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Key Decision - Yes
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HUNTINGDONSHIRE DISTRICT COUNCIL

Title/Subject Matter: Procurement of Vehicles and Containers for Weekly Food Waste Collection Service.

Meeting/Date:
O&S (Environment, Communities & Partnerships) 06.02.2025.
Cabinet – 11.02.2025.

Executive Portfolio: Executive Councillor for Parks and Countryside, Waste and Street Scene
Cllr Simone Taylor

Report by: Andrew Rogan, Head of Operational Services

Ward(s) affected: All Ward(s)

Executive Summary:

In November 2021 the amended Environment Act was enacted laying a foundation for enhanced waste management and recycling across the UK. In alignment with this the Government released the Simpler Recycling requirements in May 2024. These requirements outline consistent waste collection methods aimed at reducing landfill waste and supporting sustainable resource recovery.

Under this legislation, all Councils in England (unless transitional arrangements have been requested and agreed) are now mandated to implement a separate, weekly food waste collection service from households by 31 March 2026.

To support this transition, DEFRA allocated a capital funding payment of £1,802,468 to HDC in May 2024 to facilitate the purchase of essential equipment including food waste caddies, bins and dedicated collection vehicles. Additionally, DEFRA has committed to providing transitional resource funding for 2024/25; with ongoing resource and revenue costs to be available from 1 April 2026, though specific allocations are still pending.

Extensive route modelling has been undertaken to determine the number and size of vehicles required for the dedicated weekly food waste service. This modelling has identified that 12-ton dedicated food waste vehicles would be the most efficient and effective to deliver the service. There will be a need for eleven 12-tonne collection vehicles, nine of which will be operational and two spare vehicles to cover vehicle breakdown and maintenance. Moreover, the Council will need to procure 90,000 23-litre kerbside caddies and 90,000 7-litre kitchen

caddies and approximately 400 communal bins to support households in the transition to weekly food waste collection.

Around 50% of local authorities in England do not currently offer separate weekly food waste collections. Under the Environment Act the mandate to establish these collections across England by 31 March 2026 aims to standardise recycling practices, reduce greenhouse gas emissions from landfill and support anaerobic digestion for renewable energy generation. This will create high demand for vehicles and caddies, making early procurement essential to meet the Council's needs. With an estimated 12-month lead time for vehicle delivery, prompt action on placing orders will be crucial. The onward delivery of the project will be planned, communicated and reported through the Corporate Plan actions.

The purpose of this report is to seek Cabinet’s approval to delegate authority to the Corporate Director of Place and section 151 officer in consultation with the Executive Councillor for Parks and Countryside, Waste and Street Scene, Executive Councillor for Finance and Resources.

- To pursue the procurement of equipment and onward delivery of the separate weekly food waste collections project to meet the Government mandated deadline of April 2026.

Recommendation(s):

For cabinet to approve to delegate authority to the Corporate Director of Place and section 151 officer in consultation with the Executive Councillor for Parks and Countryside, Waste and Street Scene, Executive Councillor for Finance and Resources to pursue the procurement of equipment and onward delivery of the separate weekly food waste collections project to meet the Government mandated deadline of April 2026.

1. PURPOSE OF THE REPORT

1.1 The purpose of this report is to seek Cabinet's approval to delegate authority to the Corporate Director of Place and section 151 officer in consultation with the Executive Councillor for Parks and Countryside, Waste and Street Scene, Executive Councillor for Finance and Resources to pursue the procurement of equipment and the onward deliver of a separate weekly food waste collection service by April 2026.

2. WHY IS THIS REPORT NECESSARY/BACKGROUND

2.1 In November 2021, amendments were made to the Environment Act and became law for the UK. The Government outlined how the legislation will work, by publishing the Simpler Recycling requirements in May 2024.

2.2 All Councils are now legally required to introduce a separate weekly food waste collection from households by 31 March 2026.

2.3 To enable residents to participate and contribute to the Council achieving this a small internal food waste caddy (approx. 7 litres) will need to be provided to households for use in the kitchen. This provides the household with somewhere to store food waste in the short term and helps improve collection yields

2.4 Residents will empty their food waste into an external 23 litre food waste caddy which can be placed beside their existing bins for collection.

2.5 Where communal collections exist—currently totalling 459 sites—these locations must be evaluated to determine the necessary communal bin facilities. Typically, flats are provided with a small caddy that residents use to transfer waste into a shared 140-litre bin.

2.6 Liners are used by some Councils, but not entirely, consideration will need to be given in due course as to their inclusion into the food waste collection service.

2.7 Evidence produced by The Waste and Resources Action Programme (WRAP) indicated that higher yields are achieved if caddy liners are provided, however, this would impose a significant ongoing cost to the council along with an ongoing impact on internal services in connection with the day-to-day management of the liners. At this point Government will not commit to either capital funding, or ongoing revenue funding for caddy liners.

2.8 Waste collection teams will then empty the material from these external 23 litre caddies or communal bins into a specific food waste collection vehicle.

2.9 Food waste will then be delivered to the Alconbury waste transfer station as part of Cambridgeshire County Council's PFI contract arrangements and then processed through an Anaerobic Digestion (AD) plant.

2.10 Extensive route modelling has been undertaken to establish the most effective and efficient vehicle size and type.

2.11 This modelling indicates that a 12-ton food waste vehicle would be best suited, compared with the standard 7.5-ton variant. The Council will need to purchase new dedicated food waste collection vehicles. Current lead times are estimated at a minimum of 12 months and further pressure on the supply chain is likely as all local authorities which do not currently collect food waste will be looking to procure vehicles.

2.12 In addition to requiring additional dedicated vehicles there is a need to procure both internal and external food waste caddies, plus additional bins for communal properties.

2.13 The Government has provided the Council with new burdens capital funding of £1,802,468.00 for the purchase of food bins (this includes internal kitchen caddies, external kerbside caddies and communal bins, but not liners) and food waste collection vehicles, and has indicated it will provide ongoing new burdens revenue funding although, there had been no confirmation of the amount, what that would cover or for how long.

3. OPTIONS CONSIDERED

3.1 Separate weekly food waste collections are a legal requirement for HDC from April 2026, do nothing is not an option that had been considered due to potential legal challenge, government sanctions and reputational damage.

3.2 Options have been explored around how we could incorporate separate weekly food waste collection into our current service delivery model, however, it would be too problematic from an operational perspective, and a waste disposal perspective.

3.3 We explored options around using split bodied vehicles that have an additional compartment for food waste meaning we could collect more than one material at a time. This would require significant investment in new 26t vehicles, along with a full re-routing exercise. In addition, compartments will fill at differing rates meaning multiple trips to the tip will be required.

3.4 Collecting food waste separately increases yields and ensures we have full visibility on the amount of food waste we collect, which enables us to understand capture rates across the district. This information will enable HDC to deliver targeted communications and educational material and monitor their impacts.

3.5 Food waste that is collected separately can be treated through anaerobic digestion which efficiently captures methane for energy production. Keeping food waste separate ensures it is managed in the most environmentally friendly and efficient way.

3.6 A considerable amount of work has been undertaken to identify the number of rounds and vehicles required to service all domestic properties in Huntingdonshire. The modelling is based on data from Wrap's' Household Food Waste Collections Guide' with sensitivity analysis being included on 'put-out rates' ranging from 30%-60% to reflect the WRAP data. (Appendix 1 & 2)

3.7 All procurement will be conducted in line with the Public Contracts Regulations (PCR) to provide best value, financially, socially and environmentally, we will be receiving support from WRAP as they were pivotal in calculating the funding allocation based on market data.

4. COMMENTS OF OVERVIEW & SCRUTINY

4.1 The comments of the relevant Overview and Scrutiny Panel will be forwarded to Cabinet prior to its consideration of this report.

5. KEY IMPACTS / RISKS

5.1 It is anticipated that large numbers of local authorities will implement new or extended food waste collection services between 2024 and 2026. There will be a very high demand for new vehicles and containers during this period. This may drive up the cost of equipment as demand outstrips supply. The capital funding provided may not cover the total capital expenditure at this phase of the project. Should this be the case, HDC could look to fund and additional capital funding requirement through its current fleet capital programme.

5.2 There is a high likelihood of procurement bottlenecks which could create supply delays and impact the implementation timescales of a new service. The council should act quickly to determine requirements and to proceed with procurements as early as possible.

5.3 There is a risk that mandatory deadlines may be hard to achieve. Assurance has been sought from Government that in the event mandatory deadlines are not met due to factors outside our control, there will be no adverse financial or legal implications.

5.4 The introduction of food waste collections may carry a significant reputational risk. Service changes must be carefully designed and planned, comprehensively and clearly communicated to residents, and implemented and operated to a high standard to ensure resident satisfaction.

5.5 A clear and comprehensive communications plan will be developed as part of the ongoing project delivery. It is the aim of HDC to ensure all members are involved with the communications plan and messaging to ensure all areas of the district are fully supported during the transition.

5.6 There are many interdependencies with Cambridgeshire County Council (CCC) as the waste disposal authority. CCC do have a contract in place until 2027 for the food waste to be processed through and AD plant. We will continue to work with all partners across the region to ensure the food waste is being processed correctly.

5.7 DEFRA has committed to providing resource transitional funding for 2024/25, with ongoing resource and revenue costs to be available from 1 April 2026, although specific allocations are still pending.

6. WHAT ACTIONS WILL BE TAKEN/TIMETABLE FOR IMPLEMENTATION

6.1 The timeline below indicated the high-level milestone needed for the project, although some of the milestones may alter once we start to engage with the market.

6.2 Defra have yet to provide any details on the level of funding for councils to implement the separate weekly food waste collections, however, it is predicted the funding provided by Defra will cover items such as: communications plan; community engagement; leaflets and promotional material; updates to IT systems and In-cab systems; and additional resource. Although we are not yet at the detailed planning stage, we anticipate the roll out of the food waste service will use the same methodology that successfully delivered the changes to the garden waste collection service.

6.3 Once approval has been obtained, we will look to procure vehicles, caddies and bins as quickly as possible to ensure we can physically meet the deadline of 2026.

6.4 A survey of all communal areas will be conducted in Q1 2025/26 to establish the requirements for communal bins.

6.5 In Q2 2025/26 we would look to procure a bin delivery contractor to handle the distribution of caddies to households.

6.6 We would look to start the recruitment process in Q3 2025/26 of the additional teams needed for the new service.

6.7 In Q4 we would look to have the round fully digitised and integrated into our current systems such as the online calendar, e-forms and in-cab etc.

6.8 Throughout 2025/26 an extensive communications plan will be developed and delivered.

6.9 The above is a basic timeline showing some of the key milestones, however, a full project team will be assembled and a full implementation plan formulated.

7. LINK TO THE CORPORATE PLAN, STRATEGIC PRIORITIES AND/OR CORPORATE OBJECTIVES

(*See Corporate Plan*)

8. LEGAL IMPLICATIONS

8.1 The amended Environment Act was enacted, laying a foundation for enhanced waste management and recycling across the UK. Under this legislation, the Council is now mandated to implement a separate, weekly food waste collection service from households by 31 March 2026.

8.2 Failure to comply with the new regulation my result in the council being sanctioned or penalised by Government.

8.3 Failure to comply with the new legal requirement may result in significant reputational damage to the organisation.

9. FINANCE IMPLICATIONS

9.1 To support this transition, DEFRA allocated a capital funding payment of £1,802,468 to HDC in May 2024 to facilitate the purchase of essential equipment, including food waste caddies, bins and dedicated collection vehicles. Additionally, DEFRA has committed to providing resource transitional funding for 2024/25, with ongoing resource and revenue costs to be available from 1 April 2026, though specific allocations are still pending.

9.2 The table below show the indicative capital cost of purchasing vehicles, caddies and bins. These cost may change depending on supply and availability once we approach the market.

Description	Number Required	(soft market testing) Unit Cost	Total
12t Collection Vehicle	11	£128,135.00	£1,409,485
23ltr Kerbside Caddy	90,000	£3.30	£297,000
7ltr Kitchen Caddy	90,000	£1.15	£103,500
140ltr Communal Bins	400	£16.00	£6,400.00
		Total	**£1,816,385**
		Defra Capital Funding	£1,802,468

10. RESOURCE IMPLICATIONS

10.1 At this stage of the project there will be a resource implication on procurement, waste and recycling, waste minimisation, and the wider operational management teams.

11. ENVIRONMENT AND CLIMATE CHANGE IMPLICATIONS

11.1 In 2021/22, 6.4 million tonnes of food (and drink) waste was generated from UK households, of which 4.7 million tonnes is categorised as edible and 2 million tonnes inedible or unavoidable. This equates to 95 kg per person per year or 227 kg per household per year or 247 kg per household of four.

11.2 Producing food requires significant resources including land, energy and water. Globally, 25–30% of total food produced is lost or wasted, and food waste is estimated by the Intergovernmental Panel on Climate Change to contribute 8-10% of total man-made greenhouse gas (GHG) emissions.

11.3 The new service is targeted to divert approx. 6,000 tonnes of food waste currently collected in the refuse waste stream to a dedicated food waste recycling service. This would result in an indicative net carbon emissions savings of around minus 468 tCO2e per annum. (WRAP-Carbon Waste and Resources Metric Appendix 3)

11.4 The new fleet of food waste vehicles are able to run on Hydrotreated Vegetable Oil (HVO) which would align with the organisational goals of decarbonising the fleet.

11.5 Whilst the purchase of new vehicles and containers will have a negative impact arising from the embodied carbon (i.e. the energy and emissions arising from the manufacturing process), such negative implications can reasonably be assumed to be offset within a short period of time with the increased diversion of food waste from landfill.

12. REASONS FOR THE RECOMMENDED DECISIONS

12.1 The amended Environment Act was enacted laying a foundation for enhanced waste management and recycling across the UK. Under this legislation, the Council is now mandated to implement a separate, weekly food waste collection service from households by 31 March 2026.

12.2 DEFRA allocated a capital funding payment of £1,802,468 to HDC in May 2024 to facilitate the purchase of essential equipment, including food waste caddies, bins and dedicated collection vehicles.

13. LIST OF APPENDICES INCLUDED

Appendix 1 – WRAP-Household Food Waste Collection Guide.
Appendix 2 – WRAP-Household Food Waste Collections Elected Members Summary Guide.
Appendix 3 – Carbon WARM Report.

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Appendix 1 - https://www.wrap.ngo/sites/default/files/2024-02/WRAP-Household-Food-Waste-Collections-Guide-V17.pdf

Appendix 2 - https://www.wrap.ngo/sites/default/files/2024-02/WRAP-Household-Food-Waste-Collections-Elected-Members-Summary-Guide-INTERACTIVE.pdf

Final Report

Appendix 3 - Carbon Waste and Resources Metric

A methodology for assessing the greenhouse gas impacts of waste management

Project code: POS011-007
Research date: 2019-2020 **Date:** February 2021

WRAP's vision is a world in which resources are used sustainably.

Our mission is to accelerate the move to a sustainable resource-efficient economy through re-inventing how we design, produce and sell products; re-thinking how we use and consume products; and re-defining what is possible through re-use and recycling.

Find out more at www.wrap.org.uk

Document reference WRAP (2021) Carbon Waste and Resources Metric.

Written by: Billy Harris and Keith James, WRAP

Front cover photography: image credit: pixabay/images/id-1325882

14. EXECUTIVE SUMMARY

The Carbon Waste and Resources Metric (Carbon WARM) has been developed by WRAP on request by DEFRA to allow monitoring and evaluation of the impacts of the Resources and Waste Strategy in terms of its Greenhouse Gas emissions impact, measured as carbon dioxide equivalent (CO_2e). This is intended to supplement traditional weight-based monitoring and evaluation with an approach that focuses more on the environmental (climate) impacts of waste and resource management, and supersedes the metric published in 2012.

In addition, many of the UK's local authorities have declared a climate emergency, committing themselves to urgent action to reduce their carbon emissions. Carbon WARM can be used to show how increasing recycling of waste can contribute to this agenda.

Envisaged uses include:

- Monitoring and reporting on the CO_2e saved by moving waste management further up the hierarchy.
- Calculating the proportion of the potential CO_2e saving that has been realised.
- Modelling the GHG impacts of different combinations of waste management options.

Carbon WARM factors have different system boundaries and different scope than those published by BEIS for company Greenhouse Gas Emission reporting, though the underlying data is in many cases the same. This is to allow comparison of waste management approaches for a given material, rather than facilitate business carbon accounting. They also differ in presentation from the Scottish Carbon Metric, which provides a weighting system based on the relative merits of different materials.

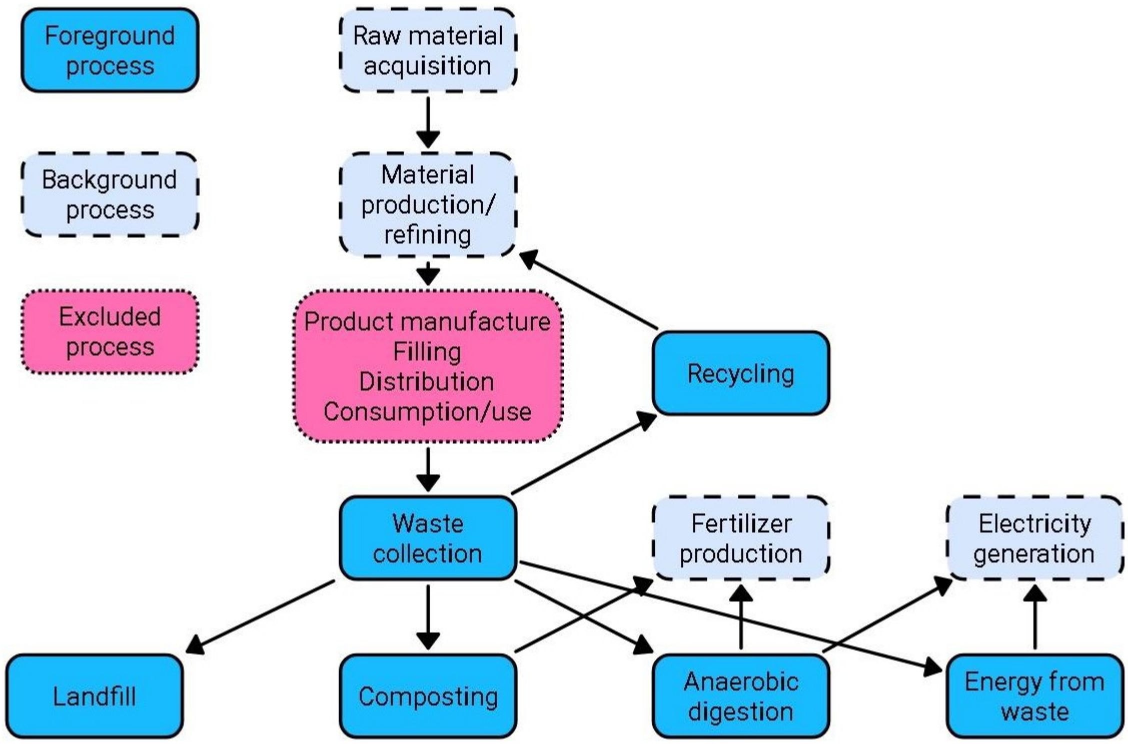
While the factors contained herein represent the best available information on greenhouse gas emissions for waste management options in the UK, the data are subject to uncertainty and are based on averages. They may not reflect specific facilities or other activities (e.g. a process powered solely by renewable energy). The results should be regarded as indicative of the relative impacts of waste treatment options, rather than as a precise carbon footprint. Care should be taken not to model scenarios that produce a spurious conclusion. For example, when modelling energy from waste, account should be taken of the required fuel mix for an EfW facility, as opposed to picking materials based purely on relative emissions.

Carbon WARM does not affect the information which Local Authorities should report through WasteDataFlow. It should be seen as complementary to the existing waste hierarchy guidance document. The hierarchy considers a wider range of environmental impacts than the carbon metric, and should, in the absence of a specific Life Cycle Assessment, be regarded as a more robust guide to the best environmental option. For further details on the waste hierarchy please also see the DEFRA evidence summary on applying the waste hierarchy.

This work does not constitute a Life Cycle Assessment, but is underpinned by a lifecycle thinking approach, in that it aims to account not only for waste treatment emissions but also for any other emissions entailed or avoided by a process. This is important as, in most cases, the main benefits of recycling are not "waste management" benefits at all but are associated with the avoided raw material acquisition. For example, recycling of metals will have a higher GHG emission from the recycling process than from landfill (metals do not biodegrade to produce CO2 or methane in landfill), but recycling metals produces a usable product and reduces the need for production of metals from raw materials (a much more carbon- intensive process), and the consequent emissions.

The system boundaries used in modelling the metric values are show in the figure below.

System boundaries for Carbon WARM



The metric values, normalised relative to landfill emissions, are shown below.

Carbon WARM, normalized vs landfill (kg.CO_2e/tonne)

	Closed loop recycling	Open Loop recycling	Energy from Waste	Anaerobic digestion	Compost used in horticulture	Compost used in agriculture	Landfill
Food	NA	NA	-664	-705	-671	-611	0
Garden	NA	NA	-656	-657	-594	-493	0
Food and garden	NA	NA	-662	-670	-616	-525	0
Paper and board	-1,146	NA	-1,260	NA	NA	NA	0
Steel	-1,071	NA	10	NA	NA	NA	0
Aluminium	-7,478	NA	15	NA	NA	NA	0
Mixed (cans)	-3,377	NA	12	NA	NA	NA	0
Glass	-335	24	-1	NA	NA	NA	0
Textiles	-14,760	NA	-7	NA	NA	NA	0
Dense plastics	-599	196	1,682	NA	NA	NA	0
Film	-541	196	1,466	NA	NA	NA	0
Wood	-1,306	NA	-1,096	NA	NA	NA	0

15. CONTENTS

Acknowledgements

The authors are grateful for the peer review carried out by Robin Curry, and the technical input throughout development from Andrew Woodend, Javier Igartua and Oliver Lysaght from Defra.

1.0 Introduction

The Carbon Waste and Resources Metric (Carbon WARM) has been developed by WRAP on request by DEFRA to allow monitoring and evaluation of the impacts of the Resources and Waste Strategy in England in terms of its Greenhouse Gas emissions impact, measured as carbon dioxide equivalent (CO_2e). This is intended to supplement traditional weight-based monitoring and evaluation with an approach that focuses more on the environmental (climate) impacts of waste and resource management.

Envisaged uses include:

- Monitoring and reporting on the CO_2e saved by moving waste management further up the hierarchy.
- Calculating the proportion of the potential CO_2e saving that has been realised.
- Modelling the GHG impacts of different combinations of waste management options.

In addition to use by DEFRA, Carbon WARM is intended to form the basis of a spreadsheet- based tool for use by local authorities or other parties seeking to make waste management decisions based on GHG emissions impact.

The approach taken has been to produce a series of carbon factors that quantify the net CO_2e emissions relative to a "default" waste management technology (landfill) for a range of materials and the following treatment options:

1) Closed loop recycling
2) Open-loop recycling
3) Energy from waste
4) Anaerobic digestion
5) Composting

This metric is not a "footprint" (i.e. it is not a statement of the absolute emission that can be attributed to a material, product or activity) but rather a relative measure that quantifies the carbon saving (or additional emission) relative to landfill for a given material / treatment combination. It is not suitable for Greenhouse Gas Inventory reporting – those who require factors for GHG Inventories should use the factors published by BEIS[1].

Carbon WARM is similar in most respects to the Scottish Carbon Metric[2], with the primary difference being that Carbon WARM is reported in kg CO_2e per tonne of material relative to landfill, rather than the Scottish approach, which uses an index-based "carbon weighting".

This work does not constitute a Life Cycle Assessment, but is underpinned by a lifecycle thinking approach, in that it aims to account not only for waste treatment emissions but also for any other emissions entailed or avoided by a process. This is important as, in most cases, the main benefits of recycling are not "waste management" benefits at all but are associated with the avoided raw material acquisition. For example, recycling of metals will have a higher GHG emission from the recycling process than from landfill (metals do not biodegrade to produce CO_2 or methane in landfill), but recycling metals produces a usable product and reduces the need for production of metals from raw materials (a much more carbon- intensive process), and the consequent emissions.

The methodology used in the development of Carbon WARM is underpinned by the following standards:

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1 https://www.gov.uk/government/collections/government-conversion-factors-for-company-reporting

2 https://www.zerowastescotland.org.uk/our-work/carbon-metric

- ISO 14040:2006: Environmental management — Life cycle assessment — Principles and framework
- ISO 14044:2006: Environmental management — Life cycle assessment — Requirements and guidelines
- PAS 2050 (2011): Specification for the assessment of the life cycle greenhouse gas emissions of goods and services
- The World Resource Institute and the World Business Council for Sustainable Development Greenhouse Gas Protocol Initiative

2.0 Methodology

2.1 Choice of metric

Global warming is widely recognised as a serious global threat (e.g. Stern 2006), and is a focus for national and international policy efforts, such as through the work of the IPCC. In this context, Carbon WARM quantifies waste management options in terms of their contribution to global warming, as an alternative to approaches based on quantifying tonnes of material, with the principal aim of supporting the UK Government's climate change policy.

Other environmental impact categories (e.g. resource depletion, acidification, eutrophication, health impacts) have not been included in this metric for three primary reasons:

a) While climate science still faces significant uncertainties, the main issues around climate change and the role of anthropogenic GHG emissions are well understood relative to many other areas.
b) This is also the area for which the most robust emissions data are available.
c) Emissions of GHG to the atmosphere have a known environmental impact that is independent of when and where the emission occurs. This is not the case with most other emissions, where the location of the impact is critical and the environmental impact may or may not occur. For example, particulate emissions that might affect human health are critically dependent on factors such as population density – it is not possible to reliably quantify an impact based simply on emissions data, and such metrics usually quantify potential rather than actual impact.

Since the main driver of anthropogenic climate change is CO_2 emissions, global warming impact is quantified in units of carbon dioxide equivalent (CO_2e).

The "strength" of a greenhouse gas is driven by two factors:

a) The quantity of infrared radiation (heat) emitted by the Earth that the gas absorbs (the higher the absorption the greater the warming effect).
b) The length of time the gas remains in the atmosphere before it is broken down (the longer the gas lasts the greater the warming effect).

For example, methane absorbs more heat than carbon dioxide but decays (into CO_2) over a period of approximately 12 years. Carbon dioxide itself, while a weaker absorber, persists in the atmosphere for a much longer period, with full removal by geological processes taking over 1 million years (Archer, 2007).

This means that, in order to compare the global warming potential of greenhouse gases, their impact must be accounted for over a period of time. The longer this period, the lower the warming potential of a short lived gas such as methane will be relative to CO_2 (because methane decays into CO_2 and CO_2 is so long lived, the rates converge over time). Carbon WARM uses the commonly accepted period of 100 years, with this metric known as GWP100.

Table 1 shows the GWP100 potential of several major greenhouse gasses, as produced by the IPPC Fourth Assessment Report (AR4, 2007) and Fifth Assessment Report (AR5, 2014). Although the AR5 factors are now the internationally recommended values, this report uses the factors from AR4, to maintain comparability with the annually published BEIS GHG conversion factors.

Table 1: Global warming potential of selected greenhouse gasses (AR4 and AR5)

	GWP100 (AR4)	GWP100 (AR5)
Carbon dioxide	1	1
Methane	25	28
Nitrous oxide	298	265
CFC11	4,750	4,660
Sulphur Hexafluoride	22,800	23,500

2.2 Treatment of biogenic carbon

Climate scientists distinguish two types of carbon cycle, the long (geological and fossil) and the short (biogenic) cycles.

The long cycles take place over millions of years. Carbon is sequestered in the earth through geological processes (such as weathering of silicate rocks) and emitted into the atmosphere through volcanic activity. Carbon is also sequestered through the production of fossil fuels (coal, gas and oil) from organic matter, and burning fossil fuels releases this back into the atmosphere, increasing the atmospheric concentration of CO_2 in a way that is effectively permanent.

The biogenic (short) carbon cycle is the cycle by which plants and animals take up carbon from the soil and atmosphere and release it back into the soil and atmosphere. This is assumed to be an ongoing process, with the carbon released by respiring and decaying organisms being effectively offset by the carbon take up from photosynthesising and growing organisms. The two cycles may not always be exactly balanced, but there is also a limit on how much CO_2 emission biogenic carbon can account for – all of life on Earth accounts for about 500 Gt of biogenic carbon, compared with around 5,000 for fossil carbon.

Table 2: Sources of biogenic and non-biogenic carbon

Source / type	**Weight of carbon (Gt)**
Ocean	
Oxidised	38,000
Dissolved organic	600
Living	1
Land	
Living organic	500
Dead organic	1,500
Earth	
Fossil fuels	5,000
Sedimentary rocks	1,200,000
Atmosphere	
Atmospheric carbon	700

Source: Archer (2007)

For this reason, climate models are traditionally based on fossil carbon emissions and treat biogenic carbon emissions as climate neutral, as, over time, carbon released into the atmosphere from organic matter will be taken back up. More sophisticated models account for biogenic carbon from land use change (LUC), with a potential total emission of around 1,500 Gt; for example, if an area of woodland is turned into buildings then the land is no longer able to take up carbon from the atmosphere. However, land use change is extremely difficult to model and to attribute to a tonne of material, and so does not figure in the calculations for Carbon WARM [3].

2.3 Territorial versus consumption based approaches

There are two primary ways of allocating emissions from production of products and services, based either on the country where the production took place (territorial approach) or where the product or service was consumed (the consumption-based approach).

1) Territorial approach. This approach is based on quantifying production emissions based on the country in which goods and services are produced. Applying this approach to England, all emissions associated with goods and services produced in England would be counted, while production emissions from goods consumed or disposed of in England but produced in other countries would be omitted (as they would be counted as emissions from these other countries).
2) Consumption-based approach. This approach allocates production emissions to the country in which the product is consumed. Using a consumption based approach, production emissions from goods and services produced overseas but consumed in England would be allocated to England, while production emissions from goods and services produced in England but exported would be allocated to the country in which they were consumed.

This metric uses a consumption-based approach to allocating carbon emissions, for the following reasons.

1) Consumption-based accounting is generally regarded as a fairer and more equitable approach to quantifying emissions, as the burden is placed on the ultimate beneficiaries of the production process (the consumers) rather than the producers (see, for example, Helm, 2014). It also avoids the distortions that can arise as an unintended consequence of policy. For example, EU emissions policy has had the effect of displacing some polluting industries to developing countries, with the end products imported to the EU for consumption. A territorial approach would tend to understate the emissions footprint of EU consumption.
2) The aim of Carbon WARM is to quantify the global emissions impact of treating products and materials at end of life. These are, almost by definition, goods consumed in the UK, but which are in many cases imported, and the resource-use impacts of waste treatment technologies would be overlooked under a territorial approach.

2.4 System boundaries

System boundaries for the analysis **include** the following stages

- Extraction and refining of raw material
- Production of material product (e.g. paper, metal ingot, plastic flake)
- Collection and of product or material at end of life (transport impacts)
- Emissions associated with the treatment or disposal option
    - Landfill (default option)
    - Closed loop recycling

[3]This is a complicated issue. For example, in the case of anaerobic digestion of food waste, Land Use Change is not a significant issue. However, food waste may be codigested with other feedstocks for which LUC is an issue (e.g. grass silage). A decision would then need to be made as to whether to allocate all LUC emission to the silage alone, or to attribute some of this to food (e.g. if grass silage functions as additive to enable more effective digestion). Such considerations are beyond the scope of this work.

- Open loop recycling
- Energy from waste
- Anaerobic digestion
- Composting

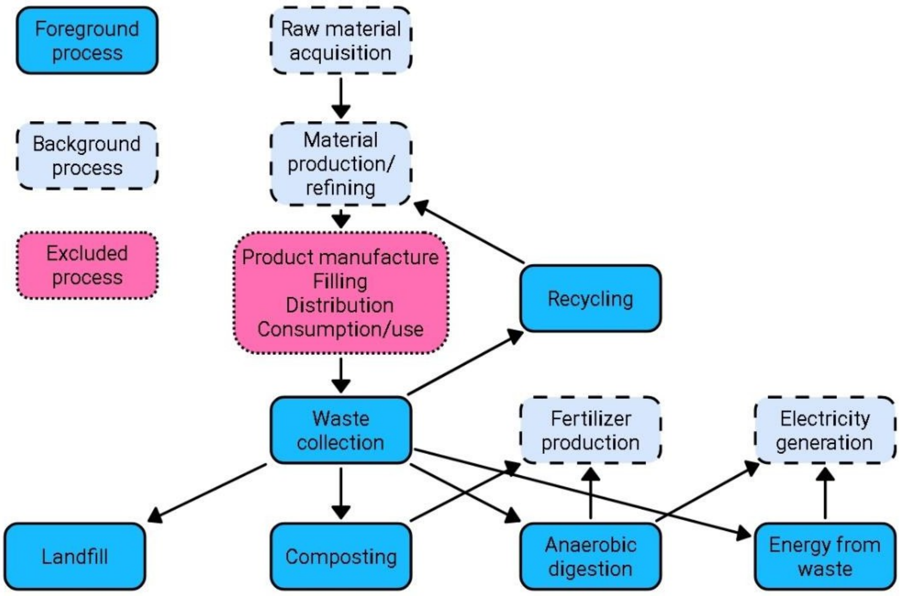
- Emissions offset by the treatment or disposal option – assumed to be electricity generation and heat for energy from waste, compost / fertiliser production for composting and a mix of electricity and digestate for anaerobic digestion.
  - Closed loop recycling offsets the raw material extraction and refining stage for the material recycled
  - Open loop recycling offsets the raw material extraction and refining stage for the material that is substituted

The following stages are **excluded** from the system:

- Production of finished product (e.g. manufacture of bottles or cans).
- Packing and filling
- Distribution
- Use

The rationale behind excluding these emissions is that they are independent of the disposal option chosen for the material and have no bearing on the relative environmental impacts of disposal options. Taking this approach simplifies the analysis and allows for a wider and more straightforward application of closed-loop recycling, which is defined here as material to material rather than product to product. This is a more realistic representation of the UK's recycling systems, which typically produce as output a raw material ready to be input into a manufacturing process rather than a finished consumer product.

System boundaries for Carbon WARM



2.5 Emissions from foreground processes

2.5.1 TRANSPORT EMISSIONS

Only transport emissions associated with collection and transport for reprocessing are included explicitly in this model. Transport emissions associated with material extraction, refining and manufacture are already accounted for in the materials factors of the BEIS Greenhouse gas reporting conversion factors 2019, while those associated with distribution, retail and use of the finished product are excluded from the scope.

Factors for emissions from disposal transport are taken from the annual BEIS Greenhouse Gas reporting conversion factors for 2019. For more detail see Hill *et al*. (2019). Key assumptions for transport distances are shown in Table 3 below.

Table 3: Transport assumptions used in calculating disposal emissions

Material / destination	One way distance	Mode of transport	Source
Initial collection to transfer station or MRF	25km	Refuse collection vehicle, average load 12.9 tonnes	ERM (2008)
Onward transport to			
Landfill	10 km	Refuse collection vehicle, average load 12.9 tonnes	ERM (2008)
MSW incinerator	10 km		ERM (2008)
Composting	10 km		Assumed comparable to landfill
Recycling / reprocessing	100km	Bulk transport	Fisher (2006)

2.5.2 LANDFILL

Landfill emissions are critical to Carbon WARM as all figures for waste management options are presented as a cost or saving relative to disposal to landfill. All landfill emissions were supplied directly by DEFRA based on the MELMod landfill emissions model and are the same as the gas emissions factors supplied by BEIS.

2.5.3 RECYCLING

Emissions from recycling processes were taken from a range of sources, based on the approach used for the calculation of the Closed-Loop Source and Open-Loop Source factors in the Material Use sector of the BEIS GHG Factors. Sources used include the Ecoinvent LCA database, lifecycle data from industry bodies and DEFRA and WRAP reports examining the impacts of waste treatment options. For a list of references see the BEIS GHG methodology (Hill, et al., 2019).

When calculating the factors, closed loop recycling emissions are assumed to offset purchase of the same material (the closed loop is material to material, not product to product). Where open loop recycling is calculated, emissions are assumed to offset another material (e.g. open loop recycling of plastics is assumed to offset wood, as garden furniture and other wood substitutes are a common end fate of open loop recycled plastics).

2.5.4 ENERGY FROM WASTE

Energy from Waste emissions factors were sourced directly from the Ecoinvent lifecycle database, which contains municipal incineration emissions for a wide range of materials and products.

Energy generation from energy from waste (used to calculate electricity generation) has been calculated using the lower heating value of the fuels and an assumed efficiency of 22% for EfW technologies. An additional 4% has been credited for generation of heat. Both these figures are derived from Tolvik (2019) and take account the calorific value of waste, aggregate UK EfW performance and the electricity only / CHP mix.

2.5.5 ANAEROBIC DIGESTION

Anaerobic digestion emissions are assumed to be 1.95% of generated methane (based on Liebetrau, J. *et al.* 2017). There is considerable uncertainty around this estimate, with fugitive methane emissions varying between facilities. Methane generation and conversion to electricity is based on performance data supplied by ADBA.

Electricity generation is based on the calorific value of the methane, assuming 40% generation efficiency and adjusting for 10% parasitic load, based on ADBA data. Use of nutrients from anaerobic digestion is assumed to offset nitrate fertiliser, consistent with its predominant use as an agricultural soil improver.

2.5.6 COMPOSTING

Composting process losses and emissions are based on published lifecycle inventories (Boldrin *et al.* 2010). Use of the outputs of the composting process as soil improver is assumed to offset nitrate, phosphate and potash fertilisers (87%) and peat (13%). Figures are based on end-market analysis from WRAP (2008) *Realising the value of organic waste*, with agricultural use assumed to offset use of fertiliser and horticultural use offsetting peat.

The methodology used in producing this metric will tend to understate the benefits of composting. In order to adopt a generic approach that can be applied to all materials with minimal change, the model takes no account of carbon sequestration, or of benefits that do not offset the use of an existing product (i.e. peat based soil improver or fertiliser). The role of compost in maintaining soil quality and organic content, an in displacing the need for manure from (highly carbon intensive) ruminant livestock is not quantified in this model and should not be underestimated. Nicholson et al (2016) and Martinez-Blanco et al (2013) recognise that the use of compost has a range of proven benefits, including pest and disease suppression, soil workability, biodiversity, crop nutritional quality, and crop yield. Many of these could also contribute to reduced greenhouse gas emissions. However, although proven these benefits are not quantified and therefore are not captured in life cycle assessment.

Boldrin *et al* (2009) suggest that between 2% and 14% of carbon input in compost may still be present after 100 years, and note that, since carbon content in compost is in the order 56–386 kg/tonne, 1–54 kg C tonnes of carbon could be bound in soil, equivalent to 4–198 kg of CO_2e per tonne of compost.

2.6 Background processes

2.6.1 EXTRACTION AND REFINING OF RAW MATERIAL

CO_2e emissions for extraction and refining of virgin materials are sourced from the annual BEIS Greenhouse Gas reporting conversion factors for 2019. Where the BEIS factors report on specific products made from a material, the factors associated with the raw material extraction and refining have been extracted from the BEIS model and used instead – this applies to steel and aluminium cans.

Emissions from extraction and refining of raw material are used to account for the benefits of recycling, where recycling of a material reduces the need to extract and refine more raw virgin materials. The extraction emissions are not added as a burden to disposal solutions (landfill and EfW) but are included as a credit to recycling approaches (i.e. the CO_2e associated with a raw material is subtracted from the recycling emissions). Note that the raw material is the one that the recycled material substitutes for – this will be the same material in the case of closed loop recycling and a different material in the case of open loop recycling (e.g. if plastics are recycled into panelling that replaces wood).

2.6.2 GENERATION OF ENERGY BY ENERGY FROM WASTE AND ANAEROBIC DIGESTION

Treatment methods that generate electricity for the grid are credited with saving the emissions necessary to generate the same amount of electricity. The factor used (0.292kg / kWh) is based on the BEIS UK grid average, including well to tank (fuel extraction for generation) emissions but excluding transmission losses, for 2019.

For heat from energy from waste, the credit for avoided emissions is based on BEIS (2019) factors for onsite heat and steam.

In these factors, a credit for generating energy is added for energy from waste and for anaerobic digestion. The MELMod figures that quantify landfill emissions already include the impact of electricity generated at the cap.

2.6.3 Benefits of soil nutrients produced from composting and anaerobic digestion

Treatment methods that produce beneficial soil additives (compost and digestate) are credited with an emission saving based on the quantity of fertiliser that would be offset. Where outputs are used in agricultural applications, they are taken to offset a quantity of nitrate, phosphate and potash fertilisers equal to the readily available nutrients in the output produced from a tonne of input material. Where outputs (compost only) are used in horticultural applications, they are taken to offset one tonne of peat-based soil improver. The impacts of producing a tonne of fertiliser are based on calculations conducted by WRAP (WRAP 2019, unpublished) which utilise data on fertilizer production and use from Brentrup et al (2016) and Fertilizers Europe. The impacts of producing a tonne of peat-based compost are taken from Boldrin et al (2010).

Compost, digestate and fertiliser emissions are restricted to production emissions only – use phase emissions (fuel use in application and nitrous oxide emissions from soil) are outside the scope of this metric.

2.7 Emissions from waste treatment options

The formulae below summarise the calculations for emissions factors for each element of the Metric.

Landfill

$$\square_{\square\square} = \square_{\square} + \square_{\square}$$

EfW

$$F_{Wi} = W_i + T_w - E_{Wi}$$

Recycling (open or closed loop)

$$F_{Ri} = R_i + T_w - P_j$$

Anaerobic digestion Composting

$$F_{Ai} = A_i + T_A - E_{Ai} - N_{Ai}$$

$$F_{Ci} = C_i + T_C - N_{Ci}$$

Where:

F – Unadjusted emission factor for waste treatment method (L, W, R, A, C) and material (i) L – Landfill emission for material

W – EfW emission

R – Recycling emission

A – Anaerobic digestion emission C

– Composting emission

T – Transport emissions for a given treatment method

E – Emissions from alternative generation of energy from a given material / treatment method (grid average)

N – Emissions from alternative (nitrate) fertilizer production offset by composting or AD.

i – Material at end of life

j – Material substituted by recycled product (for closed loop recycling i = j)

2.8 Non-standard methodology (or methodological problems)

2.8.1 **GLASS**

The report used for the production of the closed loop recycling factor for glass (Enviros 2003) includes remelt in the reported emissions factor. As such it also includes packaging forming emissions and is therefore a product-to-product factor. This does not create a significant issue however, as the remelt and forming emissions will be similar for both virgin material and recycled glass. Thus, when comparing closed loop recycling with other options, any additional credit given for recycling (due to forming being taken into account) will also be added to the emissions from the recycling process itself, so that the forming emissions cancel out.

2.8.2 TEXTILES

The majority of textiles collected via local authority recycling collections are destined for reuse. In addition, textile recycling is rarely truly closed loop and no LCA studies of 100% closed loop recycling could be located. The approach used varied from the standard in that was based on a weighted average of two scenarios – 70% reuse and 30% recycling[4].

The recycling assumptions were based on analysis of a scenario (the “downcycling scenario”) from a Masters thesis (Spathas 2017). This scenario is based on a virgin textiles mix of 40% cotton and 60% polyester, which is compared with a recycled equivalent consisting of 80% recycled and 20% virgin materials. This was converted to an emissions factor for 1 tonne of 100% recycled yarn by subtracting 20% of the emissions from the virgin equivalent and dividing the result by 80%. The results were then normalised to the appropriate reference flow of 1 tonne of materials collected for recycling.

The re-use scenario is a product to product (rather than material to material) analysis, and used different data on the CO_2e impact of the product offset (Beton et al 2009), with one tonne of reused clothing assumed to offset 280kg of new clothing purchases (Stevenson and Gmitrowitz 2013). The average lifetimes of new clothing (3.31 years) and second-hand clothing (5.31 years) were also accounted for (Langley et al 2013) and used to weight the end of life (landfill) emissions. An estimated 10% wastage was also figured into the reuse scenario, with this material assumed to offset paper towel (i.e. recycling to wipers).

2.9 Data sources

Data have been taken from a range of sources, including lifecycle assessment databases, published figures from trade associations, WRAP and DEFRA publications and third party data from sources including academic journals and the International Panel on Climate Change. Data on several waste management options has been taken from Ecoinvent and WRATE.

2.10 Data quality

All data used has been assessed against the following quality standard.

Table 4: Quality standard for data used in Carbon WARM

Time related coverage	Data should be less than five years old	Ideally, data should represent the year of the study. However, data for many material profiles is updated on an occasional basis or is a one-off value.
Geographical coverage	Data should be representative of products and technologies in England / UK	Many datasets reflect European average production. Ecoinvent reflects mostly Swiss or German production technologies.
Technology coverage	Data should represent the average technology mix for England / UK	A range of information is available, covering best in class, average or pending technology. Average is considered most

[4]*This split is an estimate, produced based on internal discussion with the Sustainable Clothing Action Plan team within WRAP. There is a lack of reliable data on the end fates of collected textiles.* WRAP’s (2016) *Textiles market situation report* estimates *that approximately 70% of textiles that remain in the UK are destined for reuse, but that the majority of textiles are exported (mostly to Africa and Eastern Europe). While the majority of these textiles will also be destined for reuse, the relative proportions of reuse, recycling and disposal are not known.*

		appropriate and has been used where available.
Precision / variance	No requirement	Many datasets provide average data with no discussion of the range. Many Ecoinvent profiles are based on a single data point. It is therefore not possible to identify variance.
Completeness	Datasets should be reviewed to ensure they cover all inputs and outputs pertaining to the lifecycle stage	
Representativeness	Data should represent UK conditions	See above data quality factors.
Consistency	Methodology should be applied consistently	Carbon WARM is based on the underlying methodology used for the BEIS GHG reporting factors. The model was externally reviewed and updated for consistency in 2016.
Reproducibility	An independent practitioner should be able to follow the same method and arrive at the same results	
Sources of data	Data will be derived from credible sources and databases	Public domain data have been used where possible and all data sources referenced. In some cases it has been necessary to use data from unpublished work or commercially sensitive data shared under a non-disclosure agreement.
Uncertainty of information		See above discussion of variance. Uncertainties will also arise from assumptions and setting of system boundaries.

2.11 Use of data below the quality standard

In many cases, material emissions inventories are updated on an occasional or periodic basis, while lifecycle inventory data for waste management processes is often based on European data and updated only infrequently. While every effort has been made to locate data that meet the standard set out above, in a range of cases it been necessary to utilise the best data available, despite not all quality criteria being met. The most commonly encountered data issues are age, geographical coverage and availability. Cases where the data quality criteria have not been met are outlined below. Each case has been classified as red (priority), amber or green (lower priority) based on the potential level of error and the likely significance of such an error on the results.

Table 5: Transport parameters below quality threshold

Reference	Data	Issue
Fisher, K. (2006) Impact of Energy from Waste and Recycling Policy on UK Greenhouse Gas Emissions, London: Defra	Typical distance travelled (100km) between MRF and reprocessor	Data are older than 5 years. Data do not account for current mix of UK and overseas reprocessing.
ERM (2008) Waste and Resources Assessment Tool for the Environment (WRATE) Version 1	Typical distance travelled (10km) between transfer and disposal	Data are older than 5 years. Some calculations assume onward travel by RCV.

Table 6: Food waste parameters below quality threshold

Reference	Data	Issue
Boldrin, A., Hartling, K., Laugen, M. and Christensen, T (2010) Environmental inventory modelling of the use of compost and peat in growth media preparation	Emissions factors for composting of food and garden wastes	Data are older than 5 years.
WRAP (2008) Realising the value of organic waste	Nutrient content of fertilisers	Data are older than 5 years.
WRAP (2010) The energy impact of waste management: recycling and energy from waste	Calorific value of food	Data are older than 5 years

Table 7: Garden waste parameters below quality threshold

Reference	Data	Issue
Boldrin., A., Hartling, K., Laugen, M. and Christensen, T (2010) Environmental inventory modelling of the use of compost and peat in growth media preparation	Emissions factors for composting of food and garden wastes	Data are older than 5 years.
WRAP (2010) Performance analysis of mixed food and garden waste collection schemes, p.3	Proportion of food and garden waste in mixed organics collections	Data are older than 5 years.
WRAP (2010) The energy impact of waste management: recycling and energy from waste	Calorific value of green waste	Data are older than 5 years

Table 8: Paper and card parameters below quality threshold

Reference	Data	Issue
Saori, S. and Bontinck, P.A. (2012) Streamlined LCA of Paper Supply Systems	Recycling impact	Data are older than 5 years

WRAP (2010) The energy impact of waste management: recycling and energy from waste	Calorific value of paper and card	Data are older than 5 years

Table 9: Glass parameters below quality threshold

Reference	Data	Issue
Enviros (2003) Glass Recycling - Life Cycle Carbon Dioxide Emissions, Sheffield: British Glass	Glass production and remelt emissions	Data are older than 5 years

Table 10: Aluminium parameters below quality threshold

Reference	Data	Issue
EAA (2013) *Environmental profile report for the European Aluminium industry*	Yield rate for aluminium scrap reprocessing	Data are older than 5 years. Note: all other data on aluminium are taken from 2018 update.

Table 11: Textiles parameters below quality threshold

Reference	Data	Issue
WRAP (2010) The energy impact of waste management: recycling and energy from waste	Calorific value of textiles	Data are older than 5 years
Spathas, T (2017) The environmental performance of high value recycling for the fashion industry	"Closed loop" recycling scenario	Data are from a Master's Thesis.
Beton, E. *et al* (2009) *Environmental improvement potential of textiles (IMPRO-Textiles)*	Emissions from clothing production (reuse scenario)	Data are older than 5 years
Stevenson, A. and Gmitrowitz, E. (2013) *Study into consumer second-hand shopping behaviour to identify the re-use displacement effect*	Displacement effect of second-hand clothing	Data are older than 5 years.
Langley, E., Durkacz, S. and Tanase, S. (2013) *Clothing longevity and measuring active use*	Average life of clothing	Data are older than 5 years

Table 12: Plastics parameters below quality threshold

Reference	Data	Issue
Shonfield, P. (2008) LCA of management options for mixed waste plastics	Recycling and energy recovery impacts	Data are older than 5 years
WRAP (2010) The energy impact of waste management: recycling and energy from waste	Calorific value of plastics	Data are older than 5 years
Plastics Europe (2014) Plastics Europe Ecoprofiles	GHG impacts of plastics production	Data are older than 5 years

Table 13: Wood parameters below quality threshold

Reference	Data	Issue
Wilson,J. (2010) "Life-cycle inventory of particleboard in terms of resources, emissions, energy and carbon", Wood and Fiber Science	Emissions from production of particleboard	Data are older than 5 years
WRAP (2010) The energy impact of waste management: recycling and energy from waste	Calorific value of wood	Data are older than 5 years

3.0 *Results*

Table 14 and Table 15 below show the calculated values for each material / waste management combination. Table 14 shows these results as a footprint (see above for details on scope and boundaries), while Table 15 shows the difference between each approach and landfill. In these tables, the value represents a carbon emission, while negative values represent a carbon saving.

Table 14: Carbon WARM, unnormalized values (kg.CO_2e/tonne)

	Closed loop recycling	Open Loop recycling	Energy from Waste	Anaerobic digestion	Compost used in horticulture	Compost used in agriculture	Landfill
Food	NA	NA	-37	-78	-44	16	627
Garden	NA	NA	-77	-78	-15	86	579
Food and garden	NA	NA	-70	-78	-24	67	592
Paper and board	-104	NA	-218	NA	NA	NA	1042
Steel	-1062	NA	19	NA	NA	NA	9
Aluminium	-7469	NA	24	NA	NA	NA	9
Mixed (cans)	-3368	NA	21	NA	NA	NA	9
Glass	-326	33	8	NA	NA	NA	9
Textiles	-14315	NA	438	NA	NA	NA	445
Dense plastics[5]	-590	205	1691	NA	NA	NA	9
Film[5]	-532	205	1475	NA	NA	NA	9
Wood	-477	NA	-268	NA	NA	NA	828

Table 15 Carbon WARM, normalized vs landfill (kg.CO_2e/tonne)

	Closed loop recycling	Open Loop recycling	Energy from Waste	Anaerobic digestion	Compost used in horticulture	Compost used in agriculture	Landfill
Food	NA	NA	-664	-705	-671	-611	0
Garden	NA	NA	-656	-657	-594	-493	0
Food and garden	NA	NA	-662	-670	-616	-525	0
Paper and board	-1,146	NA	-1,260	NA	NA	NA	0
Steel	-1,071	NA	10	NA	NA	NA	0
Aluminium	-7,478	NA	15	NA	NA	NA	0
Mixed (cans)	-3,377	NA	12	NA	NA	NA	0
Glass	-335	24	-1	NA	NA	NA	0
Textiles	-14,760	NA	-7	NA	NA	NA	0
Dense plastics	-599	196	1,682	NA	NA	NA	0
Film	-541	196	1,466	NA	NA	NA	0
Wood	-1,306	NA	-1,096	NA	NA	NA	0

[5] Due to concerns around the reliability of the heating value of plastics (the figures rely on non-peer-reviewed publications with few corroborating sources), a simple sensitivity analysis was conducted by raising and lowering the LHV by 25%. This produced an (unnormalized) range of 1,519-1,863 kg.CO2e/t for dense plastics and 1,250-1,701 kg.CO2e/t for plastic film.

4.0 *Conclusions*

This document has set out the methodology and calculated values for Carbon WARM, a tool to allow monitoring and evaluation of the impacts of waste management in England in terms of its greenhouse gas emissions impact, measured as carbon dioxide equivalent (CO_2e), as a supplement to traditional weight-based monitoring.

As noted in the methodology, the following caveats should be observed while using Carbon WARM:

1) The data contain a significant level of uncertainty. Results are based on the best available published Lifecyle Assessment data, but these assessments themselves are inevitably subject to a degree of uncertainty. In addition, production of the metric has required the combining of LCA outputs from a range of studies, some with different scopes, system boundaries and functional units. While every attempt has been made to reconcile these issues, such manipulation increases the potential for error. The results should be regarded as indicative of the relative impacts of waste treatment options, rather than as a precise carbon footprint.
2) Data are indicative of **average** performance. Carbon WARM attempts to provide an estimate of the average GHG impact of a given treatment option for a given material. It does not take account of differences in performance between different facilities, or of other activities (e.g. additional sorting requirements, or variations in transport emissions according to site location). In cases where the metric values are relatively close (e.g. within approximately 100 kg/tonne) it is likely that individual differences will be more important than differences in the values given by the metric.
3) Carbon WARM should not replace or overrule the waste hierarchy. Without a full lifecycle assessment covering a suitable range of impact categories, the Waste Hierarchy should be regarded as a more robust guide to the integrated environmental impact of a waste management approach. The metric is intended to aid decision making and impact evaluation in terms of greenhouse gas emissions. There are critical areas of impact (e.g. air quality, water quality, nitrate emissions, human and eco-toxicity, resource depletion etc.) that the metric does not capture.
4) Carbon WARM can be used to model many scenarios, but not all scenarios will be realistic or even physically possible. Care should be taken not to model scenarios that produce a spurious conclusion. For example, when modelling energy from waste it is important to take into the account the fuel requirements (and available feedstock) of an EfW plant, rather than cherry picking based purely on the Metric scores.

With these caveats observed, Carbon WARM provides a tool that Government, local authorities and businesses can use to assess the greenhouse gas impacts of their waste management activities.

16. APPENDIX 1: MATERIAL SUBSTITUTION RATES FOR RECYCLING

Table 16: Materials substitution rates for recycling

Material	**Tonnes of primary material saved per tonne of input**	**References**
Aluminium cans and foil	0.925	EAA (2013) Environmental profile report for the European Aluminium industry, p. 58
Steel cans	0.916	Broadbent, C. (2016) "Steel's recyclability: demonstrating the benefits of recycling steel to achieve a circular economy", International Journal of Life Cycle Assessment, 21:1656:1665
Glass	0.95	http://www.gpi.org/recycling/glass- recycling-facts *"Recycled glass can be substituted for up to 95% of raw materials."*
Wood	1.11	Wilson,J. (2010) "Life-cycle inventory of particleboard in terms of resources, emissions, energy and carbon", Wood and Fiber Science, 42, pp. 90-106. *Return of over 1.0 is due to inclusion of additives (wax and urea-formaldehyde resin).*
Paper	0.833	No published value. Typical estimate based on a trip value of 6 (e.g. https://recyclenation.com/2017/06/how- many-times-can-recyclables-be-recycled/) using method in Baumann and Tillman (2004)
Board	0.93	Based on input of 1.08kg of board to manufacture of 1kg of Wellenstoff (FeFCO 2018)
Plastics (all polymers and formats)	0.665	Shonfield, P. (2008) LCA of Management Options for Mixed Waste Plastics, Banbury: WRAP, p. 25. *Scenario G recalculated to include mechanical recycling of film.*
Digestate (from food) replacing fertiliser as N	0.0054	WRAP (2016) *Field experiments for quality digestate and compost in agriculture.*
Compost replacing (N) fertiliser	From garden: 0 From food waste: 0.0013 From mixed: 0.0003	Compost nutrient content: http://www.wrap.org.uk/content/compost- calculator Input to compost output rate: Boldrin, A., Hartling, K., Laugen, M. and Christensen, T (2010) “Environmental inventory modelling of the use of compost

		and peat in growth media preparation", *Resources, Conservation and Recycling*, 54(12), 1250-1260
Compost replacing peat	From garden: 0.68 From food waste: 0.43 From mixed: 0.61	Boldrin, A., Hartling, K., Laugen, M. and Christensen, T (2010) "Environmental inventory modelling of the use of compost and peat in growth media preparation", *Resources, Conservation and Recycling*, 54(12), 1250-1260. *Assumes 1 tonne of finished compost replaces 1 tonne of peat-based growth medium.*
Textiles (recycling)	0.537	Spathas, T. (2017) The environmental performance of high value recycling for the fashion industry, p. 24. *Downcycling model weighted to remove virgin component of modelled output.*
Textiles (reuse)	0.28	Stevenson, A. and Gmitrowitz. E. (2013) *Study into consumer second-hand shopping behaviour to identify the re-use displacement effect,* Banbury: WRAP

17. APPENDIX 2: GREENHOUSE GAS CONVERSION FACTORS AND EMISSION SOURCES

Table 17: GHG conversion factors and emission sources

Industrial designation or common name	Chemical formula	Lifetime (years)	Radiative efficiency ($Wm^{-2}ppb^{-1}$)	GWP 100 (AR4)	Possible sources of emission
Carbon dioxide	CO_2	Variable*	1.4×10^{-5}	1	Combustion of fossil fuels
Methane	CH_4	12	3.7×10^{-4}	25	Decomposition of biodegradable material, enteric emissions
Nitrous oxide	NO_2	114	3.03×10^{-3}	298	Manure, soil management, agricultural residue burning, sewage
Sulphur hexafluoride	SF_6	3,200	0.52	22,800	Leakage from electricity substations, magnesium smelters, some consumer goods
HFC 134a (R134a refrigerant)	CH_2FCF_3	14	0.16	1,430	Substitution for ozone-depleting substances, refrigerant manufacture / leaks, aerosols, distribution of electricity
Dichlorodifluoro- methane CFC 12 (R12 refrigerant)	CCl_2F_2	100	0.32	10,900	
Difluoromono-chloromethane HCFC 22 (R22 refigerant)	$CHClF_2$	12	0.2	1,810	

* CO_2 is an extremely stable molecule and is removed from the atmosphere by organic or geological processes rather than by chemical breakdown. No single lifetime can be given for CO_2 because of the differences in time scales associated with the short (organic) and long (geologic) carbon cycles.

18. APPENDIX 3: PEER REVIEW STATEMENT

Technical peer review: Methodology for the Carbon Waste and Resources Metric (Carbon WARM)

An independent peer review was undertaken of the methodology of the *Carbon WARM* study, with the goal of ensuring that the methodology was robust, the underlying assumptions valid and that both the methodology and assumptions were clearly described in the methodology report.

The peer review was an iterative process which involved review of a series of drafts of the Methodology and the accompanying Excel spreadsheet. The first peer review took place in March 2019 and comprised the peer review of the draft methodology report and Excel model and an accompanying document setting out recommendations for future development and updating.
This was followed by a second peer review in June 2019, of the revised methodology report and Excel model. In addition, throughout the peer review process there was ongoing dialogue and discussion with the WRAP research team, which provided a good insight into the process of methodology and model development.

Throughout the process of developing the methodology and model, the WRAP research team have made clear efforts to provide transparency in the methodological and model development, and have taken a robust approach to the gathering and use of both sources and data, for example, through the use of the data quality standard, for the assessment of the data.

In summary, I am satisfied that the research presented in this report provides a transparent and robust basis to enable the monitoring and evaluation of the impacts of the Resources and Waste Strategy in England in terms of its Greenhouse Gas emissions impact, measured as carbon dioxide equivalent (CO_2e).

Dr Robin Curry
Queen's University Belfast
January 2021

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