was near zero, e.g., glass to aggregate (Table 4-2). Because the total contribution from containers and transport is relatively small in the case of steel and all waste management systems require containers and transport, any difference between them in scenarios would be minimal and the TWG decided these steps could be omitted in further modelling, on the grounds of simplicity and that these were unlikely to be generally significant. Burdens associated with materials in infrastructure were included, because although they were not considered to be significant, they are incorporated into the model and cannot easily be removed. The modelling therefore focused on the impacts from the waste treatment processes.

Table 4-2: Proportion of the impacts from each stage of the life cycle.

Category	Steel	Glass Aggregate
Collection	0%	0%
Transport	8%	41%
Sorting	5%	26%
Recycling	-87%	-33%

Scenarios 1 and 2 were both simple landfills, with no gas collection and 75% gas collection. The underlying model allows for 150 years generation of landfill gas – approximately 99.5% of all the methane generated by the landfill. Methane accounts for over 97% of the GWP from **Scenario 1** and 100,000 tonnes of municipal waste generates almost 100,000 tonnes of CO_{2e}. In **Scenario 2**, 75% of methane is collected and most of this is converted to electricity. In both scenarios some methane is oxidized to carbon dioxide in the surface layers of the landfill.

In **Scenario 3**, all waste goes to an EfW with an efficiency of 15%, typical of such plant in operation a decade ago. The residues all go to landfill.

Scenario 4 is a 25% thermal efficiency EfW (as scenario 7) but with 30% of waste (garden waste and food waste 100%) going to composting. The process is an enclosed Agrivert process and the compost is produced to PAS 100 standard and used.

Scenario 5 models an Energos 2-line gasification process, with all the residual waste going to a landfill with 75% gas collection.

⁹³ Karak, T., Bhagat, R. M. and Bhattacharyya, P., (2012). Municipal Solid Waste Generation, Composition, and Management: The World Scenario. *Critical Reviews in Environmental Science and Technology*. 42:15, 1509-1630.

Scenario 6 is identical to Scenario 4 but the composting process is replaced by the BIOGEN-Greenfinch anaerobic digestion process. The digestate and compost are used to replace other compost.

In **Scenario 7**, an EfW plant with 25% thermal efficiency is modelled. All the ash etc. goes to a landfill with 75% gas collection

Scenario 8 uses the same EFW plant but with 10% dry recycling, via a transfer station. The recycling comprises: paper and card 6,000 tonnes, glass 2,000 tonnes (recycled to clear containers), ferrous metal 1,500 tonnes and non-ferrous metal 500 tonnes.

Scenario 9 is as Scenario 8 but with 20% dry recycling, made up from paper and card 12,000 tonnes, glass 4,000 tonnes (recycled to clear containers), ferrous metal 3,000 tonnes and non-ferrous metal 1,000 tonnes.

In **Scenario 10**, the EfW plant in Scenario 9 is replaced by a landfill with 75% gas collection, the recycling is identical.

The electricity off-set is against the grid mix for all processes, except landfill, where it is the short-term marginal fuel.

The summary waste management compositions used are shown in Table 4-3. The source of the compositions is:

- European – review of compositional analyses for England, conducted in 2007 (last year available) and reported in 2009⁹⁴.
- Developing – an unweighted, arithmetical average of waste compositions in Bangladesh (Dhaka), Cambodia, China (Beijing), Ghana (Kumasi), India, Kenya (Nairobi), Malaysia and Nigeria (Oyo)⁹⁵

Table 4-3: Example European and Developing world municipal waste compositions

Waste Fraction	European %	Developing %
Paper and card	24.0	11.0
Plastic film	3.8	3.8
Dense plastic	6.2	6.2
Textiles	2.8	2.8
Absorbent hygiene products	2.3	2.0
Wood	3.6	0.0
Combustibles	6.1	6.1
Non-combustibles	2.7	2.7
Glass	7.9	3.0
Organic	31.6	57.0
Ferrous metal	3.1	2.0
Non-ferrous metal	1.3	1.0
Fine material <10mm	2.0	2.0
Waste electrical and electronic equipment	2.2	0.0

⁹⁴ Taken from Defra, Municipal Waste Composition: A Review of Municipal Waste Component Analyses, WR0119.

⁹⁵ Karak, T., Bhagat, R. M. and Bhattacharyya, P., (2012). Municipal Solid Waste Generation, Composition, and Management: The World Scenario. *Critical Reviews in Environmental Science and Technology*. 42:15, 1509-1630.

Waste Management Background Paper

Specific hazardous household	0.5	0.5
Total	100.0	100.0

The different compositions presented certain problems for comparing the different options. Whilst it was possible to maintain the same overall proportion of municipal waste going to composting and AD, the reduced amount of normally recyclable materials in the developing composition means that 20 percent dry recycling is not even theoretically achievable. Recycling all paper, glass, ferrous and non-ferrous metal gives a total of 17 percent recycling, as close as it is possible to get to 20 percent. For the 10 percent recycling option, the amount of each material was scaled down proportionately from 17 percent to give 10 percent overall.

In all, therefore, 60 scenarios were run and the GWP impacts calculated (applying 100-year average for the GWP methane of 25). Table 4-4 gives the net (overall) results for GWP for each waste management option, for both compositions and for each of the three grid types.

Results in parentheses are negative and (by convention) relate to a net benefit in respect of climate change. The results show that the largest impact on climate change results from the landfill with no gas collection: more than three times the next highest impact.

Table 4-4: Potential Climate Change Impacts of Different Waste Management Options (100,000 tonnes MSW)

Electricity Grid/Composition	Coal European	Coal/Gas European	Low Carbon European	Coal Developing	Coal/Gas Developing	Low Carbon Developing
Waste Management Method	kg CO ₂ e					
Landfill, no gas collection	100,392,480	100,392,480	100,392,480	92,627,722	92,627,722	92,627,722
Landfill, 75% gas to electricity	17,011,821	22,633,040	32,979,449	15,698,013	20,902,169	30,480,935
EFW 15% thermal efficiency	(7,505,503)	4,943,573	27,857,331	(2,890,544)	7,568,873	26,820,467
EFW 25% Thermal, 30% composting	(31,143,873)	(11,104,564)	25,779,770	(21,306,891)	(5,000,835)	25,012,077
Gasification, residual to landfill	(31,711,367)	(11,893,589)	24,582,993	(23,257,135)	(6,707,207)	23,754,574
EFW 25% thermal with 30% AD	(37,422,437)	(16,172,833)	22,939,169	(27,316,635)	(9,857,879)	22,276,692
EFW 25% thermal	(39,505,296)	(16,375,846)	26,196,199	(29,660,611)	(10,266,313)	25,430,814
EFW 25% thermal with 10% recycling	(44,307,760)	(23,039,702)	16,106,267	(34,324,407)	(17,007,141)	14,867,002
EFW 25% thermal with 20% recycling	(49,110,220)	(29,703,554)	6,016,338	(37,771,178)	(21,848,814)	7,457,875
Landfill, 20% recycling	(6,624,920)	(2,324,821)	5,589,936	(5,502,919)	(1,507,585)	5,846,223

Note to Table 4-4 : Figures in parentheses are negative and show an improvement in overall GWP.

Table 4-5: Difference in Global Warming Potential between different waste management systems (kgCO_{2e}/tonne)

From	To	Coal European	Coal/Gas European	Low Carbon European	Coal Developing	Coal/Gas Developing	Low Carbon Developing
Landfill, no gas collection	Landfill, 75% gas to electricity	834	778	674	769	717	621
Landfill, 75% gas to electricity	EFW 15% thermal	245	177	51	186	133	37
EFW 15% thermal	EFW 25% with 30% composting	236	160	21	184	126	18
EFW 25% with composting	Gasification, residual to landfill	6	8	12	20	17	13
Gasification, residual to landfill	EFW 25% thermal with 30% AD	57	43	16	41	32	15
EFW 25% thermal with 30% AD	EFW 25% thermal	21	2	(33)	23	4	(32)
EFW 25% thermal	EFW 25% with 10% recycling	48	67	101	47	67	106
EFW 25% with 10% recycling	EFW 25% with 20% recycling	48	67	101	34	48	74
EFW 25% with 20% recycling	Landfill, 75% gas to electricity with 20% recycling	(425)	(274)	4	(323)	(203)	16

Note to Table 4-5: Positive numbers represent an improvement in overall GWP and figures in parentheses are negative – that is the change increases GWP.

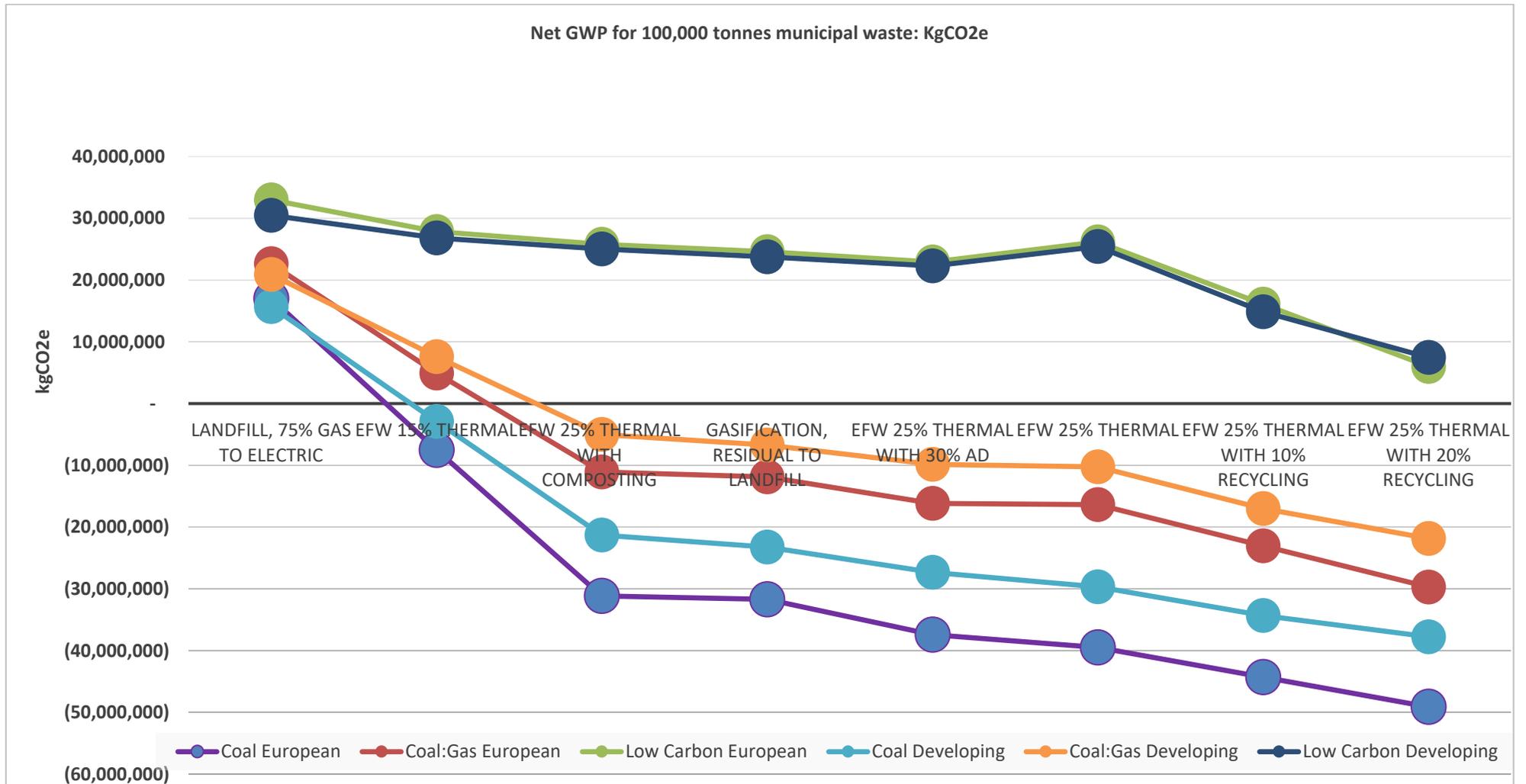
Results

The results should be seen as indicative. They are dependent on the waste compositions, electricity grids, other data and assumptions. Nonetheless, they reflect other studies and are considered reasonable to use to compare one waste management asset with another.

Table 4-5 shows the difference in Global warming potential (in kgCO₂e per tonne of waste) due to changing from the waste management option in the first (left hand) column to the waste management option in the second column. For example, to calculate the change in GWP in a developing country with a coal-based electricity grid resulting from switching municipal waste from a landfill with 75% gas collection to an EfW plant with 15% thermal efficiency read directly from the appropriate row in the column for Coal – Developing: 186 kgCO₂e benefit per tonne of waste. Figures in parentheses show a decrease in environmental performance and should be subtracted.

Figure 4-1 shows eight of the ten waste management options for the two compositions and three grid types. The figures for landfill with no gas capture have been excluded because they are substantially higher in all cases and their exclusion allows a larger scale to be used. The results for 'Landfill with 75% gas collection plus 20% recycling' have also been excluded here, because they are more beneficial (due to the recycling element) and therefore don't appear to conform to the waste hierarchy order and reduce clarity in the graph.

Figure 4-1: Net GWP for different waste management options



It is important to stress that these results are based on hypothetical, simplified scenarios using hypothetical electricity grids and example waste compositions. Therefore, the results should be seen as indicative. The results show that:

1. From Figure 4-1, There is a general decrease in the GWP impact of the options from left (landfill with gas recovery but no recycling) to right (medium-high efficiency EfW plant with 20% recycling).
2. The exception to this is 25 percent efficiency EfW for both compositions and the lower carbon electricity grid, where it contributes more to GWP than any option except landfill and 15 percent efficiency EfW.
3. Landfill with recycling shows the lowest impact of any system for the lower carbon grid. Whereas with a coal-based electricity grid: for European composition, it would have an impact between that of 15 percent thermal efficiency EfW and a landfill with no recycling and 75% gas recovery. For the developing world composition, it would have an impact between 15 percent thermal efficiency EfW and EFw 25 percent thermal efficiency with 30% composting.
4. For the coal and coal/gas grids and both compositions, sending green waste/food to high efficiency EfW rather than to composting or anaerobic digestion produces a lower GWP impact.
5. The biggest single improvement step results from installing gas recovery at a landfill – more than all the other changes combined. Installing gas recovery at a landfill reduces GWP by between 621 and 834 kgCO_{2e}/tonne. Most of this reduction is due to preventing methane emissions to atmosphere: the generation of electricity from this gas produces a much smaller benefit.

The general decrease in the GWP impact of the options with decreasing landfill and increasing energy recovery and recycling supports the broad order of the waste hierarchy. However, whereas the hierarchy holds good for low efficiency EfW plant, higher efficiency EfW performs better for green waste and food waste in this modelling than do composting and anaerobic digestion, except with the lower carbon electricity grid, where the general waste hierarchy order is restored.

From Table 4-4, for the lower carbon grid only, landfill with recycling shows marginally the lowest impact of any system. Thus, with this electricity grid, a switch from EfW to landfill whilst maintaining 20% recycling would produce a very slight benefit in GWP. However, this relative benefit is very dependent on the grid and for a coal-based grid or 50:50 coal and gas based grid would result in a substantial increase in GWP.

With a low carbon grid, waste composition makes little difference to the impact of each waste management option.

Overall it was concluded that the improvement in GWP achieved with any new waste management infrastructure depends very much on what is the existing waste management system that it is proposed to replace, as well as what products are being displaced from the economy by those produced from managing the waste, e.g. whether recycled glass is replacing packaging glass or merely aggregate. Moreover, the benefits of any change are also very dependent on both the waste composition and (particularly) on the electricity grid, which as described above, has a substantial effect on the climate change mitigation benefits of energy from waste.

LCA of Waste Materials

Having carried out the LCAs above on systems for managing all municipal waste, the next stage of modelling was to analyse the greenhouse gas emissions associated with managing different fractions of municipal waste to investigate the best ways of handling each of these.

Disposal and recovery options for different waste fractions

The first stage of the analysis was to set out the different fractions of municipal waste to be managed. The materials considered were garden or green waste, food waste, wastepaper, waste card, and plastic (only dense plastic was considered in the analysis, plastic film was ignored, due to no processes being included in the software and a lack of evidence of commercially viable recycling processes).

Modelling

The TWG considered that, whereas the proportions of each waste fraction (paper, card, glass, aluminum etc.) varied markedly with the level of economic development and urbanization, the materials themselves tended to be manufactured for global markets and, with the possible exception of food waste composition, would not vary significantly. Each practical method managing for each material was modelled – these are limited by the physical and chemical characteristics of the waste material and therefore will be similar throughout the world.

Waste Management Background Paper

The Environment Agency life cycle software for waste management, WRATE, was used to define the waste management system in each case and to calculate the greenhouse gas emissions associated with managing each waste fraction. (Note that managing glass, metals and residual waste were not modelled, because they had previously been modelled and only one or two realistic options were available for them).

Unless otherwise stated, the analysis was based on the following factors and assumptions:

- The country modelled was the UK.
- The electricity grid was assumed to be that forecast for 2020.
- The materials were as outlined above. For plastics only dense plastics were considered; the paper evaluated was: white office paper.
- Chemical and proximate analysis for the different fractions came from analysis undertaken during the UK government's national household waste analysis programme.
- As they had previously been shown to be insignificant, transport, containers and all intermediate stages were excluded from the analysis.
- Methane was given a GHG equivalence of 25 times carbon dioxide.

The methods considered for waste management were: landfill (with four different gas collection efficiencies), Energy from waste (using three different thermal efficiencies), gasification (based on data from the Energos plant), anaerobic digestion, composting and different types of recycling.

Each material was modelled in turn using the relevant models. The results for each material are reported in the following sections and shown in the graphs.

Food waste

Food waste is probably the fraction of municipal waste likely to vary most with geography in terms of its constituents and therefore quality. Unlike plastics, steel, aluminium etc. which are manufactured and supplied for a global market, the food consumed, bought, method of preparation and waste tend to be associated with the local demographics and often climate.

In general, food waste is characterised by high moisture content, ready biodegradability and low heating value (CV). The WRATE model incorporates analysis undertaken in the UK as part of the government's national household waste analysis programme⁹⁶ gave the results shown in Table 4-6.

Table 4-6: Proximate analysis of food waste used in WRATE

Gross CV	5.345	MJ/kg
Net CV	3.393	MJ/kg
C	13.455	%
H	1.895	%
N	0.985	%
S	0.095	%
O ₂ plus errors	16.01	%
Moisture	62.75	%
Ash	9.335	%

Although these figures are made up from the analysis of several samples at the time and was considered representative, the sampling dates from the 1990s when recycling was almost non-existent in the UK. Aside from changes in eating and cooking habits, it is likely that the analysis of food waste reflects some loss of moisture to co-collected paper and card.

One thousand tonnes of food waste were modelled using WRATE for the five options considered available for food waste: landfill, energy from waste, gasification, anaerobic digestion and composting. Food waste to

⁹⁶ Dept. of the Environment, National Household Waste Analysis Programme, Phase 2, Chemical analysis, 1995

Waste Management Background Paper

landfill was modelled at four gas recovery rates and food waste to EfW plant at three thermal efficiencies: the results are shown in Figure 4-2 and Table 4-7.

Under the conditions modelled (2020 electricity grid and with a GWP of 25 for methane) all the landfill options contribute to global climate change, whereas all the other waste management options show greenhouse gas reductions. The best option for managing food waste is very high efficiency (29%) EfW – approximately 23% better than anaerobic digestion. However the difference between 25% efficiency EfW, gasification and anaerobic digestion is marginal, and anaerobic digestion is better than lower efficiency EfW plant.

If the projected decarbonisation of the electricity grid had been used it would make a difference to the magnitude of the results but not to the overall order.

Figure 4-2: Greenhouse gas emissions from the management of 1000 tonnes of food waste

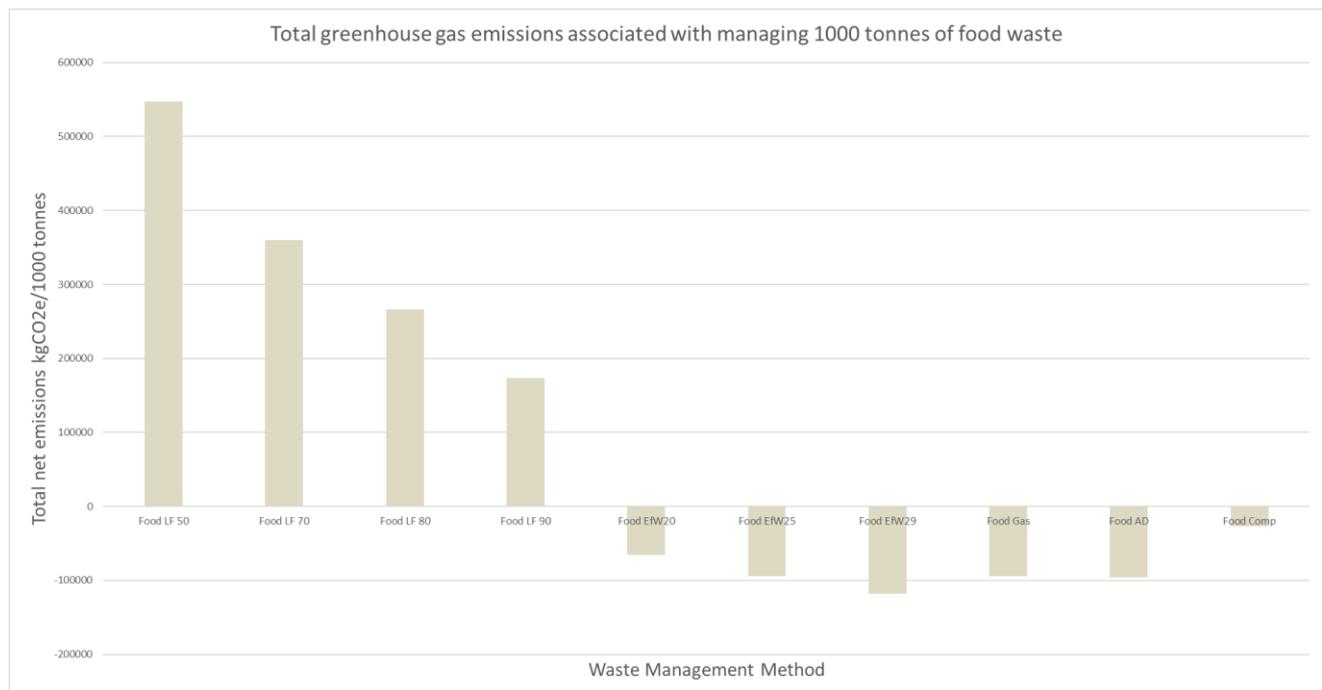


Table 4-7: Greenhouse gas emissions from the management of 1000 tonnes of food waste (kgCO₂e)

Landfill 50% gas collected	Landfill 70% gas collected	Landfill 80% gas collected	Landfill 90% gas collected	EfW 20% efficiency	EfW 25% efficiency	EfW 29% efficiency	Gasifier	AD	Compost
547,255	360,211	266,689	173,167	-65,362	-94,648	-118,078	-93,913	-95,782	-27,151

However, AD should not be discounted for food waste: EfW plant cannot burn food waste alone, requiring a calorific value approximately double that of food waste to operate effectively. Additionally, if AD is combined with gas cleaning and removal of carbon dioxide to produce biomethane, the resulting methane can be used as transport fuel or fed into the gas grid to replace fossil fuels and burned at high efficiencies, which would lead to an increased carbon benefit.

Garden waste

Garden waste (also known as green waste and yard waste) consists of plant matter such as grass cuttings, weeds and other plants, prunings, small branches, leaves and soil. It is often collected separately and is characterised by relatively high moisture content, the presence of material that does not readily biodegrade, such as lignins or ligno-cellulose in hard, woody material and also by the presence of significant quantities of 'inert' material such as soil.

Waste Management Background Paper

Table 4-8: Proximate analysis of garden waste used in WRATE

Gross CV	6.5	MJ/kg
Net CV	4.58	MJ/kg
C	17.17	%
H	2.305	%
N	0.745	%
S	0.08	%
O ₂ plus errors	17.9	%
Moisture	57.975	%
Ash	9.2	%

As for food waste, this analysis stems from a time when garden waste was not usually collected separately and soil would be recorded as a separate category in the results. The effect of separate collection would be to increase ash content and decrease the CV and unit biogas yields.

One thousand tonnes of garden waste were modelled using WRATE for the five options available for garden waste: landfill, energy from waste, gasification, anaerobic digestion and composting. Garden waste to landfill was modelled at four gas recovery rates and to EfW plant at three thermal efficiencies: the results are shown in Figure 4-3 and Table 4-8.

Figure 4-3: Greenhouse gas emissions from the management of 1000 tonnes of garden waste

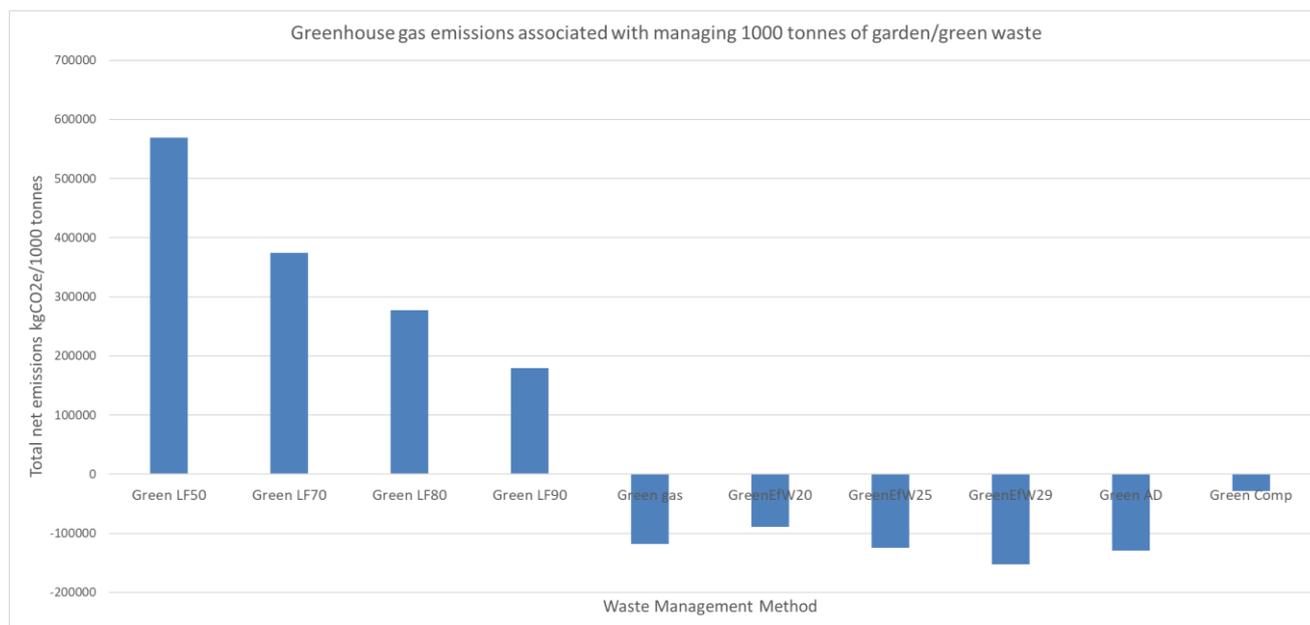


Table 4-8: Greenhouse gas emissions from the management of 1000 tonnes of garden waste (kgCO₂e)

Landfill 50% gas collected	Landfill 70% gas collected	Landfill 80% gas collected	Landfill 90% gas collected	EfW 20% efficiency	EfW 25% efficiency	EfW 29% efficiency	Gasifier	AD	Composted
569,270	374,545	277,183	179,821	-118,353	-88,774	-124,409	-152,917	-129,665	-29,049

The results are (unsurprisingly) very similar to those for food waste: the landfill options all produce greenhouse gases, whereas all other options produce a net benefit to climate change. Anaerobic digestion is on a par with higher efficiency EfW and gasification. EfW with 29% overall efficiency performs best.

Waste Management Background Paper

As above, although it performs best, an EfW plant will not operate burning only garden waste, because the CV is below the minimum requirement of approximately 9 MJ/kg.

Waste paper

Unlike glass and metals, which can in theory be recycled and reprocessed an infinite number of times, paper deteriorates in quality every time it is recycled and re-pulped due to a decrease in average fibre length. High quality paper such as office paper requires longer cellulosic fibres than newspaper or some cardboard and paper cannot therefore be recycled to the same quality fibre each time, although recycled fibres can make up a proportion of the higher quality paper.

In addition to the four landfill, three EfW and gasification options modelled for food and garden waste, three recycling options were modelled in WRATE. These were office paper to office paper (Paper rec1), office paper to newspaper (Paper rec2) and mixed paper to mixed paper (Paper rec3). The results are shown Figure 4-4 and Table 4-9.

Figure 4-4: Greenhouse gas emissions from the management of 1000 tonnes of waste paper

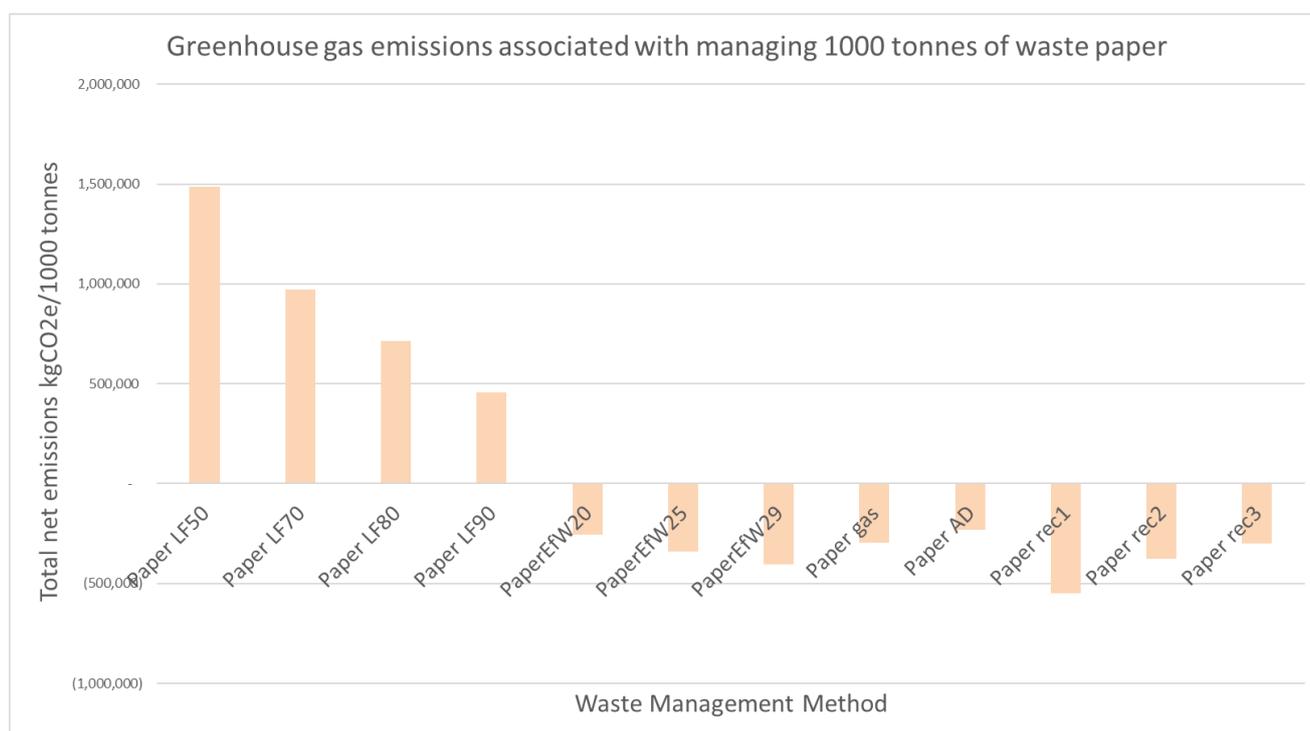


Table 4-9: Greenhouse gas emissions from the management of 1000 tonnes of waste paper (kgCO₂e)

Landfill 50% gas collected	Landfill 70% gas collected	Landfill 80% gas collected	Landfill 90% gas collected	EfW 20% efficiency	EfW 25% efficiency
1,485,327	970,686	713,366	456,046	-255,803	-338,203
EfW 29% efficiency	Gasifier	AD	Recycling 1	Recycling 2	Recycling 3
-404,123	-293,973	-231,721	-549,993	-376,265	-299,467

The pattern of the results for landfill and combustion is similar to that for food and for garden waste, except that EfW is significantly better than AD due to the dual effect of the higher CV of waste paper generating more heat to be converted into steam and electricity⁹⁷ and the fact that paper is more difficult to biodegrade than, e.g., food waste⁹⁸. However, the three recycling options also perform well but only office paper to office paper

⁹⁷ National Household Waste Analysis Programme.

⁹⁸ WRc report to the Environment Agency on 100 day anaerobic test: newspaper produced 76 litres of biogas per kg. of volatile solids compared with 312 litres for vegetables.

Waste Management Background Paper

outperforms energy from waste at 29% efficiency. Recycling paper to newspaper is a better option than 25% efficiency EfW.

Waste Cardboard

Waste cardboard is regarded as slightly easier to anaerobically digest than high-quality paper. However, it has a higher heat content than paper and will produce more electricity than paper when burned. It also has a higher carbon content, is more degradable and will therefore produce more biogas than paper under similar conditions. Waste cardboard was modelled for the same options as paper – landfill and combustion plus a single recycling option (there is only one available in the model). The results are shown in Figure 4-5 and Table 4-10.

Figure 4-5: Greenhouse gas emissions from the management of 1000 tonnes of waste card

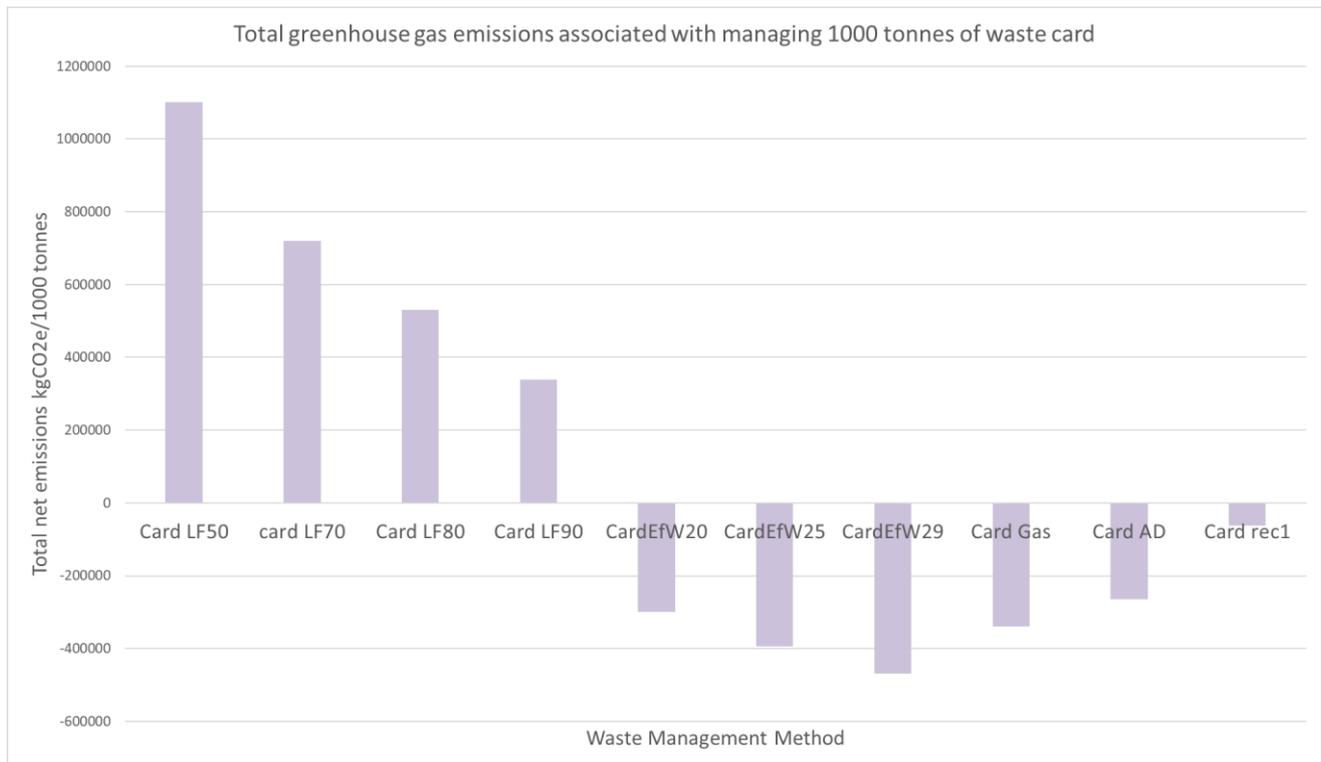


Table 4-10: Greenhouse gas emissions from the management of 1000 tonnes of waste card (kgCO₂e)

Landfill 50% gas collected	Landfill 70% gas collected	Landfill 80% gas collected	Landfill 90% gas collected	EfW 20% efficiency	EfW 25% efficiency	EfW 29% efficiency	Gasifier	AD	Recycling 1
1,100,435	720,081	529,904	339,726	-298,793	-393,407	-469,098	-339,353	-265,047	-61,607

The results show a similar pattern to those for paper: all the landfill options having the effect of increasing greenhouse gas emissions and all other options reducing them. There is a larger difference between gasification and AD, both of which are better options than the recycling option. The recycling option is for card recycled to corrugated cardboard and uses average EU data. All the energy from waste options outperform the AD and recycling options.

Plastics waste

Plastics waste is a component of municipal waste that covers both physical and chemical types. Physically, plastics waste can be separated into dense plastics (bottles, jars, food containers etc.) and plastic films. Dense plastics can themselves be separated into polymers, including: high density polyethylene (HDPE), polypropylene (PP) and polyethylene terephthalate (PET). It is possible to separate plastics by type and

Waste Management Background Paper

recycle plastics waste to displace virgin polymers and gain maximum carbon benefit or to recycle plastics as mixed plastics to a lower grade use, such as a wood substitute.

Each plastic type will have slightly different burdens associated with its production, although they will be similar in magnitude and thus the benefits of recycling each type will be similar. There are no known commercial operations for recycling plastic films successfully and therefore only dense plastics were modelled for recycling. One individual material (HDPE) and one mixed plastic recycling option were considered in the modelling. The results are shown in Figure 4-6 and Table 4-11.

Figure 4-6: Greenhouse gas emissions from the management of 1000 tonnes of waste plastics

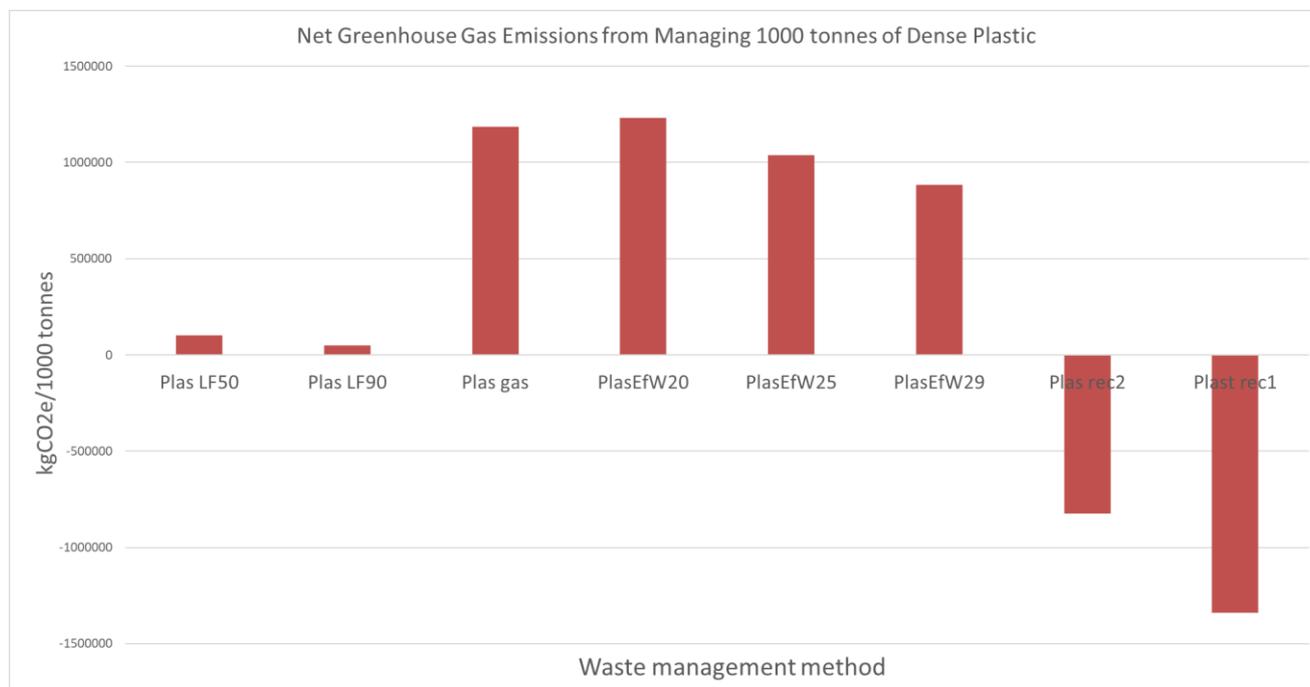


Table 4-11: Greenhouse gas emissions from the management of 1000 tonnes of waste plastics (kgCO₂e)

Landfill 50% gas collected	Landfill 90% gas collected	Gasifier	EfW 20% efficiency	EfW 25% efficiency	EfW 29% efficiency	Recycling 2	Recycling 1
100,614	48,125	1,183,723	1,232,525	1,038,187	882,716	-823,927	-1,337,950

The results for plastics waste show a different pattern from the other waste fractions considered. Whilst recycling is clearly the most beneficial, landfill clearly outperforms all energy from waste options, including gasification. This difference is due to the change in material composition from biogenic to fossil carbon.

For landfill, this means there is little or no methane produced from degradation of the waste and the emissions are principally due to the combustion of fossil fuels in on-site plant, those associated with landfill construction and electricity for leachate treatment. In contrast, EfW and gasification are generating electricity from 100% fossil fuel and at relatively low efficiencies compared with the marginal electricity displaced in 2020. Both plastics recycling options: HDPE to HDPE (Plas rec1) and dense mixed plastic to dense mixed plastic (Plas rec2) produce substantial greenhouse gas benefits, whereas the overall greenhouse emissions from landfill produce a small contribution to climate change. All energy from waste options have substantial greenhouse gas emissions and are the worst options for managing plastic waste alone.

Summary

The above results have been combined with earlier analysis of recycling metals and glass and managing residual waste in Table 7 in the main document.

Waste Management Background Paper
Changes in residual waste management impacts

The calculations below used UK data for electricity generation and some of the underlying data that went into the Environment Agency software, WRATE, developed by Golder Associates and ERM. WRATE itself was not used in this calculation.

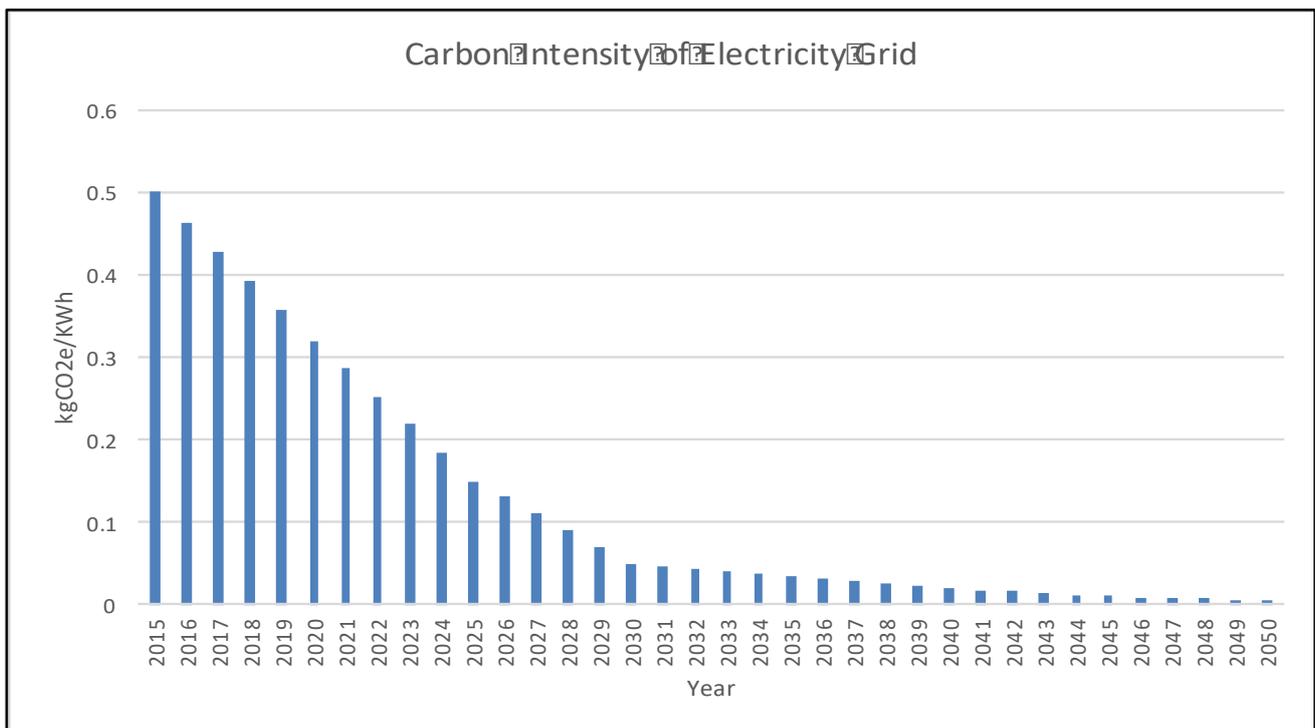
Two scenarios are considered, each for two waste compositions:

- All waste to landfill or to EfW; and
- Current waste composition and low fossil carbon waste composition.

The following assumptions were made:

- 100,000 tonnes per year of municipal waste managed.
- 'Current' is based on the waste composition for England 2009.
- The 'Low fossil' option is based on municipal waste with a similar heating value but with 20% biogenic carbon compared with 17% in the current option and 4% fossil carbon compared with just over 7% in the current option.
- Approximately 48% of biogenic carbon is assumed to degrade in a landfill.
- 75% of landfill gas is recovered to produce electricity.
- 10% of methane is oxidised to carbon dioxide through the surface layers.
- Landfill gas is 50:50 by volume methane and carbon dioxide.
- Electricity consumed by the EfW plant (the parasitic load) is approximately 3% of electricity produced.
- Emissions from waste transport and construction are excluded.
- Where a decarbonised grid is quoted, it means the grid has the downward trajectory for carbon emitted per unit of electricity generated as shown in Figure A1,
- The calculations follow the convention and do not count short-cycle (biogenic) carbon.
- Unless stated otherwise, methane is given a 100-year average GWP of 28.
- No additional allowance is made for storage of carbon within the landfill.
- Both landfill and EfW are electricity only.
- Landfill gas is used to generate electricity in gas engines with an overall efficiency of 35%.
- No benefit is given to EfW for any metals or aggregate recovery but no burdens are assigned relating to its landfill.

Figure 4-7: Decarbonisation of the UK electricity grid (Dept. for Business, Energy and Industrial Strategy)



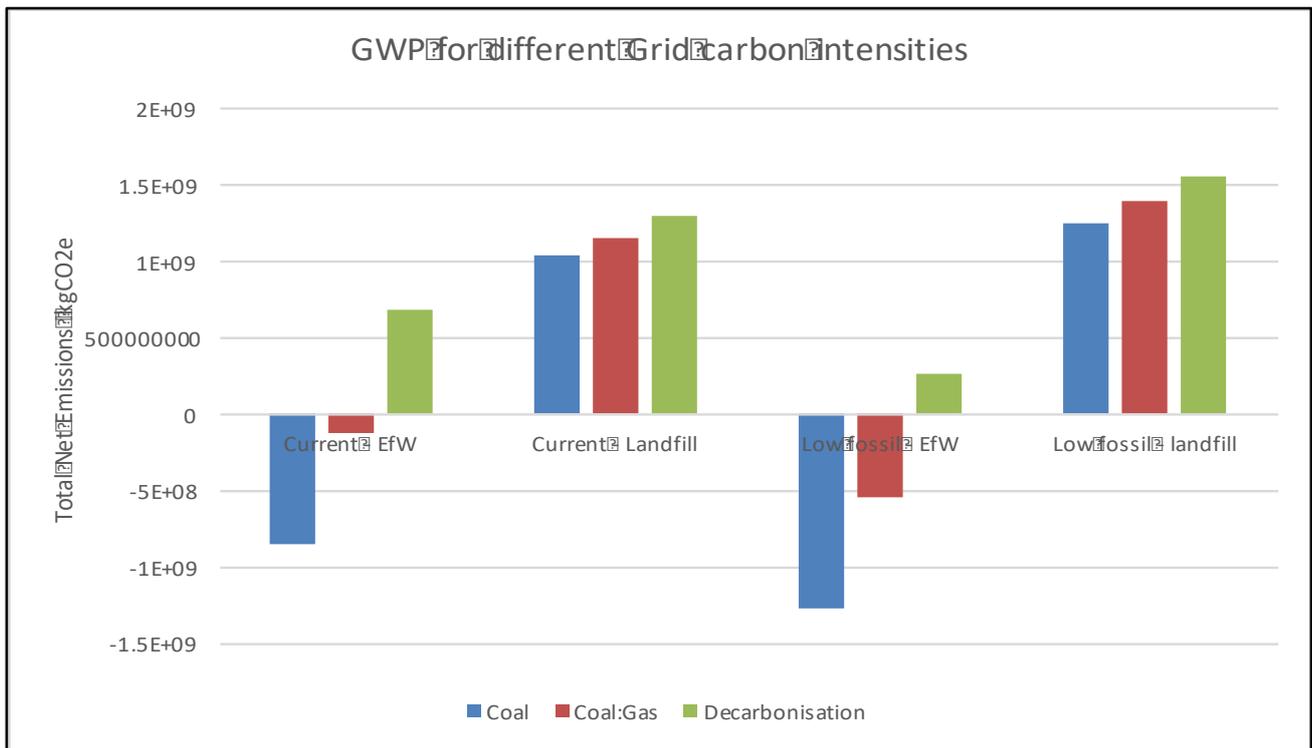
Waste Management Background Paper

Figure 4-7 shows total net greenhouse gas emissions aggregated for all years from 2015 to 2050 calculated for 100,000 tonnes of municipal waste per year. Business as usual assumes grid decarbonisation as in Figure 4-7 above. Negative results show a relative benefit in terms of global climate change, whereas positive results show a relative worsening.

Effect of changes in the carbon intensity of the electricity grid

Figure 4-8 below shows the effect of different grid mixes on the overall GWP contribution of each waste management option for both the current and a low-fossil waste composition. The effect of grid decarbonisation (from coal through coal and gas to nuclear and renewables) is progressive but more significant on EfW than on landfill. This is because the greenhouse gas impact of landfill is principally from emissions of methane which remain unaffected by the decarbonisation of the grid. On the other hand, decarbonisation of the grid has a significant effect on the impacts of EfW, changing it from a net benefit over the whole period, to a net contributor to climate change of almost 700,000 tonnes CO₂e over the 35 years. The effect on EfW is due to the fossil content of the electricity generated by the EfW plant and the relative low efficiency of current practice.

Figure 4-8: Effect of electricity grid decarbonisation on landfill and EfW



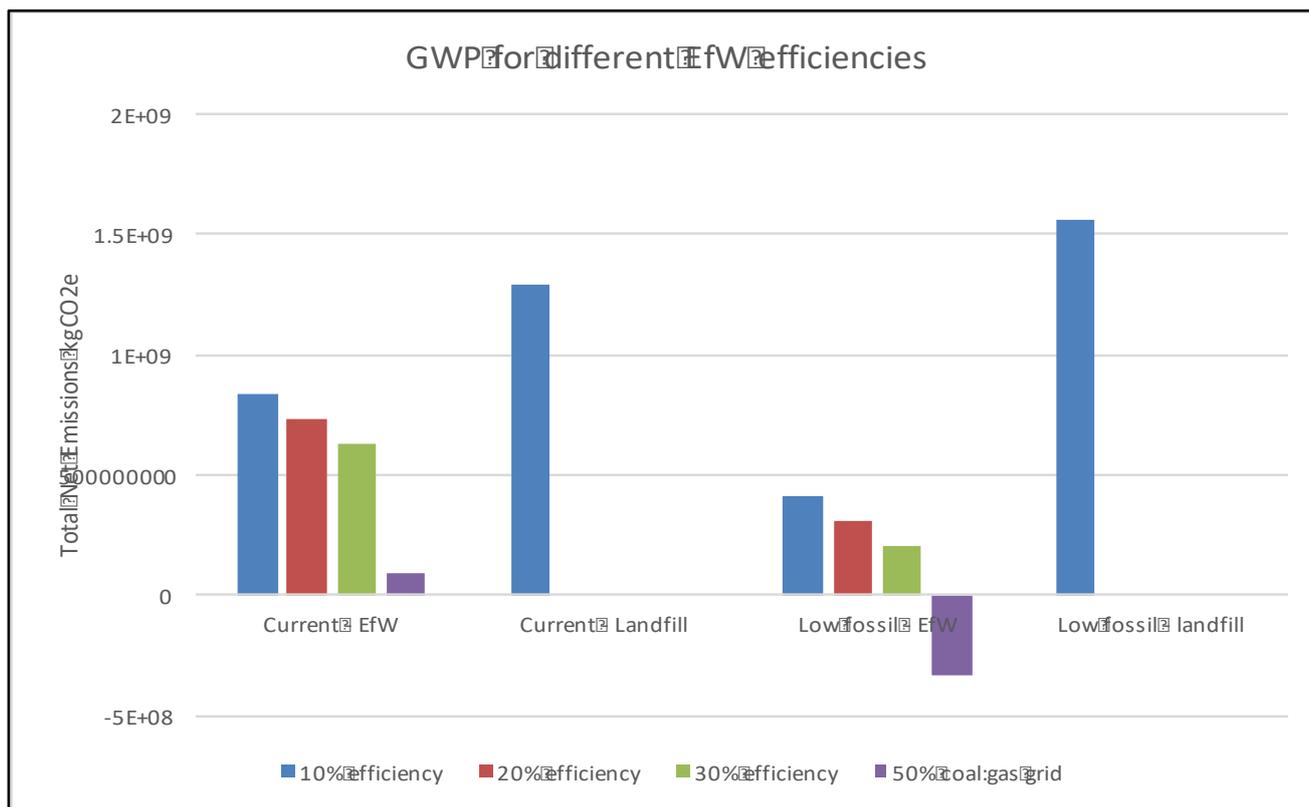
EfW still outperforms landfill in these scenarios, although for current municipal waste composition the advantage is much smaller – down from almost 900,000 to 175,000 tonnes CO₂e over the period; and the low fossil (higher biogenic) carbon municipal waste composition shows an even greater difference, reflecting greater methane emissions from the landfill and a lower carbon intensity of electricity recovered from EfW.

Effect of different EfW efficiencies

Figure 4-9 shows the total cumulative results over the period 2015-2050 for the UK projected grid decarbonisation trajectory. The graph shows how the contribution to climate change mitigation of EfW is affected by the efficiency of energy conversion in the plant.

At 10 per cent efficiency, EfW contributes some 450Mtonnes CO₂e less to climate change than landfill. This advantage increases by approximately 50 per cent for a high efficiency plant.

For comparison, the performance of EfW with a mixed (50:50) coal and gas grid is also shown.



The effect of landfill gas collection

Figure 4-10 shows the effect of a landfill with different landfill gas capture and recovery schemes. For no gas collection, all methane produced within the landfill that is not oxidised in surface layers is emitted as methane without any electricity generation. ‘Gas collection, no electricity’ shows the effect of 75 per cent gas recovery with flaring. In ‘gas collection and electricity’ the collected landfill gas is burned to generate electricity rather than being flared.

The difference between the option with no gas collection and those with gas collection is substantial – a reduction from 5.36 MtonnesCO_{2e} to 1.34 MtonnesCO_{2e}. The change does not affect EfW, which still contributes almost 700,000 tonnes CO_{2e} to global climate change. The 4 MtonnesCO_{2e} reduction in emissions from landfill due to landfill gas collection is not sustained in the change from flaring to energy generation, where the decrease is just a further 44,000 tonnesCO_{2e}. (Note that the effect with a 50:50 coal:gas electricity grid (included for completeness) is minimal.)

Annual net greenhouse gas emissions

Figure 4-11 shows the effect of a progressive reduction in grid carbon intensity (as shown in Figure 4-7) on the annual net emissions of greenhouse gases for each option. This assumes 30 per cent efficiency EfW and an artificially high 90 per cent landfill gas collection. The net global climate change impact of the current and low fossil landfill options increases relatively steadily through to 2029/2030, when it levels off. In contrast both EfW options show a net benefit to climate change in the early years but their impact increases more rapidly than for landfill again until 2029/2030, when the rate of increase is lower.

However, the overall effect is that, for these assumptions, if an investment in either EfW or landfill is being considered for climate change mitigation, a decision based solely on current electricity up to 2023 would return EfW as the preferred option, whereas one based on electricity from 2024 would favour landfill.

Figure 4-10: Effect of landfill gas capture and electricity generation

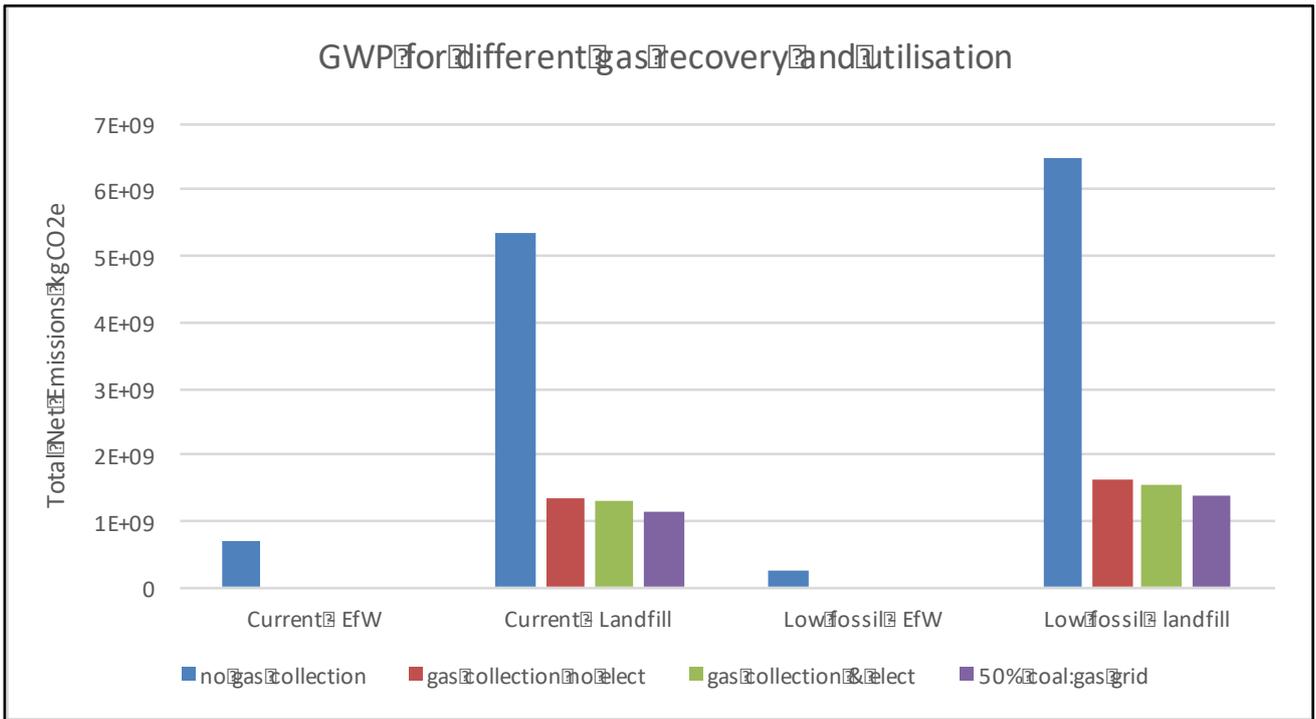
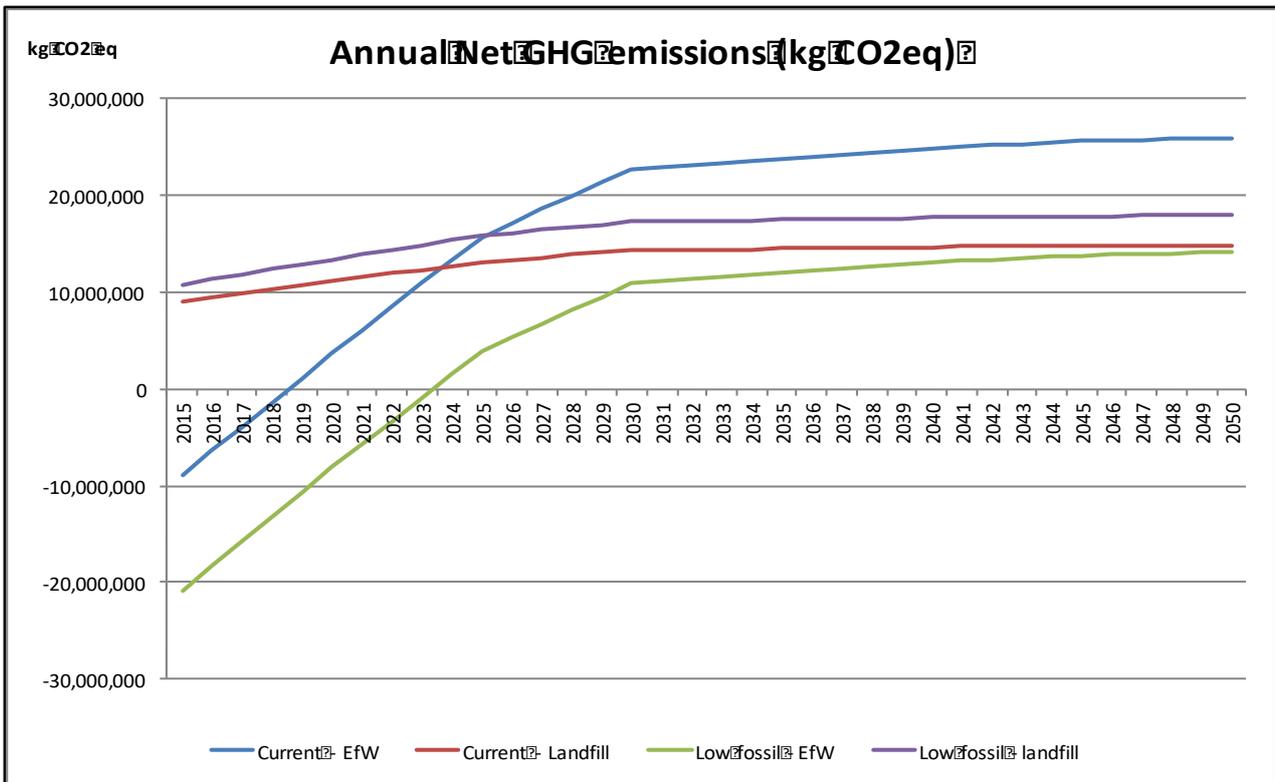


Figure 4-11: Annual net greenhouse gas emissions



Conclusions

The analysis above demonstrates the effect that the three key variables: waste composition, efficiency of operation and the greenhouse gases emitted by the energy source that is being displaced have a significant effect on the climate change performance of managing residual waste by EfW or landfill. For the scenarios and compositions considered above, the proportion of gas recovered was the most significant factor for landfill, whereas for EfW it was the carbon intensity of the electricity grid.

Gas recovery and thermal efficiency are both parameters that can be designed, engineered and therefore controlled. However, to ensure EfW plant meet the overall objectives of certification, additional consideration is required; this is given in the Energy from Waste section (page 37) and in Appendix 5.

Introduction

EfW generally has a lower impact on climate change than landfill for a given amount of residual waste and is therefore preferred to landfill for dealing with residual waste. Residual waste facilities will always deliver less benefit than facilities handling waste streams segregated for recycling, because the waste is that left over after extracting valuable materials and the benefits of recycling are excluded. Whether the proportion of waste recycled is 25%, 50% or 65%, there will still be residual waste to be managed and managing residual waste should be recognised as a necessity and therefore a need that is met by EfW. However, how beneficial an EfW plant is in relation to mitigation of climate change or how great an impact it makes will vary with factors such as:

- the efficiency of the plant;
- the composition of the residual waste; and
- the carbon intensity of the grid over the plant's operational life.

Therefore, for EfW the Criteria should also include conditions to guard against circumstances that would result in poor performance with regards to climate change and to improve the mitigation performance of all EfW plant.

EfW is dealing with the residual waste – the waste that is left after recycling and composting/AD and is generally likely to have higher emissions of greenhouse gases than recycling. Thus, there is a balance to be struck between the emissions allowed in relation to delivering effective waste management and emissions that are greater than those associated with the generation of electricity.

Future Electricity grid carbon intensities

CBI has assumed that renewable energy can be delivered with electricity grid carbon intensities of less than 100gCO₂e/kWh and this is compatible with limiting global temperature rise to below 2°C. To calculate a simple average, the average of the electricity grid intensity at the start of operations and the renewable figure of 100gCO₂e/kWh is calculated. If the electricity produced by an EfW plant matched or bettered this forecast average carbon intensity for the grid, the plant will be in line with the 2°C trajectory for electricity generation. However, this is highly unlikely. Currently an EfW plant burning typical European municipal waste with 25% efficiency will probably have a carbon intensity of between 500 and 600gCO₂e/kWh, well above most European electricity grid carbon intensities.

The effects of fossil carbon in EfW waste input

As outlined above, EfW plant do not only produce electricity and/or heat but also manage residual waste, as well as recovering some metals and ash as aggregate. These processes all have additional climate change burdens or deliver additional benefits by reducing greenhouse gas emissions and CBI considers that of these, residual waste management should be recognised by allowing additional emissions from EfW plant. The results of the LCA work for CBI (Table 7 in the main background document) show that from the viewpoint of climate change mitigation, recycling is the best option for managing plastics, whereas EfW can be the worst. Therefore, to determine what additional climate change burden the function of EfW plants in managing residual waste justifies, the carbon intensity of the electricity generated was calculated with different levels of plastics removed from the waste input. The results showed that, using a typical European composition containing approximately 10% dense and film plastics, removing all the dense plastics still produces a carbon intensity of over 400gCO₂e/kWh, due to:

- other fossil carbon containing material in the waste; and
- separate recycling of other materials (paper and card, food and garden waste) substantially reducing the weight of non-fossil carbon materials.

To explore what maximum reduction might practically be achieved, a UK waste management system with high prior recycling of other materials, (excluding textiles) was modelled. In this scenario, the removal of all plastics (both dense and film) prior to combustion reduced the predicted fossil carbon content of the waste input to 3.6% and the carbon intensity of the electricity from a qualifying plant to approximately 240gCO_{2e}/kWh. In this example, the upper limit of greenhouse gas emissions for an EfW operating in the UK would be set at the carbon intensity of 240gCO_{2e}/kWh.

Although in this example this is the lowest carbon intensity achievable by EfW through plastics recycling and represents the minimum eligibility, there is no requirement on how this limit is met. Thus, although its derivation was based on removing all plastics from the feedstock, it is not a requirement of the Criteria that this is how the limit is achieved, so long as, on average over the plant life, the carbon intensity of the emissions does not exceed the figure that was derived in this way: the limit can be achieved, for example, by increasing efficiency through delivery of heat or by a combination of measures.

Calculate the emissions intensity of the EfW plant for electricity

- Use a representative analysis of the actual or proposed waste input to the EfW plant and determine the percentage by weight of each fraction (paper, card, dense plastic, glass, metal etc.).
- Analyse each fraction to determine:
 - The moisture content and lower heating value (calorific value) for each fraction;
 - The carbon content of each fraction
- Estimate the percentage fossil carbon for each fraction.
- Using the qualifying efficiency (25%) of the EfW plant and the analysis above, calculate the emissions intensity in gCO_{2e}/kWh with all the dense plastic and plastic film fractions removed.
- This is the upper limit for the average emissions of fossil carbon dioxide from the EfW plant in gCO_{2e}/kWh over its lifetime.

As stated above, this is how the upper limit in the qualifying criteria for EfW emissions should be determined, not necessarily how it should be achieved. It does not require an EfW plant to remove all plastics but does require it to achieve the same level of emissions as would have been achieved if the plastics had been removed¹⁰¹.

In order to qualify for certification under the Criteria, operators of EfW plant must therefore demonstrate that the average carbon intensity of the electricity they produce is less the ‘allowance’ for residual waste management based on the carbon intensity of the EfW plant with the plastics removed. No allowance should be made in this calculation for the benefit from any additional recycling of metals and aggregate from EfW.

Table 5-1 shows the calculation steps to establish the predicted average electricity grid carbon intensity.

Table 5-1 Calculation of average electricity grid carbon intensity

Data	Formula
Current/starting electricity grid carbon intensity	E gCO _{2e} /kWh
Grid intensity at end of plant life	e gCO _{2e} /kWh
Year of carbon intensity (E)	Y _G
Year EfW starts operation	Y _S
Year EfW ceases operation	Y _E
Carbon intensity of grid for EfW start (W _S)	$W_S = E - (E - e) * (Y_S - Y_G) / (Y_E - Y_G)$

¹⁰¹ It is recognised that it is practically impossible to remove all plastics. However, both dense and film plastics should essentially be removed in their entirety.

Carbon intensity of grid for EfW end (W_E)	$W_E = E - (E - e) * (Y_E - Y_G) / (Y_E - Y_G)$
Average electricity grid carbon intensity for EfW operational life	$(W_S + W_E) / 2$

Dealing with heat

Where heat is also supplied, a similar procedure is followed, calculating the carbon intensity of the EfW plant from the total emissions of CO₂e divided by the sum of the amounts of electricity and heat produced in kWh.

The threshold for heat and power combined is calculated as the average carbon intensity of the grid electricity and heat displaced. The average carbon intensity for conventional electricity displaced is calculated as for the power only option above. For the heat component threshold, the carbon intensity of the current heat source displaced is used, (if not available, this can be calculated from the fuel used and efficiency of the heat source) or, if not known, generic carbon emissions factors¹⁰² for heating should be used. To be compatible with a 2°C scenario, the carbon intensity of heating will have to decrease in a similar fashion to that for electricity. Effectively, this means that heating will have to be supplied by renewable sources. Therefore, the CBI has assumed the carbon intensity of heating is also 100gCO₂e/kWh. The calculation for the average carbon intensity for heat is then similar to that shown above for electricity.

To calculate the combined heat and power threshold, the proportion of the energy output that is electricity multiplied by the average carbon intensity of electricity is added to the proportion of the output that is heat multiplied by the average carbon intensity of the heat that is displaced.

¹⁰² For example, <https://www.gov.uk/government/collections/government-conversion-factors-for-company-reporting#conversion-factors-2018>

Appendix 6: Further Reading

1. Blok, K., Hoogzaad, J., Ramkumar, S., Ridley, A., Srivastav, P., Tan, I., Terlouw, W., and de Wit, M., (2016). Implementing Circular Economy Globally Makes Paris Targets Achievable. [s.l.] [s.n.]
2. Circle Economy, (2016). *Circular Amsterdam: A vision and action agenda for the city and the metropolitan area*. [Online] Amsterdam, Netherlands: Circle Economy. Available [online](#). [Accessed 3 October 2016].
3. Cointreau, S., (2006). *Occupational and Environmental Health Issues of Solid Waste Management: Special Emphasis on Middle- and Lower-Income Countries*. [Online] Washington D.C., U.S.: World Bank. Available [online](#). [Accessed 3 October 2016].
4. Confederation of European Waste-to-Energy Plants (CEWEP). 2015. *Landfill taxes & bans*. [Online] Düsseldorf, Germany: CEWEP. Available [online](#). [Accessed 12 September 2016].
5. Department for Environment, Food & Rural Affairs (DEFRA), (2015). *Digest of Waste and Resources Statistics – 2015 Edition*. [Online] London, UK: DEFRA. Available [online](#). [Accessed 12 September 2016].
6. Ellen MacArthur Foundation (EMF), (2013). *Towards the Circular Economy: Economic and business rationale for an accelerated transition*. Isle of Wight, UK: EMF.
7. Ellen MacArthur Foundation (EMF). 2014. *Towards the Circular Economy: Accelerating the scale-up across global supply chains*. Isle of Wight, UK: EMF.
8. Ellen MacArthur Foundation (EMF). 2015. *Delivering the Circular Economy: A Toolkit for Policymakers*. Isle of Wight, UK: EMF.
9. Ellen MacArthur Foundation (EMF). 2015. *Growth Within: A Circular Economy Vision for a Competitive Europe*. Isle of Wight, UK: EMF.
10. Ellen MacArthur Foundation (EMF). 2015. *The New Plastics Economy: Rethinking the Future of Plastics*. Isle of Wight, UK: EMF.
11. Entreprises pour l'Environnement (EpE), (2013). *Protocol for the quantification of greenhouse gas emissions from waste management activities*. Paris, France: EpE.
12. European Commission, (2015). *Closing the Loop: An EU Action Plan for the Circular Economy*. [Online] Brussels: European Commission. Available [online](#). [Accessed 3 October 2016].
13. Green Investment Bank (GIB), (2015). *Green Impact Reporting Criteria – June 2015*. Edinburgh, Scotland: GIB.
14. Hoornweg, D. and Bhada-Tata, P., (2012). *What a Waste: A Global Review of Solid Waste Management*. Washington D.C., US: World Bank.
15. Intergovernmental Panel on Climate Change (IPCC), (2007). *Waste Management*. In: *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Bogner, J., M. Abdelrafie Ahmed, C. Diaz, A. Faaij, Q. Gao, S. Hashimoto, K. Mareckova, R. Pipatti, T. Zhang]. Cambridge, UK and New York, US: Cambridge University Press.
16. Intergovernmental Panel on Climate Change (IPCC). 2014. *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge, UK and New York, US: Cambridge University Press.
17. Knowledge Transfer Network (KTN), (2016). *Innovation Opportunities from Industrial Waste*. [Online] London, UK: KTN. Available [online](#). [Accessed 15 September 2016].
18. Mavropoulos, M. [No date]. *Waste Management 2030+: The future of waste management in an overcrowded planet*. [Online]. Vienna, Austria: International Solid Waste Association (ISWA). Available [online](#). [Accessed 15 September 2016].
19. OECD, (2016). *Policy Guidance on Resource Efficiency*. [Online] Paris, France: OECD Publishing. Available [online](#). [Accessed 3 October 2016].
20. Organisation for Economic Co-operation and Development (OECD), (2015). *Environment at a Glance 2015: OECD Indicators*. [Online] Paris, France: OECD Publishing. Available [online](#). Accessed 12 September 2016].
21. The Scottish Government, (2016). *Making Things Last: A Circular Economy Strategy for Scotland*. [Online] Edinburgh, Scotland: The Scottish Government. Available at: <http://www.gov.scot/Resource/0049/00494471.pdf> [Accessed 3 October 2016].
22. Turner, D., Williams, I., and Kemp, S., (2015). *Greenhouse gas emission factors for recycling of source-segregated waste materials*. *Resources, Conservation and Recycling* 105, pp.186–197.
23. United Nations Environmental Programme (UNEP), (2015). *Global Waste Management Outlook*. Osaka, Japan: UNEP Division of Technology, Industry and Economics (DTIE) International Environmental Technology Centre (IETC).

Waste Management Background Paper

24. United Nations Environmental, (2010). *Waste and Climate Change: Global Trends and Strategy Framework*. Global Waste Management Outlook. Osaka, Japan: UNEP Division of Technology, Industry and Economics (DTIE) International Environmental Technology Centre (IETC).
25. Veolia, (2015). *Imagine 2050: The innovations we will need in waste, water and energy to ensure a sustainable future*. [Online] London, UK: Veolia. Available [online](#). [Accessed 13 September 2016].
26. Veolia. [No date]. *Circular Economy Case Studies: Cleaning up in partnership with Procter & Gamble*. [Online] Available at: <http://www.veolia.co.uk/Procter-Gamble>. [Accessed 12 September 2016].
27. Waste & Resources Action Programme (WRAP). [No date]. *The Courtauld Commitment 2025*. [Online] Available [online](#). [Accessed 12 September 2016].
28. Winne, S., Horrocks, L., Kent, N., Miller, K., Hoy, C., Benzie, M., & Power, R., (2012). *Increasing the climate resilience of waste infrastructure*. London, UK: Department for Environment, Food and Rural Affairs (DEFRA).
29. World Resources Institute (WRI), (2013). *Technical Guidance for Calculating Scope 3 Emissions: Supplement to the Corporate Value Chain (Scope 3)*. [Online] Washington D.C., US: WRI. Available at: <http://www.ghgprotocol.org/feature/scope-3-calculation-guidance> [Accessed 5 Oct 2016].