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Quantification of greenhouse gas emissions from recycling and waste management activities in the UK

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Executive Summary

The UK under the Climate Change Act 2008 (CCA) has set domestic targets for reducing greenhouse gas (GHG) emissions and in June 2019, the independent Committee on Climate Change (CCC) committed the UK to achieving a significant reduction in emissions to reach Net Zero by 2050. In December 2020, the CCC published the Sixth Carbon Budget, which presents the Committee's recommendation on carbon emissions reduction, with a requirement to reduce greenhouse gas (GHG) emissions by 78% by 2035 relative to 1990 levels, or a 63% reduction from 2019 levels. Waste management has a role to play in achieving the reductions and up until now, attention has been mainly focused on methane emissions, which should be reduced by 35% by 2050 relative to 2010 levels. The priorities identified for the sector are the ban on landfilling biodegradable waste by 2025, increasing recycling to 70% by 2030, waste reduction across the whole value chain and carbon capture and storage (CCS) in all Energy from Waste (EfW) plants by 2050.

The Environmental Services Association (ESA), representing the UK waste management industry, wishes to lead the sector to align with the UK's Net Zero Agenda and reduce GHG emissions from the recycling and waste sector's activities by the earlier date of 2040. The latest emissions data for the sector, released by the Department for Business, Energy and Industrial Strategy (BEIS) for 2018, shows that the waste management sector appears to account for an average of 5% of the total UK GHG emissions, estimated to be 451.5 million tonnes of carbon dioxide equivalent $MtCO_2e$[1]. The BEIS data is calculated following the Inter-Panel Climate Change (IPCC) guidance, which accounts for waste management process emissions only and excludes energy consumption.

To understand the sector's emissions more fully, the ESA commissioned Ricardo to perform a quantification of the GHG emissions associated with the UK's recycling and waste management activities. Ricardo developed a baseline and undertook Net Zero scenario modelling for the sector's full GHG emissions reduction by 2040. This work supports the ESA to establish the current waste sector's baseline and the actions required to achieve the vision of Net Zero emissions from the UK recycling and waste management sector by 2040 at the latest. Ricardo applied the GHG Protocol Standard to the study and categorised emissions by 'direct', 'indirect' and 'avoided' emissions, including all GHG emissions associated with energy consumption and process emissions from the sector. Avoided emissions are recorded separately, representing the positive benefit associated with recycling waste into new products in place of new raw materials. The analysis looked at the waste industry process and transport emissions for England, Wales, Scotland and Northern Ireland for the baseline year 2018.

The project was divided into the following four key tasks:

- Task 1: Assess current GHG emissions of the recycling and waste management sector in UK. Calculate direct (scope 1), indirect (scope 2) and avoided emissions.
- Task 2: Identify potential emissions savings.
- Task 3: High-level assessment of GHG emissions reduction scenarios aligned to the UK Government 'Net Zero' Agenda.
- Task 4: Assess the ambition of the 2040 Net Zero targets.

The results in Task 1 reveal that the sector's activities generated a total of **35,764 ktCO2e** direct (scope 1) and indirect (scope 2) greenhouse gas emissions. Of that total, direct emissions accounted for **29,765 ktCO2e** and indirect emissions accounted for **5,999 ktCO2e.** Avoided emissions accounted for **49,904 ktCO2e**.

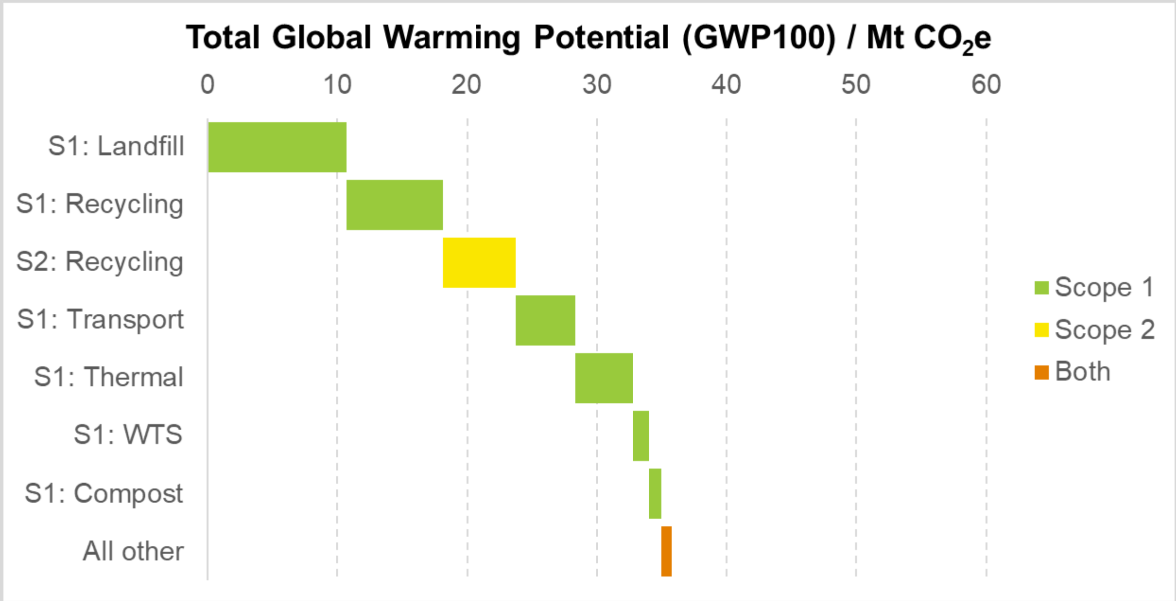
The direct emissions by activity type reveal that landfill is the single largest contributor, generating **10,701 ktCO2e** of scope 1 emissions**.** Sorting and transfer generated **8,979 ktCO2e,** transportation

[1] 2018 UK Greenhouse Gas Emissions, final figures National Statistics, from Department for Business, Energy & Industrial Strategies. Available at: https://www.gov.uk/government/statistics/final-uk-greenhouse-gas-emissions-national-statistics-1990-to-2018

4,581 ktCO2e, thermal treatment **4,474 ktCO2e,** composting **952 ktCO2e,** anaerobic digestion **69 ktCO2e** and mechanical biological treatment **10 ktCO2e.**

Of the indirect emissions by activity type, sorting and transfer generates the largest emissions of **5,739 ktCO2e**, followed by thermal treatment **105 ktCO2e**, anaerobic digestion **64 ktCO2e**, composting **47 ktCO2e**, landfill **24 ktCO2e** and mechanical biological treatment **21 ktCO2e**.

Figure i: Contribution of waste sector activities to global warming potential



Note: WTS refers to waste transfer stations

Combining direct and indirect (scope 1 and 2) emissions shows that the largest emissions come from the 'Sorting – Transfer' category, which includes all activities from transfer stations (WTS), material recovery facility activities and the recycling of the sorted materials. The sheer number of sorting and transfer facilities in the UK and the amount of energy used to sort and handle materials, is accounting for this level of emissions. Of this category, the single largest emitter is the recycling sector, which generated **13,033 ktCO2e** of GHG in 2018. This is principally due to the high temperature, energy-intensive processes involved in reprocessing collected materials, such as paper, aluminium cans and glass, into new 'raw' materials.

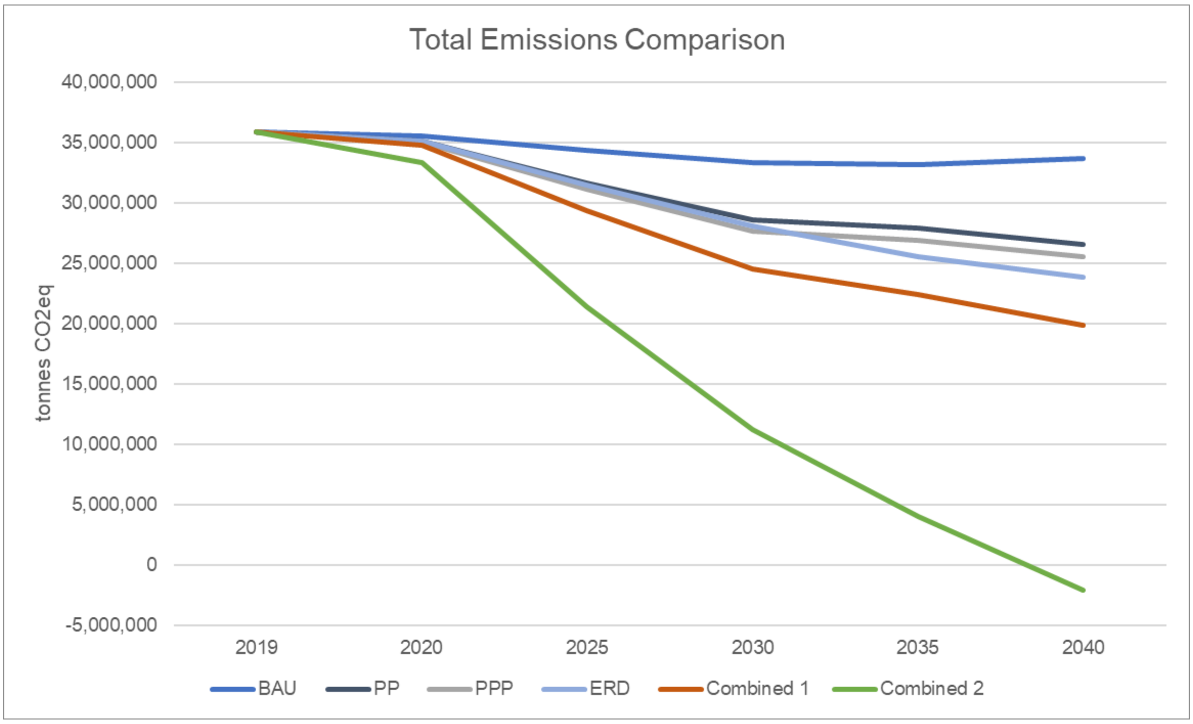
The second largest emitter of greenhouse gases comes from the landfilling of waste, which produces the release of predominantly methane fugitive emissions. By contrast, the thermal treatment of waste generated just under half of the emissions from landfill sites, with the emissions predominantly coming from fossil CO_2 emissions and N_2O from the incineration process. The transportation of waste was the third highest emitter and the principal sources of all emissions (with the exception of landfill) come from the use of fossil fuels and power bought in from the National Grid.

Having visibility on the largest emissions contributors and the sources of all emissions, provides a good understanding of possible routes and opportunities for potential savings and the feasibility of implementation. Tackling these emissions will be a priority for the UK's recycling and waste sector if the ESA's ambition for the sector to achieve Net Zero by 2040 is to be realised. The obvious potential for the largest savings in emissions would come from successful efforts to reduce waste arisings overall. Less waste requires less transportation, processing, treatment and disposal. This is evidenced by recycling being the largest carbon emitter. Adopting circular economy principles and enacting effective waste prevention is the key to reducing emissions from all processes.

Taking into account an increase in waste from household growth and assuming that fuel use remains the same, we can expect that recycling process emissions will increase as more waste is collected for recycling in the future. A key mitigation for this would involve implementing a transition away from fossil fuels to renewables for all waste management activities (transport, processing, treatment, etc). The speed at which measures could be taken to reduce emissions will depend on a number of factors including business planning, financial investment, process changes and target deadlines. Actions in response to Government policy are likely to see 'step-changes' as local authorities and businesses work towards meeting targets in specific target years e.g. meeting the policy for all households and appropriate businesses to have separate food waste collections by 2023.

A set of six scenarios were devised and modelled, encompassing a range of measures to meet targets alongside actions that individual organisations can take to reduce their own emissions. The scenarios assist the ESA with understanding the actions the UK recycling and waste management sector can take to achieve Net Zero by 2040. The analysis took account of the impact of the UK Government's Resources and Waste Strategy targets and other policy drivers, including the Sixth Carbon Budget, published in December 2020. In all scenarios, assumptions around waste growth, waste composition and electricity grid decarbonisation were embedded into the analyses and the relative performances of each scenario were compared against a 'business as usual' option. The analysis of the scenarios (section 5 of this report) reveals that the UK recycling and waste sector will continue to produce significant GHG emissions all the time that waste is being produced, managed and treated.

Figure ii: Performance of modelled scenarios



Key: BAU = Business as usual; PP = Planned progress; PPP = Planned progress plus; ERD = Enhanced reduction and diversion

The waste industry itself is expected to manage whatever waste the UK economy creates and it has little actual control over those arisings, as the biggest possible contribution to reducing emissions in the sector comes from reducing waste arisings. That said, there are several actions that could be taken to reduce emissions from the sector's activities and these are most effective and extensive in the modelled Combined Scenario 2 option.

Achieving Net Zero will involve reducing fossil fuel emissions and transitioning to renewable energy sources for transport and facility fuel use in addition to diverting waste away from landfill and thermal treatment to reuse and recycling. Electrification of vehicle fleet, plant and equipment will be key, however relying on the current grid decarbonisation trajectory (BEIS projection) will not be sufficient on its own to realise the savings of Combined Scenario 2. This is a reflection of the reality that sorting, digesting, composting and recycling materials is energy and therefore carbon intensive. As more material is diverted from disposal routes, recycling reprocessing facilities will continue to produce significant and growing energy demand emissions as more waste is collected and separated for recycling purposes. Therefore, switching to 'green tariff' renewable sources, be it through on-site or off-site (grid) generation sources will significantly reduce emissions from the processing of recyclable materials. However, these actions produce materials that significantly reduce manufacturing impacts in other sectors of the economy and by so doing, the sector is already significantly contributing to a Net Zero United Kingdom. Moreover, it is clear that through recycling, the sector is simultaneously playing a critical role in achieving a circular economy. Further research to understand in more detail how reprocessing facilities use energy and how that energy could be replaced with renewables, would shed more light on the potential to reduce emissions from these processes.

Alongside green energy, adopting an ambitious policy that brings forward the retrofitting of carbon capture and storage (CCS) units to existing energy from waste plants and ensures all new and planned facilities are fitted with CCS units as standard, is the single biggest gain the industry can influence to its own infrastructure. The earlier these units can be installed, the greater the impacts will be.

The scenarios presented in this report form the beginnings of a Net Zero roadmap, which could be developed in more detail. Understanding how emissions are generated from the various fuels and energy sources used, at each stage in the waste flow system would allow a more focussed approach to identifying and prioritising which mitigation measures to adopt. Finally, whilst not suggesting that the Greenhouse Gas Protocol Standards should be challenged, our analysis shows that the materials that the waste and recycling sector diverts already potentially more than offset all of its Scope 1 and 2 carbon emissions. The sector should absolutely make every effort it can to reduce its own emissions, but it would also be perfectly justified in pointing to the already significant contribution it makes to a Net Zero United Kingdom and a circular economy.

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Glossary

Abbrev	Definition
AD	Anaerobic Digestion
ADBA	Anaerobic Digestion and Biogas Association
ADEME	Agence de L'Environnement et de La Maitrise de L'Energie (Agency for Ecological Transition)
AFOLU	Agriculture, Forestry and Other Land Use
AR	Assessment Report
BAU	Business as Usual
BEIS	Department for Business Energy & Industrial Strategy
C & D	Construction and Demolition
C & I	Commercial and Industrial
CCA	Climate Change Act
CCC	The UK Committee on Climate Change
CCS	Carbon Capture and Storage
CEH	UK Centre for Ecology and Hydrology
CITEPA	Centre technique de référence en matière de pollution atmosphérique et de changement climatique (Technical Reference Centre for Air Pollution and Climate Change)
CNG	Compressed Natural Gas
Defra	Department for Environment, Food & Rural Affairs
DOC	Degradable Organic Carbon
DRANCO	Dry Anaerobic Composting
DRS	Deposit Return Scheme
DUKES	Digest of UK Energy Statistics
EfW	Energy from Waste
EpE	Entreprises pour l'Environnement
EPR	Extended Producer Responsibility
E-PRTR	European Pollutant Release and Transfer Register
ERD	Enhanced Reduction and Diversion
ESA	Environmental Services Association
ESP	Electrostatic Precipitator
ETS	Emissions Trading System
EU	European Union
EWC	European Waste Codes
FNADE	Fédération Nationale des Activités de la Dépollution et de l'Environnement (French National Federation of Pollution Control and Environmental Services)
FOD	First Order Decay

Abbrev	Definition
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GHGI	Greenhouse Gas Inventory
GWP	Global Warming Potential
HFC/PFC	Hydrofluorocarbon/ Perfluorinated compound
HWI	Hazardous Waste Incineration
IPCC	Intergovernmental Panel on Climate Change
IVC	In-Vessel Composting
LACW	Local Authority Collected Waste
LCA	Lifecycle Assessment
LULUCF	Land use, land use change and forestry
MBT	Mechanical Biological Treatment
MODECOM	Mode de caractérisation des déchets ménagers et assimilés (Characterisation method for household and similar waste)
MSW	Municipal Solid Waste
MSWI	Municipal Solid Waste Incinerator
$MtCO_2e$	Millions of tonnes of carbon dioxide equivalents
NAEI	National Atmospheric Emissions Inventory
NCV	Net Calorific Value
NNFCC	National Non-Food Crops Centre
NRW	Natural Resources Wales
OMINEA	Organisation et méthodes des inventaires nationaux des émissions atmosphériques en France (Organisation and methods of national inventories of atmospheric emissions in France)
OWC	Open Windrow Composting
PE	Polyethylene
PP	Planned Progress
PPP	Planned Progress Plus
RDF	Refuse Derived Fuel
SCR	Selective Catalytic Reduction
SEPA	Scottish Environment Protection Agency
SNCR	Selective Non-Catalytic Reduction
SWDS	Solid Waste Disposal Sites
UK	United Kingdom
VGF	Vegetable, fruit and garden wastes
WDF	Waste Data Flow
WDI	Waste Data Interrogator

Abbrev	Definition
WEEE	Waste Electrical and Electronic Equipment
WRAP	Waste and Resources Action Programme
WRATE	Waste and Resources Assessment Tool for the Environment
ZWS	Zero Waste Scotland

1 Introduction

The UK under the Climate Change Act 2008 (CCA) has set domestic targets for reducing greenhouse gas (GHG) emissions. In June 2019, following the Intergovernmental Panel on Climate Change (IPCC)'s Special Report on Global Warming of 1.5°C[2] and advice from the independent Committee on Climate Change, the CCA committed the UK to achieving a 100% reduction in emissions (to net zero) by 2050. The Special Report on Global Warming of 1.5°C emphasised the importance of limiting global warming to 1.5°C and the benefits of avoiding an increase up to 2°C or higher and outlined the pathways to achieve this. In the report, it is stated that *"in model pathways with no or limited overshoot of 1.5°C, global net anthropogenic CO_2 emissions decline by about 45% from 2010 levels, by reaching net zero around 2050*", thus motivating governments and policymakers to pledge to achieve net zero emissions by 2050. The role of waste management was mainly focused on methane emissions, which, to achieve the pathway mentioned above, should be reduced by 35% by 2050 relative to 2010 levels.

In December 2020, the Climate Change Committee published the Sixth Carbon Budget, which describes the UK's path to net zero[3]. The Budget presents the Committee's recommendation on carbon emissions reduction, with a requirement to reduce greenhouse gas (GHG) emissions by 78% by 2035 relative to 1990, or 63% reduction from 2019. It also sets the legal limit for UK net emissions of GHG over the years 2033-37 ('carbon budget') at 965 $MtCO_2e$. Reports that set out the approach to the Sixth Carbon Budget analysis, the emissions pathways and policy recommendations were published for each sector, including the waste sector. The policies that were identified as priorities for the sector are the ban on landfilling biodegradable waste by 2025, with recycling increasing to 70% by 2030, waste reduction across the whole value chain and carbon capture and storage (CCS) in all Energy from Waste (EfW) plants by 2050. These policies were modelled in six scenarios with different mixes and timings of measures to reduce waste sector emissions, to explore the best pathway to net zero.

The latest figures released by the Department for Business, Energy & Industrial Strategy (BEIS) for 2018, showed that UK emissions were estimated to be 451.5 million tonnes carbon dioxide equivalent MtCO2e[4]. The waste management sector appears in the last decade to have accounted for an average of 5% contribution to the total UK GHG emissions, as illustrated in Table 1. This contribution includes emissions from anaerobic digestion, composting, landfill, mechanical biological treatment (MBT) combined with composting or anaerobic digestion, incineration of general waste, chemical and clinical waste and sewage sludge, and wastewater treatment (sewage sludge decomposition). The emissions were calculated using waste tonnages retrieved from national datasets and emission factors from official sources, such as the National Atmospheric Emissions Inventory (NAEI) for landfill, the IPCC for composting, anaerobic digestion, MBT and incineration and the Environment Agency's Pollution Inventory and the Digest of UK Energy Statistics (DUKES) for incineration.

[2] IPCC, 2018: *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. In Press.

[3] https://www.theccc.org.uk/wp-content/uploads/2020/12/The-Sixth-Carbon-Budget-The-UKs-path-to-Net-Zero.pdf

[4] 2018 UK Greenhouse Gas Emissions, final figures National Statistics, from Department for Business, Energy & Industrial Strategies. Available at: https://www.gov.uk/government/statistics/final-uk-greenhouse-gas-emissions-national-statistics-1990-to-2018

Table 1: Estimated territorial GHG emissions by source category, UK 2008-2018 (in $MtCO_2e$)

Sector	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Energy supply	223.6	200.4	207.4	192.7	203.3	190.1	165.2	145.3	121.8	112.3	104.9
Business	103.9	91.5	94.3	86.1	88.0	88.8	86.8	85.2	81.7	81.1	79.0
Transport	131.4	126.4	124.5	122.4	121.4	120.0	121.3	123.5	125.9	126.1	124.4
Public	9.7	8.9	9.5	8.0	8.9	9.1	7.8	8.0	8.1	7.7	8.0
Residential	81.3	78.0	87.5	70.1	76.6	77.5	64.8	67.4	68.7	66.6	69.1
Agriculture	44.7	44.4	44.6	44.8	44.5	44.2	45.6	45.2	45.4	45.8	45.4
Industrial processes	18.6	11.9	12.7	11.3	10.8	13.0	13.0	12.7	10.6	11.0	10.2
LULUCF (†)	-8.9	-8.9	-9.3	-9.8	-9.6	-9.8	-9.7	-10.0	-9.9	-10.1	-10.3
Waste management	**38.3**	**34.2**	**29.7**	**27.6**	**26.1**	**23.2**	**21.1**	**20.7**	**20.1**	**20.4**	**20.7**
Grand Total	**642.7**	**586.8**	**600.9**	**553.2**	**570.1**	**556.2**	**516.0**	**497.9**	**472.4**	**461.0**	**451.5**
waste management % of contribution	**6%**	**6%**	**5%**	**5%**	**5%**	**4%**	**4%**	**4%**	**4%**	**4%**	**5%**

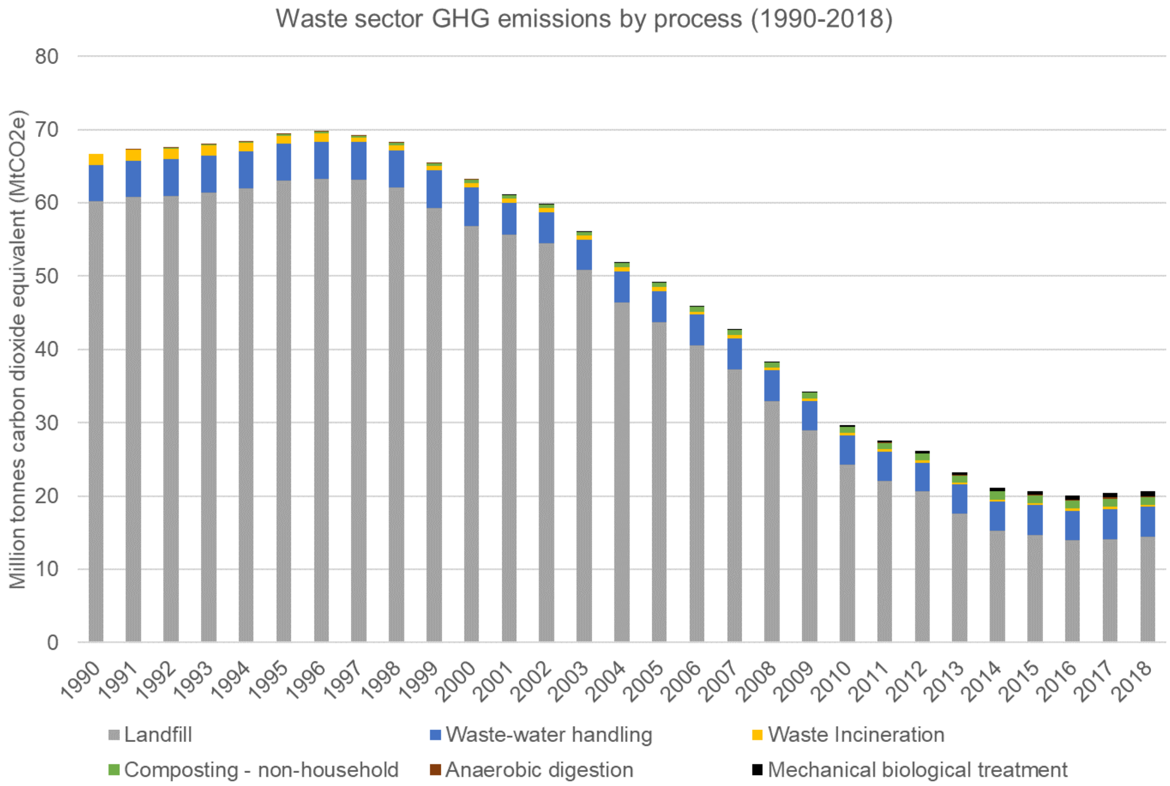
Source: BEIS, 2018 UK Greenhouse Gas Emissions report. (†) LULUCF = Land use, land use change and forestry

The waste sector had a 69% reduction since 1990 in GHG emissions, to 20.7 $MtCO_2e$, and a 46% reduction in the last decade. This reduction in emissions can be attributed to the landfill tax (which helped divert biodegradable waste away from landfill), improved methane capture rates, resources optimisation, implementation of environmental standards, circular economy initiatives and many other factors.

Figure 1 presents the progress of the GHG emissions emitted by the waste sector since 1990. The most significant reduction has occurred in the landfill emissions, which have been reduced from 60.2 $MtCO_2e$ to 14.4 $MtCO_2e$, a reduction of 76%.

The waste management sector emissions reported in Figure 1 account for process emissions from landfill, waste-water handling, waste incineration (excluding emissions from EfW), composting – non-household, anaerobic digestion, and mechanical biological treatment. These values do not account for the emissions associated to the energy used by the sector, as these emissions will be reported under the Energy and Transport sectors under Guidelines for National Greenhouse Gas Inventories (IPCC, 2006).

Figure 1: Waste sector GHG emissions by process (1990-2018)



The UK Greenhouse Gas Emissions Report from BEIS is compiled in accordance with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). The direct and indirect GHGs reported are estimated using methodologies which mostly correspond to the detailed sectoral Tier 2/3 methods in the IPCC Guidelines. It is important to highlight that the definitions of direct and indirect GHGs categories from the UK Greenhouse Report are different to the definitions offered by the GHG Protocol Standard introduced by the World Resource Institute and the World Business Council for Sustainable Development Greenhouse Gas Protocol Initiative (see section 3.2).

The above information provides a picture of the emissions arising from waste and wastewater management, however there had previously never been a study looking at the GHG emissions from the waste and recycling sector in the UK applying the GHG Protocol Standard methodology.

The UK Greenhouse Report values account for process emissions associated with landfill, composting, anaerobic digestion, wastewater handling, waste incineration and mechanical biological treatment. However, in this project and by applying the GHG Protocol Standard, Ricardo was able to calculate GHG emissions associated with all waste management activities, including all energy consumed through the activities associated with collecting, handling and processing recycling and waste materials. In addition to this, the sector's potential to avoid emissions elsewhere due to the efforts made through energy and material recovery was calculated and accounted for.

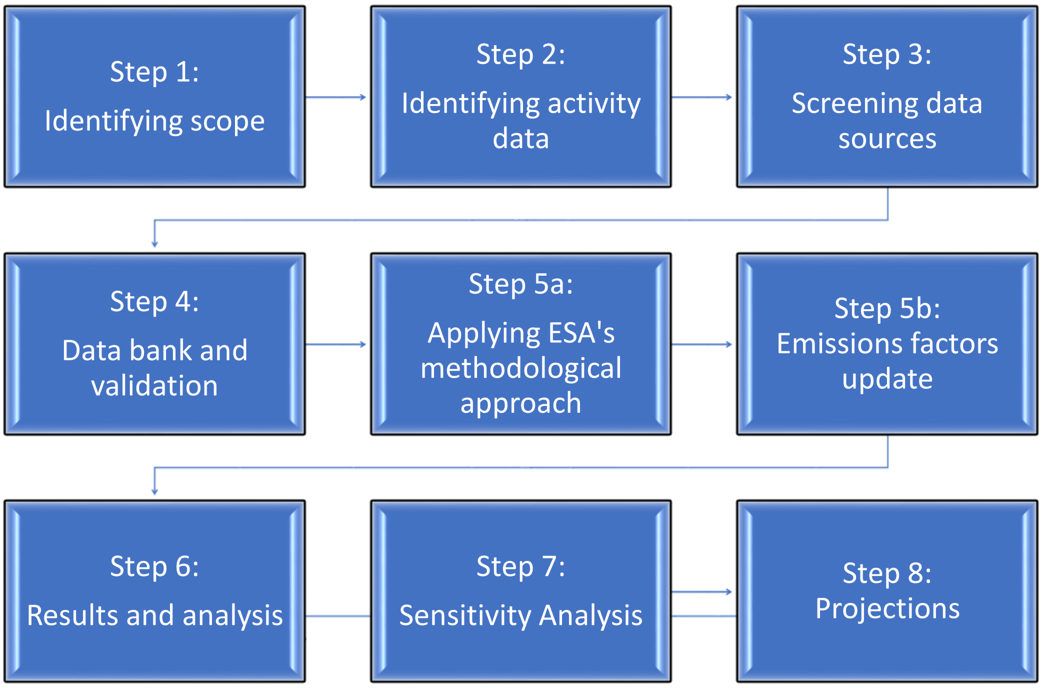
There arealso differences between the UK Greenhouse Report and the GHG Protocol Standard with regard to emissions calculations, based on each unique method applied, including elements such as the residual waste composition; this latter data set results from a background study performed by Ricardo and ESA's Steering Group.

2 Overview

The Environmental Services Association (ESA) commissioned Ricardo to quantify the current level of the direct, indirect, and avoided greenhouse gas emissions associated with the recycling and waste management sector in the UK. This work will help the ESA establish the current waste sector's baseline and the actions required to get the UK recycling and waste management sector to net-zero by 2040 at the latest.

In order to quantify the level of greenhouse gas emissions associated with the recycling and waste management sector, Ricardo took the steps depicted in Figure 2. ESA's first task, to evaluate the current GHG emissions associated with the UK recycling and waste management sector, was delivered using steps 1-6. Further analysis in step 6 delivered Task 2, while Tasks 3 and 4 were delivered during step 8.

Figure 2: Ricardo's calculation approach



The steps are described in detail in the sections below. The seventh step was added to provide a clearer picture of the impact of the global warming potential (GWP) used to calculate the emissions by switching from a 100-year horizon to a 20-year horizon. The main objective of this sensitivity was to analyse the impacts on global warming over a shorter timeframe. A GWP20 timescale is a scientifically recognised accounting method and allows comparison of the impact of certain greenhouse gases that have a short residency period in the atmosphere, principally methane.

3 Task 1: Current GHG emissions of the waste sector – Baseline GWP100

3.1 Step 1: Identifying Scope

The assessment considers the following waste categories:

- Municipal waste;
- Commercial waste;
- Industrial waste;
- Construction & Demolition waste;
- Hazardous waste;
- Clinical waste.

The recycling and waste management activities in scope are:

- Collection and transportation;
- Transfer stations;
- Mechanical pre-treatment (dismantling);
- Sorting, recycling and material recovery;
- Physicochemical treatment;
- Biological treatment (composting, in-vessel composting, anaerobic digestion);
- Landfilling;
- Thermal treatment;
- Mechanical biological treatment (MBT).

3.2 Step 2: Identifying Activity Data

In order to identify the activity data, Ricardo followed the GHG Protocol standard definitions for Direct, Indirect and Avoided emissions.[5]

- Direct GHG emissions occur from process or equipment owned or controlled by the entity. For example, emissions from combustion installations, landfills (fugitive emissions), company-owned vehicles, etc. In accordance with the GHG Protocol, direct emissions are also known as 'Scope 1' emissions. In the context of this exercise the 'entity' refers to the entire UK waste and recycling sector.
- Indirect GHG emissions are emissions that are consequences of the activities of the entity but that physically occur at sites or during operations owned or controlled by an organisation other than the reporting entity. In accordance with the GHG Protocol, indirect emissions can be distinguished into two categories known as scope 2 and scope 3 emissions. Indirect emissions resulting from imports of electricity, heat or steam not self-produced have to be accounted for as scope 2 emissions. For example, the electricity purchased from the grid. All other indirect emissions correspond to scope 3 emissions. For example, the emissions from vehicles not owned (or not controlled) by the entity.
- Avoided GHG emissions arise when an activity leads to avoiding emissions that would otherwise have occurred elsewhere. In ESA's case, materials that are diverted to reuse or recycling can offset the need to make new products from virgin materials, and so can be assigned a credit for the emissions avoided by not making those new products. Analogously, energy created from waste (notably via anaerobic digestion and incineration) can offset the need for that electricity and or heat to be generated from other sources, whose associated emissions are therefore avoided. It should be noted that in accordance with the GHG Protocol, avoided emissions cannot be discounted from total scope 1 and 2 emissions.

[5] https://ghgprotocol.org/sites/default/files/Waste%20Sector%20GHG%20Protocol_Version%205_October%202013_1_0.pdf

Ricardo identified the activity data from the recycling and waste management activities, following the GHG emissions definitions and their associated data categorisation.

3.3 Step 3: Screening Data Sources

The initial list of sources considered was:

- Waste Data Flow;
- The various statistical reports of the national environment agencies e.g. EA Waste Data Interrogator (WDI);
- Statistics from the national governments;
- CEH (UK Centre for Ecology and Hydrology);
- WRAP published datasets;
- The Digest of UK Energy Statistics ("DUKES");
- BEIS (including the Company Reporting factors that Ricardo supports);
- The Association for renewable energy and clean technology;
- Defra, UK Inventory Improvement Programme task: "AQ_IP_2016_9: Review of Mechanical Biological Treatment (MBT) processes" (Ricardo Energy & Environment, 2016). Reviewed and consolidated in 2018;
- The ESA's own data;
- Ricardo's own data.

For the first screening for activity, data the team looked at the following data sources:

- National Atmospheric Emissions Inventory (NAEI)[6];
- WRATE;
- Environment Agency's Waste Data Interrogator (WDI) for 2018[7];
- Scottish Environment Protection Agency's (SEPA) 'Waste from all Sources' database for 2018[8];
- Zero Waste Scotland (ZWS) organic recycling surveys for 2018;
- ZWS 'Carbon Metric: Technical Report' for 2018[9];
- Natural Resources Wales' Waste Data Interrogator for 2018[10];
- Northern Ireland's Local Authority waste collected dataset for 2018[11];
- NNFCC/ ADBA AD map;
- WRAP recycling reports[12];
- Tolvik Consulting's 'UK Energy from Waste Statistics 2018'[13];
- The Digest of UK Energy Statistics ("DUKES") for 2018[14];
- The Ecoinvent database[15];
- Articles from scientific literature.

After this screening, the team identified some data gaps, for which the ESA members were asked to provide information, so that the modelling was as close to the actual processes and technologies followed in the waste sector as possible.

The following sections present the activity data required for each process, the sources and the approach used under each scope. The waste tonnages for all the processes were calculated using data from the English and Welsh WDI and the waste databases of Scotland and Northern Ireland.

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6 https://naei.beis.gov.uk/
7 https://data.gov.uk/dataset/312ace0a-ff0a-4f6f-a7ea-f757164cc488/waste-data-interrogator-2018
8 https://www.sepa.org.uk/media/500275/waste-from-all-sources-waste-data-tables-2018.xlsx#:~:text=This%20application%20contains%20SEPA%20data%20%C2%A9%20Scottish%20Environment,use%20of%20data%20under%20an%20Open%20Government%20Licence
9 https://www.zerowastescotland.org.uk/sites/default/files/2017-18%20ZWS%20Carbon%20Metric%20Technical%20Report%20V02.00.pdf
10 https://naturalresourceswales.sharefile.eu/share/view/sae217ec1e71419c8/fo32643a-bb38-4031-b6a8-ae66a79b848e
11 https://www.daera-ni.gov.uk/publications/northern-ireland-local-authority-collected-municipal-waste-management-statistics-2018
12 http://www.wrap.org.uk/sites/files/wrap/asori%202015.pdf
13 https://www.tolvik.com/wp-content/uploads/2019/06/Tolvik-EfW-Statistics-2018-Report_July-2019-final-amended-version.pdf
14 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/904823/DUKES_2020_Chapter_6.pdf
15 https://www.ecoinvent.org/

3.3.1 Direct Emissions (Scope 1) and Indirect Emissions (Scope 2)

The project team looked into a number of data sources to retrieve the necessary metrics for this task. However, in many cases, the data was not satisfactory in terms of representativeness, either geographical or time related. In these cases, data provided by ESA members for the processes in their own facilities were extrapolated over facilities of the whole sector in two ways, forming an upper and lower level. The upper level was calculated by extrapolating ESA's member sample values to sector level facilities, while for the lower level the calculation was done by taken ESA's member sample values extrapolated to entire sector, assuming the fraction of facilities consuming a fuel was a percentage representative to the UK sector as a whole.

The values for energy consumption mentioned in the sections below can be found in Appendix A1. The waste data flow for calculation of process air emissions can be found in Appendix A1.

3.3.1.1 Transportation

The calculation of the emissions associated with the collection and haulage of waste required knowledge on the waste tonnages and the fuel consumption of the activity. The data sources for fuel consumption comprised of processes modelled on WRATE, Ricardo's in-house waste collection model background data and data provided by ESA members. These sources provided data on consumption of compressed natural gas (CNG), diesel, petrol, gas oil and marine gas oil. For CNG, the metric that was selected was the data provided by ESA members as reported from 56 sites, extrapolated over the entire sector's sites. The estimate for diesel was calculated using the waste tonnages and Ricardo's in-house waste collection model background data, while for gas oil we used the average consumption for collection and transportation processes on WRATE. Finally, for petrol and marine gas oil, the consumptions were extrapolated from ESA members data and the lower level was used.

3.3.1.2 Transfer Stations

For the transfer stations, our sources were the ESA members' data and WRATE process data. The upper level of the extrapolation was used for natural gas and diesel, while the lower was used for burning oil. For the consumption of gas oil within the facility, the data available on WRATE was used. The electricity consumption was also retrieved from WRATE.

3.3.1.3 Sorting

To capture the total amount of fuels used in sorting facilities, a combination of data from ESA members, WRATE, Ecoinvent and literature was used. Gas oil and electricity consumption data were retrieved from WRATE, while data for natural gas, fuel oil and propane consumption were retrieved from Ecoinvent. For diesel, the consumption was based on material recovery facilities (MRF) in Denmark[16].

3.3.1.4 Recycling

For recycling facilities, there were data available from Ecoinvent and the ESA members. The consumption of heavy fuel oil, light fuel oil, natural gas, propane, diesel and electricity was based on Ecoinvent data for the recycling processes of paper, aluminium, plastic and glass. For fuels with more than one datapoint available, an average was used.

3.3.1.5 Anaerobic Digestion

For anaerobic digestion, there were data available from WRATE, Ecoinvent and the ESA members. The diesel consumption was calculated using Ecoinvent data, as no data was provided by ESA members. For electricity, natural gas and gas oil consumption, data from the WRATE process 'Large Dry Anaerobic Composting (DRANCO)' was used, as data from an ESA member only referred to one facility. Heat consumption data was also used from the Ecoinvent database.

[16] Pressley, P.N., Levis, J.W., Damgaard, A., Barlaz, M.A. and DeCarolis, J.F., 2015. Analysis of material recovery facilities for use in life-cycle assessment. Waste Management, 35, pp.307-317.

3.3.1.6 Composting

For composting, there were data available on WRATE, scientific articles and by ESA members. For diesel and electricity, we used the upper estimate of the consumption provided by ESA members. For gas oil, the total consumption in both Open Windrow Composting (OWC) and In-Vessel Composting (IVC) processes was retrieved from WRATE. For the IVC process, an average between Agrivert's and Viridor's processes as modelled in WRATE was used.

3.3.1.7 MBT

For MBT, the diesel and fuel oil consumption were calculated based on data from one facility, as reported by an ESA member, while the electricity, gas oil and natural gas consumption were calculated based on WRATE process data, from which the 'MBT Anaerobic Digestion with Liquid Phase Composting (Hasse)' process was considered the most representative.

3.3.1.8 Landfill

For the consumption of natural gas, burning oil, gas oil, fuel oil and electricity we used the upper estimate of the data provided by ESA members. For diesel, the WRATE process data for the flexible landfill process had higher consumption than the data provided by ESA members, and was, thus, used, following a more conservative figure.

3.3.1.9 Thermal treatment

For the thermal treatment process there were data available in WRATE, Ecoinvent and from ESA members. For natural gas we used the value available on the Ecoinvent database, as it was higher than the ones provided by ESA members and a more conservative approach was preferred. For fuel oil, gas oil, diesel, other petroleum gas and electricity, the team used the values provided by the ESA members, which were higher than the values on WRATE.

3.3.1.10 Physicochemical treatment

For physicochemical treatment, the only data available was provided by ESA members. The value used in the calculations for gas oil and electricity was extrapolated over the whole sector facilities from four sites.

3.3.2 Avoided Emissions

The data sources used for calculating the Avoided Emissions were retrieved from the waste data input to direct and indirect emissions.

The EpE tool[17] quantifies avoided emissions by energy and material recovery. In order to calculate such emissions, the project team applied several assumptions in terms of yields and derived by-products benchmarks from validated sources which are explained in the following two sections.

3.3.2.1 Avoided Emissions – Energy Recovery

The EpE tool quantifies avoided emissions from the energy recovery from processes such as thermal treatment, waste derived fuel, anaerobic digestion, and landfill. To calculate these emissions, the project team applied the following assumptions listed in Table 2.

[17] http://www.epe-asso.org/en/protocol-quantification-greenhouse-gases-emissions-waste-management-activities-version-5-october-2013/

Table 2: Applied assumptions to the calculation of Avoided Emissions from energy recovery by waste management processes

Waste Management Treatments	Description	Value	Source
Anaerobic digestion	Biogas yield per tonne of food waste treated (m3/tonne)	100	Ecoinvent
Anaerobic digestion	Electricity yield per tonne of food waste treated (kWh/tonne)	1,319	Dukes 2019
Waste derived fuel	Net calorific value of RDF (kWh/tonne)	705	WRAP report[18]
Landfill	Electricity production from landfill (kWh/tonne)	109.29	WRATE, 2003
Thermal treatment	Electricity production from energy from waste facilities (kWh/tonne)	536	Tolvik Consulting, UK Energy from Waste Statistics-2018
Thermal treatment	Heat production from Energy from Waste Facilities (kWh/tonne)	97	Tolvik Consulting, UK Energy from Waste Statistics-2018

In the EpE tool, the Avoided Emissions result of the energy recovered from thermal treatment, landfill, anaerobic digestion and waste derived fuel treatments are calculated as gross with no discount from the Direct and Indirect emissions from such processes. Ricardo understands that even though the EpE tool aims to demonstrate the potential of the energy recovery from such waste management treatments, the final analysis should consider a full net emissions calculation.

3.3.2.2 Avoided Emissions – Material Recovery

The Avoided Emissions were calculated using emission factors from the Scottish Carbon Metric[9]. These emissions factors originate from life-cycle assessments performed on each waste material. In addition, the assumptions used for the substitution of nitrogen fertiliser from digestate and the yield from composting were taken from the Ecoinvent database as per Table 3. Ricardo will consider using a published English metric in the future when it becomes available.

Table 3: Applied assumptions to the calculation of Avoided Emissions from material recovery by waste management processes

Waste Management Treatments	Description	Value	Source
Anaerobic digestion	Digestate yield per tonne of food waste treated (tonne)	0.62	Ecoinvent
Composting	Yield of compost (tonne composted/tonne input)	0.5	Ecoinvent

[18] http://www.wrap.org.uk/sites/files/wrap/WDF_Classification_6P%20pdf.pdf

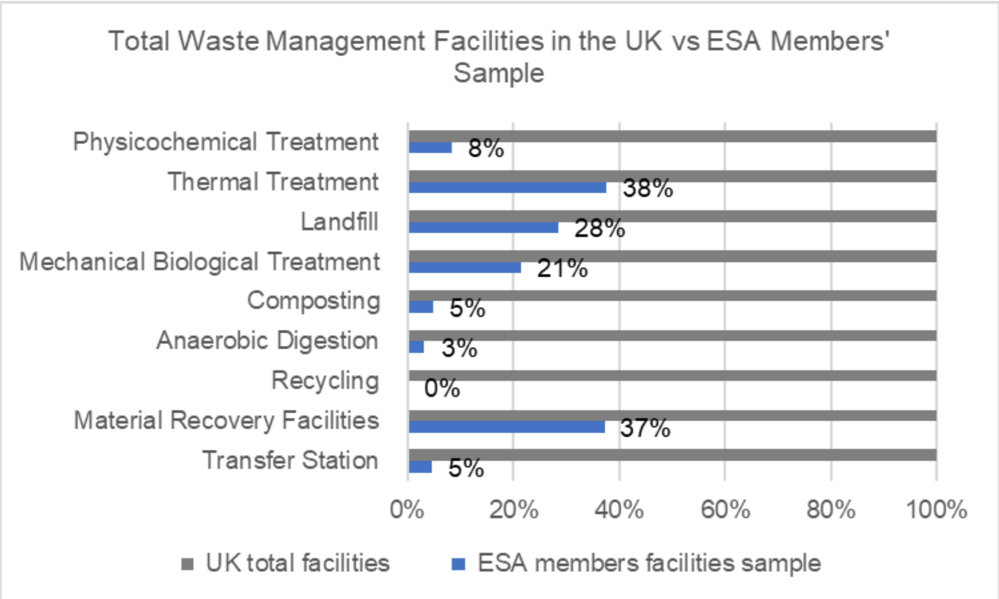
3.4 Step 4: Data Bank and Validation

The next step after identifying the relevant data sources and collecting the data, was to assess the quality of the selected values.

3.4.1 Data Quality

The assessment of the data quality was focused on the representativeness. The first issue that was identified was the representativeness of the data coming from the ESA member's sample. The data received were for a fraction of the facilities owned by all the ESA members, as shown in the graph below, which illustrates the total of waste management facilities in the UK and the ESA members' sample by percentage. For representative purposes where data was not available, Ricardo assumed that the sample data was representative of all the waste sector facilities in the UK, or just the fraction of the ESA members' sample. Even though we understand that each facility may vary, such assumptions were required to proceed with the calculations. Also, the main datasets used to retrieve waste tonnages processed in facilities (Environment Agency's WDI, SEPA's 'Waste from all Sources' database, Natural Resources Wales' WDI, Northern Ireland's Local Authority waste collected dataset) were using different assumptions and methodologies. While the English and Welsh WDIs provides granularity on EWC level, the SEPA dataset presents waste per waste material category, while the Northern Irish dataset had the least granularity of all. We performed a detailed analysis and review to minimise double-counting, but there may be some occasions where it was impossible to disaggregate the tonnages according to sources and destinations. Finally, some of the process data were retrieved from WRATE. We paid attention to select the most up-to-date processes and excluded outdated ones, but most of the data is more than 10 years old and may not be representative of all the facilities in the UK.

Figure 3: Proportion of waste management facilities covered with the sample provided by the ESA members



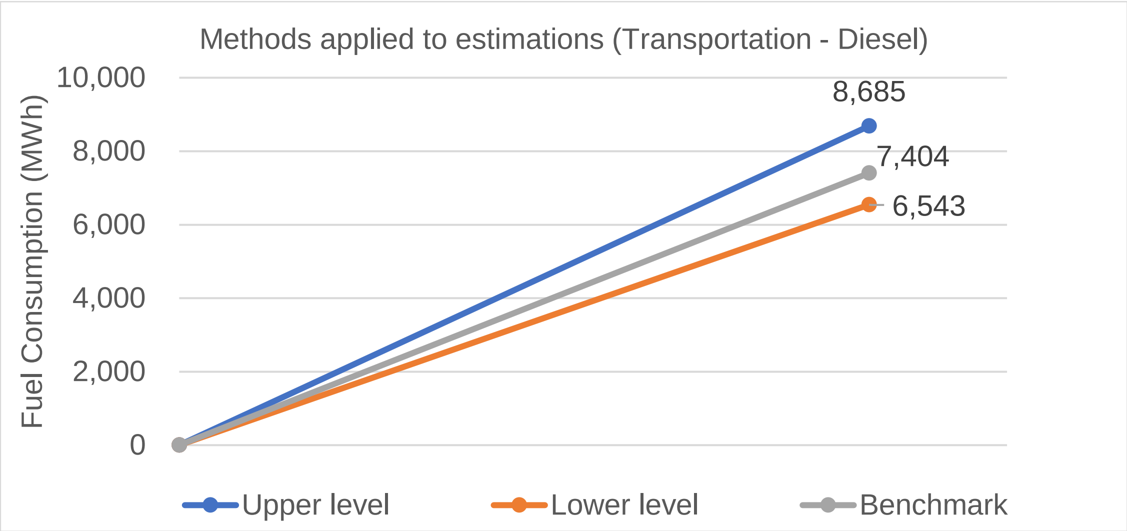
3.4.2 Comparability

We analysed tonnages, process data and emission factors from a range of data sources, as mentioned in section 3.3. The values obtained were compared against each other, but in most cases, they varied as the processes and the assumptions used in calculations are usually different. In addition, as this exercise has not been performed before in the UK in such detail, it was not possible to compare our results with officially published data.

3.4.3 Level of Certainty

The level of certainty varies, depending on the number of assumptions that were made in the calculations. To establish a certain level of confidence for the values used in the modelling process, those were compared to upper and lower levels of the data provided by the ESA members (see Figure 4).

Figure 4: Upper and lower level and benchmark for diesel consumption in transportation



3.5 Step 5a: Applying ESA's methodological approach

According to its website, the Entreprises pour l'Environnement (EpE)[17], created in 1992, "gathers around 50 French and international large companies from all sectors of the economy, who work together to better integrate environment into both their strategies and their day-to-day management". The Waste Sector GHG Protocol is intended to provide guidelines for calculating and reporting GHG emissions associated with a waste management service, over a specific time period (usually one year) and based on simple operational data. This tool has the "Built on GHG Protocol" label, which reassures users wanting to follow the GHG Protocol standard. A brief summary of the benefits and disadvantages of using this tool is presented below.

The benefits from using this tool are:

- It does not recommend one methodology more than the other because it is dependent on the source type.
- The Excel calculation tool gives the possibility to use either a measurement or a calculation approach to quantify emissions from each source type.
- The Protocol was originally developed to support waste managers or practitioners to prepare their annual GHG emissions inventories.
- This Protocol was built on the Greenhouse Gas Protocol Standard.

The disadvantages of the tool are:

- It contains outdated emission conversion factors.
- It does not include methodologies (carbon metrics) for calculation of emissions from some waste management activities.
- It excludes some waste management processes such as secondary reprocessing, autoclave, reuse/repair and waste prevention.

In order to calculate the GHG emissions of the waste and recycling sector, the Ricardo project team applied some updates to the EpE tool:

- A functionality was added to allow the user to select which IPCC Assessment Report (AR, 4 or 5) and time horizon for the GWP (20, 100 or 500), according to which different GWPs for the GHGs (CO_2, CH_4, N_2O, SF_6, NF_3, PFCs, HFCs) are used.
- All the emission factors were updated.

These updates were deemed sufficient for the purposes of this exercise. However, a fully functional, user-friendly EpE tool would require a number of other modifications, too. For example, the current amendments in English would need to be built into the tool's translation engine, so that users could see the modifications in French and potentially Spanish, too.

3.6 Step 5b: Emissions factors update

The project team created a dedicated document for the updated emissions factors that were used to model the emissions from the waste and recycling sector. The document outlines all the aspects that were considered, the methodologies that were examined and the agreed emission factor with the ESA working group for each waste treatment process. The emission factors used in the modelling for each process can be found in Appendix A2.

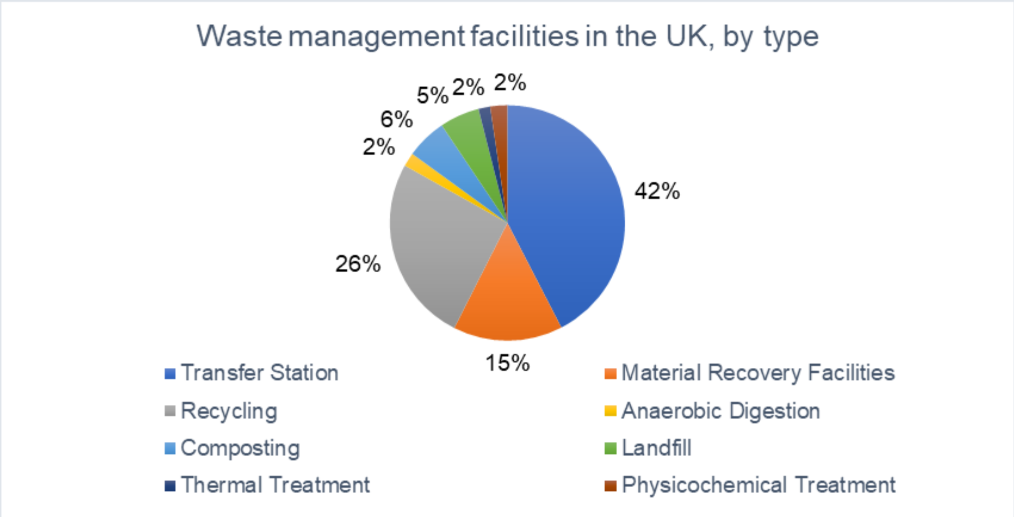
3.7 Step 6: Results and Analysis

Ricardo agreed with the ESA that 2018 should be the baseline year for this exercise, being the most recent year that full UK waste tonnage data was available. The results and analysis are synthesised to show the following: the percentage contribution of the waste management facilities in the UK by type, the tonnes of waste handled and the total GHG emissions from the UK waste sector resulting from direct (scope 1), indirect (scope 2) and avoided emissions (scope 3) calculations.

3.7.1 UK waste management facilities

Figure 5 illustrates the percentage distribution of the UK waste management facilities. From 6,761 waste management facilities registered, transfer stations represented 42% of the total, recycling 26%, material recovery facilities 15%, composting 6%, landfill 5%, thermal treatment 2%, physicochemical treatment 2%, and anaerobic digestion 2%.

Figure 5: Number of waste management facilities in the UK, by type

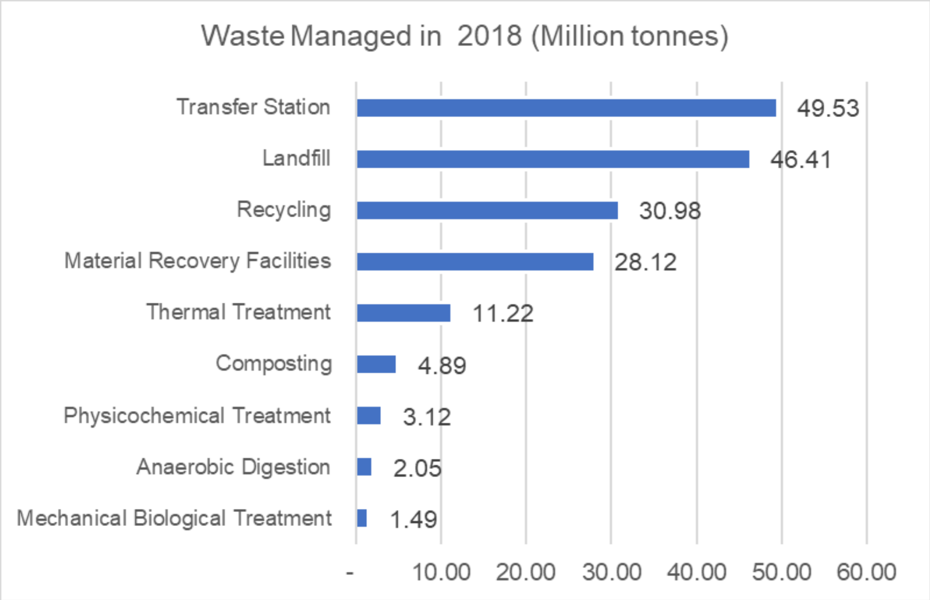


3.7.2 Waste tonnages

The waste tonnages analysis is based on the waste tonnages input to each waste management facilities. The inputs values are illustrated in Figure 6 and 7 with the aim to note on the consequential impact on waste management activities further in this report and their associated GHG emissions assessment by facilities type.

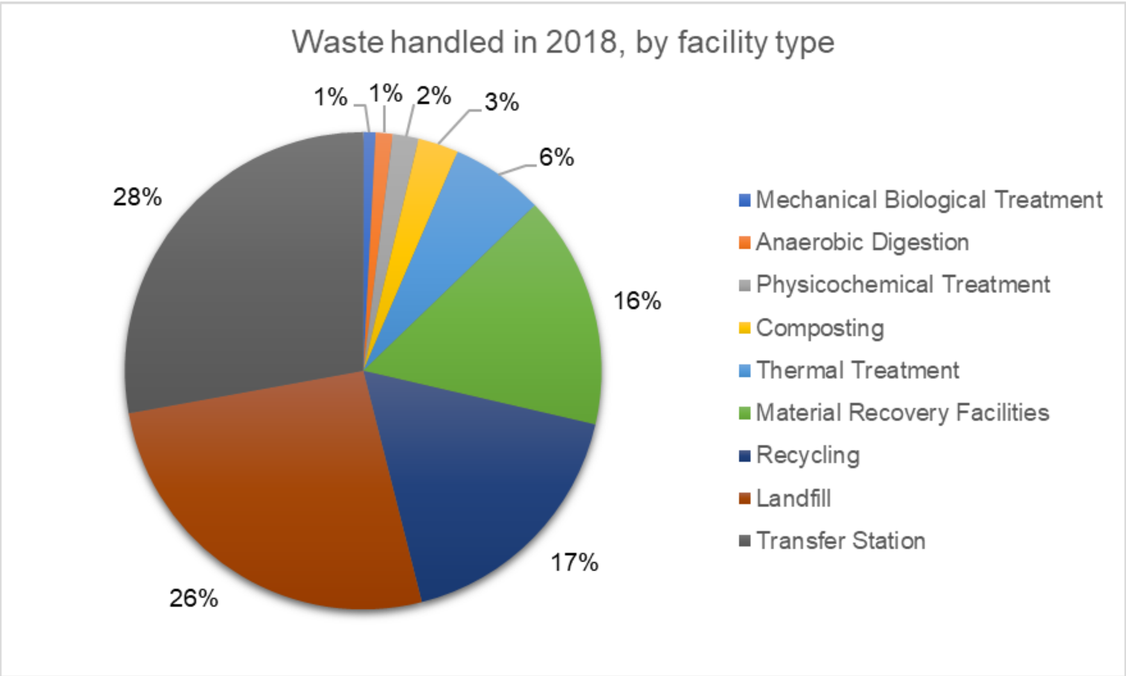
Figure 6 presents the waste tonnages input for each facility type. The largest amount of waste is managed in transfer stations, as the majority of the waste is directed to transfer stations after collections and before being sent to a waste management facility. The tonnage in recycling is higher than that for MRFs, as some materials are directly delivered to the reprocesses.

Figure 6: Waste managed inputs by facility type in the UK in 2018, in million tonnes



The percentage contribution by waste management type in 2018 is illustrated in Figure 7.

Figure 7: Waste managed in 2018 in the UK, by facility type



The graph shows that landfill was the main final waste management treatment option for the UK in 2018, taking 26% of all waste throughputs. This was followed by recycling and material recovery facilities, with 17% and 16% respectively. Thermal treatment has only a 6% share, followed by composting (3%), physicochemical treatment (2%), anaerobic digestion (1%) and mechanical biological treatment (1%).

Being the first stage in the waste management process, transfer stations (at 28%) were expected to handle a high percentage of the total waste handled.

3.7.3 GHG emissions in $ktCO_2e$ for 2018 baseline year

The total GHG emissions for 2018 baseline year were calculated using the EpE tool as mentioned in section 3.5 (see Appendix A3). The tables and graphs intentionally maintain the EpE format and the analysis synthesis.

Ricardo updated the EpE tool to allow calculations of emissions based on fuel's energy content. The project team converted each fuel into factors based on kWh units, applying gross calorific values.

Ricardo updated the emissions factors in the EpE tool with the associated Global Warming Potential following the IPCC Fourth and Fifth Assessment Reports[19]. For the purposes of the baseline calculation, the AR4 was applied using a GWP time horizon of 100 years (GWP100).

3.7.3.1 Direct (Scope 1) and Indirect (Scope 2) emissions in $ktCO_2e$ from process and energy consumption

The EpE tool calculates direct (scope 1) and indirect (scope 2) emissions from processes and energy consumption. Table 4 illustrates the results in kilotonnes of CO_2 equivalent.

Table 4: Direct (Scope 1) and Indirect (Scope 2) emissions

Source	Direct emissions (scope 1) ktCO2e	Indirect emissions (scope 2) ktCO2e	TOTAL ktCO2e
Transport	4,581	-	4,581
Sorting - Transfer	8,979	5,739	14,718
Anaerobic Digestion	69	64	133
Composting	952	47	999
MBT	10	21	31
Landfilling	10,701	24	10,725
Thermal treatment	4,474	105	4,578
Total	**29,765**	**5,999**	**35,764**

Transport: the results show a total of **4,581 $ktCO_2e$** for transport. This value includes all emissions associated with road vehicles for the collection and transportation, excluding emissions from off-road vehicles, which are later covered in the associated waste management treatment.

Sorting and Transfer: the results show a total of **14,718 $ktCO_2e$** for sorting and transfer. The EpE tool consolidates all emissions generated by transfer stations, recycling and material recovery facilities (including mechanical pre-treatment) as a whole. Table 5 offers the description of emissions generated by transfer stations, recycling and material recovery facilities. The total emissions coming from recycling are **13,033 $ktCO_2e$,** with direct (scope 1) emissions accounting for 7,400 $ktCO_2e$ and indirect (scope 2) emissions for **5,633 $ktCO_2e$**. The results from recycling are clearly higher than the transfer stations and material recovery facilities. The reasons for this include that recycling can involve energy-intensive processes, and the sheer number of facilities (26% in the UK compared to the whole treatments and diversion of waste almost 31 million tonnes representing 17% of waste managed in 2018).

[19] Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey, J. Haywood, J. Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz and R. Van Dorland, 2007: Changes in Atmospheric Constituents and in Radiative Forcing. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Table 5: Emissions from transfer stations, material recovery and recycling facilities

Source	Direct emissions (scope 1) ktCO2e	Indirect emissions (scope 2) ktCO2e	TOTAL ktCO2e
Transfer stations	1,218	31	1,249
Material Recovery Facilities	361	75	436
Recycling	7,400	5,633	13,033
Total	**8,979**	**5,739**	**14,718**

Anaerobic digestion: the results show **133 $ktCO_2e$** for anaerobic digestion. The total includes emissions from energy consumption and process emissions from CH_4 and N_2O and fugitive methane emissions from the biogas combustion process. The assumptions taken for the calculation of the last process are a 95% combustion efficiency with a 59% content of CH_4 and 41% content of CO_2 short life cycle.

Composting: the results show a **999 $ktCO_2e$** for composting. The emissions included in the composting process are derived from the process emissions natural methanisation process and nitrous oxide emissions from the waste and the energy consumption.

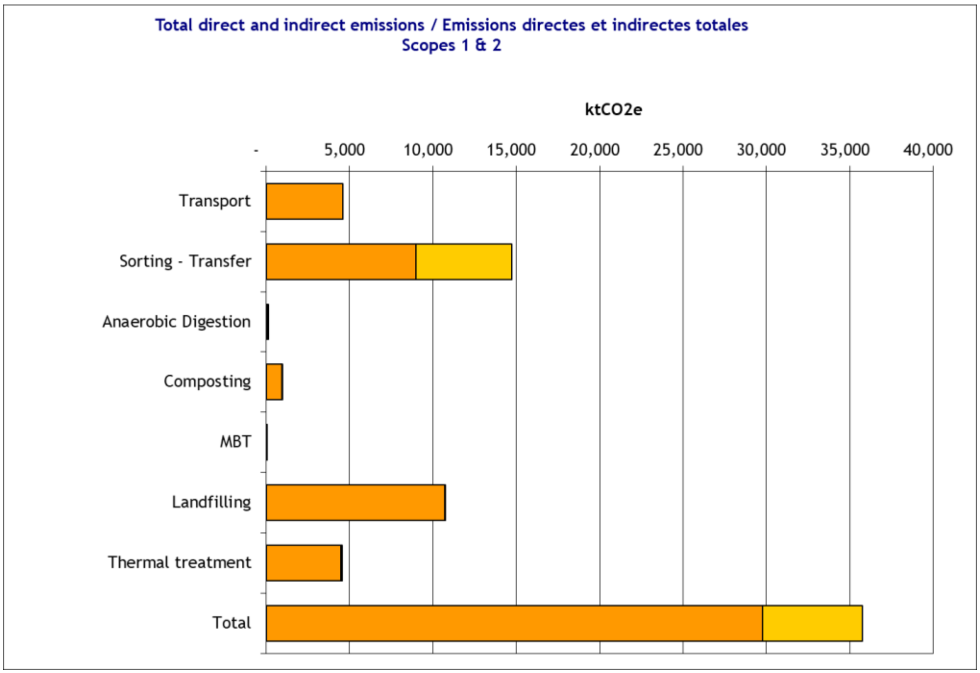
Mechanical biological treatment (MBT): the results show **31 $ktCO_2e$** for MBTs processes. The emissions from the MBT originate mainly from the energy consumption and the biological process of the natural methanisation of the waste when anaerobic digestion or composting is the final end treatment. The number of MBT plants in the UK is small, with only 13 sites in England and one in Scotland, meaning capacity is low with 1% of waste handled in 2018.

Landfilling: the results show **10,725 $ktCO_2e$** for landfill. The emissions from landfill come mainly from methane fugitive emissions **9,864 $ktCO_2e$**. Emissions from fuel combustion and electricity consumption are negligible **540 $ktCO_2e$** compared to the impact from methane emissions. Finally, emissions from biogas combustion are **320 ktCO2e**, with the assumption of combustion efficiency of 95%. The tonnes of waste diverted to landfill in 2018 is high being 26% compared to other final end treatments.

Thermal treatment: the results show **4,578 $ktCO_2e$** for thermal treatment. The emissions coming from thermal treatment come from the incineration process (fossil CO_2 and N_2O emissions). The biogenic CO_2 emissions are not accounted on the final emissions calculation and are reported separately in section 3.7.3.2. Emissions from fuel and electricity consumption were accounted in the final calculation. The UK in 2018 incinerated around 12 million tonnes of waste, which represents 6% of waste managed.

Figure 8 illustrates the results of Direct (Scope 1) and Indirect (Scope 2) emissions from process and energy consumption.

Figure 8: Direct (Scope 1) and Indirect (Scope 2) emissions



3.7.3.2 Biogenic emissions $ktCO_2$

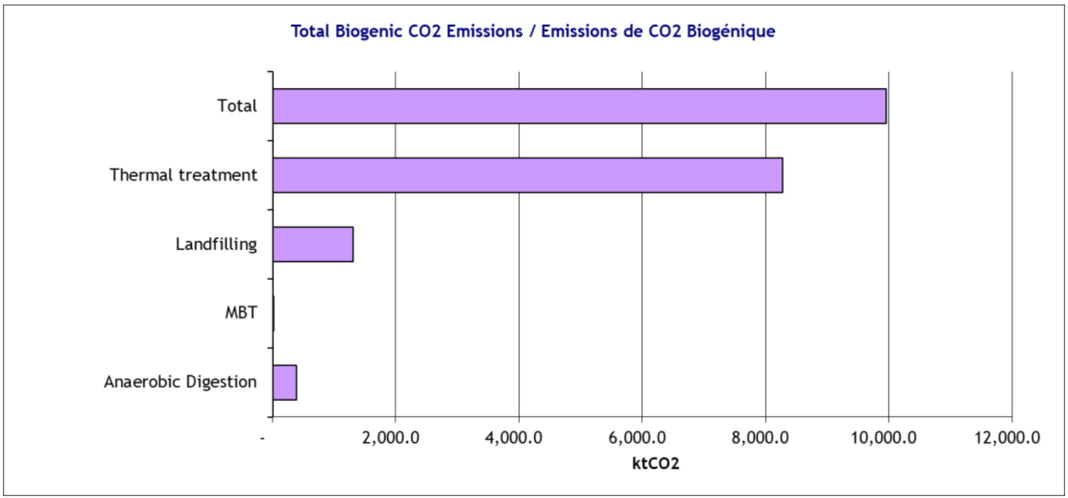
Biogenic emissions are not accounted in final emissions calculations, because they are considered as a CO_2 short life cycle. The biogenic emissions come mainly from thermal treatment when organic materials are incinerated.

The results show a contribution from anaerobic digestion of **382 $ktCO_2e$**, from MBT (due to anaerobic digestion being the biological treatment) **0.2 $ktCO_2e$,** landfilling **1,303 ktCO2e** and thermal treatment **8,272 $ktCO_2e$**.

Table 6: Biogenic emissions $ktCO_2$

Source	Biogenic CO2 emissions ktCO2
Anaerobic Digestion	382.2
MBT	0.2
Landfilling	1,303.2
Thermal treatment	8,271.8
Total	9,957.4

Figure 9: Biogenic emissions $ktCO_2$



3.7.3.3 Avoided emissions

The EpE tool calculates avoided emissions by energy and material recovery from waste management process. This calculation provides an opportunity to explore the potential of the waste and recycling sector in the UK to make a difference to reduction of emissions from substitution of virgin materials and offset of fossil fuel intensive energy sources.

Table 7 illustrates the results of the avoided emissions in $ktCO_2e$ in negative values, to illustrate the savings of emissions by energy and material recovery.

Table 7: Avoided emissions

Source	Total avoided emissions ktCO2e
Energy recovery from the produced biogas	- 1,436
Energy recovery from thermal treatment	- 1,907
Energy recovery from anaerobic digestion	- 768
Recovery of incineration by-products	- 28
Sorting and recycling	- 44,752
Waste-derived fuel preparation	- 969
Compost landspread	- 44
Total	**- 49,904**

Energy recovery

It is important to mention first of all that, in line with the GHG Protocol, the EpE tool does not discount direct and indirect emissions by any amounts of avoided emissions from energy recovery.

Energy recovery from the produced biogas: the results show **-1,436 $ktCO_2e$**. The avoided emissions are calculated based on the recovery of the biogas arising from landfill processes. Ricardo applied a factor of 109 kWh/tonne of waste, based on WRATE figures. That is then factored by the BEIS 2018 electricity emission factor for the exported energy potential.

Energy recovery from thermal treatment: the results show **-1,907 $ktCO_2e$**. The avoided emissions are calculated based on the material energy content generation when incinerated. Ricardo applied a factor of 536 kWh/tonne based on Tolvik Consulting's 'UK Energy from Waste Statistics 2018'[13].

Energy recovery from anaerobic digestion: the results show **-768 $ktCO_2e$**. The avoided emissions are calculated based on the biogas recovered from the anaerobic digestion process. Ricardo applied a electricity yield per tonne of waste of 1,319 kWh/tonne based on the DUKES report[14].

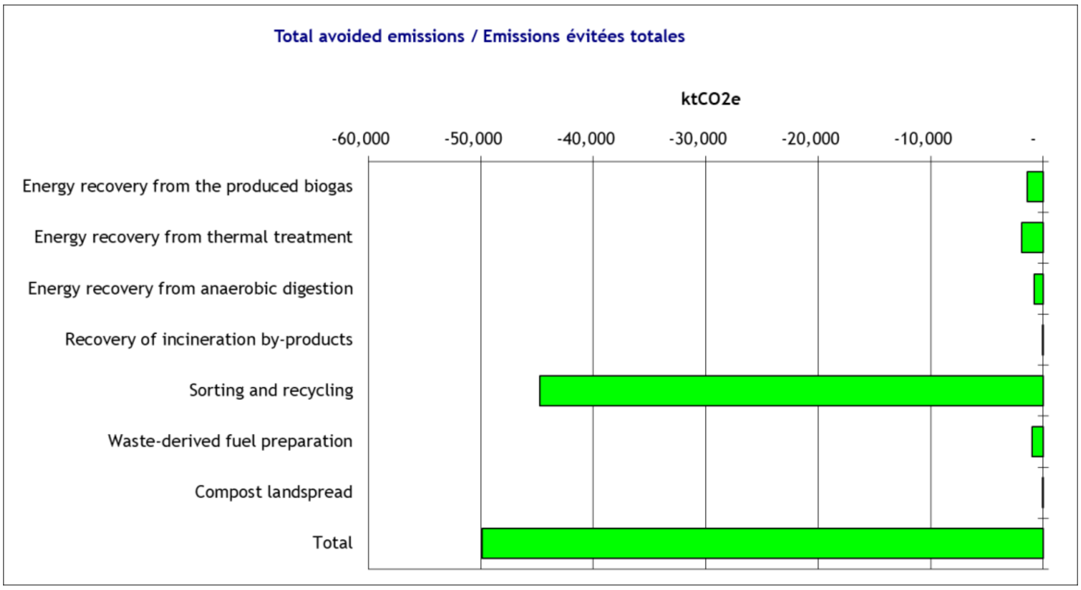
Material recovery

Recovery of incineration by-products: the results show **-28 $ktCO_2e$**. The avoided emissions are calculated based on IBA recovery of 19% from Tolvik Consulting's 'UK Energy from Waste Statistics 2018'[13].

Sorting and recycling: the results show **-44,752 $ktCO_2e$**. The avoided emissions are calculated by factoring the recovered materials by the lifecycle assessment emissions factors offered by the Scottish Carbon Metric[9].

Waste derived fuel preparation: the results show **-969 $ktCO_2e$**. The avoided emissions are calculated based on the production of RDF and then energy content when incinerated. Ricardo applied an electricity yield per tonne of waste of 705 kWh/tonne based on a WRAP report[18].

Figure 10: Avoided emissions



3.7.3.4 Emissions Synthesis per GHG

Table 8 provides the synthesis of emissions by GHG type for direct (scope 1) and indirect (scope 2) emissions category.

Table 8: Emissions per facility type and GHG

Source	Direct emissions							Indirect emissions
	ktCO2	ktCH4	ktN2O	ktHFC	ktPFC	ktNF3	ktSF6	ktCO2e
Transport	4,581							0
Sorting - Transfer	7,504			0	0	0	0	5,739
Anaerobic Digestion	17	2	0					64
Composting	113	20	1					47
MBT	10	0	0					21
Landfilling	517	407						24
Thermal treatment	4,395		0	0	0	0	0	105
Total	**17,136**	**429**	**1**	**0**	**0**	**0**	**0**	**5,999**

This table illustrates all the GHG emissions considered in this exercise, CO_2, CH_4, N_2O and HFC for each waste management treatment. It is worth noting here that 'Sorting – Transfer' consolidates all emissions generated by transfer stations, recycling processors and material recovery facilities (including mechanical pre-treatment) as a whole.

3.7.4 Comparison of emissions per tonne

The figures below include emissions from fuels and process emissions (Scope 1), as well as emissions from the use of electricity and heat (Scope 2). The emissions were calculated by taking the sum of the total fuels (diesel, gas oil, natural gas, fuel oil, other petroleum gas, burning oil) and electricity and heat consumption and dividing this sum by the total waste tonnage entering each facility type in 2018. The process emissions metric is based on the emission factors used during the modelling. The largest consumption of fuels occurs in EfW facilities, where 27 kg CO_2eq are emitted for each tonne input, compared to 11 kg CO_2eq for landfill sites and 8 kg CO_2eq for anaerobic digestion facilities.

When comparing emissions from food waste treatment options, EfW generates fewer emissions, as the cardon dioxide emissions from incinerating organic materials are characterised as being of biogenic origin. When comparing against emissions from residual waste treatment options, EfW also generates fewer emissions, because of the methane emissions from landfill due to the decomposition of the organic materials.

Table 9: Fuels, electricity and heat emissions (tonnes CO_2eq)

		Landfill	EfW	AD
		Scope 1		
Fuels	Diesel	280,940	35,395	13,736
	Gas oil	128,130	70,408	580
	Natural gas	129	74,969	2,737
	Fuel oil	105,851	120,480	-
	Other petroleum gas	-	4,323	-
	Burning oil	1,460	-	-
	Total fuels	**516,511**	**305,575**	**17,053**
Biogas		**320,316**	**-**	**10,840**
		Scope 2		
Electricity		23,725	104,534	37,978
Heat		-	-	25,761
Total		**860,551**	**410,109**	**91,633**

Table 10: Emissions per tonne breakdown (kg CO_2eq/tonne)

		Landfill	**EfW**	**AD**
		Scope 1		
Fuels	Diesel	6.1	3.2	6.7
	Gas oil	2.8	6.3	0.3
	Natural gas	0.003	6.7	1.3
	Fuel oil	2.3	10.7	-
	Other petroleum gas	-	0.4	-
	Burning oil	0.03	-	-
	Total fuels	**11.1**	**27.2**	**8.3**
Process Emissions	Food waste	**646.3**	**0.0**	**20.0**
	Municipal Solid Waste	**591.9**	**404.0**	**-**
	Commercial & Industrial Waste	**665.1**	**412.0**	**-**
Biogas		**6.9**	**-**	**5.3**
		Scope 2		

	Landfill	EfW	AD
Electricity	0.5	9.3	18.5
Heat	-	-	12.6
Total – Food waste	**664.8**	**36.5**	**64.7**
Total – Municipal Solid Waste	**610.5**	**440.5**	**-**
Total – Commercial & Industrial Waste	**683.5**	**448.5**	**-**

Figure 11: Emissions per tonne of food waste treatments comparison (kg CO_2eq/tonne)

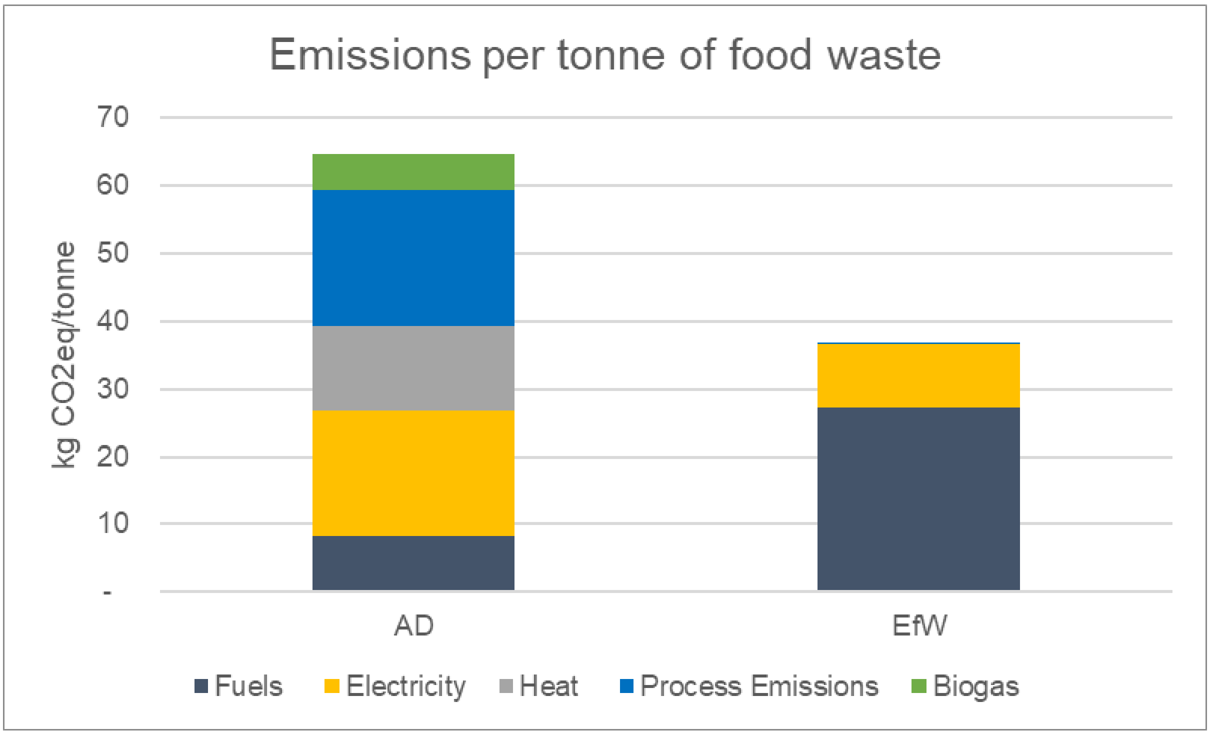


Figure 12: Emissions per tonne of residual MSW treatments comparison (kg CO_2eq/tonne)

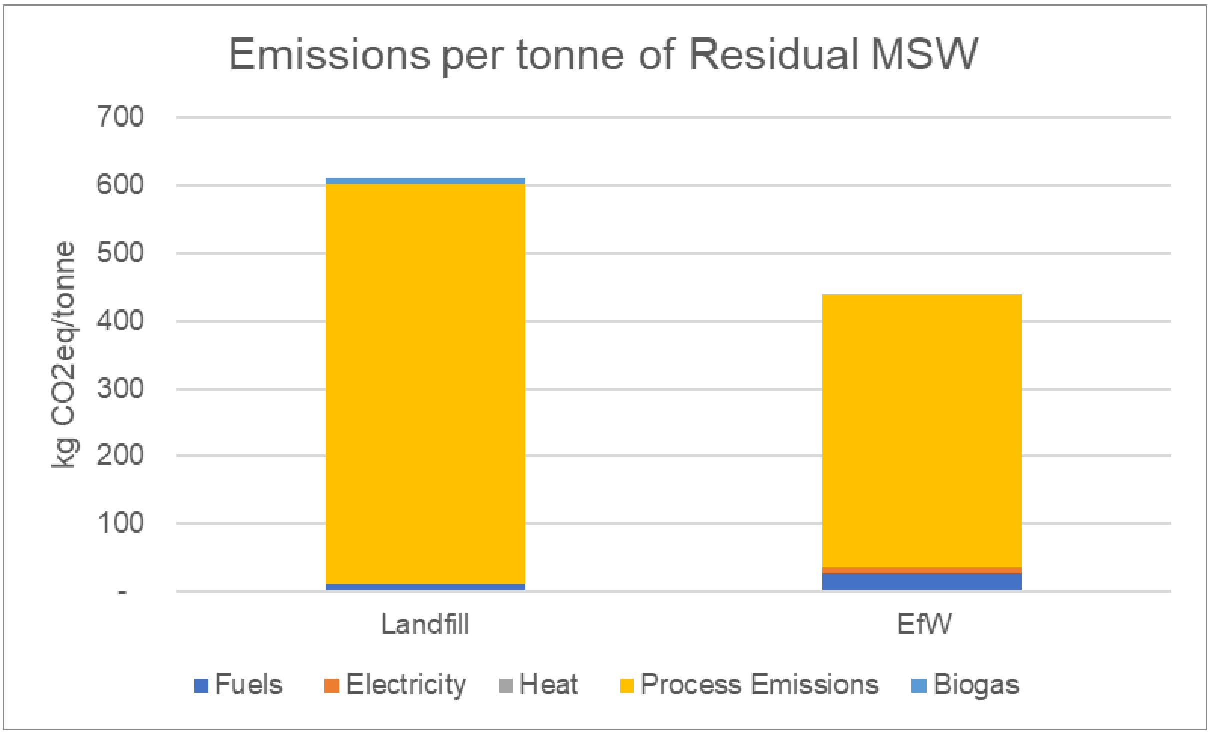
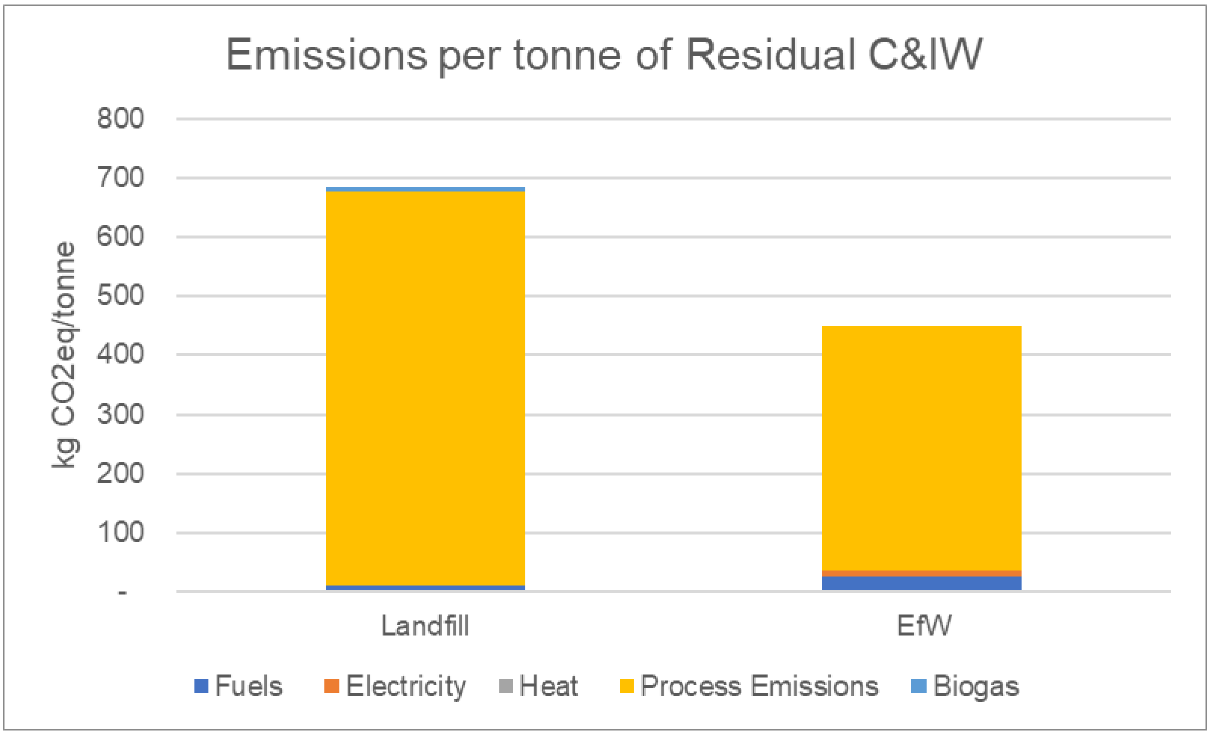


Figure 13: Emissions per tonne of residual commercial & industrial waste treatments comparison (kg CO_2eq/tonne)



3.8 Step 7: Sensitivity Analysis with GWP20

Since the ESA aims to achieve the net zero goal by 2040 or sooner, it was considered useful to estimate the results using a shorter term GWP. GWP factors are available from the IPCC for 20-, 100- and 500-year timeframes, but considering the timeframe for net zero actions, the GWP20 seemed the most appropriate. For the purposes of this exercise, the change to the calculation of the emission factors using GWP20 mostly affects the methane emissions. The 100-year GWP is based on the energy absorbed by a gas over 100 years, while the 20-year GWP is based on the energy absorbed over 20 years[20]. As a result, because all GWPs are calculated relative to CO_2, GWPs based on a shorter timeframe will be larger for gases with lifetimes shorter than that of CO_2, and smaller for gases with lifetimes longer than CO_2. As the lifetime of methane is 12.4 years, it is considered much more potent within the 20 years, than within the 100 years, when most of it will have decayed in the atmosphere and, consequently, its GWP20 is three times higher than the GWP100, as shown in Table 11.

Table 11: GWP20 and GWP100[19]

	Lifetime (yr)	Cumulative forcing over 20 years	Cumulative forcing over 100 years
CO_2	-	1	1
CH_4	12.4	72	25
N_2O	121	289	298
CF_4	50,000	5,210	7,390
HFC-152a	1.5	437	124

3.8.1 GHG emissions in $ktCO_2e$ for 2018 baseline year – GWP20 sensitivity analysis

The results below were developed using the IPCC Fourth Assessment Report GWP20 factors. All emission factors applied were recalculated to apply the GWP 20 years.

The results demonstrate that landfill, anaerobic digestion and composting see a significant increase in their CO_2e emissions, due to the GHG emissions impact of methane over a shorter carbon cycle.

3.8.1.1 Direct (Scope 1) and Indirect (Scope 2) emissions in $ktCO_2e$ from process and energy consumption

The direct (scope 1) and indirect (scope 2) emissions were calculating following the same principles as for the GWP100, with the update to the emissions factors to reflect the GWP20 timeframe.

Table 12: Direct (Scope 1) and Indirect (Scope 2) emissions (GWP20 timeframe)

Source	Direct emissions (scope 1) ktCO2e	Indirect emissions (scope 2) ktCO2e	TOTAL ktCO2e
Transport	4,585	-	4,585
Sorting - Transfer	8,994	5,763	14,757
Anaerobic Digestion	166	64	230
Composting	1,861	47	1,908
MBT	10	21	32
Landfilling	25,759	24	25,783
Thermal treatment	4,472	105	4,577
Total	**45,846**	**6,025**	**51,871**

[20] https://www.epa.gov/ghgemissions/understanding-global-warming-potentials

Transport: the results show a marginal change to **4,585 $ktCO_2e$** for transport.

Sorting and Transfer: the results show a marginal change **14,757 $ktCO_2e$** for sorting and transfer.

Anaerobic digestion: the results show a significant increase to **230 $ktCO_2e$** for anaerobic digestion, compared to **133 $ktCO_2e$** with GWP100.

Composting: the results show a significant increase to **1,908 $ktCO_2e$** for composting, compared to **999 $ktCO_2e$** with GWP100.

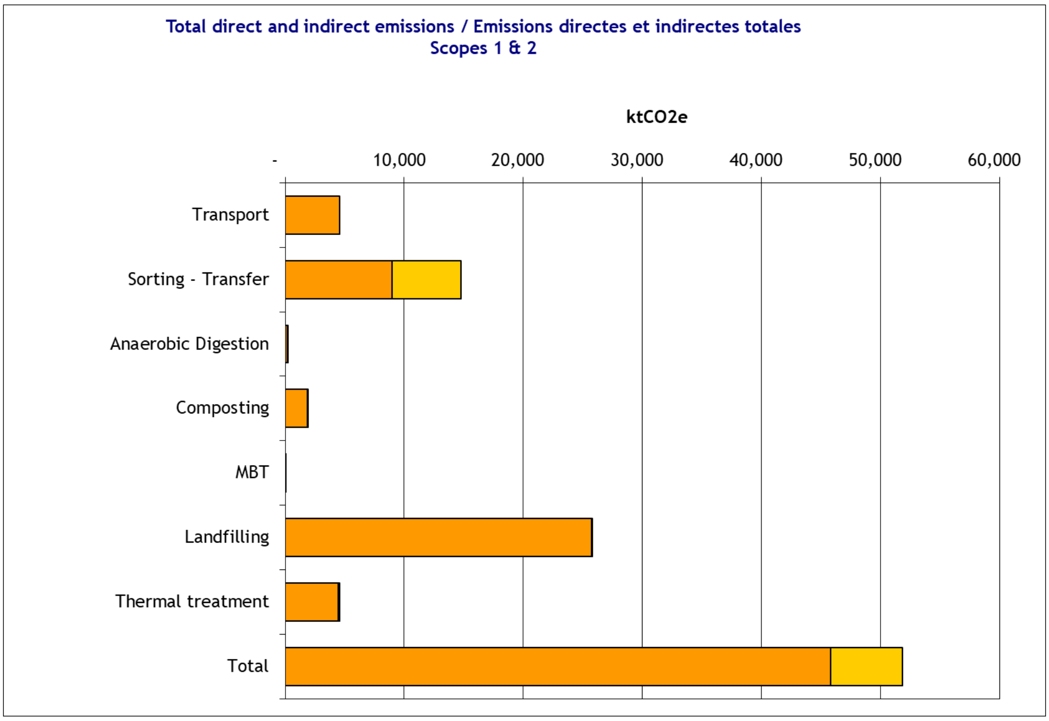
Mechanical biological treatment (MBT): the results show a marginal increase of **1 $ktCO_2e$** to **32 $ktCO_2e$** for MBTs processes.

Landfilling: the results show a very significant increase to **25,783 $ktCO_2e$** compared to **10,725 $ktCO_2e$** for landfill. This is because GWP from landfill is predominantly caused by methane emissions.

Thermal treatment: the results show a marginal decrease to **4,577 $ktCO_2e$** compared to **4,578 $ktCO_2e$** with GWP100.

Figure 14 illustrates the results of Direct (Scope 1) and Indirect (Scope 2) emissions from process and energy consumption.

Figure 14: Scope 1 and 2 emissions (GWP20 basis)



3.8.1.2 Biogenic emissions $ktCO_2$

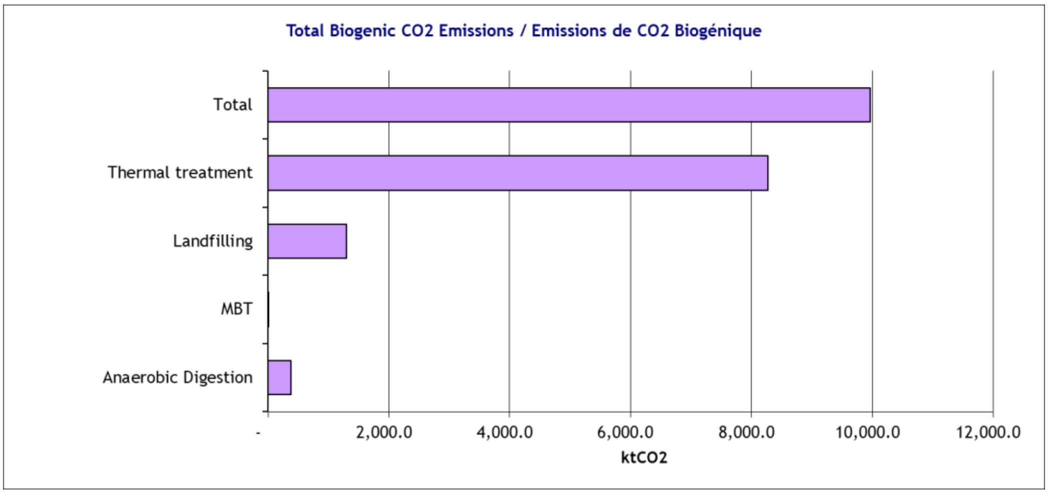
Biogenic emissions are not accounted in final emissions calculation, because they are considered as a CO_2 short life cycle. The biogenic emissions come mainly from thermal treatment when organic materials are incinerated.

The results show no difference from GWP100 (see Table 6) as the GWP for CO_2 is one.

Table 13: Biogenic emissions $ktCO_2$

Source	Biogenic CO2 emissions ktCO2
Anaerobic Digestion	382.2
MBT	0.2
Landfilling	1,303.2
Thermal treatment	8,271.8
Total	9,957.4

Figure 15: Biogenic emissions



3.8.1.3 Emissions Synthesis per GHG

Table 14 provides the synthesis of emissions by GHG type for direct (scope 1) and indirect (scope 2) emissions category.

Table 14: Emissions synthesis per GHG

Source	Direct emissions							Indirect emissions
	ktCO2	ktCH4	ktN2O	ktHFC	ktPFC	ktNF3	ktSF6	ktCO2e
Transport	4,585							0
Sorting - Transfer	7,519			0	0	0	0	5,763
Anaerobic Digestion	17	2	0					64
Composting	113	20	1					47
MBT	10	0	0					21
Landfilling	517	351						24
Thermal treatment	4,396		0	0	0	0	0	105
Total	**17,155**	**372**	**1**	**0**	**0**	**0**	**0**	**6,025**

This table illustrates all the GHG emissions considered in this exercise, CO_2, CH_4, N_2O and HFC for each waste management treatment.

4 Task 2: Identify potential emissions savings

The next task was to identify which emissions have the potential to provide the largest savings and which savings could potentially be realised most quickly. From our experience of the recycling and waste management sector, we expected potential emissions savings to come from at least the following operational areas:

- Vehicle fleet, transport and fuel;
- Energy efficiency measures;
- Greener electricity;
- New and improved processing and treatment infrastructure;
- Diverting waste to more carbon efficient solutions;
- Reducing waste arisings.

Taking these into consideration, we proposed a set of scenarios around these expectations and presented these to the ESA project team. The scenarios were refined to ensure they included efforts that tackle the largest emissions, from our analysis of the baseline emissions. The scenarios are described in detail in section 5 below and we have provided interpretation of the impact of measures in the Results and Analysis section 5.4.

4.1 Largest savings

The baseline emissions results reveal that the largest scope 1 and 2 emissions (combined) derive from the following sources in order of magnitude:

- Recycling (reprocessing of materials)
- Landfill
- Transport
- Thermal treatment
- Transfer stations

These emissions come from all fuel sources and power bought in from the National Grid that is required to collect, process and treat waste materials and reveals the amount of energy required to manage the UK's recycling and waste materials. Therefore, the obvious potential for the largest savings in emissions would come from successful efforts to reduce waste arisings overall. Less waste requires less transportation, processing, treatment and disposal. This is evidenced by recycling being the largest carbon emitter. Taking into account growth in waste from household growth, we can expect that recycling process emissions will increase as more waste is collected for recycling in the future. However, we would expect to see a corresponding decrease in waste to landfill and thermal treatment as a result of diverting waste away from these treatments to recycling. Reprocessing of materials such as glass, paper, plastic, aluminium and steel (commonly collected in local authority dry recycling schemes) requires levels of heat of the kind found in foundry and manufacturing processes e.g. recycling aluminium cans requires the material to be heated twice, once at 500^{o}C and then at 750^{o}C[21]. Efforts to reduce these emissions will therefore not be straightforward but should focus on efficiency measures within the process.

Further scrutiny of scope 1 emissions reveals significant diesel use, particularly from transport, which is to be expected, but also from transfer stations. Switching from diesel to renewable energy sources will have a significant impact on emissions. The largest savings therefore have the potential to come from the processes highlighted above. We have taken these into account in the scenarios described in section 5 below and provided further interpretation of emissions savings potential in the results section.

[21] https://novelis.com/

4.2 Quickest savings

With regard to identifying which activities will produce the fastest savings, from our knowledge of the recycling and waste management sector, we understand that in many cases significant operational changes will be required to reduce carbon emissions. These changes will have a bearing on how quickly the identified savings could be realised. In broad terms, actions to reduce emissions can be categorised into:

- Actions that are in the control of the waste management industry i.e. facility and fleet operators and consist of actions that operators can take themselves to reduce emissions from their business processes;

- Actions that are reliant upon Government policy, targets and the associated behaviour change of householders and businesses.

Using the example of transport emissions, a number of factors would feed into the decision-making process for procuring a new lower carbon vehicle fleet, such as:

- Expected remaining lifetime of the existing fleet;
- Cost of the new lower carbon replacement fleet;
- Technical capability and availability of the new fleet;
- Proportion of vehicles that could practicably be converted based on daily use e.g. distance travelled each day;
- Associated new infrastructure needed e.g. installation of electric charging points;
- Depot space for charging points and associated change in vehicle parking arrangements;
- Synergy with other business functions.

Assuming that collection vehicles have an expected operational lifetime of seven years on average, it is possible to project forward when the opportunity will arise for a new and lower emission fleet to be procured. This provides a guide to when carbon saving measures could be applied i.e. at the next procurement cycle.

Other interventions will have a variety of differing timeframes. For example, the installation of energy efficiency measures at recycling plants could be expected to take effect on a year by year basis with smaller incremental changes. Significant changes in waste management infrastructure would constitute more longer-term measures e.g. the installation of carbon capture and storage at EfW facilities will require a significant financial investment but once installed will provide an immediate 'step-change' in reducing emissions.

The speed at which measures could be taken to reduce emissions will depend on a number of factors including business planning, financial investment, process changes and target deadlines. Actions in response to Government policy are likely to see 'step-changes' as local authorities and businesses work towards meeting targets in specific target years e.g. meeting the policy for all households and appropriate businesses to have separate food waste collections by 2023. We have overlaid our operational sector experience and conducted research to provide a practical 'reality check' to the baseline emissions results and have fed this into the scenarios. Interpretation is provided in the results section 5.4.

5 Task 3: High-level assessment of emissions scenarios

The ESA wanted to understand what actions the UK recycling and waste management sector can take to achieve net-zero by 2040 at the latest. The analysis was to include the impact of the UK Government's Resources and Waste Strategy for England and other similar UK legislations. Therefore, this included actions and scenarios that minimise waste, promote resource efficiency and move towards a circular economy, including activities that repair, remanufacture and reuse waste materials in order to measure the contribution that these activities make towards saving carbon emissions.

The direction of travel within the recycling and waste industry is a move away from a focus on waste to a focus on resources and prioritising actions that move waste management activities higher up the waste hierarchy. Key objectives from the Resources and Waste Strategy that were believed should form part of the emissions scenarios include the established targets for the management of municipal solid waste:

- 50% of household waste to be recycled by 2020
- 75% of packaging to be recycled by 2030
- 65% of MSW to be recycled by 2035
- 10% or less of MSW to be landfilled by 2035
- Eliminate food waste to landfill by 2030

In addition, a range of policy initiatives were proposed, aimed at having a positive impact on the sector's carbon emissions, including the introduction of:

- A Deposit Return Scheme (DRS) by 2023 to encourage greater recycling (plastic bottles, cans and glass containers);
- Separate food waste collections for householders and appropriate businesses by 2023 (reducing greenhouse gas emissions from landfill);
- Extended producer responsibility (EPR) for packaging by 2023 (packaging, WEEE, batteries, ELV waste);
- Promoting UK based recycling and exporting less waste to be processed abroad (impact on transport emissions);
- Driving greater efficiency of Energy from Waste plants;
- Improving recycling rates by ensuring a consistent set of dry recyclable materials is collected from all households and businesses (six main dry recycling materials);
- A move away from weight-based towards impact-based targets and reporting, focusing initially on carbon and natural capital accounting;
- A circular system that keeps plastic in the economy and out of the natural environment, through the 2025 UK Plastics Pact targets (100% reusable, recyclable or compostable);
- A measure to eliminate avoidable plastic waste, doubling resource productivity and eliminating avoidable wastes of all kinds by 2050 (Environment Plan).

During the delivery of this project, in December 2020, the Climate Change Committee published its Sixth Carbon Budget[22] which provides a sector summary for Waste which covers both solid waste and wastewater management. The summary sets out a range of mitigation options including:

- Reduced landfill methane generation
- Increased landfill methane capture
- Installation of carbon capture and storage at energy from waste plants.

We have taken into consideration these options and incorporated key measures of relevance to the solid waste sector into our scenario analysis.

Having established the baseline position in task 1, we set out a scenario that tracks business as usual (BAU) to which the impact of other scenarios can be compared.

Upon agreement with the ESA, the scenarios were set out as following:

1. Business as Usual - in which the management of waste continues according to the current baseline activities, but efforts to decarbonise the production of electricity distributed through the National Grid are modelled;
2. Planned progress – builds on BAU and takes into account the implementation of known recycling and waste management policy and strategy targets as mentioned above and includes key measures from Carbon Budget 6;
3. Planned Progress Plus – provides an enhanced version of Planned Progress, through 'stretched targets' and performance from the measures set out in Planned Progress and the same measures from Carbon Budget 6;

[22] https://www.theccc.org.uk/publication/sixth-carbon-budget/

4. Enhanced Reduction and Diversion – to assess the impact of enhanced energy and waste saving (reduction and reuse) activities and the impact of additional measures operators could take to reduce carbon emissions.

In addition to this first set of scenarios, two sensitivities were modelled that combine scenarios and these are reported on in section 5.5. Scenario measures have been researched and quantified using an evidence-based approach and a set of general assumptions for underlying waste growth have been applied to all scenarios. These assumptions are described below and are followed by descriptions of the measures for each subsequent scenario.

5.1 Growth assumptions

The underlying assumptions to calculate and project forward waste growth for the UK to 2040 are discussed below. These are assumed to be realised in all scenarios and have been modelled before each intervention is quantified and applied. There are four principle waste streams to consider and each of these is taken in turn below:

- Household waste expressed as Local Authority Collected Waste i.e. waste collected by and within the control of local authorities, in some cases including elements of commercial waste similar in nature to household waste;
- Commercial and Industrial waste;
- Construction and Demolition waste;
- Hazardous and Clinical wastes.

5.1.1 Household waste growth assumptions

Table 15: Household waste growth assumptions

General Assumption	Description / metric	Growth per year	Source data
Housing growth to 2040: Assume generation of waste per household remains constant. Growth comes from the increase in the number of households.	UK Households 2018 = 27,772,873 2028 = 29,672,429 2039 = 31,465,951. Total increase of 3,693,078 households. Average household size = 2.3 people	175,861 households	https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationprojections/methodologies/householdprojectionsacrosstheukuserguide
Impact: LACW waste growth	Percentage growth per year	0.6%	

5.1.2 Commercial and Industrial waste growth assumptions

Table 16: C&I waste growth assumptions

General Assumption	Description / metric	Growth per year	Source data
GDP growth to 2040: Assume there is a correlation between GDP and C&I waste arisings. Assume C&I waste are treated similarly. Phase in growth up to 1.1% with 0% for the 5 years to 2025, 1% up to 2030, 1.1% to 2040	Analysis of retrospective 10 years of UK GDP growth. Analysis of retrospective 10 years of UK C&I waste growth.	1.9% 1.1%	Waste Data Interrogator, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/936250/Forecomp_November_2020.pdf
Impact: C&I waste growth	Percentage growth per year	Phased	

The most recent GDP forecasts from November 2020 project forward from 2020 to 2024 as follows:

Table 17: GDP growth forecast

	2020	2021	2022	2023	2024
GDP Growth %	-10.9%	5.1%	4.3%	2.5%	2.1%

It is evident that these projections are significantly different to the analysis of retrospective GDP growth calculated as 1.9% average growth. Our conclusion is that the recent forecasts take into account the impact of the Covid-19 pandemic and the reduced economic output seen as a result of the lockdown measures. This impact appears to take effect up to 2024, however the Net Zero Roadmap will go beyond this to 2040, during which time we could expect GDP to return to near 'normal' levels. In addition to this further analysis of the actual retrospective C&I waste arisings reveal a lower level of growth of 1.1% for the UK as a whole. In consultation with the ESA, we have factored in an impact from Covid-19 on C&I waste growth, as shown in Table 17 above.

5.1.3 Construction and Demolition waste growth assumptions

Table 18: C&D waste growth assumptions

General Assumption	Description / metric	Growth per year	Source data
That waste growth will be consistent with trends for arisings and allow for Covid-19 impact by phasing in growth up to 2% with 0% for 5 years to 2025, 1% to 2030, 2% to 2040.	Analysis of retrospective 7 years of waste generation and recycling stats for the UK reported by Defra.	2%	https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/918270/UK_Statistics_on_Waste_statistical_notice_March_2020_accessible_FINAL_updated_size_12.pdf
Impact: C&D waste growth	Percentage growth per year	Phased growth	

It could be expected that C&D waste growth would also follow GDP, however other elements come into play, such as Government policy targets for housebuilding. Despite this and taking into account that the UK is experiencing the impact of the Covid-19 pandemic and the change in status with the European Union, it is unlikely that a 2% growth rate for C&D waste year on year will be realised and that this could be adjusted to take account of these factors. A phased growth up to 2% has been applied as shown in Table 18 above.

5.1.4 Hazardous and Clinical waste growth assumptions

This waste stream is small in comparison to the others described above, although an important stream in terms of the nature and management of the material. Our assumptions for modelling growth are set out below:

Table 19: Hazardous and Clinical waste growth assumptions

General Assumption	Description / metric	Growth per year
That waste generation remains constant	Apply assumption to baseline	
Impact: H&C waste growth	Percentage growth per year	0%

5.2 Scenario assumptions

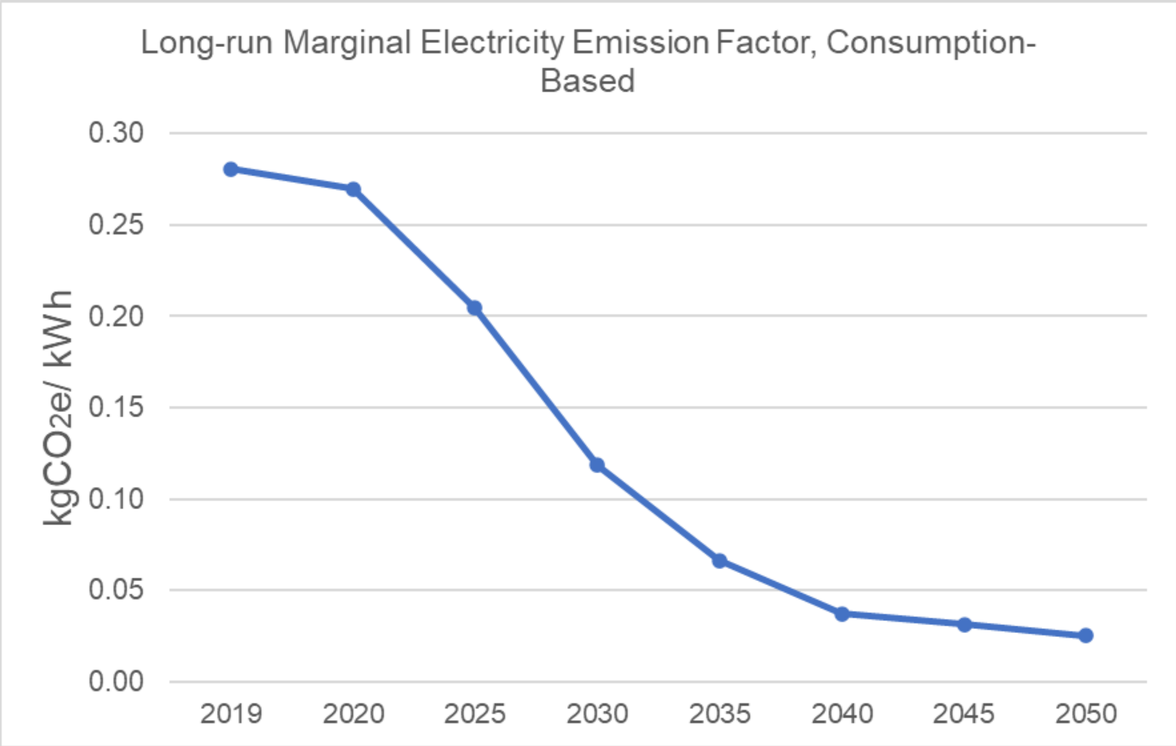
5.2.1 Waste composition

In addition to waste growth, we have considered waste composition and have applied underlying analyses for Household and C&I waste that form the basis for the scenarios. As measures are applied in the scenarios, we consider how the residual waste composition may change as a result of applying the measure in question e.g. an increase in separate food waste collections will see a corresponding reduction in food waste in the residual stream.

5.2.2 Scenario 1: Business as Usual (BAU)

Having established the baseline position, the first scenario tracks BAU, as a benchmark to which the impact of other scenarios can be compared. This is effectively the ‘do nothing’ scenario, whereby no improvements are implemented to reduce carbon emissions by the recycling and waste management sector or by other external products and services that the industry procures in terms of products and fuel for plant and transport. However, as mentioned above, we have included the impact from known measures that are already proposed, planned or in implementation to decarbonise the electricity grid. This is displayed in Figure 16 below.

Figure 16: Electricity grid decarbonisation



5.2.3 Scenario 2: Planned Progress (PP)

Scenario 2 incorporates waste growth, waste composition and BAU assumptions and adds the following eight measures from the Resources and Waste Strategy[23] and Carbon Budget 6[24]:

- Food waste prevention
- Food waste collections – all local authorities
- Food waste collections – all appropriate businesses
- Deposit return schemes (DRS)
- Extended producer responsibility (EPR) for packaging waste[25]
- Landfill methane capture
- Landfill biodegradable waste ban
- Carbon capture and storage from EfW plants

Assumptions for these measures are set out below:

Food waste prevention

Table 20: Food waste prevention assumption

Assumption	Description / metric	Impact	Source data
Courtauld 2025 target to reduce food waste (post farm gate) by 20% per person against 2015 baseline.*	Reduction 2018 - 2025 and 2025 to 2030	-1.7% per year	Courtauld Commitment 2025
Impact: LACW & C&I food waste arisings	**Percentage reduction per year**	-1.7% per year	
**current progress has seen 2% reduction between 2015 and 2018*			

[23] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/765914/resources-waste-strategy-dec-2018.pdf
[24] https://www.theccc.org.uk/publication/sixth-carbon-budget/
[25] Targets are subject due for review during 2021

The Courtauld Commitment 2025 sets voluntary targets for the reduction of total food waste generated in the UK from a 2015 baseline of 10.2 million tonnes. Targets are set for 2018, 2025 and 2030 for reductions in food waste arisings that equate to -1.7% per year, as reflected in the table above. The actual performance seen between 2015 and 2018 was -2% per year and this performance has been applied to Scenario 3 Planned Progress Plus to model enhanced performance against PP.

Food waste collections – all local authorities

Table 21: Local authorities food waste collections assumption

Assumption	Description / metric	Impact	Source data
All UK local authorities to offer separate food waste collections by 2023. Assume phasing between 2023 and 2030.	Analysis of current performance against new collections based on number of LAs running separate collections and total waste recycled.	34%	WasteDataFlow 2018-19
Impact: Household food waste recycling performance	**Percentage increase per year**	4%	

The performance improvement above has been calculated taking the total tonnage of food waste recycled in 2018/19 analysed against the number of local authorities offering collection services in the same year, to provide an average food waste tonnage per authority. This average tonnage has been applied to the remaining number of local authorities that will need to commence collection services by 2023. This represents a 34% increase in food waste separately collected for the UK as a whole based on 2018 levels. Assuming the phasing of new collections takes place in a linear pattern between 2023 and 2030 to meet this target, this amounts to an average performance increase of 4% in food waste recycling each year on 2018/19 levels.

Food waste collections – all appropriate businesses

Table 22: Business food waste collections assumption

Assumption	Description / metric	Impact	Source data
All UK appropriate businesses have separate food waste collections by 2023. Assume phasing between 2023 and 2030. Current 22% recycling rate improves to 25% and 30% against a reducing baseline.	2018 total C&I food producing portion of total C&I arisings is 31%. Current 22% recycling rate increases to 25% and 30% in 2025 and 2030.	25% in 2025 30% in 2030	https://wrap.org.uk/sites/files/wrap/food-waste-reduction-roadmap-toolkit.pdf
Impact: Business food waste recycling performance	**Percentage increase per year**	0.8%	

The target for business food waste collections mirrors the local authority target in that all appropriate businesses are to have separate collections by 2023. The challenge here is the lack of available data on the number of appropriate businesses, therefore we have taken an approach based on current recycling performance from 2018 (22%) of the total C&I food-producing portion of UK total C&I waste arisings. A modest increase in recycling performance has been applied, which takes account of food waste prevention measures applied to this waste stream, hence increasing targets are based on a decreasing available tonnage.

Deposit return schemes

Table 23: DRS assumption

Assumption	Description / metric	Impact	Source data
Includes drinks containers only: glass, plastic, aluminium, steel, cartons to achieve targets of 85% per material in 2030. Assume new DRS scheme encourages behaviour change towards targets.	Based on tonnes placed on the market in 2018 and uplift on current performance to achieve targets.	24% increase by 2030	Valpak Deposit Return Schemes report 2018
Impact: Household and C&I waste recycling performances*	**Percentage increase per year**	2.1%	
**some of this material will be diverted away from current kerbside recycling schemes & bring banks*			

The expected performance for a DRS scheme uses 2018 data on the quantity of drinks containers placed on the market and the reported UK recycling rate for each material separately and the average rate for all materials of 61%. The increased performance is calculated to achieve the 2030 target of 85% by material stream.

EPR packaging waste

Table 24: EPR assumption

Assumption	Description / metric	Impact	Source data
Defra projected performance of 70% in 2025 and 71% in 2030. Current performance is maintained and improved on to meet targets.	Projection of baseline 2017 performance at 64% with linear improvement to 2030.	7% to 2030	https://consult.defra.gov.uk/environmental-quality/consultation-on-reforming-the-uk-packaging-produce/supporting_documents/packagingeprconsultdoc.pdf
Impact: Household and C&I waste recycling performances*	**Percentage increase per year**	0.5%	
**will include DRS as a form of EPR, hence double-counting needs to be eliminated if applying both interventions together*			

The expected performance for EPR packaging waste uses 2017 data on the quantity of packaging materials recycled as reported for the UK at a 64% recycling rate. The increased performance is calculated to achieve the target of 70% recycling by 2025 and 71% by 2030.

Landfill methane capture

Table 25: Landfill methane capture assumption

Assumption	Description / metric	Impact	Source data
Carbon Budget 6 Net Zero roadmap assumptions to achieve 71% by 2030 and 80% by 2050. This equates to a mid-point of 75.5% for 2040.	Baseline of current performance at 60%. Assume linear improvement.	26%	Carbon Budget 6 Balanced Net Zero Pathway
Impact: Capture of emissions from landfill	**Percentage increase per year**	1.3%	

Carbon Budget 6 provides targets to 2030 and 2050 for the increased capture of methane emitted from landfill sites. For the purposes of ESA's roadmap to 2040, the mid-point target between these two dates is 75.5%. Starting at a baseline of 60% capture, this represents a 15.5 percentage point increase over a 20-year period or a 26% increase over the current performance, which translates into 1.3% increase each year.

Landfill biodegradable waste ban

Table 26: Landfill biodegradable waste ban assumption

Assumption	Description / metric	Impact	Source data
Carbon Budget 6 Net Zero roadmap assumptions to achieve 100% ban of BMW to landfill by 2025 with a scenario to 2030.	Baseline of 7.2 million tonnes of BMW to landfill in 2018. Linear reduction to 2025 and 2030 of 2018 levels.	100% reduction	Carbon Budget 6 Balanced Net Zero Pathway
Impact: BMW to landfill reduction	**Percentage reduction per year***	20% / 10%	
**equated to a reduction in $CO2eq$ emissions based on assumption of how the diverted BMW waste is treated*			

It was noted during our research that the waste industry views the target to divert 100% of biodegradable waste from landfill by 2025 to be extremely challenging. A scenario within the Carbon Budget 6 provides a further 5 years to achieve this by 2030. The impact will be through a reduction of landfill emissions measured in tonnes of CO_2eq. Assumptions on the treatment processes for the diverted BMW material have been applied to the modelling e.g. assume a proportion of reduction comes from prevention action and of the remaining portion, 50% is treated through AD / composting facilities and 50% through EfW facilities.

Carbon capture and storage at EfW plants

Table 27: Carbon capture and storage assumption

Assumption	Description / metric	Impact	Source data
Carbon Budget 6 Net Zero roadmap assumptions to achieve 100% CCS on EfW plants by 2050 with scenario assumptions that fitting will start in late 2030's. Assume new plants will be built with CCS already fitted.	Linear reduction to 2050. Assume 2035 start year.	100% by 2050	Carbon Budget 6 Balanced Net Zero Pathway Catapult report May 2020
Impact: Reduction in CO_2eq emissions	**Percentage reduction per year**	6.25%	

The assumptions on the rate of installation set out above are the first stage in the calculations for modelling impact on carbon emissions. The second stage involves calculating and applying an assumed capture of CO_2eq per EfW plant from the CCS installation. Catapult's report: Energy from Waste Plants UK with Carbon Capture, May 2020 calculates the potential for 94% capture by plant.

5.2.4 Scenario 3: Planned Progress Plus (PPP)

Scenario 3 builds on scenarios 1 and 2, incorporating the assumptions from the BAU scenario and uplifting the performance assumptions from scenario 2, PP, with the objective of modelling more ambitious performance than current targets and policy intend to achieve.

Table 28 below sets out the assumed performance enhancements by measure.

Table 28: Performance enhancements in the PPP scenario

Measure	Enhancement assumption	Impact
Food waste prevention	Reduction 2018 - 2025 and 2025 to 2030 from -1.7% to -2% per year.	-2% per year
Food waste collections – all local authorities	Increase yields per household.	64% increase from 2018/19
Food waste collections – all appropriate businesses	Increased capture of food-producing portion of C&I waste arisings to 30% in 2025 and 35% in 2030.	plus 5% in 2025, plus 5% in 2030
Deposit return schemes	Improvement on target performance by 3% per target material.	3% increase
EPR packaging waste	Improvement on each target year performance by 2% to 72% and 73%.	additional performance of 2% in 2025, and 2% in 2030
Landfill methane capture	Increase in the capture rate	16% increase

The performance uplifts are calculated using the following assumptions:

- Food waste prevention – actual performance between 2015 and 2018 saw a 2% reduction per year in total UK post-farm food waste, which is an improvement on the Courtauld target, hence prevention in this scenario has been enhanced in line with these levels.
- Food waste collections all local authorities – current performance has been analysed to show kg/household/week and compared against WRAP's food waste Ready Reckoner, which provides a range of low, medium and high capture assumptions. The PPP enhancement has been calculated by increasing capture by 25kg/household/week in line with the Ready Reckoner.
- Food waste collections all appropriate businesses – current recycling performance for the food producing portion of C&I waste has been increased by 5% for each target year.
- Deposit return schemes – the target to recycle 85% of eligible containers by material stream is already ambitious based on current performance, therefore the enhancement achieves an additional 3% by material stream to achieve 88% recycling.
- EPR packaging waste – applies an enhancement of 2% recycling performance over and above PP for the target years in 2025 and 2030.

5.2.5 Scenario 4: Enhanced Reduction & Diversion

Scenario 4 provides a standalone set of measures that investigate the impact of enhanced reduction and diversion activities that focus on waste prevention, energy efficiency and emissions reduction measures. The measures and assumptions are set out below.

Circular Economy - enhanced waste prevention

Table 29: Enhanced waste prevention assumption

Assumption	Description / metric	Impact
1% reduction in waste generation year on year for Household & C&I waste; 1.4% reduction in C&D waste year on year.	Linear reduction to 2040.	1% reduction year on year; 1.4% reduction year on year.
Impact: Reduction in waste arisings		

The adoption of circular economy business models leading to a reduction in waste arisings includes such initiatives as the sharing economy, leasing, repair and remanufacturing and have been adopted by the Welsh and Scottish Governments.[26][27] The assumptions on the reduction in waste arisings have been derived from these adopted Waste Prevention Targets by waste stream. England's Waste Prevention Plan 2013 was reviewed in 2020 and an updated plan is yet to be adopted.

Electrification of waste transport

Table 30: Electrification of waste transport assumption

Assumption	Description / metric	Impact
That a 25% switch to electric vehicles would be achievable by 2040; assume diesel replacement with electricity drawn from the National Grid.	Linear reduction to 2040. Assume 2020 start year.	25% reduction in diesel emissions from 2018 levels.
Impact: Reduction in fossil fuel consumption.		As above

The assumptions for decarbonising waste transport have been derived from case study research of proposals to transition waste collection services from diesel to electric vehicles. Our assumption is conservative at 25% and allows for a proportion of vehicles to remain using diesel that would be more challenging to convert based on the weight of the vehicles and the distance travelled against the performance range of current electric batteries.[28]

Transfer station emissions savings

Table 31: Transfer station savings assumption

Assumption	Description / metric	Impact
That a 25% switch to electric vehicles would be achievable by 2040; assume diesel replacement with electricity drawn from the National Grid.	Linear reduction to 2040. Assume 2025 start year.	25% reduction in diesel emissions from 2018 levels.
Impact: Reduction in fossil fuel consumption.		

The analysis of the baseline emissions reveals that 85% of emissions from transfer stations derive from diesel usage. Our assumption is that diesel is predominantly used by vehicles and other on-site plant and equipment and that 25% switch from diesel to electric could be achieved based on research of currently available electric plant and vehicles.[29]

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[26] https://www.zerowastescotland.org.uk/sites/default/files/ZWS1444%20ZWS%20Corporate%20Plan%202020%20UPDATE.pdf
[27] https://gov.wales/sites/default/files/publications/2019-05/the-waste-prevention-programme-for-wales.pdf
[28] https://www.commercialfleet.org/news/truck-news/2020/11/30/councils-convert-refuse-vehicles-to-battery-power
https://www.oxford.gov.uk/news/article/1488/oxford_to_trial_all-electric_refuse_collection_vehicle_to_further_zero_emissions_ambitions
https://www.veolia.co.uk/press-releases/veolia-trial-electric-refuse-collection-vehicles
[29] https://www.jcb.com/en-gb/products/mini-excavators/19c-1e
https://www.mantracgroup.com/en-uk/api/new-products/7295-electric-rope-shovel/#0
https://vertikal.net/en/news/story/35463/all-electric-truck-crane

Recycling processes efficiency savings

Table 32: Recycling savings assumption

Assumption	Description / metric	Impact
Energy efficiency savings implementation.	Linear reduction to 2040. Assume 2020 start year.	2% reduction per year.
Impact: Reduction in fuel and electricity consumption.		

The assumptions for efficiency savings at recycling processes plants stem from research of Sustainability Policies and contact with the major UK-based reprocessors for paper and card, aluminium, glass and plastic. A 2% reduction per year in energy use is modelled which takes account of incremental energy efficiency measures (such as installation of LED lights, latent heat recovery) of the kind that would be considered for other manufacturing processes.

5.3 Modelling scenarios in the Net Zero tool

Using Ricardo's Net Zero tool, we have modelled the impact of each scenario separately. The tool does allow scenarios to be combined as additional scenarios if required. As grid decarbonisation is built into all scenarios, the logical progression would be to consider the impact of combining either Planned Progress or Planned Progress Plus with Enhanced Reduction and Diversion. The tool also provides the functionality to analyse the measures based on the two GWP timeframes set out in section 3.7.4 above over 20 and 100 years. For the purposes of this project we have displayed the results below for GWP100.

It is noted that target dates for the modelled measures aligned to the Resources and Waste Strategy are projected up to 2030 for modelling purposes and we have assumed a flat performance beyond 2030 for these measures. The impact is that waste growth, which continues to 2040 begins to impact on the reduction in emissions from applying the measures in the absence of any other mitigating interventions. Where we have modelled measures relating to increased recycling we have assumed that the target materials will be diverted from landfill and EfW principally and have therefore applied a change to the emissions factors for these facilities to reflect the change in residual waste composition. Reductions in transport emissions have not been modelled, as it is likely that a proportion of the prevented waste will still require transportation e.g. to reuse, repair or remanufacturing facilities, but we have assumed these materials would no longer arise within the waste stream.

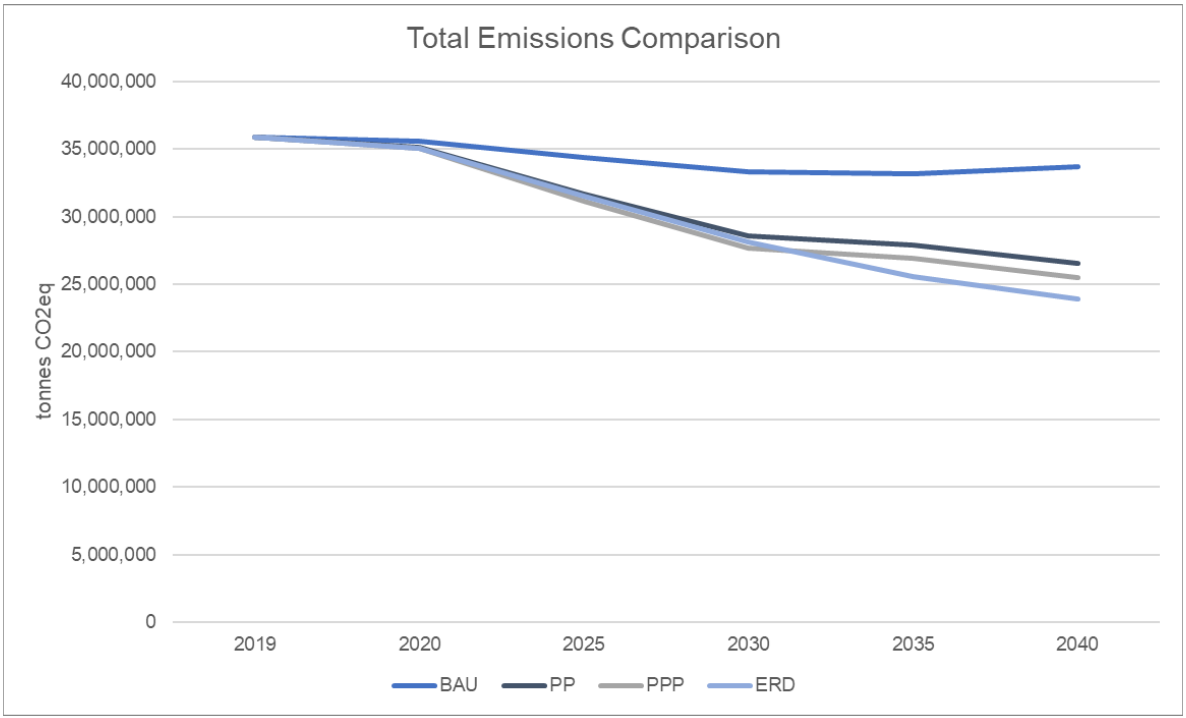
5.4 Results and analysis

This section sets out key results from the modelling of scenario measures using Ricardo's Net Zero Tool. For reference the scenarios compared are:

- Business as Usual (BAU)
- Planned Progress (PP)
- Planned Progress Plus (PPP)
- Enhanced Reduction and Diversion (ERD)

Figure 17 presents the progress of the GHG emissions until 2040 and compares the baseline against the four modelled scenarios. The ERD scenario shows a steady decline in the GHG emissions, due to the implementation of measures that are developing until 2040, while the PP and PPP scenarios have a two-step decrease, with a more steep decline until 2030, as a result of actions to meet proposed targets by the target dates. Following 2030 modelled waste growth begins to reduce the impact of those measures in the absence of new targets. The largest savings in the GHG emissions until 2030 are achieved under the PPP scenario, which includes enhanced performance on modelled interventions.

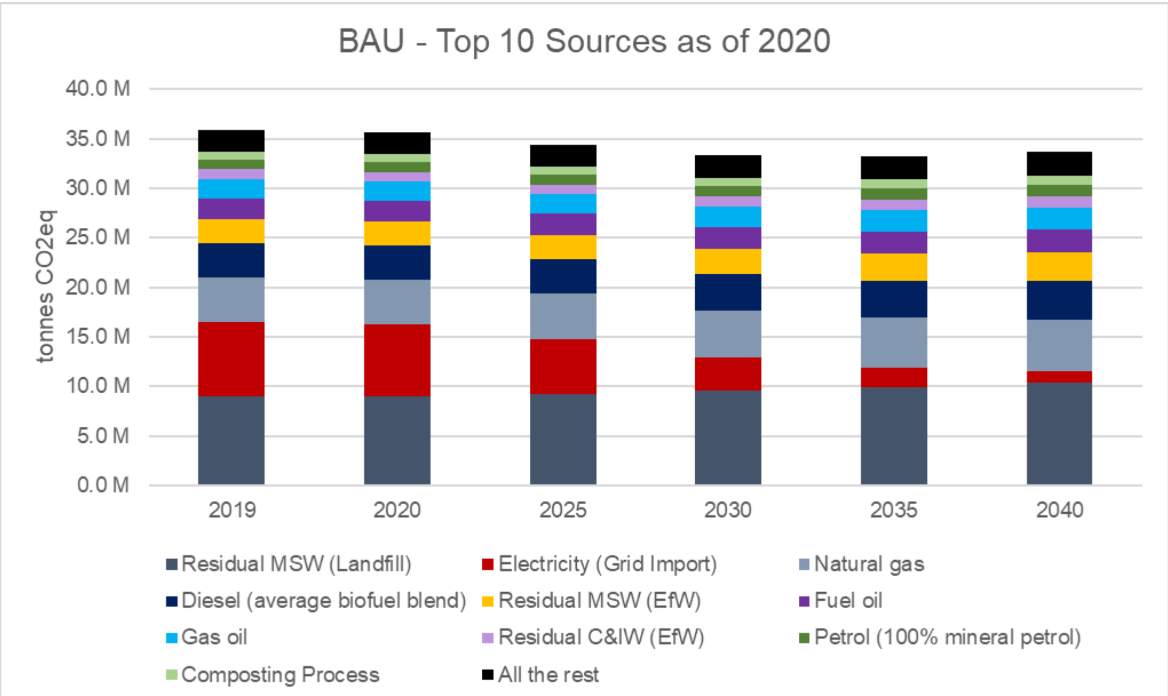
Figure 17: Comparison of emissions between the baseline and the three scenarios



5.4.1 Business as Usual

In the BAU scenario, the GHG emissions are decreasing until 2030, as seen in Figure 18. This effect can be attributed to the decarbonisation of the electricity grid, which is the second top contributor in the emissions. Between 2020 and 2030, the GHG emissions from electricity drop by 54%, which cancels out the increase in emissions due to waste growth. However, after 2030, the impact of the waste growth begins to increase emissions following completion of the planned electricity grid decarbonisation measures.

Figure 18: Emissions timeline with top 10 contributors - Business as Usual scenario



5.4.2 Planned Progress

In the Planned Progress scenario, a decrease of 26% on 2019 levels of GHG emissions is achieved by 2040. As seen in Figure 19, the main components of this reduction are the decrease in residual waste tonnages managed in landfills or EfW facilities achieved by reducing food waste arisings, diverting more materials to recycling through increased collections of food waste, drinks containers (DRS) and packaging waste (EPR). The impacts from decarbonisation of the electricity grid are modelled throughout all scenarios.

Figure 19: Emissions timeline with top 10 contributors - Planned Progress scenario

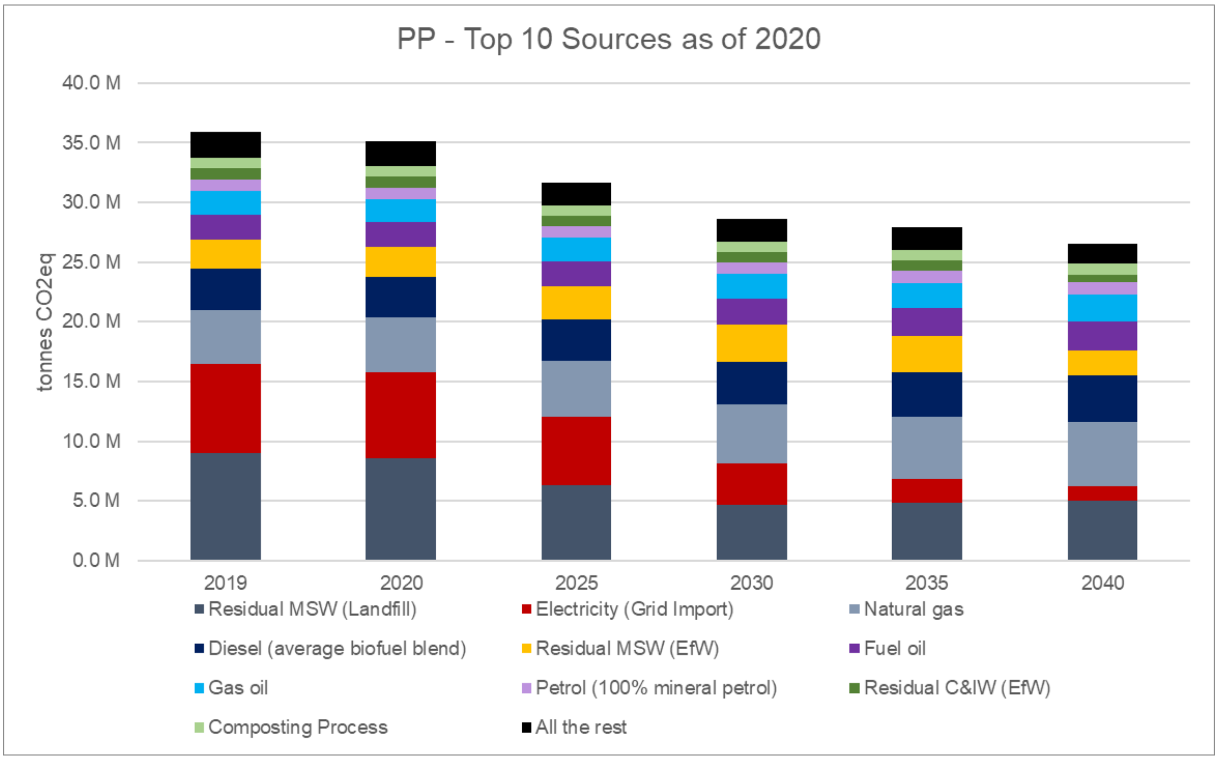
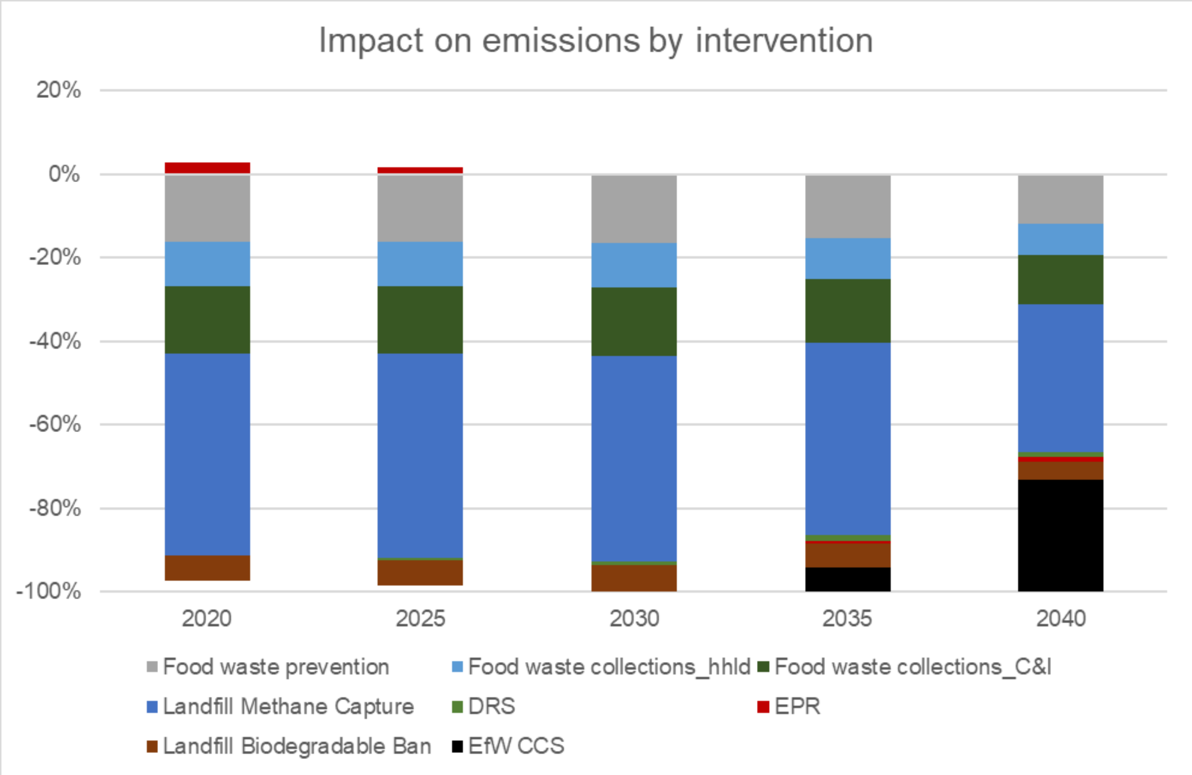


Figure 20 presents the impact each modelled intervention had on the reduction of GHG emissions. The largest savings are achieved with the increased landfill methane capture, followed by the food waste prevention in the early years. It is worth mentioning that CCS, despite being implemented in 2035, achieves 27% of the reductions in 2040. Also, it can be seen that until 2030, the introduction of EPR generates carbon emissions. This occurs because of the increased demand in electricity from the recycling plants processing the additional packaging material.

Figure 20: Impact on the GHG emissions by each intervention, PP scenario



5.4.3 Planned Progress Plus

With the implementation of the interventions modelled under the Planned Progress Plus scenario, a reduction of 29% on 2019 levels of GHG emissions is achieved in 2040. The decrease can be attributed to the same factors as for the PP scenario, as the same interventions were modelled. However, in this scenario, a further reduction is achieved due to the increased performance in comparison with the PP scenario.

Figure 21: Emissions timeline with top 10 contributors - Planned Progress Plus scenario

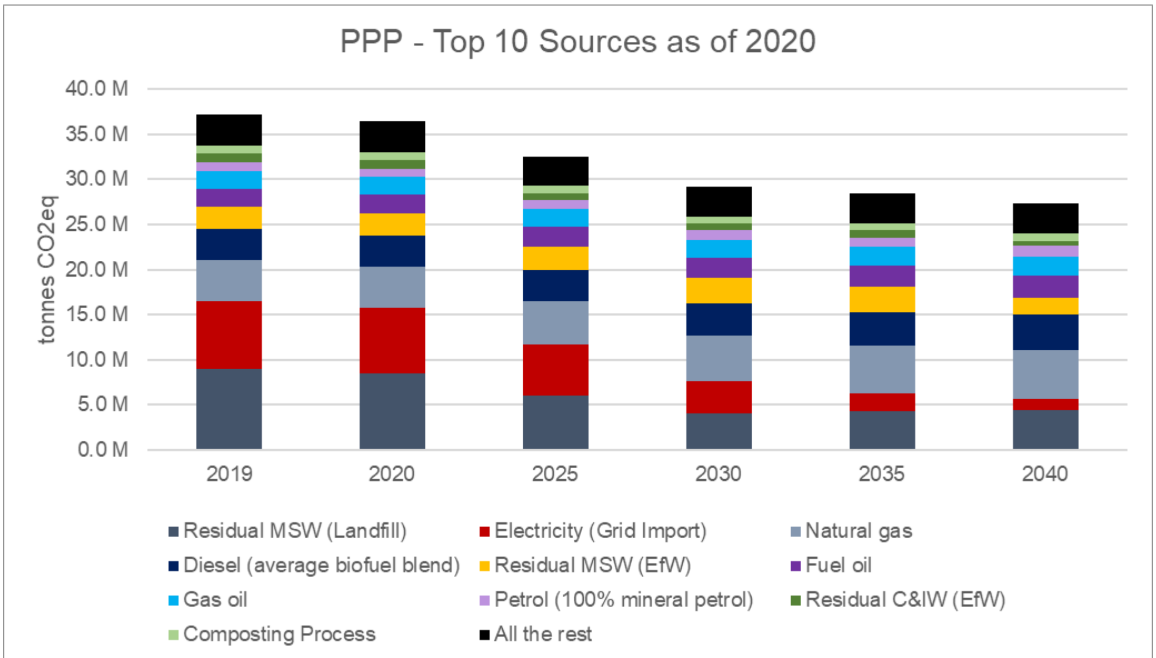
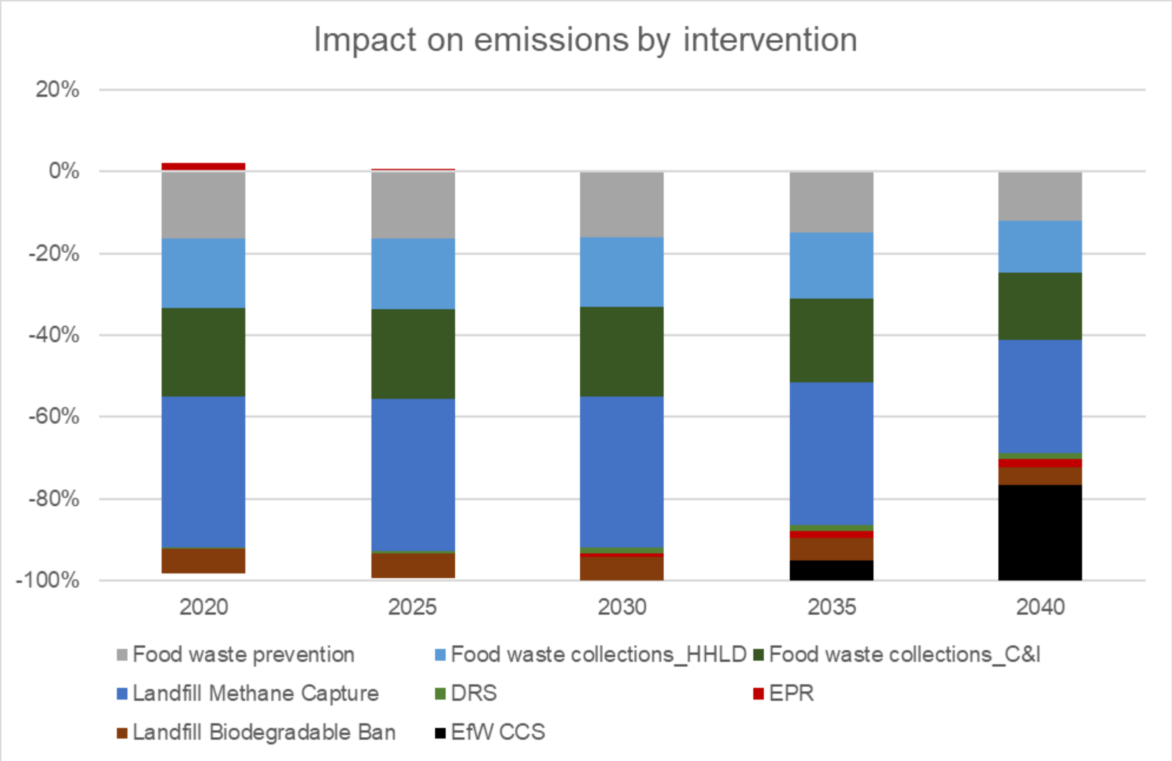


Figure 22 presents the impact each modelled intervention had on the reduction of GHG emissions. The largest savings occur with the same interventions as in the PP scenario. However, in the PPP scenario the EPR has a larger effect, due to the increased diversion of waste from the landfill and EfW facilities.

Figure 22: Impact on the GHG emissions by each intervention, PPP scenario



5.4.4 Enhanced Reduction and Diversion

In the ERD scenario, the reduction achieved in the GHG emissions is 33% of the 2019 levels. This scenario includes waste prevention measures, electrification of diesel-operated vehicles and increased efficiency in recycling process. The waste prevention measures result in reduction in emissions due to reduced residual waste being sent to landfill and EfW facilities. The largest savings are found in the decarbonisation of the electricity grid combined with the reduction in the electricity consumption from energy efficiency savings at recycling reprocessing plants. In addition, as seen in Figure 24, the waste prevention measure accounts for more than 50% of the reductions.

Figure 23: Emissions timeline with top 10 contributors - Enhanced Reduction & Diversion scenario

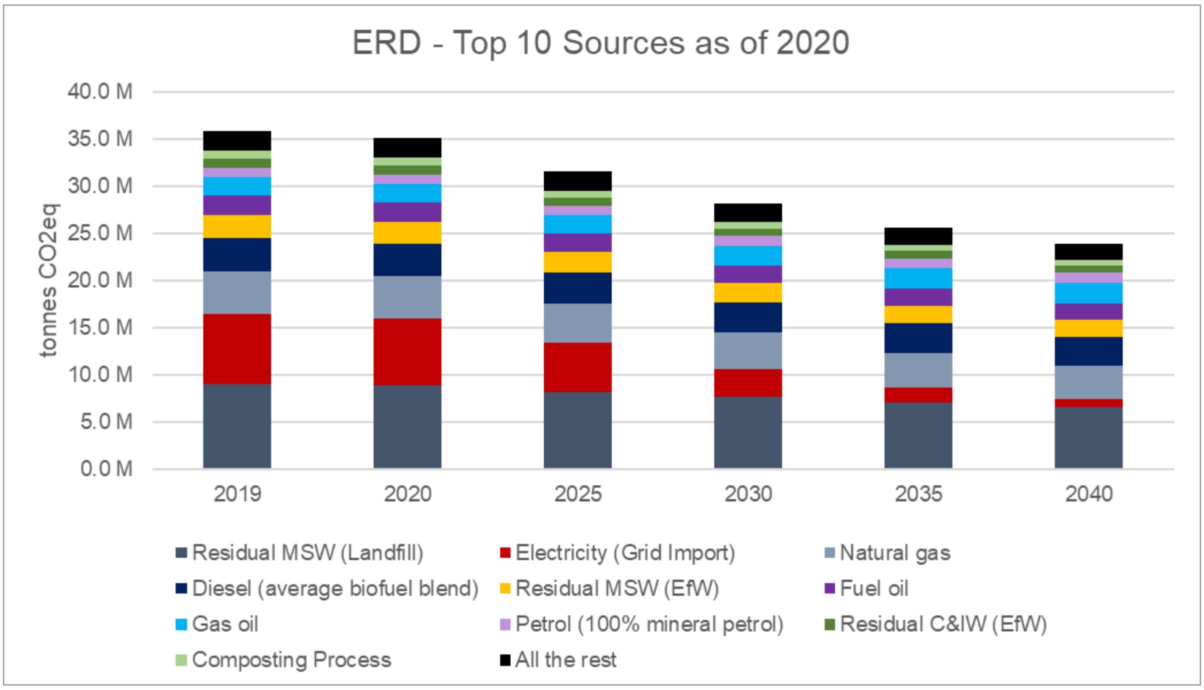
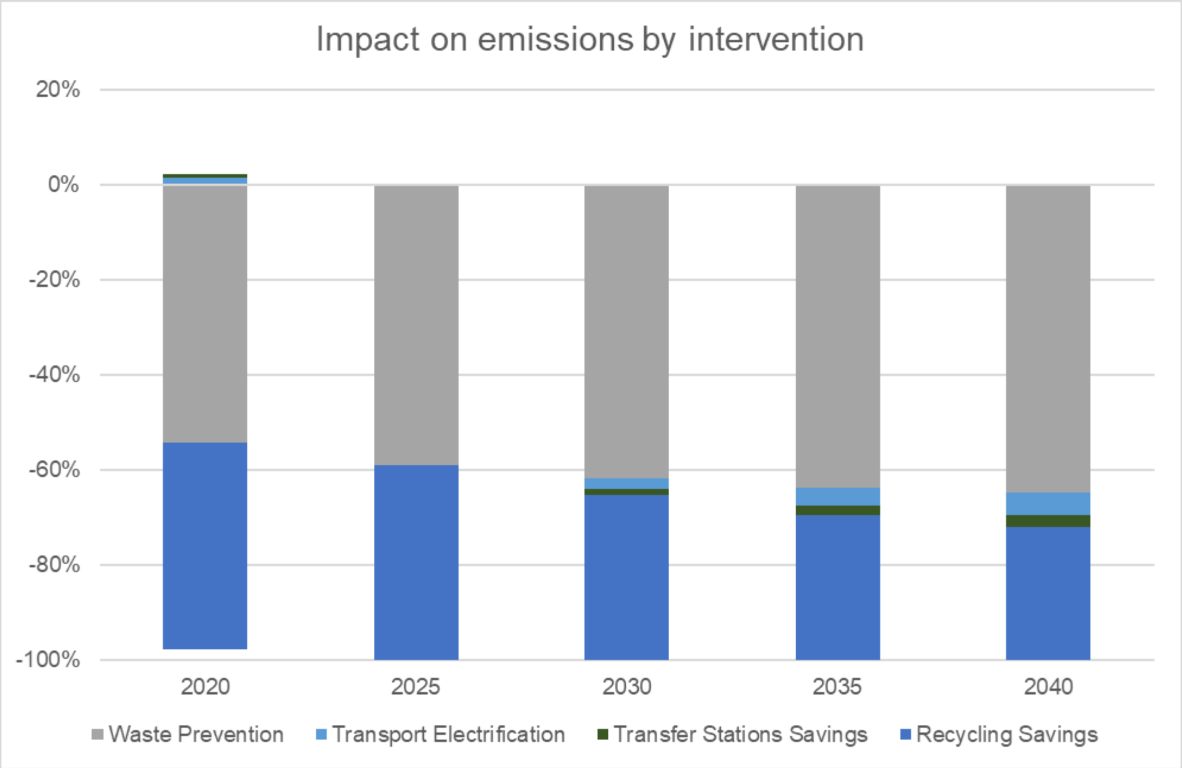


Figure 24: Impact on the GHG emissions by each intervention, ERD scenario



5.5 Sensitivities

Following an initial review of the scenario results, Ricardo undertook two sensitivity analyses to investigate how emissions could be reduced further with more ambitious action and measures. It was agreed with the ESA to build on the existing modelling, using the best performing scenarios and reviewing the assumptions. The two modelled sensitivities are:

- Combined Scenario 1: A scenario that combines the PPP and ERD scenarios,
- Combined Scenario 2: A second version of the combined PPP/ERD scenario with more ambitious assumptions.

5.5.1 Sensitivity Assumptions

Combined Scenario 1 retains the assumptions for each measure of the original scenarios. With the exception of waste prevention, these two scenarios contain complementary measures and hence in combination, they should improve on emissions savings. Food waste prevention was already modelled in the PPP scenario and so was excluded from the total waste prevention that was modelled in the ERD scenario.

Combined Scenario 2 retains the same measures, but the assumptions have been adjusted in the following way:

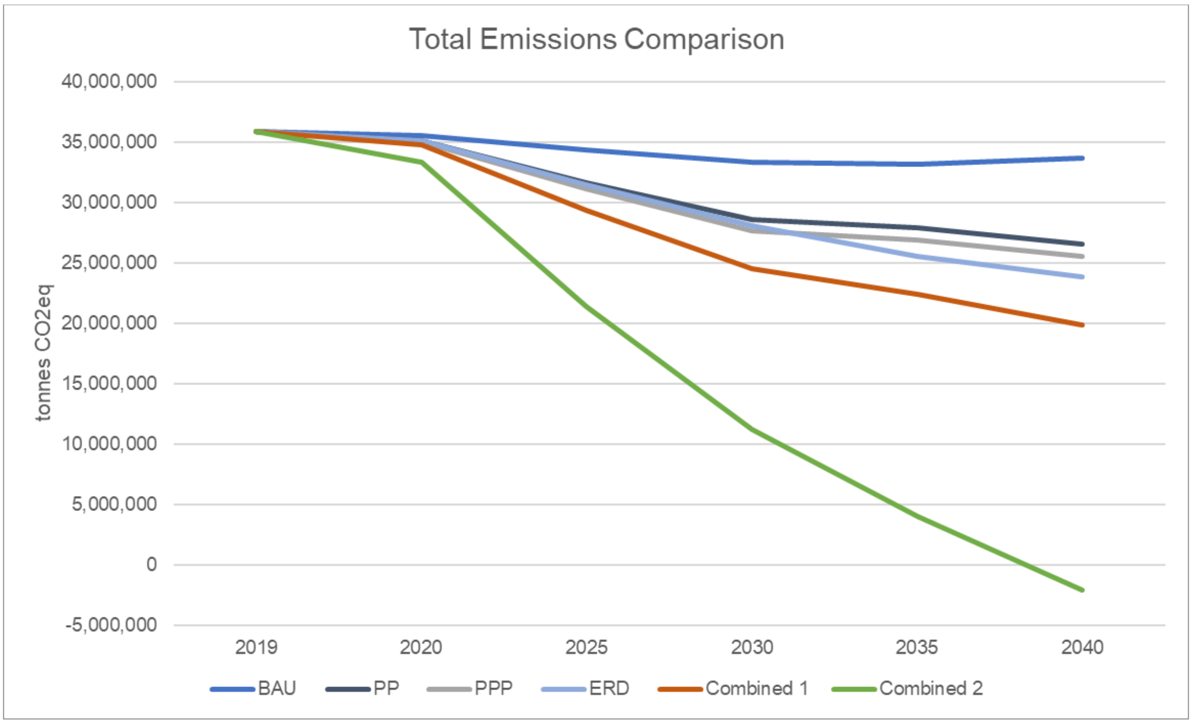
Table 33: Combined Scenario 2 assumptions

Measure Assumption	Metric
Electricity Grid: to be fully decarbonised by 2040	Requires an element of renewables
Transport: all vehicles to be net zero emissions by 2040	Switch diesel to zero carbon(green tariff) electricity by 2040
Transfer stations: all on-site vehicles to be net zero emissions by 2040	Switch diesel to zero carbon (green tariff) electricity by 2040
Recycling, Transfer Stations, MRFs, Composting, AD, EfW: all on-site fuels to be replaced with electricity	100% zero carbon (green tariff) electricity by 2040. The sector would need to set a target using a market-based approach to gain the benefit associated with using a green tariff.
EfW: remove plastics from residual waste stream	Plastic diverted to recycling processing plants
EfW: Bring forward CCS to start in 2030; with 100% capture by 2045	Linear reduction to 2045
EfW: CCS biogenic carbon as a separate measure	Reduction of the emissions by capturing the biogenic content of the waste streams
Landfill: Increase capture on landfill methane emissions	85% by 2030

5.5.2 Sensitivity Results and Analysis

Figure 25 presents the results of the two sensitivities that were modelled, reported here as two scenarios. The first scenario, in which the effect of the PPP and ERD scenarios on the emissions is combined, achieves a reduction of 45% on 2019 GHG levels by 2040. With the second combined scenario, in which more ambitious measures where modelled, the GHG emissions drop by 106% on 2019 levels, resulting in negative emissions.

Figure 25: Emissions comparison between the modelled scenarios and sensitivities



5.5.2.1 Combined Scenario 1

In the first combined scenario, the top contributors are the residual MSW being disposed of to landfill, the electricity used in the facilities and the fuels. However, over time and due to the impact of the modelled measures, the emissions from the top two contributors reduce and the fuels become the most significant GHG emitter.

Figure 26: Emissions timeline with top 10 contributors - Combined Scenario 1

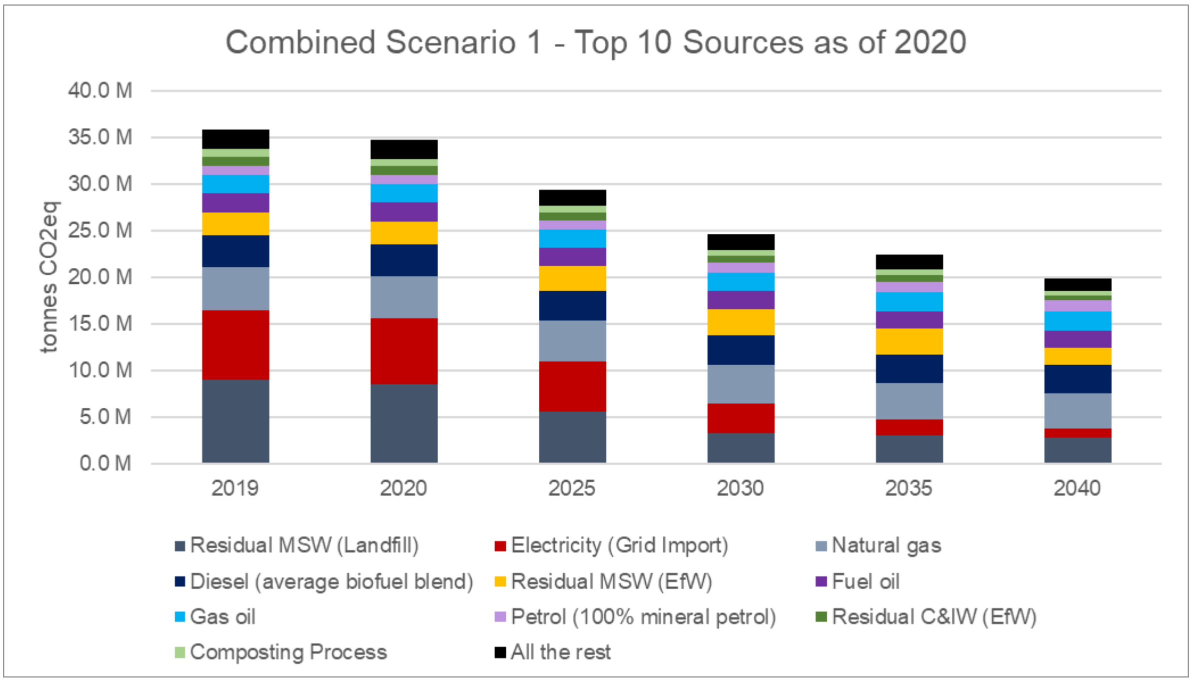
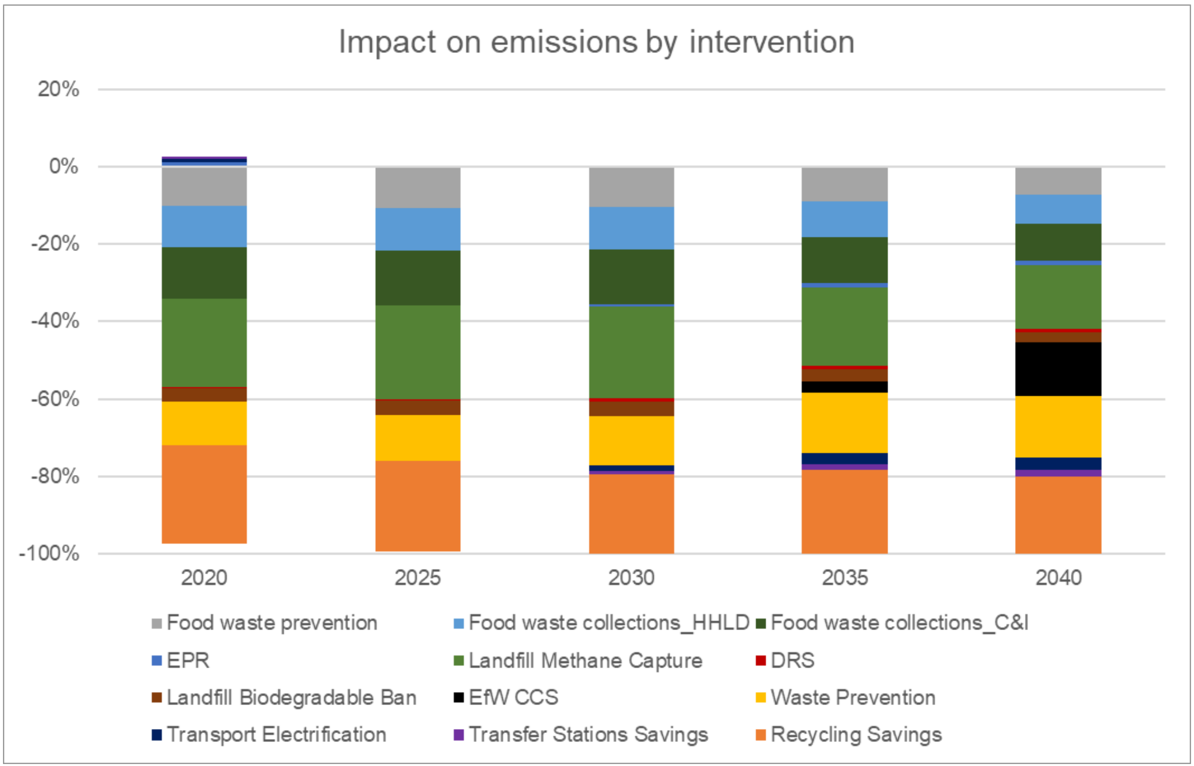


Figure 27 illustrates the impact of each measure on the GHG emissions. Starting in 2020, the largest savings are achieved by the recycling process savings, which result from efficiency savings in recycling plants thereby reducing the amount of fuels and electricity required by the recycling processes. The next largest savings are due to increased capture of methane in landfills, followed by increased C&I food waste collections and efforts to prevent waste generation. Moving towards 2040, the CCS in EfW also provides significant savings. It is worth mentioning that the measure to electrify transport in collections and transfer stations still continues to produce emissions in 2020, due to the impact of grid electricity and how that electricity is generated. As the grid is decarbonised, these emissions are reduced, gradually leading to negative emissions from 2025 onwards.

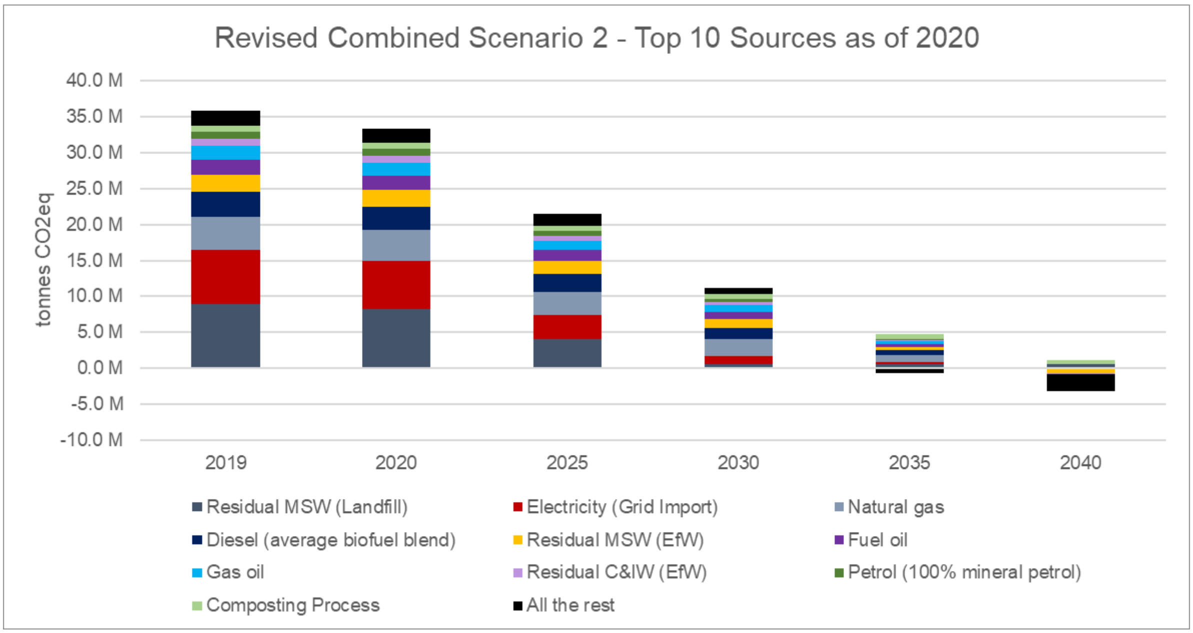
Figure 27: Impact on the GHG emissions by each intervention, Combined Scenario 1



5.5.2.2 Combined Scenario 2

In the second combined scenario, the top contributors in 2020 broadly follow those of the first combined scenario. However, as more ambitious measures are applied, the emissions drop significantly, with residual waste sent to landfill and emissions from the composting process constituting 74% of the GHG emissions in 2040.

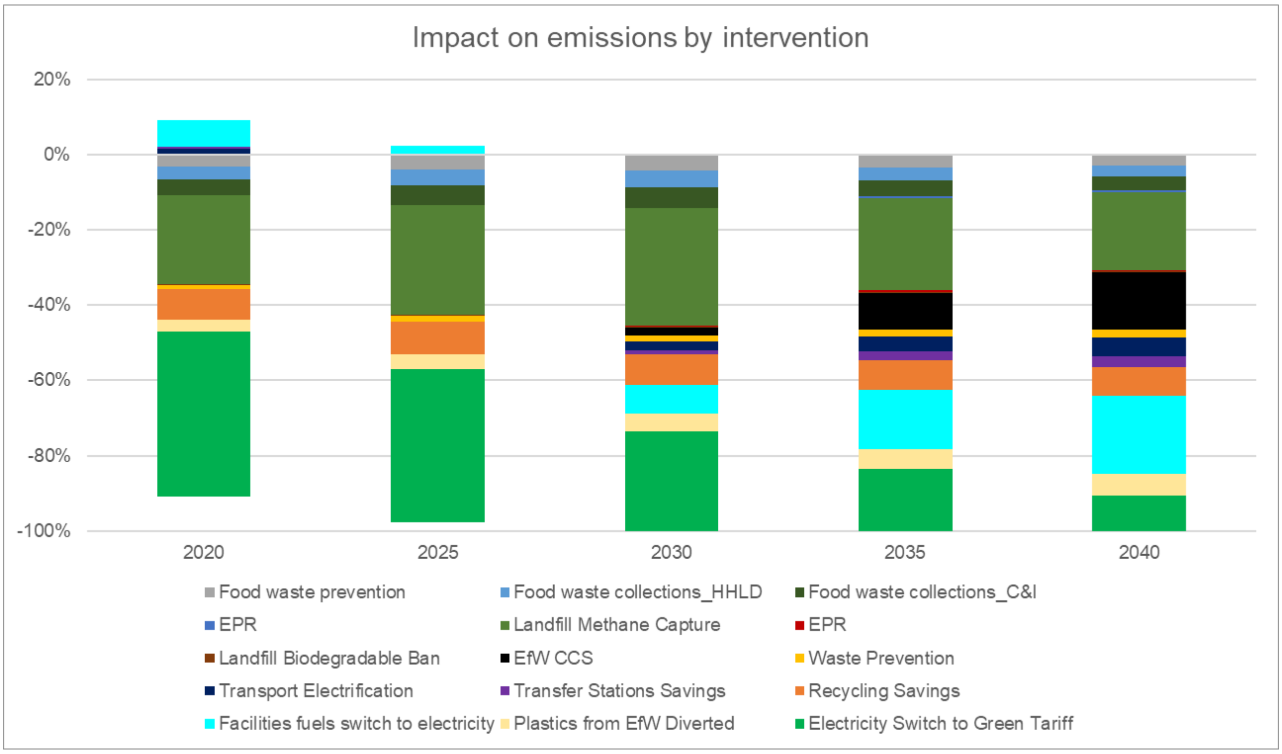
Figure 28: Emissions timeline with top 10 contributors - Combined Scenario 2



In the revised Combined Scenario 2, the largest savings are achieved due to the switch of the electricity to a green tariff by 2040 and the improvements in landfill methane capture. In 2020, due to the electricity grid emission factor, the switch of all the fuels to electricity still continues to produce emissions. However, as the grid is decarbonised over time, the substitution of fuels with electricity results in the largest savings in 2040, at 21% of the total. CCS provides a further significant saving of 15% on emissions. In this scenario, the “Plastics from EfW Diverted” measure includes the diversion of plastics from EfW facilities resulting from the implementation of DRS and EPR, as this allows to show the impact of diverting plastics with a variety of policies. It should be noted that certain measures that may be expected to generate higher savings, namely a ban on biodegradable waste to landfill, in this scenario accounts for less than 1% of savings. This is principally due to assumptions applied to the scenario which divert biodegradable waste away from landfill through other measures i.e. waste prevention (amounting to almost 5% of emissions savings) and increased food waste collections, amounting to 7% of emissions savings for both household and commercial waste combined.

Figure 29 below details the impact on emissions that is contributed by each modelled intervention.

Figure 29: Impact on the GHG emissions by each intervention, Combined Scenario 2



6 Task 4: Assess the ambition of the 2040 Net Zero target

This task aimed to provide an assessment of whether a target to achieve Net Zero by 2040 is achievable or indeed sufficiently ambitious. We understand the backdrop of this assessment lies in the UK Committee on Climate Change's (CCC) recommendation to set a target for the UK to achieve net zero greenhouse gas emissions by 2050. The analysis of the scenarios in section 5 reveals that the UK recycling and waste sector will continue to produce significant GHG emissions all the time that waste is being produced, managed and treated. To some extent, the waste industry is in a tricky position, in that it is expected to deal with whatever waste the UK economy creates, and it has little actual control over those arisings. The biggest possible contribution to reducing emissions in the sector comes from reducing waste arisings, but this is not within its control.

A further significant challenge is that, within its own system boundary, the waste and recycling sector could (simplistically) minimise its processing carbon emissions by incinerating all biogenic waste and landfilling everything else. Whilst this would still not achieve Net Zero, it reflects that sorting, digesting, composting and recycling materials is energy and therefore carbon intensive. However, these actions produce materials that significantly reduce manufacturing impacts in other sectors of the economy. Table 4 concludes that total Scope 1 and 2 emissions from the waste sector amounted to ~36Mt CO_2e in 2018. However, Table 7 reports that ~45Mt CO_2e are currently avoided by creating materials and energy from the handled waste that therefore does not have to be made by more polluting means. We fully understand why the Greenhouse Gas Protocol Standards do not allow discounting and are not suggesting that the Standards be challenged. Rather, there is a very compelling narrative here for the waste and recycling sector to convey, to explain its already significant contribution to a Net Zero United Kingdom. Moreover, it is clear that the sector is simultaneously playing a critical role in achieving a circular economy.

Of the scenarios that we have examined in this study, when looked at in isolation, each one does not reduce emissions sufficiently to meet ESA's objectives. Combining the PPP with ERD scenarios improves on the reduction in emissions, however, without considering significant changes in assumptions, the sector will struggle to achieve Net Zero on any timeline. Combined Scenario 2 models the most ambitious assumptions and by 2040, the emissions have been minimised to such an extent that this has led to savings of 2Mt CO_2e. By 2040, the total emissions have dropped to 1.5Mt CO_2e, with landfill accounting for 872 kt CO_2e, composting for 557 kt CO_2e and 100 kt CO_2e arising for EfW and AD facilities. If we follow the trajectory beyond 2040 to 2050 the savings could be as great as 4Mt CO_2e, due principally to the impact of increased carbon capture through the additional CCS installations.

The key actions to reducing fossil fuel emissions involve transitioning to renewable energy sources for transport and facility fuel use (to tackle emissions generated from handling and processing waste) and diverting waste from landfill and EfW to reuse and recycling. However, recycling reprocessing facilities will continue to produce significant and growing energy demand emissions as more waste is collected and separated for recycling purposes. The key is to source this energy from 'green tariff' renewable sources, be it on-site or off-site (grid) generation sources. Relying on the current grid decarbonisation trajectory (BEIS projection shown in Figure 16) will not be sufficient on its own to realise the savings of Combined Scenario 2. Further research to understand in more detail how reprocessing facilities use energy and how that energy could be replaced with renewables, would shed more light on the potential to reduce emissions from these processes. By contrast, carbon capture from EfW plants has the potential to reduce the sector's total emissions significantly. Adopting an ambitious policy that brings forward (i.e. before 2030) the retrofitting of CCS units to existing EfW plants and ensures all new and planned facilities are fitted with CCS units as standard, is the single biggest gain the industry can influence to its own infrastructure.

Ricardo's work with other sectors can be used as a comparator for assessing the waste sector's ambition. An example is our current work with the Water Industry, which is responsible for 2% of the total UK GHG emissions, in comparison to the waste sector's 5% contribution to UK GHG emissions. In 2019, the water sector made various commitments to achieving net zero emissions, including a Public Interest Commitment to achieve net zero for operational emissions by 2030, twenty years ahead of the UK Government target and 10 years ahead of the waste sector's target. The actions to achieve this do include significant off-setting measures, using carbon capture measures such as tree planting or other engineered carbon capture and storage techniques.

Therefore, if we reflect on the analysis provided in this study, we can see how the waste sector can make significant in-roads into its carbon emissions through reduction measures. However, it will hit an inevitable floor associated with underlying levels of material and energy consumption that will be extremely hard to reduce without ambitious measures being adopted by the waste industry itself and from other external industries that supply the waste industry. If these measures are not realised, the waste sector must turn to measures such as those proposed by the water industry, off-setting impacts by carbon capture techniques. Using these to entirely bridge the remaining gap to Net Zero will be extremely challenging, so we would suggest that the target to achieve that goal by 2040 is quite tough enough. To achieve that target any sooner will presumably involve significant investment in off-setting activities, but could perhaps be done if the industry decided that was important enough to merit the investment.

7 Conclusions

This report provides the ESA with primary analysis of the UK recycling and waste management sector's carbon emissions, by process, using the EpE tool and updated emissions factors. This work establishes the current waste sector's baseline and conducts a high-level evaluation of actions required to assist the UK recycling and waste management sector to achieve net-zero by 2040 at the latest. From the analysis undertaken our key conclusions are:

- Adopting circular economy principles and enacting effective waste prevention is the key to reducing emissions from all processes.
- The largest emissions derive from recycling processing plants (scope 1 and 2 emissions combined) and these are expected to increase with more materials collected for recycling.
- Landfill produces the largest direct (scope 1) emissions, followed by direct emissions from transport, EfW and transfer stations.
- Landfill and EfW emissions are expected to reduce as waste materials are diverted to recycling processing plants.
- EfW emissions have the potential to be significantly reduced by installing carbon capture and storage units and the impact will be greater, the earlier these can be installed.
- The bulk of emissions from transport and transfer stations derive from diesel use, which could be tackled through electrification of vehicle fleet, plant and equipment.

In line with the ESA's requirements, Ricardo's analysis provided high-level analysis using a range of data sources, extrapolation techniques and assumptions discussed with the ESA project team during execution of the project. We would recommend requesting waste operators to complete the EpE tool for the following year to allow progress to be tracked against this baseline analysis, although it may be a challenge to gather data from smaller waste companies and commercial collectors. Better reporting of C&I waste management collection and treatment processes would assist with more granular analysis of UK waste data sets.

The scenarios presented in this report form the beginnings of a Net Zero roadmap, which could be developed in more detail including consideration of accounting for off-setting measures and their relative contribution to achieving net zero. Understanding how emissions are generated from the various fuels and energy sources used, at each stage in the waste flow system would allow a more focussed approach to identifying and prioritising which mitigation measures to adopt. Ricardo's Net Zero tool has the functionality to run additional scenarios for both GWP20 and GWP100 timescales and can combine scenarios to demonstrate cumulative impacts within a Net Zero roadmap. To complement a roadmap, a Net Zero guidance document could also be developed providing guidance and tools for individual waste companies to develop their own action plans.

Finally, whilst not suggesting that the Greenhouse Gas Protocol Standards should be challenged, our analysis shows that the materials that the waste and recycling sector diverts already potentially more than offset all of its Scope 1 and 2 carbon emissions (avoided emissions). The sector should absolutely make every effort it can to reduce its own emissions, but it would also be perfectly justified in pointing to the already significant contribution it makes to a Net Zero United Kingdom, and a circular economy.

Appendices

A1 Appendix 1 – Data Bank

See separate document.

A2 Appendix 2 – GHG Emission Factors Review

See separate document.

A3 Appendix 3 – EpE tool

See separate file.

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