National Infrastructure Commission

National Infrastructure Assessment: Waste Infrastructure Analysis for England

Main Report

Report prepared by: Peter Scholes, Claudia Amos, Thomas Milne

Report Approved by: Susan Harris, Debbie Hitchen

Date: May 2018

Disclaimer

Anthesis Consulting Group PLC has prepared this report for the sole use of the client and for the intended purposes as stated in the agreement between Anthesis and the client under which this report was completed. Anthesis has exercised due and customary care in preparing this report but has not, save as specifically stated, independently verified information provided by others. No other warranty, express or implied, is made in relation to the contents of this report. The use of this report, or reliance on its content, by unauthorised third parties without written permission from Anthesis shall be at their own risk, and Anthesis accepts no duty of care to such third parties. Any recommendations, opinions or findings stated in this report are based on facts and circumstances as they existed at the time the report was prepared. Any changes in such facts and circumstances may adversely affect the recommendations, opinions or findings contained in this report.

National Infrastructure Commission Disclaimer

This report was commissioned as part of the evidence base for the National Infrastructure Assessment. The views expressed and recommendations set out in this report are the authors’ own and do not necessarily reflect the position of the National Infrastructure Commission.

National Infrastructure Assessment: Waste Infrastructure Analysis for England

(Reference: CCCC17A49)

Prepared for:

National Infrastructure Commission
5th Floor,
11 Philpot Lane
London EC3M 8UD

Report written by:
Peter Scholes, Claudia Amos, Thomas Milne

Analysts:
Hannah Dick, Beth Simpson, Nick Cuomo (Anthesis)
Nick Fellows (Fellows Environmental)

Quality Assurance
Analysis:
Peter Scholes, February 2018
Report:
Susan Harris, Debbie Hitchen, April 2018

Prepared by:

Anthesis Consulting Group
The Future Centre
9 Newtec Place,
Magdalen Road,
Oxford
Ox4 1RE

Email: contact@anthesisgroup.com
Website: www.anthesisgroup.com

Tel: 01865 250818
Fax: 01865 794586

Company registration: 08425819

May 2018

Anthesis Consulting Group

Anthesis is a specialist global sustainability services and solutions provider founded on the belief that sustainable business practices are at the heart of long-term commercial success.

We develop value-driven sustainability strategy which is underpinned by technical experience and delivered by innovative, collaborative teams across the world. We not only develop solutions for clients, but act as a delivery partner too.

We combine the reach of big consultancies with the deep expertise of our practice leaders from across the globe.

Anthesis

Executive summary

The purpose of this study is to inform the National Infrastructure Commission's (NIC) first National Infrastructure Assessment (NIA) due to be published in 2018. This report aims to inform the development of a best value waste management infrastructure investment strategy for England to 2050, by weighing the costs of material separation at source and different treatment/disposal pathways against the economic and environmental benefits.

It should be noted that this study does not provide recommendations as to the preferred option: rather, it is intended to provide the objective background information to enable the NIC to make informed decisions about the preferred route, when considered alongside other related infrastructure assessment studies. It should be noted that this study does not seek to comment upon variable externalities (such as the current public and political views around landfilling of plastic, or the rapidly changing situation in external waste markets such as China).

The aims of this study are therefore to:

- Highlight the potential capacity and gaps within the English waste infrastructure system from 2020 to 2050 by mapping material and waste flows of Local Authority Collected Waste (LACW) and Commercial and Industrial waste (C&I);
- Model a series of potential material separation options over the defined time horizon 2020 to 2050;
- Assess the costs and benefits of directing the separated waste streams down different treatment/disposal pathways.

The following summarises the methodology applied to this study and the results obtained.

What options were modelled?

In order to achieve the aims of the study, the following options were developed as scenarios to model:

- Materials segregation options were determined following consultation by the Commission with waste sector stakeholders. The selected material segregation scenarios were:
    - Food waste segregation at source: an increased tonnage of food waste is collected at source (from households and businesses) via separate food waste collections. The additional food waste is treated at anaerobic digestion (AD) facilities, producing combined heat and power (CHP) or biogas to grid (GtG);
    - Biodegradable waste segregation at source: in addition to the increase in separate food waste collection at source, the volume of garden waste (separately collected or collected mixed with food waste) and paper and card collected at source also increases, as does separately collected wood waste. The additional garden waste is treated at either in-vessel composters (IVC) or open windrow composting (OAW) facilities, paper and card is recycled and wood waste is recycled or energy recovered;
    - Plastics waste segregation at source: an increased tonnage of plastic is collected from source (either commingled with other dry recycling or through a separate collection) and recycled;
    - Plastics waste to landfill: this scenario is as with the previous plastics segregation scenario (i.e. source segregated plastics to recycling), with additional plastic removed from the residual waste stream through intermediate residual waste treatment facilities e.g. residual waste material recovery facilities (MRF). Therefore, a reduced volume of plastic goes to energy recovery and the additional

mixed plastic removed at the intermediate stage is landfilled rather than recycled. This scenario runs through an infrastructure pathway of energy from waste (EfW) capacity forecast at 2020 plus additional new heat and power (CHP) enabled EfW from diversion of the remaining residual waste from landfill;

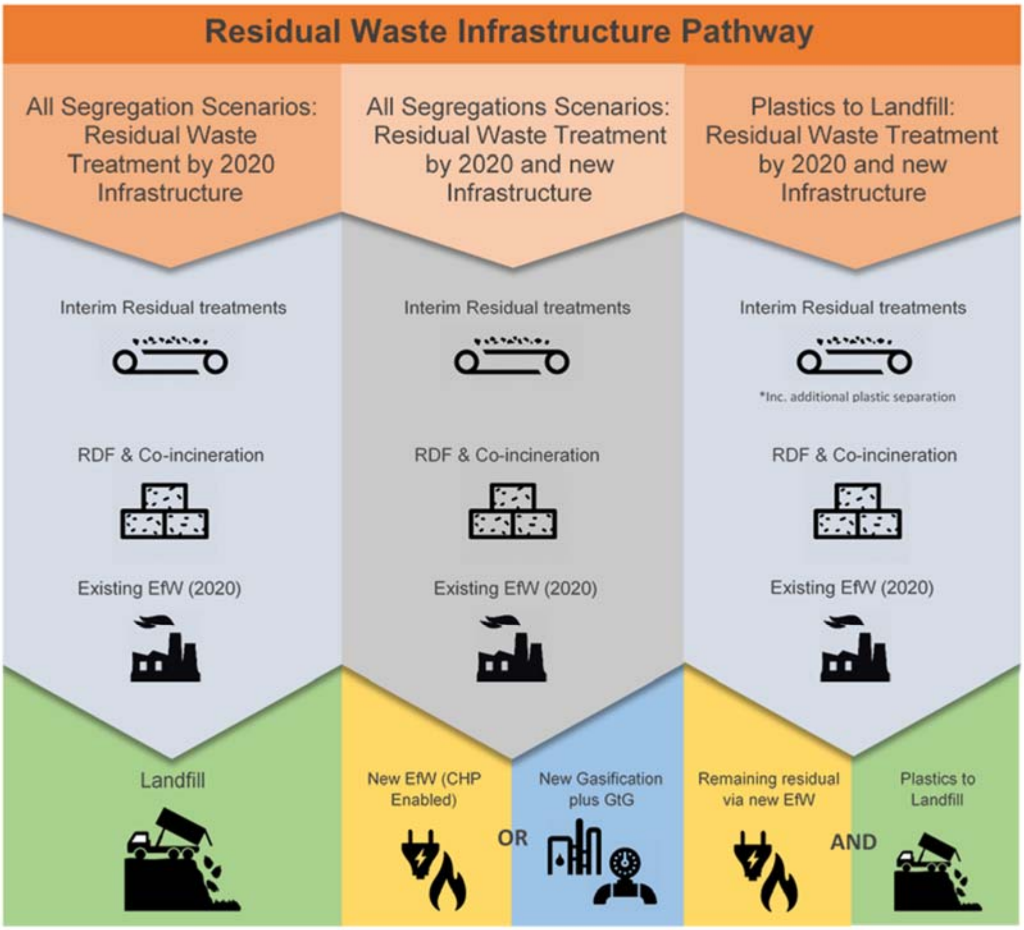
  - High recycling: Dry recyclates segregation at source to achieve EU Circular Economy (CE) recycling rates (i.e. 60% in 2030, 65% in 2035, applied to both municipal waste (as the CE targets) and C&I waste); the biodegradable materials (food, garden paper and wood) are collected as per the 'biodegradable waste segregation' option above and the volume of the remaining dry recyclate (plastics, metals and glass) collected from source also increases.

- Each segregation option was modelled through two residual waste infrastructure pathways:
  - Via the capacity of Energy from Waste (EfW) facilities forecast to be available in 2020, with the remaining volume going to landfill ("business as usual");
  - Via the EfW infrastructure available in 2020 plus diversion from landfill to new EfW capacity producing heat and power (CHP) or new gasification capacity producing gas to grid (GtG) to fill the capacity gap.

In both cases a fixed volume of residual waste was assumed exported as refuse derived fuel (RDF) and energy recovered via co-incineration i.e. at cement kilns.

These scenarios are explained in detail in chapter 4 of this report, and summarised in the figure below:

Figure 1: Modelled segregation scenarios and residual infrastructure pathways



Segregation scenarios were then modelled in terms of waste flows, capacity requirements, environmental impact and financial (cost benefit) impact for the forecasting period 2020-2050. The methodology used is explained in detail in Appendix IV to this report, along with assumptions made and data applied. This has been extensively stakeholder reviewed and quality assured.

Model Outputs

This report provides a summary of the outcomes from waste flow and environmental impact modelling and cost benefit analyses, which were evaluated to give a picture of the potential infrastructure requirements of the English LACW and household like C&I waste systems from 2020 through to 2050. The study does not extend to waste from other sources, such as construction and demolition wastes. This information can be used by the Commission to inform thinking about the required LACW and C&I waste infrastructure, the preferred route to decarbonisation, and the required physical, administrative and governance infrastructure required to achieve the desired outcomes.

Key outputs include:

- Waste flow, compositions and volumes per key waste and infrastructure type;
- New infrastructure forecasts based upon forecast demand;
- GHG impact of the new infrastructure pathways developed;
- Energy output forecasts as power, heat and where applicable, biogas or synthetic natural gas;
- Discounted capital cost and residual value[1] based upon new infrastructure requirements;
- Discounted operational cash inflow[2] and resultant Net Present Value (NPV)[3].

Results are reported as difference from baseline rather than absolute figures. Note that for the baseline, the cost of collection is greater than the benefit from treatment giving an overall negative NPV. Despite positive changes to this when modelling the range of segregation scenarios, all result in an overall negative NPV.

Overall Findings

- England is currently (2015 data) landfilling some 12.4 Mtpa of residual waste (LACW and household like C&I) and exports 3.2 Mtpa (2016 data) of refuse derive fuel (RDF). With landfill void capacity declining in some parts of the country, and landfill diversion of residual waste encouraged via landfill tax, energy recovery from residual waste is growing. This study estimates that 15.3 Mtpa of energy recovery capacity will be operational by 2020, meaning that landfill will be required for between 2.8 Mtpa and 4.2 Mtpa[4] of residual waste, unless alternative infrastructure is built;

---

[1] Residual Value is a measure of the additional benefits and costs infrastructure will deliver after 2050 until they reach end of life, as a measure of the value of these facilities at the end of 2050

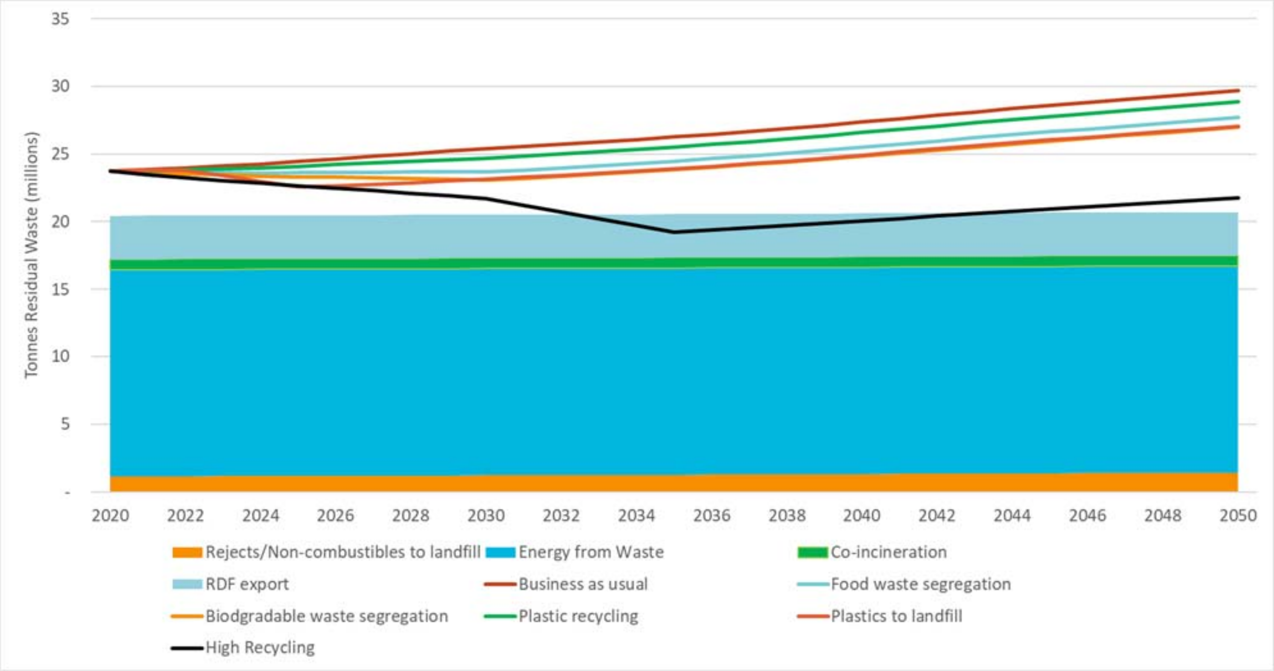
[2] Net Operational Cash Inflow is cash inflows (e.g. revenues from material sales, energy sales) less cash outflows (e.g. collection costs, operating costs, disposal costs)

[3] Net Present Value is a standard measure of the attractiveness of an investment, where the more positive the NPV, the more attractive the investment. Net Present Value (NPV) = Discounted Net Operational Cash Inflow – Discounted capital cost

[4] Assuming 3.2 Mtpa of RDF is exported and 0.8 Mtpa is recovered via co-incineration, and including losses from intermediate treatment including mechanical biological treatment (MBT)

- Projections relating to future infrastructure requirements are very sensitive to waste growth within LACW and C&I streams. If waste growth is high due to the impact of population and economic growth, and if waste infrastructure, excluding landfill, in 2020 is not expanded, then the gap between available residual waste treatment capacity and amount of residual waste produced could increase to as much as 16 Mtpa by 2050[5]. If waste growth is low due to the impact of waste minimisation, packaging weight reduction and other initiatives, this could be as low as 2 Mtpa;
- To further diversion of residual waste from landfill, most of the segregation scenarios modelled require additional residual waste treatment infrastructure. This is summarised in the following chart, taking a central forecast of available residual waste (i.e. average of high and low growth models) against each segregation scenario, compared to 2020 EfW capacity (plus RDF export, assumed volume to co-incineration and MBT rejects to landfill) across the forecast period (Figure 2):

Figure 2: Central forecast residual waste volume for each of the modelled segregation scenarios, compared to 2020 EfW infrastructure capacity, RDF and rejects/non-combustibles to landfill forecast, plus co-incineration volume assumptions.



Only with the high recycling scenario is there a risk of 2020 capacity exceeding demand for part of the forecast period, although this would be mitigated by the diversion of exported refuse derived fuel to domestic capacity. However, there is an estimated ~11 Mtpa of EfW capacity at various stages of development and yet to reach financial close. If all of these facilities are financed and built, and the waste growth experienced during the forecast period is central to low, there is a risk of overcapacity;

- Energy from Waste (EfW) generating both heat and power (i.e. CHP enabled) offers a prime option to fill this capacity gap because of its greater efficiency than EfW to power alone. Modelling suggests that the total output of heat and power from the expanded EfW network could be between 14 TWhpa to 32 TWhpa by 2050. However, the cost of heat distribution to respective users is outside the scope of this study and

---

[5] Assuming no change in recycling rate, 3.2 Mtpa of RDF is exported and 0.8 Mtpa is recovered via co-incineration

part of the national energy infrastructure assessment. Experience in the UK from the last 20 years has shown that sustainable heat demand can be difficult to find;

- Gasification with gas to grid (GtG) promises several advantages over traditional EfW in terms of cost and greenhouse gas (GHG as CO_2 equivalent) benefits, across a range of potential application options for the synthetic natural gas (syngas) generated; however, this technology is not commercially proven and recent experience with gasification in England has been problematic[6].

Studied Segregation Scenarios and Infrastructure Pathways

Results generated are compared to a baseline consisting of the anticipated recycling rate for 2020 (50% for LACW and 55% for household like C&I) and the expected infrastructure operational in 2020. All options studied are developments from this 'business as usual' baseline. Note that residual waste capacities quoted assume 3.2 Mtpa of RDF is exported for energy recovery – if not exported this would add to the England EfW capacity requirement. Modelling has shown:

- Food waste segregation at kerbside requires additional anaerobic digestion (AD) capacity of 1.1 to 2.7 Mtpa. It delivers positive GHG avoidance (from 15,615 to 27,098 tCO_2e in total 2020-2050) and economic NPV benefits (from £416 to £425 million). A potential barrier to this expansion in food waste processing may be the storage and land spread demand generated by the resulting digestate;
- Segregating all biodegradable waste at kerbside will require an additional food waste AD capacity of 1.1 to 2.7 Mtpa and up to 0.5 Mtpa MRF capacity due to the segregation of other recyclates. It provides similar overall GHG (17,776 to 37,224 tCO_2e) and NPV benefits (£53 to £338 million) compared to food waste alone;
- Increased plastic waste segregation at kerbside is forecast to require additional transfer station (0.5-1.2 Mtpa) and MRF (up to 0.6 Mtpa) infrastructure. It delivers a significant GHG benefit (36,488 to 41,812 tCO_2e) and a positive NPV (£808 to £927 million). This positive financial impact is, however, sensitive to the market value of the recycled plastics collected. These conclusions could be impacted if the use of bioplastics or renewable plastics increases over the forecast period;
- When including plastics separation for landfill, between 16.5 and 28.2 Mtpa of new residual waste separation facilities are required. GHG avoidance is significantly increased (115,134 to 219,713 tCO_2e) with landfill functioning as a carbon sink, but with a significant cost penalty (NPV -£5,878 to -£2,163 million). There are also potential degradation issues in landfilling plastics, although modern landfill design should be able to deal with this;
- High recycling requires an increase in MRF (1.5 to 3.3 Mtpa) and AD capacity (1.8 to 3.7 Mtpa). It delivers a significant GHG benefit (117,821 to 194,993 tCO_2e), and sizable cost benefits (£2,698 to £3,773 million). However, this economic impact is influenced significantly by recyclate selling prices so market volatility can impact on this negatively.

Relative performance of the scenarios modelled, compared to baseline, is summarised in the charts below. On the basis that an optimum scenario combines high GHG avoidance and high positive NPV benefit, these show the relative good performance of high recycling and plastic recycling options over those others modelled. However, all scenarios give better results than baseline. Plastics sent to landfill is an exception, with a negative NPV compared to the baseline, but the scenario has a high environmental benefit, second only to high recycling.

---

[6] For instance, the 2016 failure to commission 0.7 Mtpa of advanced gasification capacity in Tees Valley.

Figure 3: Plot of Central Growth GHG avoided against NPV with residual value, modelled scenarios using 2020 residual waste infrastructure CHP

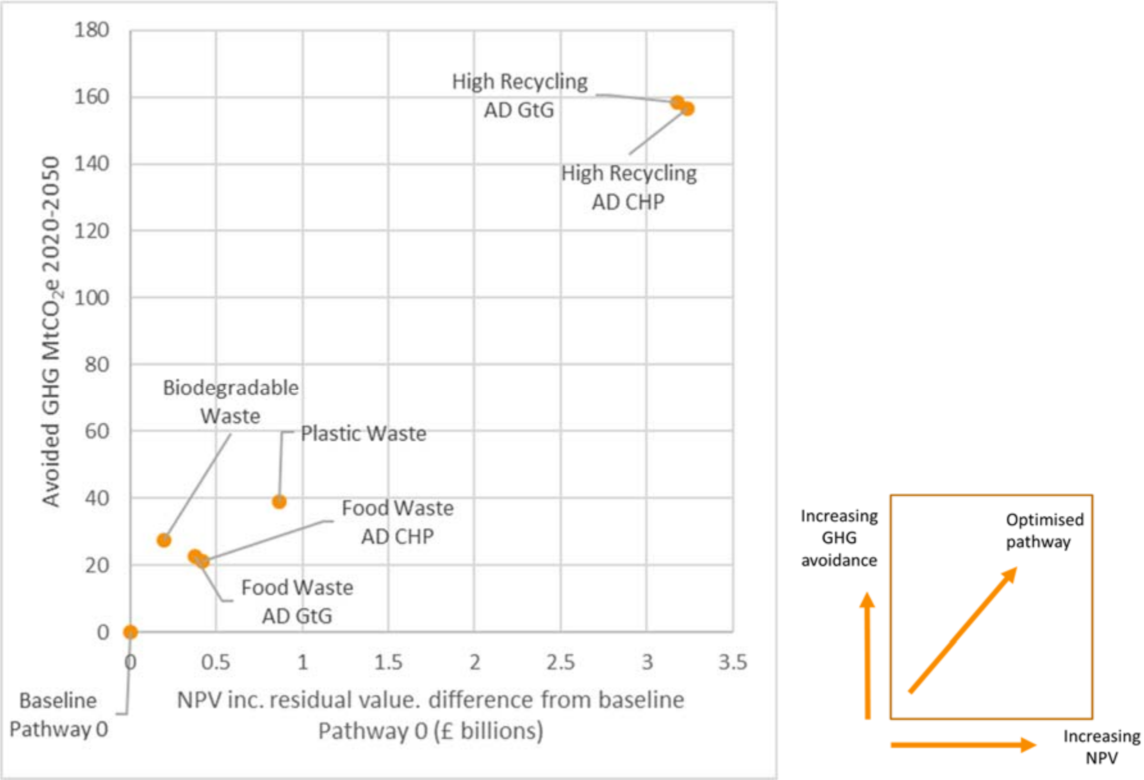
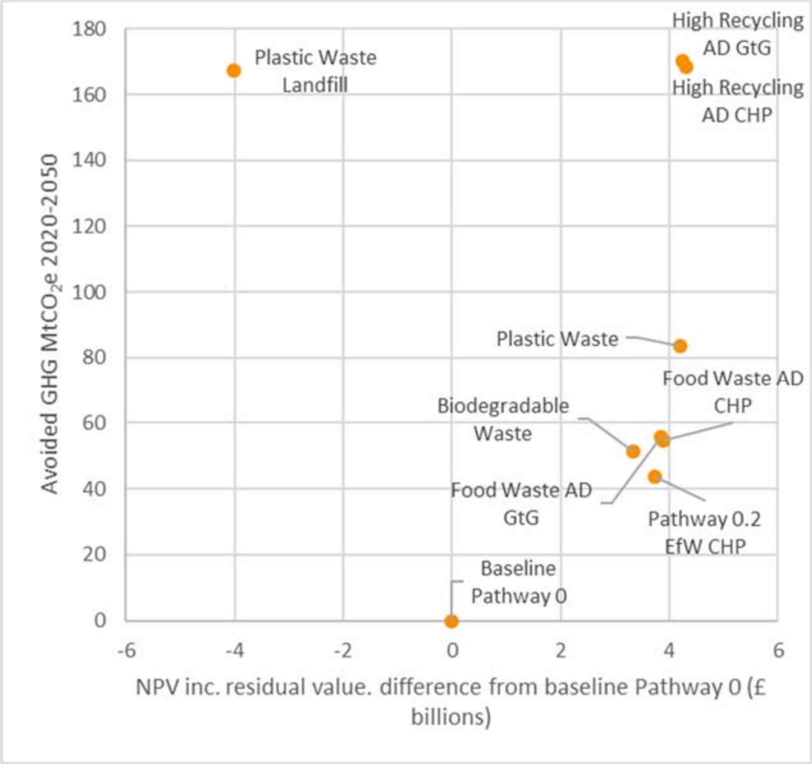


Figure 4: Plot of Central growth GHG avoided against NPV with residual value, modelled scenarios diverting residual waste from landfill to EfW with CHP (i.e. filled capacity gap)



Conclusions

Waste infrastructure in England that delivers high recycling and high GHG avoidance is predicated on a raft of government policies via taxation, subsidies and other financial interventions to produce a ‘financially net positive’ supply chain for LACW and C&I waste management services. Although a number of segregation options have been modelled which show benefits over the baseline (i.e. what is delivered now), all scenarios still deliver a negative overall NPV suggesting continued intervention in the sector is essential for its long-term viability.

This study has shown that key improvements to the existing infrastructure can be achieved by:

- Implementing collection infrastructure to increase segregation of materials for recycling, which has shown to be a key component in decarbonising the waste sector;
- Improvements in the energy efficiency of residual waste recovery, which is beneficial for all scenarios as it reduces the overall financial impact of all pathways and supports the decarbonisation of waste infrastructure.

The waste infrastructure modelling undertaken in this study needs to be considered within the wider context of national infrastructure assessments carried out for energy, transport etc., as well as in the context of the changing regulatory, economic and political framework. It should be noted that:

- Changes in residual waste composition through the increased segregation of materials at kerbside and residual waste volume can have a significant impact on energy production from residual waste. This impacts the efficiency of current energy from waste infrastructure as well as the need for new infrastructure. This impact on the use of energy from waste as an energy generation option needs to be considered carefully when developing future policy;
- The additional cost of building up England’s heat distribution infrastructure to take advantage of the higher energy efficiencies possible in using combined heat and power technology, is not included in the modelling. In this context, the option for gas-to-grid energy production from residual waste should be investigated further as this energy carrier will utilise an existing network and might provide better value for money outside of any considerations related to waste infrastructure. However, this technology needs to be demonstrated both technically and commercially before such advantages can be sought;
- Separating plastics from residual waste to send to landfill appears to deliver a substantial GHG reduction from carbon storage, but at a considerable cost. However, this is a complex and evolving picture given government action on plastics and the increase in the use of biopolymers and plastics made from biogenic sources. The full GHG effect has also not been considered in this study and landfill has mainly been applied as a carbon storage option without a detailed assessment of potential future environmental implications. Therefore, the impact of future changes in how plastics are used and how they are produced, on all stages of the waste management supply chain, requires more investigation;
- The scenarios based upon creating value through recycling of dry recyclates are impacted negatively by reductions in material pricing. Volatility in material prices in the last few years makes it difficult to forecast prices going forward;
- The modelling carried out for this study has shown that, irrespective of chosen residual waste options, the most beneficial waste infrastructure pathway options include:
    - increased organic waste recycling through the segregation of food and other biodegradable waste;

- increased plastics recycling via kerbside collection;
- and high recycling of a variety of organic and dry recyclable materials.

These options are preferred segregation routes, where material segregation takes place at source via single material or co-mingled kerbside collection and therefore doesn't require extensive residual waste processing infrastructure to segregate additional materials from the residual waste stream.

Figure 5: Summary of Study Conclusions (central scenario)

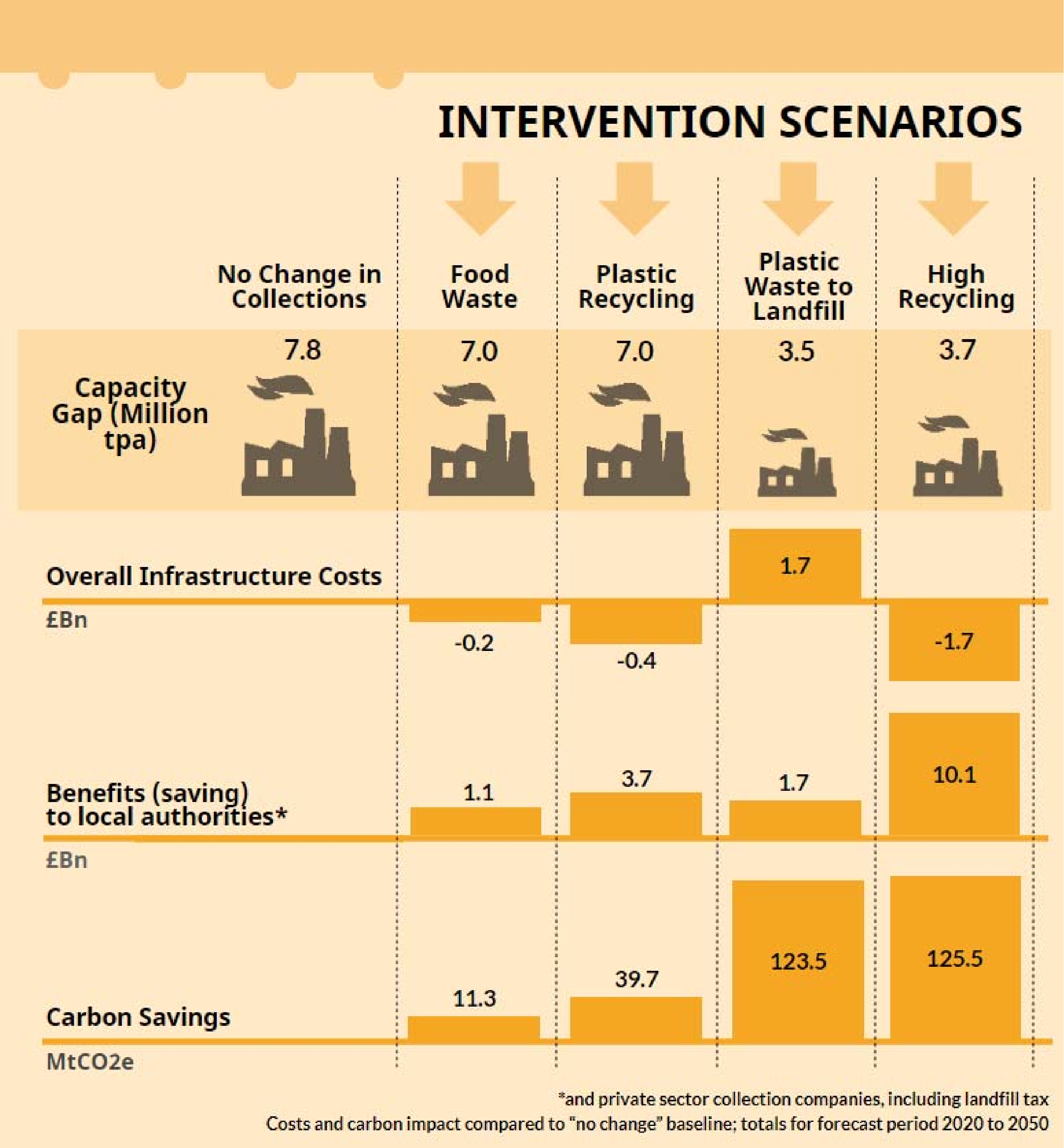


Table of contents

Table of figures

Table of Tables

Acknowledgements

The authors would like to thank Geoff Watson, Adrian Judge and Pat Wheeler for peer review of this report, and a range of industry stakeholders for their input.

Abbreviations

Acronym	Definition
ABP	Animal By-Products
AD	Anaerobic Digestion
BEIS	Department for Business, Energy & Industrial Strategy
BioSNG	Biomass fuel derived Substitute Natural Gas
C&I	Commercial and Industrial (Waste)
CA	Civic Amenity site
CAGR	Compound annual growth rate
CCS	Carbon Capture and Storage
CD&E	Construction, Demolition and Excavation Waste
CV	Calorific Value
Defra	Department for Environment, Food and Rural Affairs
DUKES	Digest of United Kingdom Energy Statistics
EA	Environment Agency
EfW	Energy from Waste
EU ETS	European Union Emissions Trading Scheme
EWC	European Waste Code
GHG	Greenhouse gas
GJ	Gigajoule
HMRC	HM Revenue & Customs
HWRC	Household Waste Recycling Centre
IVC	In-Vessel Composting
ktpa	Thousands of tonnes Per Annum
LACW	Local Authority Collected Waste
LFT	Landfill Tax
LHV	Lower Heating Value
MBT	Mechanical Biological Treatment
MHT	Mechanical Heat Treatment
MRF	Materials Recycling Facility
MSW	Municipal Solid Waste
Mt	Million Tonnes
OWC	Open Windrow Composting
PAYT	Pay as you throw
RDF	Refuse derived fuel
RTFO	Renewable Transport Fuel Obligation
SNG	Substitute natural gas (also synthetic natural gas)
SOC	Substance Oriented Classification
tCO_2e	Tonnes of Carbon Dioxide Equivalent
tpa	Tonnes Per Annum

Acronym	Definition
TWh	Terawatt Hour(s)
TWhpa	Terawatt Hour(s) per Annum
WEEE	Waste Electrical and Electronic Equipment
WRAP	Waste and Resources Action Programme
WRATE	Waste and Resources Assessment Tool for the Environment

Glossary

Term	Definition
Agricultural Waste	Waste from a farm or market garden, consisting of matter such as manure, slurry and crop residues.
Anaerobic Digestion	A process where organic matter is broken down by bacteria in the absence of air, producing a biogas, which can be used to generate renewable energy, and a digestate, which can be spread to land to provide agricultural benefit.
Animal By-products Category 1	Animal By-Products - entire bodies or parts of dead animals and carcasses containing specified risk materials at the point of disposal (unless the specified risk material has been removed and disposed of separately).
Animal By-products Category 3	Animal By-Products - carcasses and parts of animals slaughtered or, in the case of game, bodies or parts of animals killed, and which are fit for human consumption in accordance with EU legislation.
Arisings	Total amount of a particular waste stream that is generated and requires management
Bioenergy	Renewable energy made available from materials derived from biological sources.
Biogas	Gas composed mainly of methane and carbon dioxide, produced from the anaerobic digestion of biomass.
Biogenic Waste	An organic waste produced by life processes (animal or plant), such as food waste, or cellulose fibres including wood and paper
Biomass	Organic materials of either animal or plant origin (which might be used for energy generation)
Biomethane	'Upgraded' biogas, which is almost entirely methane and is suitable for injection into the natural gas network and/or as a replacement for compressed natural gas for transport.
BioSNG	A form of synthetic natural gas (SNG), which is produced via the gasification of biomass.
Biosolid	Organic matter recycled from sewage, especially for use in agriculture
Carbon Dioxide Equivalent (e.g. as tCO_2e)	An amount of GHGs with the equivalent global warming potential of one tonne (in this case) of Carbon Dioxide.
Carbon Sequestration	A natural or artificial process by which carbon dioxide is removed from the atmosphere and held in solid or liquid form.
Commercial Waste	Controlled waste arising from trade premises.
Construction, Demolition & Excavation Waste	Controlled waste arising from the construction, repair, maintenance and demolition of buildings and structures.
Cost Benefit Analysis (CBA)	CBA is a systematic approach to estimate the strengths and weaknesses of alternatives (for example in transactions, activities, functional business requirements or projects investments);

Term	Definition
Dry Recycling	Dry recycling is comprised of ‘dry’ materials (i.e. not food/garden waste, organic waste) such as paper, cardboard, plastics, metals and glass.
Energy from Waste	The conversion of waste into a useable form of energy, often heat or electricity.
Green Book	Guidance published by HM Treasury setting out the principles for appraisal and evaluation of Government Policies
Hazardous Waste	Waste that poses substantial or potential threats to public health or the environment (when improperly treated, stored, transported or disposed). This can be due to the quantity, concentration, or characteristics of the waste.
Household like Commercial & Industrial Waste	Waste from commercial and industrial sources that has a similar composition to household waste
Household Waste	Refuse from household collection rounds, waste from street sweepings, public litter bins, bulky items collected from households and wastes which householders themselves take to household waste recycling centres and "bring” sites.
Incineration	The controlled burning of waste. Energy may also be recovered in the form of heat (see Energy from Waste).
Industrial Waste	Waste from a factory or industrial process.
Inert waste	Waste not undergoing significant physical, chemical or biological changes following disposal, as it does not adversely affect other matter with which it may come into contact, and does not endanger surface or groundwater.
In-Vessel Composting	A system that ensures composting takes place in an enclosed but aerobic (in the presence of oxygen) environment, with accurate temperature control and monitoring to produce a stabilised residue.
Kerbside Collection	A kerbside collection of waste material is a method of collection whereby the resident sorts their domestic waste according to type of material e.g. recyclate, food waste, residual waste, into specially provided bins. The bins are then placed on the kerbside or nearest collection point outside the property by the householder on a weekly, fortnightly or less frequent basis for emptying by the local collection body.
Landfill	The permanent disposal of waste into the ground, by the filling of man-made voids or similar features.
Landfill Directive	European Union requirements on landfill to ensure high standards for disposal and to stimulate waste recycling and minimisation.
Landfill Gas	Similar to biogas but produced via the degradation of biomass within a landfill.
Local Authority Collected Waste	Household waste and any other waste collected by a waste collection authority, including trade waste and municipal parks and gardens waste, beach cleansing waste and waste resulting from the clearance of fly-tipped materials.
Materials Recycling Facility	A facility for sorting and bulking recyclable waste.
Mechanical Biological Treatment	The treatment of residual waste using a combination of mechanical separation and biological treatment.
Municipal Waste	Municipal waste consists of waste collected by or on behalf of municipal authorities, or directly by the private sector (business or private non-profit institutions) not on behalf of municipalities. The bulk of the waste stream originates from households, though similar wastes from sources such as commerce, offices, public institutions and selected municipal services are also included. (Eurostat definition)

Term	Definition
Net Present Value	A measure of cost: benefit, where an increasingly positive NPV represents an improving investment option. In this study, NPV is calculated by discounted net operational cash inflow minus discounted capital cost.
Non-Hazardous Landfill	A landfill that is licensed to accept non-inert (biodegradable) wastes e.g. municipal and commercial and industrial waste and other non-hazardous wastes (including inert) that meet the relevant waste acceptance criteria.
Open Windrow Composting	A managed biological process in which biodegradable waste (such as green waste and kitchen waste) is broken down in an open-air environment (aerobic conditions) by naturally occurring micro-organisms to produce a stabilised residue.
Organic Waste	Biodegradable waste from gardening and landscaping activities, as well as food preparation and catering activities. This can be composed of garden or park waste, such as grass or flower cuttings and hedge trimmings, as well as domestic and commercial food waste.
Recyclate	Raw material collected for recycling (i.e. plastics, metals, glass, paper, card).
Refuse derived fuel	Refuse derived fuel (RDF) consists of residual waste that is subject to a contract with an end-user for use as a fuel in an energy from waste facility (Defra definition). It is usually produced from residual waste from municipal, commercial or industrial sources.
Renewable Gas	Umbrella term which includes biogas, biomethane and bioSNG
Reprocessor	Business that takes a collected recycled material, and reprocesses it to a form that can be reused by industry, usually supported by a quality specification.
Residual Waste	Waste remaining after materials for re-use, recycling and composting have been removed.
Syngas	Synthetic gas or synthetic natural gas, produced from coal or other carbon sources using gasification.
Waste Hierarchy	A framework for securing a sustainable approach to waste management. Waste should be minimised wherever possible. If waste cannot be avoided, then it should be re-used; after this it should be prepared for recycling, value recovered by recycling or composting or waste to energy; and finally, disposal.

1 Introduction

1.1 Scope of the study

The purpose of this study is to advise the National Infrastructure Assessment by informing the development of a best value waste management infrastructure investment strategy for England to 2050, weighing the costs of separation and different treatment/disposal pathways against the economic and environmental benefits.

The aim of this study is to:

Map material and waste flows of:

- Local Authority Collected Waste (LACW) and
- Household like[7] Commercial and Industrial waste (C&I)

through the English waste system, highlighting capacity and potential capacity gaps, from 2020 to 2050 by:

- Modelling a series of potential separation options (scenarios) over the defined horizon, and;
- Assessing the costs and benefits of directing the separated waste streams down different treatment/disposal pathways.

1.2 Structure of this Report

This report details the methodologies employed and results obtained in delivery of this study. To this end, the content covers:

- A review of the current waste and waste infrastructure landscape in England;
- Technologies employed in the processing and treatment of waste, and technology innovations taken into account in modelling requirements to 2050;
- Forecasting model development and key assumptions, including selection of segregation scenarios and infrastructure pathways;
- Results generated and conclusions developed from these results.

---

[7] Household like C&I waste is commercial and industrial waste of a composition similar to that of household waste, and in the case of this study, uses the same types of waste infrastructure as household waste.

2 Waste Production and Waste Infrastructure in England

To establish a baseline from which new infrastructure requirements can be developed, the current waste sector in England and the type of technologies employed, is reviewed in this chapter.

2.1 Waste landscape in England

Defra's "Digest of Waste and Resource Statistics – 2017 Edition" published in March 2017, summarises the waste landscape in England as follows:

- Households in England generated 22.2 million tonnes of waste in 2015 (of a UK household waste total of 26.7 million tonnes), collected for recycling, treatment and disposal by local authorities. This figure has been reasonably static for the last 5 years. This amounts to 407 kg per person;
- The quantity of business waste (i.e. commercial and industrial waste) generated in England is not as effectively monitored as household waste, and although figures are published in the Defra digest, these are under review. The last time C&I waste arisings in England were surveyed was in 2010, giving a total arising of some 48 million tonnes for 2009. Estimating C&I waste arisings is discussed in more detail in Appendix IV;
- The recycling rate from households in England in 2015 was 43.9%, compared to a target of 50% in 2020. There is no equivalent published figure for C&I wastes. Total packaging waste arising in 2014 was 11.4 million tonnes (at UK level). This includes key recyclable materials such as paper & card, plastic, glass and metals. In 2014, 64.1% of packaging waste was either recycled (59.2%) or recovered (4.9%) in the UK;
- Waste which is not recycled, i.e. residual waste (which from municipal waste amounts to 12.5 million tonnes in England in 2015; there is no published figure for C&I wastes) is mostly energy-recovered using energy from waste facilities or landfilled. Landfill tax on a retail price index (RPI) inflator is making landfilling disposal a more expensive option year-on-year compared to other treatment methods;
- Only a small proportion of food waste (approximately 9% from households, potentially 60% from businesses[8]) is collected for reuse or recycling of the estimated 10 million tonnes generated each year (UK estimate, from households, retail & wholesale, manufacturing and the hospitality sector). Anaerobic digestion and in-vessel compositing are key technologies for the recycling of this waste stream. Only 33% of local authorities in England collected food waste as a separate stream in 2016/2017 (compared to 100% in Wales). Around 12% collect food waste mixed with garden waste[1].

2.2 Existing English Waste Infrastructure & Waste Market

An extensive network of waste facilities in England collect and process the waste collected from households and businesses. To date, investments in waste treatment infrastructure have largely been tied to local authority waste contracts, driven by government targets, grants, subsidies and increasing landfill tax rates. However, there are an increasing number of merchant plants in development to treat C&I wastes as well as household wastes.

Sections 2.2.1 to 2.2.5 following, detail the existing waste infrastructure in England across collection and bulking; material separation and sorting; organic waste treatment; residual waste treatment and landfill.

---

[8] Deduced from published WRAP figures

2.2.1 Collection & bulking

The collection of wastes from households and some public sector premises is the responsibility of Local Authorities. The collection and management of commercial and industrial wastes is the responsibility of the businesses that generate the waste, under their duty of care responsibilities laid out in Section 34 of the Environmental Protection Act 1990[2].

England has a wide and varied range of recyclables collection systems representing the individual collection rotas, bins, vehicles and recycling approaches taken by individual local authorities. This contrasts with Wales, Scotland, the Netherlands and Germany for instance, where more consistent approaches are taken (see the case studies in Appendix II to this report). This in turn has led to a wide range of collection and bulking infrastructure mostly operated by the private sector in England aligned to the local requirements for municipal waste.

It is estimated that about 50% of LACW collected in England is collected by Local Authority owned services and the other half by third party private contractors[3]. The actual figures vary year on year with some Local Authorities deciding to take collections back or alternatively outsource the services to private contractors if this is commercially beneficial. England has three key collection systems including i) kerbside collection from households, ii) bring collections via glass, paper, plastics and other recyclables containers, as well as iii) the operation of civic amenity (CA) sites or household waste recycling centres (HWRC). CA and HWRC sites are open to the public and some businesses to bring unwanted bulky goods, wood products, garden wastes as well as other recyclables and wastes. Much of the bulking infrastructure is operated by private contractors owning waste transfer and bulking stations, however there has been some move in returning local authority related services back in-house to address concerns regarding service levels and budget constraints[4].

C&I waste is mainly collected and managed via private contractors with businesses organising their own waste collection and disposal. In some areas, Local Authorities provide commercial waste collection services. However, this depends on the arrangements with their collection services and if there is a local business case.

In 2015/16 WRAP undertook a study to determine the impact of moving to more consistent recycling collection practices across England. This focussed upon a set of core materials (paper, card, metals, glass, plastics and food waste) that would be collected from kerbside schemes across England with a limited number of collection approaches. The framework and vision for greater consistency with supporting analysis and business case was published in September 2016[5]. The study concluded that “greater consistency can contribute to making it easier for households to recycle more; making it more cost effective for councils and others to provide services; and improving the quantity and quality of materials available to industry”.

Contamination of collected recyclates can impact considerably on the value of the materials collected and the cost of onward processing. Broadly speaking there are three types of contamination that occur in dry recycling collection services:

- Non-target materials (for example including plastic pots, tubs or trays in a recycling service that does not accept these items even though they are recyclable);
- Non-recyclable materials (for example nappies, sanitary products or pet bedding, these are items that are not recyclable or are recyclable but only through specialist collection services); or
- Recyclable materials that are contaminated with unwanted items (e.g. food cans that still contain food residues or milk bottles containing milk).

The items contaminating recycling collections can cause a range of issues from lowering the value of the recyclable material to damaging the sorting or reprocessing equipment. The pressure to reduce the level of contamination, and hence reduce the consequential cost of dealing with it, has increased over recent years. This has become increasingly important in 2017 and 2018 as China's National Sword programme came in to force in January 2018. This programme aims to improve the quality of imported recyclable materials into China by significantly reducing the levels of contamination allowed.

There is a myriad of factors that contribute to the level of contamination within a given recycling service, including service design (for instance single stream v. co-mingled, number of materials collected, frequency of collection), service delivery and resident behaviour. WRAP has published research that considers these factors and undertakes an annual survey of UK households that gathers evidence on consumers' current attitudes, knowledge and behaviour in relation to recycling[6].

2.2.2 Material separation and sorting

The WRAP MRF portal[7] states in its latest report that nearly 90 material recovery facilities (MF or MRF) in England submitted data to the portal in line with the requirements of the Environmental Permitting (England and Wales) Regulations 2016 (Schedule 9). 'A qualifying MF is defined as a regulated facility that receives mixed waste material in order to separate it into specified output material (SOM) for the purpose of selling it, or transferring it to other facilities or persons to enable that material to be recycled by those facilities or persons'[8].

The level of sorting and separation capacity available differs from site to site and will depend on the respective mix of dry recyclables arriving at the site. The latest MRF report (Q3 2017) stated that 'waste supplied to the responding MRFs in England was attributed directly to 220 local authorities and 290 other suppliers (such as waste management companies or other waste facilities).' In total just over 811,000 tonnes of mixed materials were sorted and separated in reporting MRFs in quarter 3 of 2017, which represents an estimated 3.2 Mtpa of mixed materials capacity in England including some seasonal variations. The total tonnage of target materials leaving the responding MFs in quarter 3 of 2017 was approximately 693,000 tonnes (not including rejects), which corresponds to a total of around 2.8 Mtpa of glass, plastics, metal, paper and cardboard being sorted for further re-processing and recycling in England. This corresponds to target materials making up 85.5% of input materials entering the facilities, the balance being 7.4% of non-target recyclable materials and 7.0% of non-recyclable materials.

However, some facilities that are considered MRFs are actually bulking facilities and other sorting and separation facilities focussing on commercial or industrial wastes, which are not obliged to report under this arrangement. Therefore, the actual capacity to process comingled dry materials for recycling in England is not clear, additionally as a number of these facilities are operating under environmental permit exemptions and therefore not reporting on their annual throughput and overall capacity. For this reason, the portal reported annual capacity figures are likely to be underestimates.

Infrastructure tends to be closely aligned with the associated collection infrastructure. In essence, materials are collected in a way that the local and regional infrastructure can sort and separate them. Similarly, if there is a change in collection, then the separating and sorting infrastructure will be adapted and expanded. In 2016, WRAP undertook a focussed study to evaluate the infrastructure capacity for recycling and reprocessing in England and to assess the potential future capacity need to respond to more consistent recyclables collection in England.[9] To date this report and associated research has not been made publicly available and therefore no further empirical evidence on capacity and requirements is available for this waste infrastructure analysis.

---

[9] WRAP PMP009-002 TID – July 2016

It needs to be noted that this study has taken into account sorting and separation infrastructure in England to ensure completeness of the model, but has not included the actual re-processing and industrial re-use infrastructure for these key materials i.e. paper mills, glass, metal and plastics manufacturing. Based upon available data[10], it has been assumed that 45% of the material collected is comingled at kerbside and processed via a suitable MRF.

2.2.3 Organic waste treatment

2.2.3.1 Composting

The composting sector in England is the most mature sector for organic treatment, and continues to grow albeit at a slow rate. There were approximately 310 permitted operational compost sites in 2014 processing an estimated 5 million tonnes of food and green waste into compost, of which >50% is accredited to BSI PAS100 [9] i.e. meets established compost quality requirements. Garden waste is permitted to be composted in open windrows or aerated piles, whereas any combination of food and garden waste containing animal by-product materials will need to be composted in closed facilities using in-vessel composting (IVC) technologies. Today, there are approximately 50 IVC plants in the UK providing ABP compliant composting capacity to mainly Local Authority collected mixed organic waste.

The market for expansion of IVC has slowed considerably as food waste today is either treated in anaerobic digestion (AD) facilities or potentially left in the residual waste. Many English Local Authorities have focussed on providing separate garden waste collection facilities (251 compared to 78 operating mixed organic collections) as this provides a cheaper processing option to mixed organic waste, in particular where householders are paying a subscription or annual fee to have their garden waste collected.

2.2.3.2 Anaerobic digestion

The UK is now the second largest anaerobic digestion utilising nation in Europe. The AD industry experienced a strong growth in English AD Capacity in 2012 – 2015, due to**:**

- Initial strong growth in food waste collected from households and commercial /industrial premises to meet recycling targets and sustainability aspirations;
- Renewable electricity subsidies via renewables obligations (RO) and feed-in tariffs (FIT), followed by renewable heat incentive (RHI) support for renewable heat and biomethane.

This growth has slowed in 2016/17 due to a significant reduction in subsidies as well as concerns regarding feedstock supply as food waste segregation has not grown significantly in the recent years. Today, there is a competitive English waste AD market being utilised by food waste, energy crops and agricultural residues. The actual split between input materials is difficult to determine and subject to seasonal and annual changes, so quoting a definitive England capacity for food waste is difficult to achieve. There is a move towards replacing energy crops with waste where technically and commercially feasible to ensure facilities meet all relevant sustainability criteria.

In the UK in 2015, it was estimated that 7.3 Mt of food waste was generated by households plus 1.2 Mt from retail, wholesale, hospitality and food services as well as 1.7 Mt from food manufacturing[10]. Using a range of WRAP reports[11]–[13], of the food waste generated, around 2.7 Mt of segregated food waste is collected from households and commercial sources, for processing by a range of treatment and disposal options including AD. This volume compares to an estimated 3.0 Mt[14] of English commercial AD in 2017, although

---

[10] Extrapolated from data from http://www.wastedataflow.co.uk

much of this capacity also processes waste and non-wastes, such as energy crops, manures, slurries and sludges.

In recent years there has been an increased focus on the production of biomethane for the gas grid with approximately 90 plants of all types and sizes taking advantage of renewable heat incentive (RHI) support and greater efficiencies in comparison to electricity generation. Today, AD market expansion is mainly driven by:

- General growth in waste increasing the amount of food waste collected, especially if capture rates can be maintained or improved through communication and the implementation of best practice;
- Voluntary recycling and renewable energy commitments to support sustainability aims of businesses and Local Authorities.

The WRAP organic recycling industry status report for 2015 (published in 2017)[9] identified growth in the industry with around 515 English developments in various stages of planning, to potentially double or triple the size of the sector between 2014 and 2019. The report suggested a requirement of an additional 15 Mt of feedstock by 2019 to supply these facilities. However, this growth assumes all of these facilities would be financed, built and operated, which is unlikely. If only half of these planned facilities were delivered, a capacity of around 10 Mt, and if their input reflected the feedstock mix of current plants, they would need 3.8 Mt of additional food waste by 2019.

This suggests that, even with the higher-end 2019 forecasts, there is sufficient food waste potentially available to feed planned capacity, all that is required are higher collection and segregation rates. However, the steady decline of operational gate fees in England over the last 3 years[15] does suggest that supply in some geographic areas is falling short of available capacity at current collection rates. It has been suggested that further increases in food waste collection will be slow in the absence of regulatory intervention.[16]

2.2.4 Residual waste treatment using MBT and Energy Recovery

The Government's Private Finance Initiative (PFI) programme has encouraged a strong growth in residual waste processing infrastructure, including mechanical biological treatment (MBT) and energy from waste (EfW), for local authority collected waste (LACW). While the programme stopped funding new infrastructure in 2011/12, the last plants being delivered under this programme are currently being built and commissioned. The existing English EfW capacity consisting of over 40 EfWs, mainly processes residual LACW under long term PPP/PFI arrangements with only an estimated 10 – 15% assigned to third party commercial industrial waste. Due to a lack of domestic capacity, residual C&I waste is either:

- Traded on the spot market or under short term domestic arrangements using spare EfW capacity;
- Processed into a range of waste derived fuels including refuse derived fuel (RDF) for use in UK EfW facilities using grate technology, fluidised bed or advanced thermal conversion technologies (ACT) or for export to Europe. Alternatively, it may be processed into solid recovered fuel (SRF) for UK or European cement kilns;
- Disposed of in landfills incurring £ 86.10[11] per tonne of active waste, in Landfill Tax (annual increase per RPI) plus gate fee.

The final destination for residual waste is determined by capacity availability and pricing; i.e. landfill is typically the most expensive option (due to the landfill tax), and hence, RDF/SRF production with export to Europe is desirable if no domestic energy recovery capacity is available under short to medium contracts or at spot

---

[11] Rate for 2017/18. This will increase to £88.95/tonne from 1st April 2018

market prices. It needs to be noted that there are some circumstances and locations where landfill (including landfill tax) can still be cheaper than other options.

EfW capacity is continually increasing with the final PFI EfW plants being built and more merchant plants for C&I waste or RDF reaching financial close and entering construction and commissioning stages. In 2015/16 nearly 7 million tonnes of capacity came on-line in the UK reaching full capacity by the end of 2017. A number of plants using advanced thermal treatment technologies (ATT) instead of more traditional combustion have gained planning permission, however anecdotal evidence suggests[17] that the recent issues at a number of facilities have dented confidence in these technologies. These plants are built under the Renewable Obligation Certificate (ROC) regime subsidising renewable electricity production, which will need to be operational by March 2017 (or March 2018 at the latest) to qualify. There are also a few plants with Contract for Difference (i.e. CfD which is the replacement auction based subsidy scheme for renewable electricity from ROCs) approval from the first round. During the second CfD round in April/May 2017 only six waste ATT schemes qualified for funding.

There is also currently around 3.5 Mt of capacity at mechanical biological treatment (MBT) facilities in England. MBT is an interim residual waste preparation process rather than a final treatment or disposal, preparing materials for recycling and energy recovery in the main. MBT facilities vary significantly in their nature, utilising different biological processes (composting, AD or bio-drying) and separate different dry recyclates depending on the mechanical technology adopted. Therefore, the outputs vary from facility to facility with differing volumes of RDF, dry recyclates, compost like output (CLO) and/or digestate generated. The quality of the outputs can also vary, with a number of facilities having reported high levels of rejects and higher than expected quantities of output going to landfill. As a consequence there have been some contract terminations, for instance in Lancashire[18] and Manchester[19].

Despite the available EfW and MBT capacity, there is still some 20 Mt of waste (both non-hazardous and inert) being disposed of in non-hazardous landfill in England (2015[20]), of which it is estimated 12.5 Mt comes from LACW and household like C&I sources, providing an opportunity for further treatment and recovery facility development. In total, there are an estimated 11 million tonnes of potential EfW capacity with planning permission or in the planning process[12], and 1 million tonnes of MBT/RDF production capacity (which may in turn take a proportion of this new EfW capacity to recovery the RDF it produces). It is highly unlikely that all this potential capacity will achieve financial close and be built. Much of this potential recovery capacity is advanced thermal technologies (ATT) based. However, the ATT market has experienced a high attrition rate in the past, with the recent mothballing of 0.7 Mtpa proposed capacity at Tees Valley as well as a number of smaller projects, as examples.

Therefore, for baseline modelling for this study it has been assumed that 5.1 Mt of additional EfW capacity will be delivered and operational by 2020, giving an overall operating capacity in England of 15.3 Mt (excluding co-incineration). An additional 7.6 Mt has been left out given the considerations above.

This assumed capacity is summarised in Table 1.

---

[12] Anthesis estimate

Table 1: Modelled EfW capacity: 2020 baseline operational facilities, England

Facility Type	No of facilities	Capacity	Active CHP Capacity	Notes
EfW operational	42	10.2 Mt	2.2 Mt	
EfW assumed delivery by 2020	22	5.1 Mt		Includes facilities with planning permission, in construction and those that have achieved CfD funding
Co-incineration	6	1.3 Mt[13]		Cement Kilns

Most domestic EfW projects will treat loose ‘un-prepared’ residual waste, however, the increasing number of ATT combustion plants will require an RDF for their operation, which could either come from specialist RDF production facilities focussing on mixed C&I residual wastes, or MBT type facilities recovering recyclables from residual waste. This requirement was also modelled.

2.2.5 Landfill

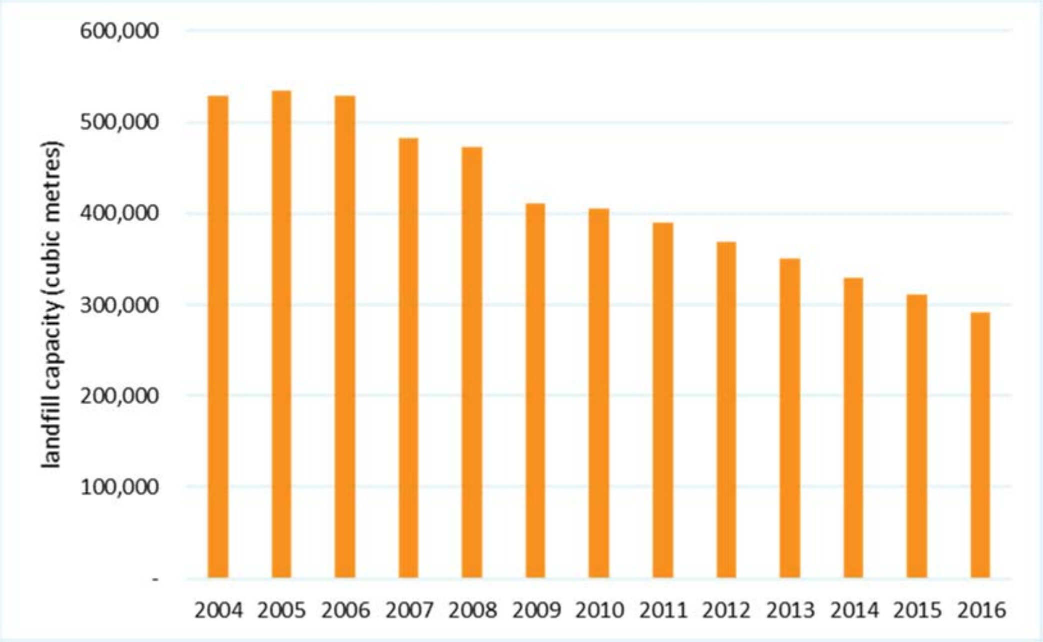
The availability of landfill capacity is reducing significantly with 465 million m^3 remaining landfill void space in England in 2016[21]. It is likely to continue to reduce: therefore, it is assumed not to be a long-term waste disposal option or a competitor for energy recovery for the purpose of this study. Data published by the Environment Agency[22] for England shows a 4.7% average reduction in landfill capacity (as cubic metres) annually from 2010. The capacity of non-hazardous and restricted landfill in England in 2015 was 338.2 Mm^3. If landfill volumes continue to reduce by the rate of input seen in 2015, the available landfill capacity would be exhausted in just under 10 years. Therefore, if new landfill void is not permitted, from 2025 England could be in a situation where the available void space would only allow for processing residues to be landfilled, with the remainder having to be diverted for recycling or recovery, unless more landfill capacity is consented.

Landfill tax is currently set at £86.10 per tonne, making landfill an expensive residual waste disposal route. Planning authorities are sometimes reluctant to give planning consent for new facilities, or for the extension of existing facilities due to a multitude of reasons, including there being a conflict with other targets such as housing provision[23]. This is particularly noticeable in regions with considerable EfW capacity. Contracts tend to be short term (1–5 years), and therefore switching to alternative recovery routes can be straightforward if the capacity is available.

---

[13] Note that cement kilns can take a range of fuels and waste types as well as SRF produced from residual waste, so this capacity for waste derived fuels can vary

Figure 6: Non-Hazardous Landfill Capacity in England (in cubic metres x 1,000) 2004-2015



Source: Environment Agency Waste Management Information 2016

2.3 Future Infrastructure Needs - Recent Residual Waste Infrastructure Studies

There have been a number of reports in recent years looking at the medium-term requirement (to 2030) for residual waste infrastructure in the UK, from a number of sources including from commercial waste management companies. These are summarised in Appendix IV to this report. These studies assess capacity requirements based on a range of source data and assumptions, and exclusively look at the UK as a whole. These reports have been used to benchmark the estimates generated in this study, and test assumptions such as waste growth rates and recycling rates which are key to the arisings and capacity modelling.

3 Technology Horizon Scan

An evaluation of the future waste treatment technology options has been carried out, to ensure that the associated pathway modelling incorporates improved and innovative waste treatment technologies that could provide commercial solutions in the future. Technologies were selected based on ability to significantly influence the waste treatment and infrastructure sector in England. All technologies included have either proven commercial track record or are undergoing commercial demonstrator projects with a potential of progressing to scaled roll out. The following section contains a summary of the technologies analysed and impact on the modelled scenarios. Further detail from the horizon scanning exercise is contained in Appendix I to this report. Table 2 following lists the technologies reviewed.

Table 2: Summary of Technologies covered in Horizon Scan

Minimisation and reuse	Waste minimization Waste reuse
Anaerobic digestion	Feedstock pre-treatment Biogas Digestate
MBT	MBT with IVC MBT with AD MBT with RDF production
Biofuels	
Thermal technologies	Energy from waste Gasification Pyrolysis
Residual waste changes	Residual waste composition changes Calorific value changes
Landfill	Carbon Sequestration Landfill mining

3.1 Impact of Waste Minimisation and Reuse

3.1.1 Minimisation

Evidence published by WRAP suggests that between 2015 and 2025, ~20 million tonnes of food waste could be prevented. If this is waste already segregated, this would have a significant impact upon the food waste available for AD treatment and therefore the growth of this sector; if unsegregated, this would impact on residual waste volumes and the biogenic content of residual waste, which has potential impacts in local authority areas serviced by mechanical biological treatment contracts.

A review of European waste minimisation initiatives[24] shows that relatively few targets have been proposed for waste streams other than food, for which 11 targets have been proposed. Similarly, waste minimisation in the UK has tended to focus on the food sector and encouraging householders to home compost.

3.1.2 Re-use

The EU Circular economy package and HM Government's "A Green Future: Our 25 Year Plan to Improve the Environment" published in January 2018[25], propose measures to promote re-use and stimulate industrial symbiosis – turning one industry's by-product into another industry's raw material. In England from 2005 to 2013, industrial symbiosis generated 47 million tonnes of landfill diversion[26]. However, as future measures will focus on industrial wastes, industrial symbiosis will likely have only a marginal potential impact on the types of residual waste treatment highlighted in this study.

The Reuse Commission in 2013 estimated that in England 358,200 tonnes of reusable textiles, 20,000 tonnes of reusable WEEE and 236,000 tonnes of reusable furniture were disposed of. Further research[27] from WRAP undertaken in 2012 estimated that there is potentially 525,000 tonnes of bulky products taken to HWRCs and 129,600 tonnes of bulky products collected from the kerbside, that could be reused. Public reuse initiatives are active in many areas of England including furniture schemes, white goods refurbishment and web based reuse organisations such as Freecycle, Freegal, and Preloved. Distributing unused food via charities and food banks has also grown in recent years. Although reuse is promoted generally via EU legislation such as End-of-Life Vehicles Directive (2000/53/EC) and WEEE Directive (2012/19/EU), these measures do not include explicit targets for reuse.

3.1.3 Impact on Study & Modelling

To reflect the potential impact of continued waste minimisation initiatives such as packaging light-weighting and single use plastics, a low waste growth profile has been modelled to reflect recent waste growth history and address the potential impact of waste minimisation initiatives in the future.

3.2 Anaerobic Digestion (AD)

3.2.1 Review of improvement options

Although AD has long been commercial, further technology optimisation and cost reduction is still possible. Developments could improve the economic viability of existing facilities operating under current market conditions and support the viability of new facilities. The main focus is: to improve pre-treatment (to reduce digestion time); to reduce costs and to improve reliability of two-stage technologies; to improve biogas cleansing processes (mainly of corrosive H_2S); and to increase the robustness of the thermophilic process[28].

The current preferred approach of lower temperature (mesophilic) AD is considered unlikely to change across the industry[29], with the AD sector currently focussing on maximising biogas yield through the selection of feedstock with high biogas potential, pre-treatment of feedstocks, and increasing the value of primary biogas and digestate outputs. Single stage AD technology is relatively inefficient with respect to semi-solid waste, but will continue to be applied as it provides greater flexibility when feedstocks are prone to change from season to season or even daily. Multi-phase AD provides greater energy yield, but is relatively costly (because of additional tankage, the quality of digestate, high level of control etc.)[28].

Various pre-treatment technologies have been developed (including milling, hot water, microbial, enzymatic, steam explosion, extrusion, acid and alkali treatments) to increase the availability for AD of sugars and other small molecules in biogas substrates, particularly in lignocellulosic material. Some pre-treatment methods can stabilise biogas plants that have stability problems (for example by adjusting the pH) and can potentially make new substrates available for digestion. In particular, thermal treatments (such as steam explosion) have achieved significant improvements in biogas production and reduced residence time in the waste water (sewage) treatment industry[30].

3.2.2 Impact on Study & Modelling

The key improvement in the past years has been the growing number of AD facilities producing biomethane for the gas grid, which has become a commercially valuable and environmentally friendly option, which will help the UK to meet their renewable targets by supporting the efforts to decarbonise heat consumption by replacing natural gas with biomethane. Therefore, AD with biogas to grid could become a cornerstone of future waste treatment infrastructure and therefore this has been incorporated into the waste infrastructure pathway modelling.

3.3 Mechanical Biological Treatment (MBT)

3.3.1 Review of improvement options

In the UK, MBT is positioned to increase recyclable extraction from residual waste streams and process the separated organic fractions for further use, as well as a pre-treatment process for RDF and SRF production. Lower quality recovered recyclables are extracted compared to source-separated recyclables. As a result, there has been a shift towards using MBT for readying material for fuel production.

3.3.2 MBT with IVC

MBT with IVC was initially positioned as an alternative to EfW, taking non-source-separated waste and producing a more biologically stable product to go to land. However, environmental regulations do not permit agricultural spreading of non-source-separated wastes which limits markets and uses for a “compost-like output” CLO. The latest version of the EU Fertiliser scheme does not include compost from residual mixed wastes, therefore the markets for CLO, MBT / IVC are not likely to increase and MBT is purely a volume reduction process. The organics fraction is likely to be used for landfill engineering and similar purposes, but will not be acceptable as a comparable-quality compost product.

3.3.3 MBT with AD

In this option, material suitable for AD is separated from a residual waste stream through a MBT process. AD associated with MBT differs from AD which treats a source-separated waste, as it requires increased pre-processing requirements. Source-segregated collections will provide a purer organic stream but may not capture a high enough percentage of relevant materials to achieve the required level of landfill diversion in isolation. Digestates from the AD element of this process, however, suffer from the same market issue as CLO from MBT with IVC.

3.3.4 MBT with RDF Production

Current demand for energy recovery has shifted the focus of MBT facilities to increase production of a refuse derived fuel. In some types of process, the entire raw waste input is first processed in a biological (non-thermal) drying stage followed by mechanical separation systems to provide an overall treatment process. However, most processes that seek to produce a marketable bio-output, whether fully bio-stabilised or not, utilise some degree of post-biological mechanical processing to remove contaminants from the output or to change the output materials into a suitable form for their end-use applications (e.g. for reducing the particle size, baling or pelletising).

3.3.5 Impact on Study & Modelling

Current MBT capacity has been modelled in this study, but due to the issues with disposal of the organic fraction CLO, MBT has not been modelled as a viable alternative to kerbside collection for the segregation of organic wastes. However, additional intermediate treatment capacity has been modelled where RDF manufacture is required for ATT technology, for instance, or for the separation of plastics from residual waste for landfilling.

3.4 Thermal Processes

3.4.1 Review of Improvement Options

3.4.1.1 Combustion

Over the last c. 15-20 years, the mass burn sector has shown a continual drive towards plant optimisation to improve combustion efficiency[31], reduced parasitic load and increase energy conversion efficiency. Much of this change has been driven by legislation specific to the industry and this has improved emissions from individual installations. This is expected to continue driven by competition, with the sector now focussing on techniques which limit costs, whilst maintaining or improving environmental performance. With potential improvement opportunities, electrical (turbine) efficiencies up to around 35-40% are theoretically possible if steam temperatures can be raised and combustion conditions improved at the larger sites (>20 MWe)[32]. Much higher overall efficiencies are available if a proportion of the heat produced is used in addition to the power, using combined heat and power (CHP) technology. However, as the heat supply rate rises, power production falls at a rate determined by the type of steam turbine, although efficiencies of up to 78% can be achieved if suitable uses for the heat can be supplied. The impact of conversion to CHP of existing plants to increase overall efficiency of the existing thermal infrastructure, as well as improving future EfW infrastructure, has been included in the waste infrastructure pathways modelled for this study.

3.4.1.2 Gasification

Most gasification technology developments can be split into: gasification to raise steam via close-coupled combustion; or syngas-focussed gasification for use in gas engines or as upgraded Bio-SNG for injection into the gas grid:

- **Gasification focussed on steam raising using closed - coupled combustion technology** – This option is considered relatively “bankable”, although its success commercially is yet to be demonstrated, as it relies upon steam-turbine energy generation with limited or no syngas cleaning. Any syngas cleaning is employed to improve plant life, but ultimately is still immediately combusted in an adjacent steam raising boiler as the gas is not clean enough to deliver the flexibility opportunity sought from gasification. Due to the steam-utilising similarities with traditional mass burn, overall turbine energy efficiencies for the largest plants can be considered c. 30% when optimised for power generation. However, the additional processes (and parasitic demands) involved in converting the fuel to a syngas typically result in lower overall efficiencies than modern incineration technology;

- **Gasification focussed on syngas production -** The focus on syngas production requires syngas cleaning equipment to yield an ultra-clean, tar free product. Once the output syngas has been cleaned, it can be used to provide a variety of end-use sectors, many of which are not available via moving grate and other combustion technologies. To date, the ability to achieve these levels of cleaning has not been robustly demonstrated to enable widespread commercial roll-out. A sufficiently cleaned syngas can be used to take advantage of better energy conversion via gas engines or turbines. With development and experience, it should be possible to increase engine efficiencies to about 40%. A standalone gasification configuration that might result in a higher overall electrical efficiency than combustion technology is based on the use of a combined cycle gas turbine (CGT) for power generation, but this configuration is currently unproven on residual waste. Gas cleaning technologies are currently pioneered in the UK with government funding of commercial demonstration projects. Therefore, this technology has been included in the waste infrastructure pathways for this study as this option could provide efficiency and carbon savings producing renewable gas to replace natural gas and therefore decarbonise the heat network. However, it should be treated as experimental until the results of the demonstrator are published.

3.4.1.3 Pyrolysis

In most pyrolysis reactions, a combination of gas, solid and liquid by-products are created[33]. Effectively utilising these product streams is required to retain processing efficiencies. Producing high-value products from the generated bio liquids are being researched but similar hurdles in upgrading of syngas are at present delaying industry development[34]. The control of homogenous feedstock inputs and the commercialisation of clean outputs have been identified as major technical development hurdles to apply pyrolysis at medium to large scale to replace moving grate combustion. Therefore, the technology has not been included in the waste infrastructure pathway scenarios for this study as the development of commercial options will need to progress further to produce sufficient data sets for potential modelling as national solution for residual wastes as well as separated plastics waste.

The technology to pyrolyse waste plastics not suitable for recycling (i.e. end of life plastics) into oils, chemicals, carbon black and hydrogen is still under development with a number of developers trying to match operational robustness with market need. A review by Zero Waste Scotland[35] notes that the oil produced is suitable for use as a heating fuel but could be refined for other applications. With systems where refining is an integral part of the process, this is normally achieved by distillation, to produce a diesel and kerosene set of products suitable for use as a vehicle fuel, as well as a heavier residue which can be used for process heat. The only commissioned and operationally scaled facility in the UK was designed and is operated by Suez at Avonmouth in Bristol, converting commercial waste plastic to diesel. Little has been published regarding the effectiveness of this facility and it is understood that the facility is not in continuous operation due to fluctuations in oil price.

3.4.2 Residual Waste Composition Changes and Calorific Value

The changes in residual waste composition will depend upon the individual scenarios modelled, and how other waste streams are collected as part of the overall collection regime, and whether additional pre-treatment of the residual waste will be applied to meet the additional waste limitations proposed for EfW and landfill. As a result, any change in the composition of the residual waste to EfW and the energy or calorific content in the material, will determine the amount of energy produced per tonne of waste. Currently the CV of the residual waste is expected to be around 8–10 MJ/kg. The existing EfW facilities are designed to deal with a CV range as residual waste is a heterogeneous waste stream. Most mass burn incinerators will have an operational envelope to process residual waste with CVs of 6–11 MJ/kg and a design point around 9.5-10 MJ/kg when the energy production is optimised. The existing facilities are likely to only experience significant technical operational impacts if the CV of the residual waste streams falls outside their existing operational envelope. This would require a significant CV change as the operational range is quite broad and none of the scenarios modelled have produced a change in CV outside of these limits.

3.4.3 Impact on Study & Modelling

The horizon scan of thermal technologies has shown that incineration (particularly moving grate) is continuously improving and the application of CHP energy conversion concepts can achieve significant improvements in energy efficiency. Therefore, this option has been included in the waste infrastructure pathways modelled in this study to compare residual waste options. Similarly, the gasification to BioSNG option has been modelled to evaluate the impact of improved efficiency and sustainable gas supply from residual waste, even though the technology has not yet been technically or commercially demonstrated at scale. In addition, CV forecasting, based upon changes in residual waste composition has been included in the model.

3.5 Other Relevant Technologies

3.5.1 Review of Improvement Options

3.5.1.1 In-Vessel Composting (IVC)

IVC can be used to treat source-separated food and garden waste mixtures into a compost product. In contrast to AD, these systems rely on aerobic decomposition of organic waste in an enclosed environment, with temperature control and monitoring. Different composting technology suppliers are experimenting with different time/temperature profiles to increase composting efficiency and reduce energy use. Nevertheless, the key process concept does not change and therefore in-vessel composting is expected to continue to be used in the future, mainly for green waste and food and green waste combinations to ensure peat-free compost products are produced from mixed organic waste.

3.5.2 Feedstock pre-processing options for improvement

3.5.2.1 Enzymic Hydrolysis

In the REnescience (Ørsted) process, warm water with proprietary enzyme is added to residual waste to achieve temperatures appropriate for enzymatic hydrolysis. Through enzymatic action, biodegradable materials are liquefied (and ultimately converted to biogas via AD) which permits, the developers say, easy separation of non-degradable solids. Tested at pilot scale for a number of years, a first commercial scale unit is in commissioning in Northwich, England with a stated capacity of 120 ktpa, designed to recover c. 95% of recyclable materials and creating feedstock for 5 MWe AD facility.

3.5.2.2 Thermal Hydrolysis

This process has widespread waste water treatment applications operating on sewage sludge and is being developed for organic and food waste applications in Europe, particularly in Norway. The thermal hydrolysis process (THP) is a high-pressure, high-temperature steam pre-treatment application for AD feedstocks. The feedstock is heated and pressurised by steam within a reaction tank before being rapidly depressurised (flashed). This results in the breakdown of cell structure within the biomass; as the organic matter is presented to the digester in a broken-down condition, the digestion process is more effective resulting in increased gas production and improved digestate quality.

3.5.2.3 Autoclave Systems

An autoclave can be used to pre-treat wastes in a similar manner to thermal hydrolysis. The autoclave is a pressure vessel that steam treats its contents at a constant temperature and pressure, serving to pasteurise, clean and break-down organic matter within the feedstock. The organic matter can be presented to AD processing in a broken-down condition, making the digestion process more effective resulting in increased gas production and improved digestate quality.

3.5.3 Digestate Post-Processing options for improvement

Upgrading digestate to form a revenue-earning product is particularly relevant for digestates from MBT applications, as the use of digestates derived from mixed waste materials is currently restricted to use on land restoration projects only. However, WRAP-funded reviews[36] of alternative options for digestate enhancement suggest that the scale and throughput of commercial AD facilities are too small to warrant application of many capital-intensive enhancement and recovery technologies that can deliver digestate-derived fertiliser products. The use of digestate as growing media for algae and other nutrient rich potential fertilisers seems to be more promising, but again at very early stages in the development and not sufficiently commercialised for this project.

3.5.3.1 Hydro Thermal Carbonisation (HTC)

Digestates are not the ideally suited for heat and pressure technologies or for lignocellulosic hydrolysis, as most thermal processes typically require a dry solids concentration of 70% or more. However, Hydro Thermal Carbonisation (HTC) is unusual in that it is designed to accept wastes with much lower dry solids (as low as 20%) and it is not troubled by the presence of high ash, nitrogen and other contaminants. Its main application has been in the conversion of biowaste to a carbon dense material (biochar).

3.5.3.2 Product Synthesis

A significantly active research area is the application of microorganisms to generate novel, high-value products. In particular, anaerobic fermentation is being studied to convert digestate and MBT residues into chemical intermediaries. A large amount of optimisation and scale-up work is required before a biorefinery process can be commercially developed.

3.5.4 Impact on Study & Modelling

For the modelling for this study, CV of resultant RDF-type output was calculated to assess impact of segregation on resultant energy from waste efficiency and energy output. In addition, IVC was included in the GHG and cost models, but not extensively modelled due to lack of energy or other output benefit.

3.6 Landfill

3.6.1 Review of Impacts and Improvement Options

In 2015, landfills accounted for 2.4% of total UK GHG emissions (on a CO_2 equivalent basis) compared to 8% in 2000[14]. Although some captured methane is flared, around 450 landfills in the UK capture methane for energy generation via a gas engine. Generation of electricity from landfill gas was 4.8 TWh in 2015 from an installed capacity of 1.1 GW[37]. Although policies at EU, UK and England level for many years have been reducing dependency upon landfill, there is a small proportion of material which is unrecyclable and non-combustible, for which landfill will continue to be a necessary option. Also landfill of residual waste generally is likely to continue where long-term landfill void exists and alternative treatment or recovery capacity is not available or is too far away from the point of generation to be a viable landfill diversion option. This should ensure the continued commercial viability of a small number of landfill sites.

To meet regulatory and planning requirements, landfill design will maintain minimal environmental impact using leachate capture and treatment and methane capture for energy generation, although future innovations may include methods to boost methane generation and hence financial viability, such as leachate recirculation, whilst the construction of landfill “bioreactors” will allow closer control of decomposition conditions and increased capture of the methane generated. Future landfill developments are therefore likely to further reduce environmental impacts, giving landfill an extended role in the disposal of certain wastes.

3.6.2 The Role of Landfill in Fossil Carbon Sequestration

Landfill also has a potentially significant role in carbon sequestration, particularly of fossil plastics. Although policy development appears to be focussed on reducing plastic to landfill, with increasing EU plastic recycling targets and the European plastics industry lobbying for a landfill ban, there is some support for the landfilling of plastics. The Defra publication “*Guidance on applying the Waste Hierarchy*“(2011)[38] lists landfilling plastics as an environmentally acceptable disposal option, and “*Environmental Benefits of Recycling“* WRAP

---

[14] This compares to 0.06% from waste incineration (BEIS, 2017).

(2010)[39] states “In terms of greenhouse gas emissions, sending plastics to landfill is preferable to conventional energy recovery, but is less preferable in terms of all other environmental indicators commonly considered in life cycle assessment” i.e. as a form of carbon sequestration. However, there are risks involved in landfilling plastics, which need to be managed. The impacts of plastic waste on our health and the environment are only just becoming apparent. Although there is little research on the specific impacts of plastic waste on land-based wildlife, there is concern that incorrectly managed landfills could lead to either the escape of plastic waste or the escape of landfill leachate containing the chemicals associated with plastic. Leachate acidity and chemicals can break down plastics[40]. In addition, the potential increased use of bioplastics or renewable plastics adds further complexity.

3.6.3 Landfill Mining

The European Enhanced Landfill Mining Consortium (EURELCO) states that “where higher added value outputs are targeted, the net economic balance of the combined remediation-landfill mining activity can even become positive, which is especially the case for larger landfills where economies of scale become relevant. As such, remediation combined with enhanced landfill mining can generate an income for public waste agencies, and this can then be used to cover the costs of remediating and mining smaller, less economic landfills that pose short-term environmental and health risks[41].” The enhanced landfill mining approach is currently being demonstrated in two flagship projects funded by the European Commission’s Horizon 2020 Programme, ETN NEW-MINE (for municipal solid waste) and METGROW+ (for industrial waste) and is also being considered as part of the ‘Waste Package’, the latest revision of the European Policy. This states that “the Commission shall further examine the feasibility of proposing a regulatory framework for enhanced landfill mining so as to permit the retrieval of secondary raw materials that are present in existing landfills. By 31 December 2025 Member States shall map existing landfills and indicate their potential for enhanced landfill mining and share information.” The consideration for this change is that enhanced landfill mining does not only enable the recovery of valuable materials which can be brought back into the cycle, but also allows for recovering land area, taking into account that a large part of the EU’s 0.5 million historic landfills are situated in a (semi-) urban environment, which could be made available for other economic use[42].

3.6.4 Impact on Study & Modelling

The model assumes sufficient capacity for landfilling of residual wastes generated, and therefore the cost of opening new landfill facilities was not included in the financial analysis (although the cost of operation was). The scenario modelling was focussed on providing recovery capacity for wastes and mainly providing landfill disposal for pre-treated residues. Landfilling of plastic waste was modelled, along with impact on CV of residual waste when plastics are removed.

3.7 The potential for bio-fuel and biogas for heat and HGVs

3.7.1 Review of Impacts and Improvement Options

An opportunity yet to be fully exploited in the UK is the use of natural gas or biomethane as a transport fuel. This market is growing significantly worldwide. Statistics given in Appendix I to this report, give some indication of the scale. The main environmental advantage of biomethane as a vehicle fuel is that it can substantially reduce greenhouse gas (GHG) emissions in the transport sector (typically between 60% and 80% compared to diesel). The main challenge for biomethane as a fuel solution is the cost of the product. The product cost mainly depends on the cost of the feedstock used. Purification and upgrading (from biogas to biomethane) costs depend partially on trace gases resulting from the feedstock being used and mainly on the size of the biogas upgrading unit[43].

To encourage the use of biofuels in transport, the Renewable Transport Fuel Obligation (RTFO) was set up in the UK in 2007 and has been amended four times, most recently in 2015. It places an obligation on suppliers of fossil fuels in the UK to ensure that certain amounts of sustainable biofuel are supplied. It considers fuels such as biodiesel, bioethanol and biomethane – in 2015/16 biomethane only represented <1% of the biofuels market. The obligation can be met by redeeming renewable transport fuel certificates (RTFCs). These are awarded to biofuel suppliers when sustainability criteria are met. RTFCs are traded between producers and suppliers and the value of RTFCs is determined by the market. New targets were announced in 2017, with an obligation level of 9.75% biofuel in 2020, rising to 12.4% in 2032. The Department for Transport (DfT) has also published changes to the RTFO which will now include sustainable jet fuel within the incentive scheme.

There is already a small supply sector in the UK. Despite the potential issues of manufacture and scale, biomethane can be cheaper than diesel. To compare usage costs to traditional fossil fuels, Sweden is one of the most reliable sources of cost data due to being one of the most developed biomethane transport markets in Europe. Cost of biomethane there is €0.65-€0.75 per kg, excluding taxes. On an energy basis this is equal to €0.47-0.57 per litre of diesel. This compares to a (at the time) price of €0.75/litre of diesel without tax.

3.7.2 Impact on Study & Modelling

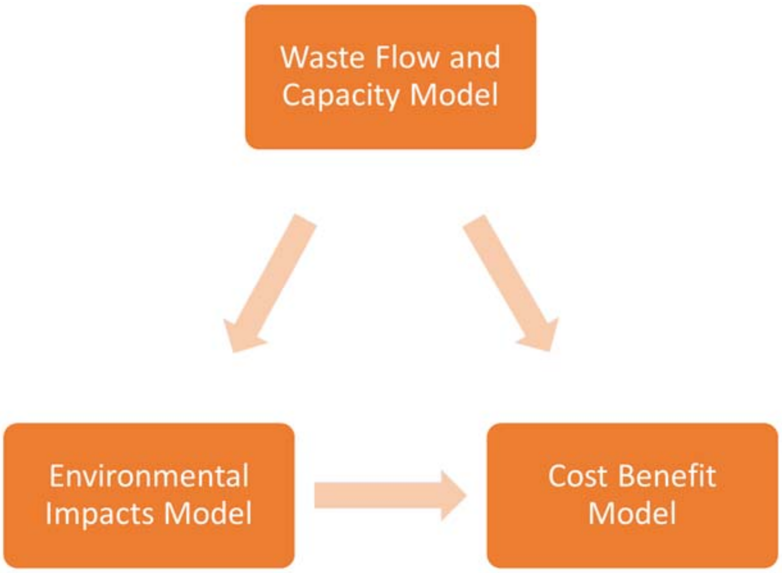
A number of gas to grid infrastructure options were modelled for this study e.g. using AD and gasification as likely biomethane generators.

4 Waste infrastructure analysis

4.1 Overview of the Delivery Methodology

To deliver the NIC National Waste Infrastructure Assessment, Anthesis has devised a model based upon 3 elements as shown in the following diagram:

Figure 7: National Waste Infrastructure Assessment Model elements (Anthesis)



Terminology used in this report: Modelled changes in collection practices are 'segregation scenarios'; different waste management infrastructure combinations used to manage waste collected are 'infrastructure pathways'.

The design, source data and inter-relationships of these elements is explained in detail in Appendix IV to this report, and summarised here.

4.1.1 Waste Flow Model

The design of the waste flow model (WFM) is based upon review of past infrastructure work and recent capacity gap models, including those generated by Anthesis. It was designed to model LACW and "household-like" C&I[15] separately, generating waste arisings estimates (i.e. how much waste is collected) and waste flows (i.e. where this waste goes in the waste management supply chain after it has been collected) per key waste facility type, to feed flow data into the environmental impact and cost benefit models. Arisings forecasts from 2020 to 2050 were developed using population and economic growth forecasts. The baseline capacities used were based upon those facilities forecast to be operational or in construction by 2020 including:

- Energy from waste (EfW - including gasification);
- Anaerobic digestion (AD), in-vessel composting (IVC) and open-air windrow composting (OAW);
- Mechanical Biological Treatment (MBT and BMT/MHT) focussed on RDF production;
- Material recovery facilities (MRF) and bulking/transfer stations (WTS).

---

[15] Household like C&I waste is commercial and industrial waste of a composition similar to that of household waste, and in the case of this study, uses the same types of waste infrastructure as household waste.

4.1.2 Environmental Impact Model

The environmental impact model used waste flow data per year, in the forecast period 2020-2050, from the waste flow model to generate relative GHG impact of developed infrastructure pathway options. This was based upon the use of in-built models within the Environment Agency tool WRATE to simulate the infrastructure pathways generated i.e. in-built waste management infrastructure models were modified to represent the performance of that infrastructure at a national level.

4.1.3 Cost Benefit Analysis

The cost benefit analysis (CBA) financial model used waste flow data per year, in the forecast period 2020-2050, to identify changes in infrastructure requirements from baseline. It valued changes in terms of:

- Capital investment;
- Operating costs;
- Income (in terms of operator) and expenditure (in terms of collector) from gate fees;
- Income from energy outputs;
- Net Present Value based upon Green Book[44] and private finance discount rates.

Detail of the modelling methodology used to deliver this study is presented in Appendix IV to this report. The developed model and the key assumptions used, were exposed to extensive peer review.

4.1.4 Terminology

In the modelling, a number of waste collection and waste management combinations were modelled, so that the outputs could be compared to rank options and identify favourable material and infrastructure combinations.

For the purpose of this study:

- Modelled changes in collection practises such as the increased capture of specific target materials, e.g. separate food waste collection, have been termed “segregation scenarios”.
- Different waste management infrastructure combinations used to manage the wastes collected, such as the use of anaerobic digestion for segregated food waste and EfW for residual waste, are termed “infrastructure pathways”.

Specific “segregation scenarios” can therefore be modelled with multiple “infrastructure pathways” and vice versa.

4.2 Inclusions and Exclusions

The following factors, summarised in Table 3, were included or excluded in the development of the infrastructure assessment model:

Table 3: Waste NIA modelling - inclusions and exclusions

Included	Excluded
English waste arisings and waste management infrastructure.	Waste arisings and waste management infrastructure in the rest of the UK. The implicit behavioural costs of households having to separate their waste.
Municipal (LACW) and municipal like Commercial & Industrial (C&I) wastes (i.e. that with similar composition to municipal waste).	Industrial wastes, agricultural wastes, mineral wastes, construction and demolition and other inert wastes.
Kerbside collections and collection costs.	Collection vehicles and depot costs other than those contained in the WRAP collection cost data.
Collection and waste treatment infrastructure, including: waste transfer and bulking, material recovery facilities, organic recycling including anaerobic digestion, in-vessel composting, open windrow composting, residual waste treatment including intermediate processing (such as mechanical biological treatment), energy from waste, landfill.	Onward recyclate reprocessing and industrial re-use. Hazardous waste treatment. The impact of transport of wastes between facilities.
Energy production (in terms of power, heat, biogas to grid or synthetic natural gas to grid) from energy from waste infrastructure and anaerobic digestion.	Energy from landfill biogas. Energy from biomass energy recovery of segregated wood waste. Cost of heat distribution infrastructure (heat network).
Capital cost of new infrastructure.	Capital cost of existing infrastructure. Refurbishment costs of existing infrastructure. Land, planning, permitting and other development costs.
Operational costs of existing and new infrastructure.	
Gate fees, revenue from material and energy sales.	Landfill tax and renewable energy rebates (in line with the Treasury Green Book).

4.3 Key Assumptions

All elements of the custom-built waste infrastructure analysis model were driven by a set of key assumptions. These influence and shape the results, as well as dictate the limitations of the model. Key assumptions adopted were as follows:

4.3.1 Baseline Waste Arisings and Datasets Used

The prime source of data for estimating LACW arisings for the baseline year (2015), was Defra's WasteDataFlow database (at http://www.wastedataflow.org/). Using data supplied directly by local authorities, this is generally accepted in the sector as a robust dataset.

For commercial and industrial waste, the estimates for this study have focussed upon the "household like" fraction of C&I waste i.e. that C&I waste with a similar composition to LACW, which uses similar waste facilities to LACW to process this waste. The key source of data from which C&I arisings could be derived, and waste flow estimated, is Environment Agency's "Waste Data Interrogator" (WDI)[45].

C&I waste arisings are notoriously difficult to estimate, given the severe lack of historical and current data. A review of previous work carried out in this area is summarised in Appendix IV to this report.

A major gap in WDI data is that for recycling; to partially fill this gap, data from the Environment Agency "National Packaging Waste Database" (NPWD), for England, was used. Recycling data from other sources was of insufficient granularity to enable effective modelling. Finally, total residual LACW plus "household like" C&I arisings have been calculated using returns data for non-hazardous landfill (WDI data, household like materials only), EfW inputs (from EA returns data[46]), Co-Incineration (from EA returns data) and RDF exports (from EA/HMRC data[47]). Developed baseline arisings were benchmarked against other recent studies.

4.3.2 Waste Growth

Economic and population growth rates to 2050 were based upon papers produced by the Commission[48], [49]. Both factors have been used to generate forward forecasts of arisings of both LACW and C&I waste. Two growth scenarios (High growth and Low growth) have been established, the difference between the two resulting from the use of different decoupling rates.

- For the high growth scenario, a decoupling rate of 1% has been applied (to give average annual growth of +1.4% from 2020-2050); and
- For the low growth scenario, a rate of 2.5% applied (average overall growth -0.1% 2020-2050).

This results in a growth in waste annually for the higher growth scenario and a small annual decrease for the lower growth scenario. The low growth model represents a future based upon continued waste minimisation, although there is likely to be a limit to this, whereas the high growth model reflects the potential impact of economic growth on consumer habits and the production of waste by businesses. The lower rate is based upon actual LACW performance in the last 10 years, which has generally trended downwards, although there are a number of external factors which may also have impacted upon reported LACW annual totals. There is no such annual data for commercial and industrial waste upon which growth forecasts could be benchmarked. The figures chosen, however, do mirror growth rates applied in other recent studies and have been tested with stakeholders and peer reviewers.

4.3.3 Baseline Recycling Rates

- A LACW recycling rate of 50% was assumed for 2020 to match UK statutory recycling targets (actual LACW recycling rate for 2015 was 43.9% (Defra)).

- For C&I wastes, a baseline recycling rate of 55% has been used (the latest known C&I recycling rate was 52% in the 2009 survey[50], and this accounted for recycling of all C&I waste arisings; there is no other data available since this survey, on which a more up to date recycling rate could be based, and the figure selected reflects assumptions used in other published studies, and again has been tested with stakeholders and peer reviewers).

These baseline recycling rates remain constant throughout the forecast period, supplemented by additional segregation of the particular target material modelled for each segregation scenario.

4.3.4 Waste Compositions

Waste compositions have been assumed based upon those published in the review by Resource Futures (2013)[51]. From this review, typical compositions for LACW and Local Authority collected commercial waste were utilised for LACW and C&I modelling respectively. It is assumed that this top-level composition remains constant throughout the forecasting period.

4.3.5 Collections services

For increased collection of target materials modelled using ‘segregation scenarios’, it has been assumed that material is collected via kerbside collection. Modelling HWRC or bring banks collection has not been included.

In addition, it was assumed that 45% (by weight) of all dry recyclates are collected co-mingled and are separated at a MRF, based upon actual data from WasteDataFlow 2015 (i.e. 55% collected already segregated and sent to reprocessors via a bulking/transfer station). This proportion was maintained throughout the forecast period.

It was also assumed that bulking/transfer was used for all dry recyclates and residual (black bag) waste and that mixed recyclates were delivered directly to the MRF and organics (including food) delivered directly to AD, composting etc., as is usual practice. Note that for recyclates, the modelling ends at collection and bulking, at which point the material is valued at a typical market price. Onward processing by reprocessors or industrial users is not considered.

4.3.6 EfW Capacity v Calorific Value (CV)

The majority of mass burn energy from waste facilities have wide operating envelopes which can deal with variable calorific values (CV) of input residual waste, commonly from 6–11 MJ/kg. However, based on the need for a constant energy input to drive steam generation and therefore power production, changes in CV need to be compensated for by increasing throughput of lower CV residual waste (compared to the process optimum), or slowing the throughput of high CV residual waste. The changes in kerbside segregation modelled in this study, impact upon the composition of the resultant residual waste, and hence upon its calorific value, and this has been forecast. The methodology used is explained in more detail in Appendix IV to this report. To adjust assumed throughput for likely changes in forecast CV, the impact of CV on EfW capacity summarised in Table 4 was used:

Table 4: Assumed residual waste calorific valve v. EfW capacity (central CV baseline 9.7 MJ/kg)

CV range		Assumed Capacity factor (where 100% = nominal capacity at baseline CV)
min	**max**	
7.7	8.2	115%
8.2	8.7	110%
8.7	9.2	105%
9.2	10.2	100%
10.2	10.7	95%
10.7	11.2	90%

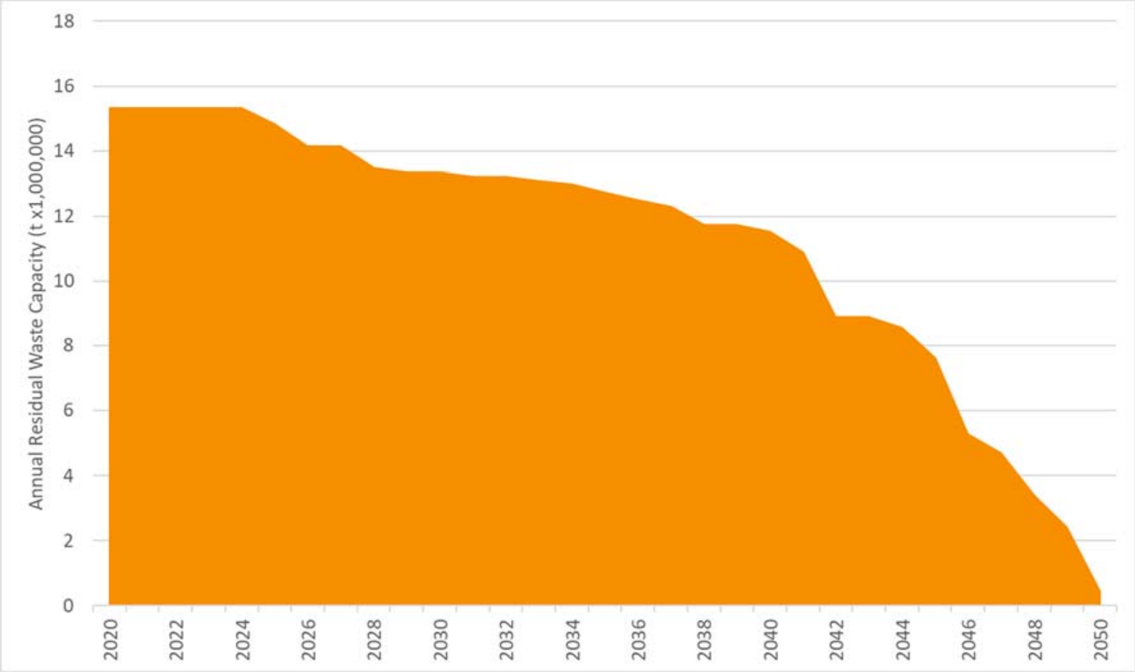
As an example, modelling maximising food waste segregation in this study increased the forecast CV of the resultant residual waste to approximately 10.2 MJ/kg. To adjust for this increase, effective capacities of existing and future EfWs were reduced by 5%. Taking the assumed 2020 EfW capacity as 15.3 Mtpa, for modelling this scenario the total effective capacity was reduced to 14.5 Mtpa.

Note that although change in EfW throughput has been modelled, this does not take into account the practicalities of processing volumes of waste outside the design specification of the EfW facilities and the ability of feed infrastructure such as waste pits and hoppers, to deal with increasing volumes of waste.

4.3.7 EfW Facility End of Life and Refurbishment

Infrastructure modelling assumes that infrastructure operating in 2020 is available for the whole of the forecast period. The capital cost of this existing infrastructure is not included in the financial model, although the costs of operation, income from gate fees and energy, are included. As Figure 8 shows, most of the assumed 2020 EfW capacity will reach the end of their initial waste contract during the forecast period (assuming contract end at 30 years after commissioning).

Figure 8: Contracted English EfW capacity over time (assuming 30 year contract period after commissioning) of EfW capacity operational in 2020) (Source: EA, Anthesis)



The current English EfW network consists of a range of facilities with ~2.5 Mtpa capacity built before 2000 and ~12.8 Mtpa since 2000 (including those anticipated to be in place by 2020). Due to the cost and relatively longer life of the buildings containing the energy from waste facilities, compared to that of the equipment itself, it is likely practice that at end of contract facilities will be refurbished to extend their life [16]. Assuming a refurbishment cost of £30-£60 million per facility, this cost over the forecast period could amount to between £1.7 and £3.5 billion, in addition to the capital costs modelled. On the basis that this cost will the common to all the scenarios modelled, this cost has not been taken into account in the model capital cost and NPV outputs.

4.3.8 Capture Rates for waste streams collected for recycling

Capture rates (or recycling rates) define how much of a target material is separated at kerbside for recycling, as a proportion of the total of that material available. For instance, if 40% of a particular target material is segregated for recycling at kerbside, that leaves the remaining 60% in the collected residual waste. Capture rates are therefore key to modelling the impact of segregation scenarios and for forecasting residual waste composition upon which calorific value (CV) estimates and GHG impact calculations are based. It was important too that the capture rates used were based upon best practice elsewhere so keep the outputs of the model realistic.

4.3.8.1 Food Waste

WRAP has delivered significant insight through its studies into collection costs, capture rates and related issues, particularly related to food waste. WRAP's cost and capture rate data is reported in kg per household per year (kg/hhld/yr). These data are average performance rates, taking into account differences in household type (multi-occupancy etc.) and deprivation levels (socio-economic variation). Utilising this data for this study required the use of a bottom up approach based on the total number of English households.

WRAP work has confirmed that the best configuration for kerbside collection of food waste remains separate weekly collections, where householders are provided with kerbside containers, kitchen caddies and liners and where residual waste is collected fortnightly. This has the benefit of driving maximum participation and set out rates, whilst off-setting additional collection costs (as long as they are introduced simultaneously). In this way, rates of 80 kg/hhld/yr can be achieved as reported in the WRAP Household Food Waste Collections Guide[52]. Higher rates have been achieved in Wales (82 kg/hhld/yr), supported by strong policy measures (including high local authority recycling targets) which are not in operation in England. WRAP analysis (not published) using Waste Data Flow, has determined that an average of 58 – 60 kg/hhld/yr throughout England is currently being achieved.

Using household totals from the Office of National Statistics (ONS), and overall food waste volumes reported by WRAP, 80 kg/hhld/yr amounts to a capture rate for England of 42%. This compares to a reported 2015 capture rate in Wales of 47%[53], and in the Netherlands of 48% (all biowaste)[54].

Generally, there is good understanding of the collection scheme characteristics required to keep contamination to a minimum. Quality of feedstocks are not seen as an enduring problem and many food waste treatment facilities have de-packaging equipment at the front end to deal with packaged food waste (usually C&I), which might include back of store and out of specification products presented in a packaged form.

---

[16] This is demonstrated by the network of energy from waste facilities in Germany, where many of the existing plants were built in the 1970's and 1980's. (Source UBA, "The Role of Waste Incineration in Germany")

4.3.8.2 Other Recyclates

For modelling collection scenarios in this study, realistic material capture rates for key materials have been selected based upon benchmarking with data from a number of sources, particularly with capture rates achieved in high performing nations, Wales and the Netherlands. As reported in the case studies presented in Appendix II of this report, recycling rates in Wales and the Netherlands are amongst the highest in the world, and both countries are delivering >60% recycling rates from municipal waste. Using data for Wales reported in WRAP (2016)[53], and for the Netherlands by the Royal Dutch Waste Management Association[54], capture rates have been generated per material type to use as benchmarks in selecting capture rates to model for this study. These are presented in Table 5, along with England capture rates for 2015 and modelled capture rates selected for 2030.

Table 5: Modelled capture rates - key materials per segregation scenario

Segregation scenario	**This study**		**Wales (2015)**		**Netherlands Kerbside Capture Rate**
	Existing modelled capture rate (2015)	**Modelled 2030 capture rate**	**Kerbside Only**	**All capture routes**	
1. Food waste	11%	42%	47%	41%	
2. Biodegradable wastes					
Paper & card	54%	64%	64%	60%	70%
Wood	68%	75%	N/A	N/A	
Garden waste	79%	85%	N/A	85%	
Food waste	11%	42%	47%	41%	
All biowaste					48%
3. Plastic wastes					
Dense Plastics	21%	46%	66%	46%	20% (*)
Plastic film	11%	16%	N/A	16%	
4. High CE recycling					
Paper & card	54%	64%	64%*	60%	70%
Dense Plastics	21%	46%	66%	46%	
Plastic film	11%	16%	N/A	16%	
Wood	68%	75%	N/A	N/A	
Garden waste	79%	85%	N/A	85%	
Food waste	11%	42%	47%	41%	
Glass	67%	79%	87%	79%	68%
Ferrous metals	54%	63%	74%	63%	
Non-ferrous metals	47%	55%	49%	55%	
Textiles	-	-	-	-	33%

(*) packaging only

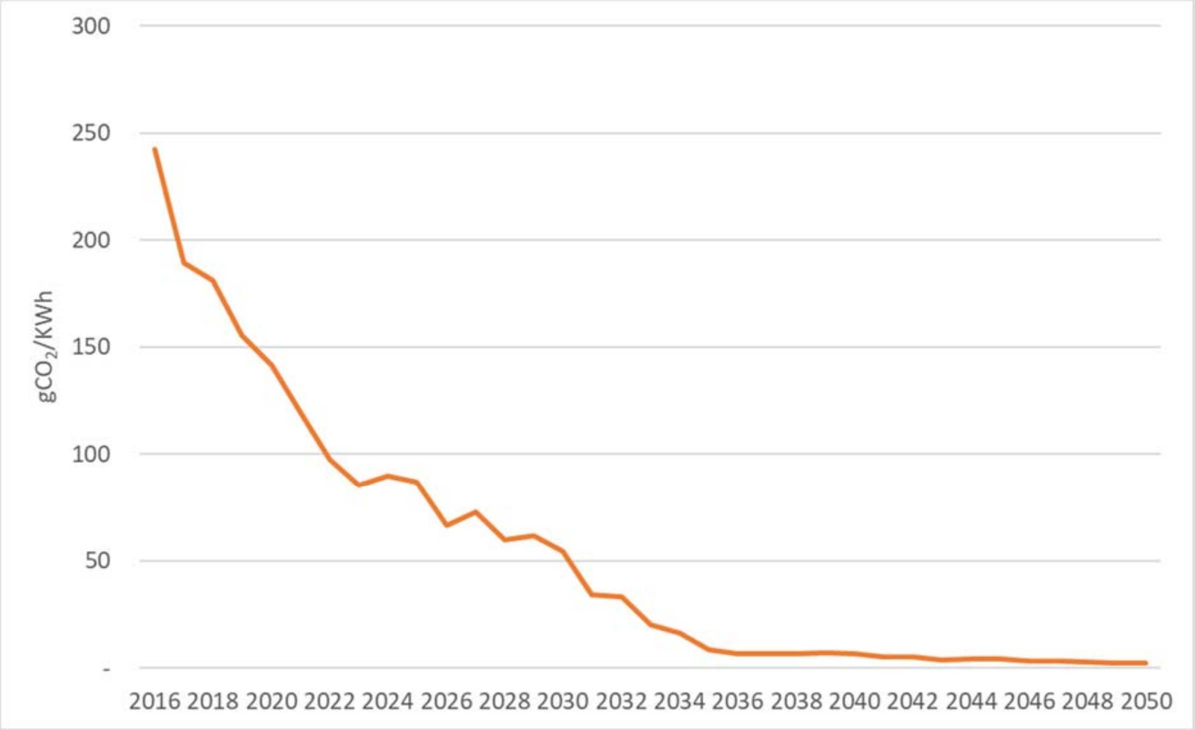
Because of the lack of published data for commercial collections, the same capture rates for municipal waste were used in the modelling.

Capture rates have been applied in the waste flow model assuming a fixed waste composition across the forecast period. This may not in reality be the case. Proposed waste minimisation initiatives covering areas such as food waste, avoidable single-use plastics and the potential substitution of fossil-based plastics with bioplastics, along with other unforeseen changes in consumer behaviour, may all impact on the assumed waste composition during the forecast horizon, and therefore on the findings of this study.

4.3.9 Energy Mix

WRATE modelling compared GHG impact of the energy generated to the following forecast energy mix, which shows increasing use of renewable energy sources by 2050 (renewable from 38% in 2020 to 67% in 2050) mirroring the National Grid energy sector carbon intensity forecasts[66] presented in Figure 9. This will mean for all EfW based scenarios, EfW is mostly offsetting renewables by 2050.

Figure 9: Carbon Intensity of power generation 2016-2050 (Source: National Grid)



4.4 Modelled Infrastructure Pathways and Segregation Scenarios

For modelling future options, segregation scenarios were developed (impacting on how waste is collected) along with waste management infrastructure pathways (impacting on how collected waste is managed). These were applied in combinations to assess the impact of changes to the waste management supply chain from 2020 to 2050.

4.4.1 Segregation scenarios

The following segregation scenarios were modelled:

- No change (business as usual) i.e. fixed collection practises and recycling rates from 2020;
- Increased food waste segregation at kerbside;
- Increased biodegradable waste segregation at kerbside;
- Increased plastics waste segregation at kerbside;
- Increased plastics waste segregation at kerbside and from residual waste to landfill;

- Increased dry recyclates segregation at kerbside to achieve high recycling rates.

Increased segregation capture rates i.e. how much of the available waste stream was separated for collection for recycling, were modelled on those achieved elsewhere, as explained in section 4.3.8. More information on specific segregation options is given in Appendix IV to this report.

4.4.2 Infrastructure Pathways

The Infrastructure Pathway dictates how waste is managed (treated, recovered or disposed of) after its been collected. The selection of infrastructure for these pathways was based upon the conclusions of the technical horizon scan (reported in chapter 3), focussing on technologies either already commercially available or close to commercialisation. Modelled pathways were:

- No change (business as usual) i.e. current EfW infrastructure (available at 2020);
- Increased efficiency of the current infrastructure (available at 2020) by delivering CHP to capable facilities;
- New EfW with CHP – filling the capacity gap between 2020 EfW capacity and available residual waste with CHP enabled energy from waste (i.e. diverting from landfill);
- New ATT (gasification) with GtG - filling the capacity gap between 2020 EfW capacity and available residual waste with GtG enabled gasification (i.e. diverting from landfill).

Combinations of the segregation scenarios and infrastructure pathways were modelled as follows (summarised in Table 6):

Table 6: Modelled Segregation Scenario and Infrastructure Pathway combinations

	No Change - Current EfW Infrastructure as of 2020 Pathway 0	**Current EfW Infrastructure with CHP Improvement Pathway 0.1**	**Current EfW Infrastructure plus landfill diversion to new EfW with CHP Pathway 0.2**	**Current EfW infrastructure with landfill diversion to new Gasification with GtG Pathway 0.3**
No Change (Baselines)	✓ **Baseline**	✓	✓	✓
Food Waste segregation	✓ with food waste options to AD CHP or AD GtG		✓ with food waste options to AD CHP or AD GtG	
Biodegradable Waste Segregation	✓		✓	
Plastic Waste Recycling	✓		✓	
Plastic Waste to Landfill			✓ with plastics removed from residual waste sent to landfill	
High Recycling	✓ with food waste options to AD CHP or AD GtG		✓ with food waste options to AD CHP or AD GtG	

4.5 Modelling Outputs

4.5.1 The infrastructure modelling was delivered in two phases, Phase 1 looked at the waste collection (from the viewpoint of the collection authority, usually the local authority), and Phase 2 the treatment of this collected waste (from the viewpoint of the infrastructure operator, usually a private company).

4.5.2 Impact of Collections (Phase 1)

The first phase of the modelling focussed on the collection of waste materials at source, and therefore forecasted:

- Waste Flows: collected volumes from the segregation of dry recyclates, organic waste and residual waste at kerbside, as dictated by the segregation scenario chosen, for each forecast year 2020 to 2050, applying high and low growth factors;
- Operational Cash Inflow: a net operation cash inflow was calculated by estimating such cash outflows as cost of collection, gate fees applied for treatment or disposal of the collected materials, costs of operating transfer stations and inflows from the dry recyclates collected and subsequently sold;
- Capital Cost: the capital cost of any additional infrastructure required to deal with the collection of the forecast waste, particularly transfer stations, was also determined[17];
- Net Present Value[18]: collating cash inflows and outflows allowed calculation of net present value (including the residual value of any new collection infrastructure required). Comparison of NPV between the different pathways then allows identification of the pathways with the most benefit for the least cost.

The cost benefit analysis does not include the cost of landfill tax as recommended by the Treasury Green Book[44]. However, this can generate phase 1 outputs that look counterintuitive. Outputs were therefore produced also including landfill tax for comparison.

4.5.3 Impact of Treatment and Disposal (Phase 2)

The second phase of the modelling looked at the waste management pathway used for the treatment, recovery or disposal of the waste collected in Phase 1, and generated estimates of:

- Waste flow: estimates of volumes of waste inputs into and outputs from key waste infrastructure types, as dictated by the infrastructure pathway chosen, for each year 2020 to 2050;
- New Facility requirement: from the volumes estimated per waste facility type, the model compared waste demand to available capacity, and calculated what new infrastructure was needed. From this need for new infrastructure, capital cost figures were generated;
- Energy Outputs: From waste volume estimates through key facility types, relevant energy outputs such as heat, power and gas to grid (as heat) were calculated;
- Operation net cash inflows: calculated from inflows such as energy income, recyclate sales and gate fees, and outflows such as operation costs and reject disposal costs;

---

[17] Note that the cost of additional collection vehicles and depots was not included directly in the financial model, although WRAP report that this element is included in their published collection cost rates[52] which were used to model collection costs.

[18] Net Present Value is a standard measure of the attractiveness of an investment, where the more positive the NPV, the more attractive the investment. Net Present Value (NPV) = Discounted Net Operational Cash Inflow – Discounted capital cost

- Net Present Value: generated capital costs and operation net cash inflow estimates were used to generate Phase 2 NPV estimates.

4.5.4 Overall Impacts

By taking the outputs from the Phase 1 and Phase 2 analyses, overall impacts are estimated in terms of:

- Overall Capital Cost: from the sum of capital costs for new infrastructure from both phases;
- Residual Value: a measure of the value of all Phase 1 and Phase 2 operational facilities at the end of 2050, made up from the benefits accrued by the facility from 2050 until its end of life;
- Overall Net Present Value: from the sum of NPV from both phases;
- Overall GHG impact: from waste flow outputs and forecast waste compositions.

4.5.5 Reporting Net Present Value

NPV is reported throughout this report as relative to baseline i.e. as the difference from the baseline pathway 0, on the basis that reported NPV for a given scenario and pathway = absolute NPV for that scenario minus absolute NPV for Pathway 0.

Absolute NPVs are not intended to represent a £ value for the English waste management sector, because of the exclusions made (as already reported in section 4.2). Absolute NPV outputs varied depending upon scenario and pathway. Ranges of results obtained (from min to max) are reported in Table 7. These show, excluding landfill tax, collection scenarios (Phase 1) were always negative i.e. costs outweighed revenues from recyclates, for instance. Conversely for infrastructure operation (Phase 2) NPVs were positive, with revenues exceeding costs. Overall, Phase 1 plus Phase 2 NPVs were negative for all scenarios and pathways modelled, with the costs of collection (to the collection authority, usually public sector) outweighing the benefits of processing the wastes collected (to the operating company, usually private sector).

Table 7: Model outputs: Absolute Net Present Value per scenario – ranges (min to max) for high and low growth models (excluding landfill tax) in £ billion 2020-2050

	Phase 1 (Collection)	Phase 2 (Infrastructure)	Overall (Phase 1 + Phase 2)
High Growth	-95.9 to -78.9	62.1 to 81.8	-21.8 to -12.5
Low Growth	-73.0 to -63.7	47.9 to 56.8	-22.6 to -14.0

4.6 Modelling Results

The following section summarises the results obtained from the modelling of the selected segregation scenarios and infrastructure pathways. More detailed results are presented in Appendix V to this report.

4.6.1 Baseline Infrastructure Pathways Modelling (no change in segregation)

4.6.1.1 Waste flow results

To understand the relative impacts of the infrastructure pathways, without the influence of changes in collection, the 4 infrastructure pathways selected were modelled assuming no change in collections and recycling rate over the forecast period. In modelling these pathways, outputs from the waste flow model forecast:

- Residual waste collections of up to 22.1-37.2 Mtpa (low growth to high growth, at 2050);
- Residual waste calorific value based on estimated compositions, of ~9.8 MJ/kg.

This compares to a 2020 forecast English EfW infrastructure capacity of 15.3 Mt and RDF exports of 3.2 Mt.

4.6.1.2 Cost Benefit Results

To allow for direct comparison between pathways, all outputs from the model are reported as difference from the baseline pathway (Pathway 0) i.e. based upon the 2020 operating EfW infrastructure. Note that for NPV, a positive NPV shows benefits over this baseline pathway, negative shows increased costs (reduced benefits) compared to baseline. Phase 1 Collection outputs showed:

- Zero NPV including residual value, for pathways 0 and pathway 0.1 (Increased efficiency of the current infrastructure by delivering CHP to capable facilities) due to no change in collection practices over the forecast period;
- Pathway 0.2 (CHP enabled EfW to fill capacity gap) - NPV including residual value of -£1,182 to -£8,701 million excluding landfill tax, £913 to £6,722 including landfill tax;
- Pathway 0.3 (ATT GtG to fill capacity gap) – similar results of -£1,576 to -£11,602 million excluding landfill tax, £519 to £3,821 including landfill tax.

The difference is explained by a change in charge for gate fees from landfill (in pathways 0 and 0.1) to EfW (in pathways 0.2 and 0.3). Excluding landfill tax this shows an increase in cost through negative NPVs, due to the higher modelled gate fee for EfW compared to landfill. When landfill tax is including, giving a more realistic picture of the benefit to the collecting authority, collection costs are cut as shown by a positive NPV.

For Phase 2 results, the impact of the need for new infrastructure (up to 15.4 Mtpa) is shown clearly in Table 8, giving NPV values of up to £17 billion for pathway 0.2 (new EfW with CHP) and £15.4 billion with pathway 0.3 (gasification with gas to grid).

Table 8: Infrastructure pathways, Phase 2 Treatment: Discounted Capital Cost and NPV including residual value, and overall NPV - difference from baseline pathway 0 (in £ millions)

Segregation Scenario	New Capacity Forecast (Mtpa)	Discounted Capital Cost (Phase 2)	NPV including residual value (Phase 2)	Overall NPV including residual value (Phase 1 + Phase 2)
Pathway 0 (baseline, 2020 infrastructure)	0	0	0	0
Pathway 0.1 (improved efficiency 2020 infrastructure)	0	0	£62	£515 to £516
Pathway 0.2 (CHP enabled EfW to fill capacity gap)	0.4 to 15.1	£229 to £7,158	£1,923 to £15,426	£741 to £6,725
Pathway 0.3 (ATT GtG to fill capacity gap)	0.4 to 15.4	£173 to £5,496	£2,063 to £17,139	£487 to £5,537

Overall NPV is calculated from the sum of Phase 1 Collection NPV and Phase 2 Treatment NPV. For the two new infrastructure pathways, increased collection costs in Phase 1 (excluding landfill tax) were more than compensated by additional revenues from operating the new infrastructure required. Combined NPV including residual value gave positive NPV figures varying from between £0.5 to £6.7 billion depending upon the infrastructure pathway and growth model chosen, as also shown in Table 8, with CHP enabled EfW giving a slightly higher NPV than gasification to GtG.

4.6.1.3 Outputs

Estimating waste flows through key facility types such as EfW and anaerobic digestion (AD) allows calculation of energy outputs, as power, heat and syngas.

Over the forecast period 2020-2050, the baseline pathway 0, based upon 2020 infrastructure, is forecast to deliver between 407 and 418 TWh energy output in total over the 30 year period. The additional energy produced by the variations of infrastructure pathway to the baseline pathway are summarised in Table 9 following, showing up to 420 TWh additional energy output from pathway 0.3 involving new gasification gas to grid capacity, to 314 TWh with pathway 0.2 and new CHP enabled EfW capacity.

Table 9: Infrastructure pathways, Outputs (energy and GHG) - difference from baseline pathway 0

Infrastructure Pathway	**Power Generation (compared to baseline 2020-2050 TWh)**	**Heat Generation (compared to baseline 2020-2050 TWh)**	**Total Energy Generation (compared to baseline 2020-2050 TWh)**	**GHG Avoidance compared to baseline (total 2020-2050) (tCO_2e x 1000)**
Pathway 0 (baseline, 2020 infrastructure)	0	0	0	0
Pathway 0.1 (improved efficiency 2020 infrastructure)	-5	23	17	4,800 to 4,816
Pathway 0.2 (CHP enabled EfW to fill capacity gap)	17 to 143	20 to 171	37 to 314	10,316 to 77,418
Pathway 0.3 (ATT GtG to fill capacity gap)	-2 to 0	50 to 423	50 to 421	13,603 to 119,978

As shown in Table 9, pathways 0.2 and 0.3 deliver additional heat and power (from EfW) and gas to grid capacity (from gasification) respectively. They also deliver increases in the energy and heat delivery over baseline, with GtG quantified as heat in TWh.

With calculated energy outputs and waste flows, overall GHG impact can also be calculated using factors generated by WRATE based upon waste material type, facility type, waste composition and background energy mix. These totals too are reported in Table 9. These show considerable GHG avoidance compared to baseline for the two new infrastructure pathways, with gasification and gas to grid delivering significant GHG benefits over CHP enabled EfW.

4.6.1.4 Performance per £ NPV

Comparing the efficiency of £ investment and NPV in delivering improved outputs per pathway are summarised in Table 10. This shows increasing benefits per £ NPV in both energy production and GHG avoidance in diverting residual waste from landfill to EfW with CHP and to gasification with gas to grid.

Table 10: Baseline Scenarios, Outputs/£ Capital Investment and NPV (energy and GHG) - difference from baseline pathway 0

Segregation Scenario	Energy Generation per £ NPV compared to baseline (kWh)	GHG avoidance per £ NPV compared to baseline ($kgCO_2e$)
Pathway 0.1 (improved efficiency 2020 infrastructure)	33.4 to 33.5	9.32 to 9.34
Pathway 0.2 (CHP enabled EfW to fill capacity gap)	46.7 to 50.0	11.51 to 13.93
Pathway 0.3 (ATT GtG to fill capacity gap)	76.0 to 102.0	21.67 to 27.94

4.6.2 Waste Segregation Scenarios Modelling results

Comparing the results of the changes in collection practices (as segregation scenarios) against the infrastructure baselines results already reported in section 4.6.1, allowed the environmental and economic impacts of the individual segregation changes to be isolated and compared.

4.6.2.1 Waste Flow Results

The waste flow modelling generated forecasts of increased collection of target materials over the forecast period 2020 to 2050, plus volume estimates of the remaining residual waste. Increased segregation volumes per segregation scenario are presented in Table 11 following. Residual waste volumes and estimated calorific values are given in Table 12.

Increased segregation at kerbside reduces the amount of residual waste collected depending upon the materials collected and the capture rates assumed. Figure 10 and Figure 11 show how this availability of residual waste compares to the amount of EfW capacity at 2020.

Figure 10: Residual waste volumes per segregation scenario compared to 2020 infrastructure capacity, RDF exports and non-combustibles to landfill - High growth model

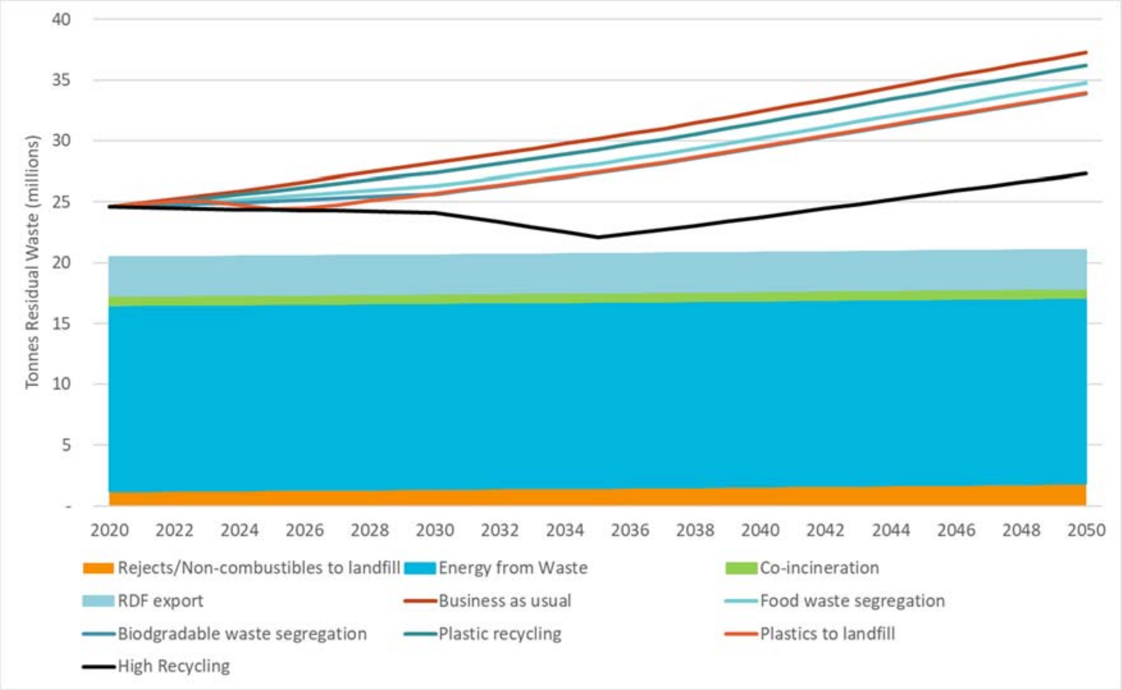
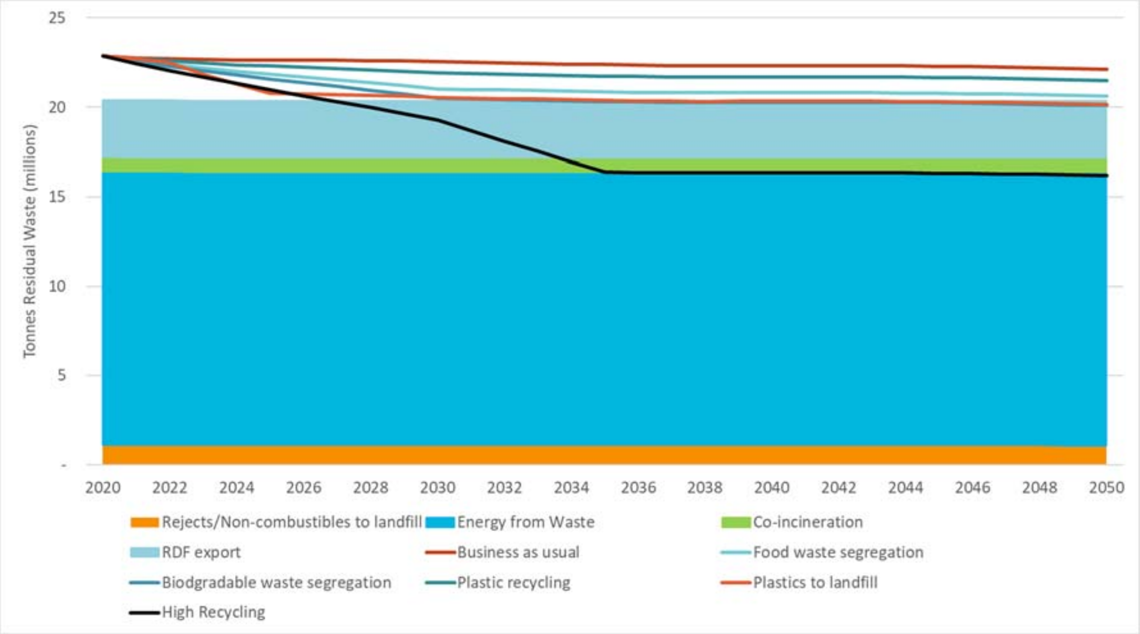


Figure 11: Residual waste volumes per segregation scenario compared to 2020 infrastructure capacity, RDF exports and non-combustibles to landfill - Low growth model



In the case of the high recycling scenario, the amount of available residual waste dips below the available capacity figure from 2030 onwards, using the low growth model only. The capacity figures assume 3.2 Mtpa of RDF is exported to Europe. If this waste is energy recovered in England, the reduction in exports compensate somewhat for the reduction in residual waste, put still leave a potential overcapacity based upon 2020 infrastructure, of 0.7 Mtpa after 2030.

As mentioned in section 2.2.4, there is an estimated ~11 Mtpa of EfW capacity at various stages of development and yet to reach financial close. If all of these facilities are financed and built, and the waste growth experienced during the forecast period is central to low, there is a risk of overcapacity.

4.6.2.2 Impact on Collections (Phase 1)

The impact of increased material segregation on collections (Phase 1) for each scenario is summarised in Table 11 showing the additional segregation achieved, and the financial impact of the change in segregation with relevant baseline results shown for comparison. All results are given as difference from the baseline pathway 0 to improve clarity and to give a measure of change from “business as usual”. Note that a positive NPV shows benefits (revenue or reduced costs) over this baseline, a negative NPV increased costs or reduced revenue compared to baseline.

Additional kerbside segregation volumes vary depending upon the materials being segregated, peaking at 6-8.6 Mt additional segregation (annual average over the forecast period) for the high recycling scenarios.

The Phase 1 financial model assumes that:

- dry recyclates and residual waste are bulked at a transfer station;
- all segregated food waste is assumed sent directly to an anaerobic digestion (AD) facility for treatment;
- and mixed recyclables directly to a MRF for separation.

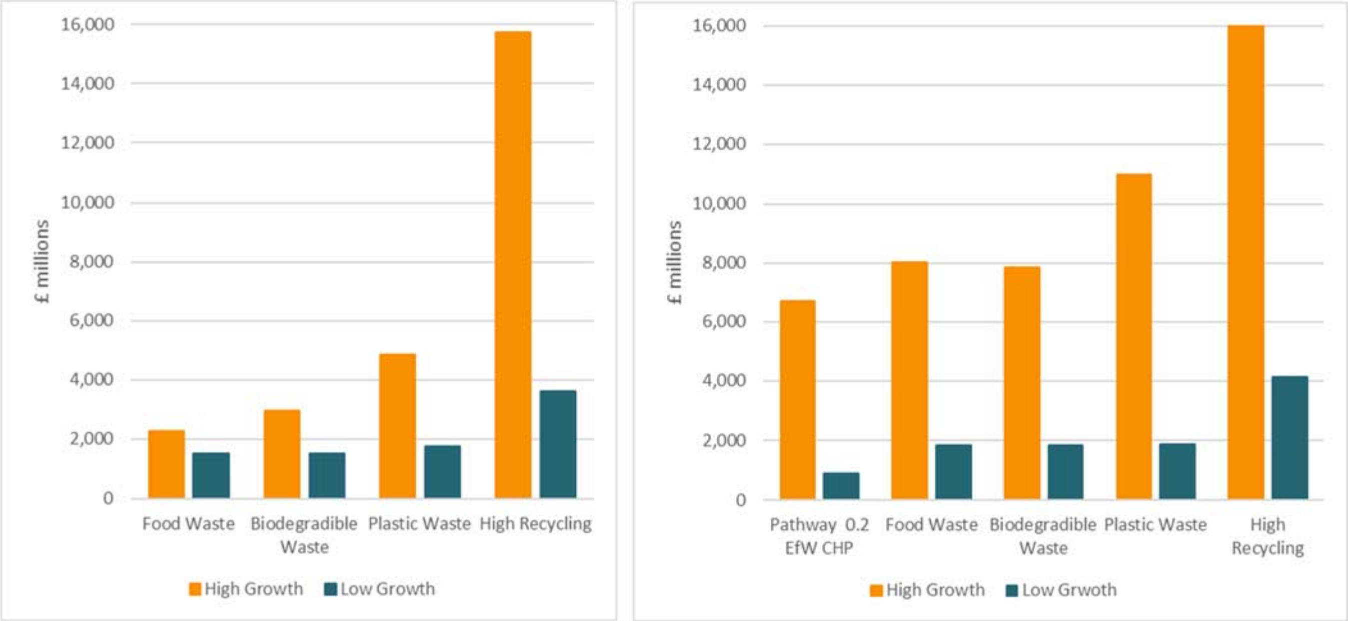
Table 11: Increased Segregation scenarios, Phase 1 Collections: NPV excluding and including Landfill Tax - difference from baseline pathway 0 (in £ millions)

Segregation Scenario	Additional Segregation (annual average over 2020-2050) Mt	Discounted Capital Cost (Phase 1)	NPV including residual value (Phase 1)	NPV including residual value (Phase 1) including Landfill Tax	Residual waste infrastructure as 2020	Residual waste diversion from landfill to EfW with CHP
Baseline Residual waste Pathway 0.2 (for comparison)	0	0	-1,182 to -8,701	913 to 6,722		✓
Food waste to AD CHP	1.2 to 1.8	0 to -36	102 to 20	1,504 to 2,258	✓	
	1.2 to 1.8	0 to -36	-322 to -7,456	1,832 to 8,033		✓
Food Waste to AD GtG	1.2 to 1.8	0 to -36	102 to 20	1,504 to 2,258	✓	
	1.2 to 1.8	0 to -36	-322 to -7,456	1,832 to 8,033		✓
Biodegradable Waste	1.9 to 2.7	0 to -54	-218 to -1,292	1,761 to 2,961	✓	
	1.9 to 2.7	0 to -54	-329 to -7,645	1,847 to 7,868		✓
Plastics Waste to recycling	1.5 to 2.1	8 to 20	2,656 to 3,517	3,620 to 4,835	✓	
	1.5 to 2.1	8 to 20	2,003 to -4,457	4,124 to 10,994		✓
Plastics Waste (plastics to landfill)	1.5 to 2.1	8 to 20	914 to -8,045	3,252 to 7,765		✓
High Recycling (food waste to AD CHP)	6.0 to 8.6	5 to -74	7,695 to 5,473	9,830 to 15,748	✓	
	6.0 to 8.6	5 to -74	7,646 to 2,489	9,868 to 18,053		✓
High Recycling (food waste to AD GtG)	6.0 to 8.6	5 to -74	7,695 to 5,473	9,830 to 15,748	✓	
	6.0 to 8.6	5 to -74	7,646 to 2,489	9,868 to 18,053		✓

Therefore, change in discounted capital cost reflects the impact of additional segregation on the amount of waste transfer stations required. For instance, for increased food waste segregation, 1.25 to 1.76 Mt (annual average) food waste is additionally segregated at kerbside and sent directly to AD for onward processing, without bulking. The subsequent reduction in the residual waste volume reduces the need for residual waste bulking and therefore this is reflected in a capital saving compared to baseline i.e. a negative discounted capital cost.

Phase 1 NPV including landfill tax show an increasingly positive NPV i.e. overall benefit, compared to baseline pathway 0. Despite the change in the cost of collection (for instance, increased recycling collection costs, with reduced residual waste costs due to changes in collection volumes), the results show that the more waste is segregated at kerbside for AD or recycling, the greater the saving from diversion from landfill or energy recovery, and the more positive overall the Phase 1 NPV. The value of the segregated recyclates has a significant impact on this, reflected in peak NPVs for plastics and high recycling scenarios. Results are summarised in Figure 12 following, which show this trend.

Figure 12: Phase 1 (Collection) for the range of segregation scenarios using i) baseline residual waste pathway 0 i.e. 2020 infrastructure, and ii) diverting residual waste from landfill to EfW with CHP as pathway 0.2. In all cases, results are presented as difference from baseline pathway 0.



4.6.2.3 Impact on Treatment/Disposal Infrastructure Requirements (Phase 2)

For each segregation scenario, the impact of greater segregation of target materials on the waste management of those materials, plus that of the resultant residual waste, was modelled. The residual waste resulting from the increased segregation was modelled in terms of volume and composition for each year of the forecast period. For instance, if more food waste is collected at kerbside and therefore does not go into the residual waste stream, then the collected volume of the residual waste is reduced and the food waste content of the collected residual waste is similarly reduced, impacting both the composition and calorific value of the residual waste. From the resultant residual waste composition, calorific value (CV) of the waste was estimated. More detail on the methodology for CV forecasting is given in Appendix IV to this report. As described in section 4.3.6 changes in CV can have an impact upon the throughput of energy recovery facilities, and this change was modelled.

For each scenario and infrastructure pathway combination, discounted capital cost was calculated based upon the amount of new treatment infrastructure required to manage the waste from that combination. Results of this financial modelling are given in Table 12. Again, for clarity these are presented as £ differences from baseline pathway 0.

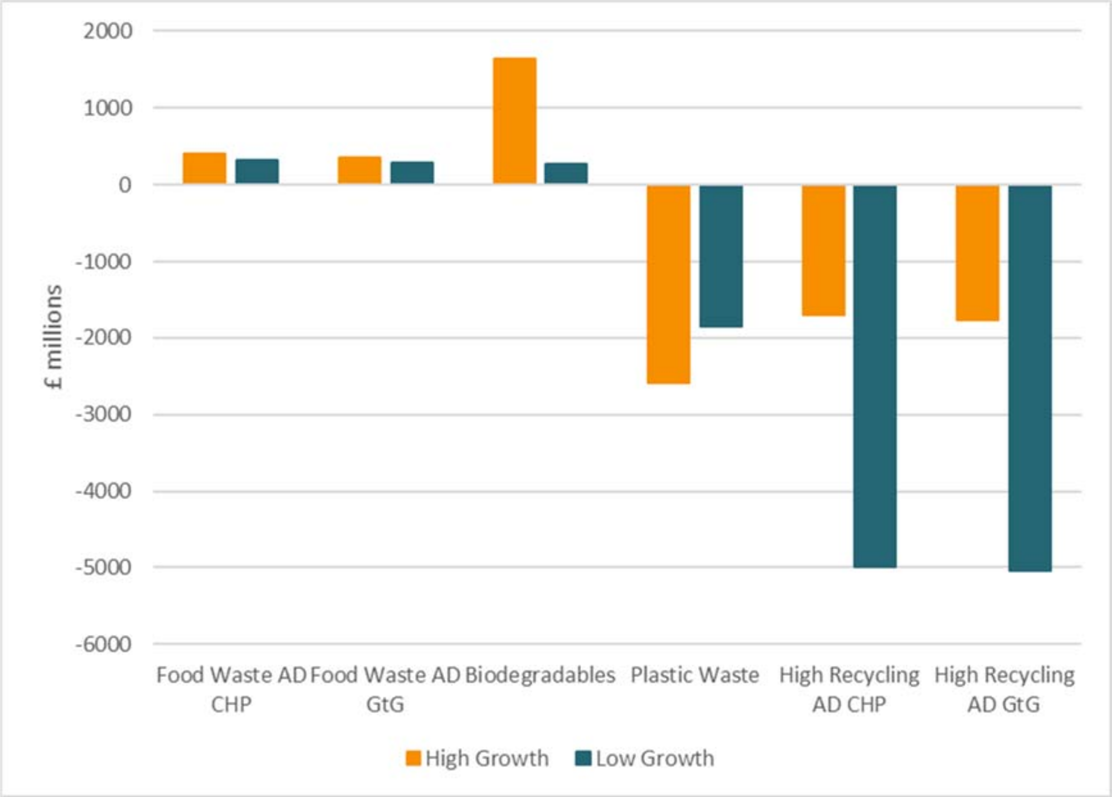
Table 12: Increased Segregation Scenarios, Phase 2 Treatment: Residual Waste volumes and CV as forecast actuals, Discounted capital Cost and NPV including residual value - difference from baseline pathway 0 (in £ millions)

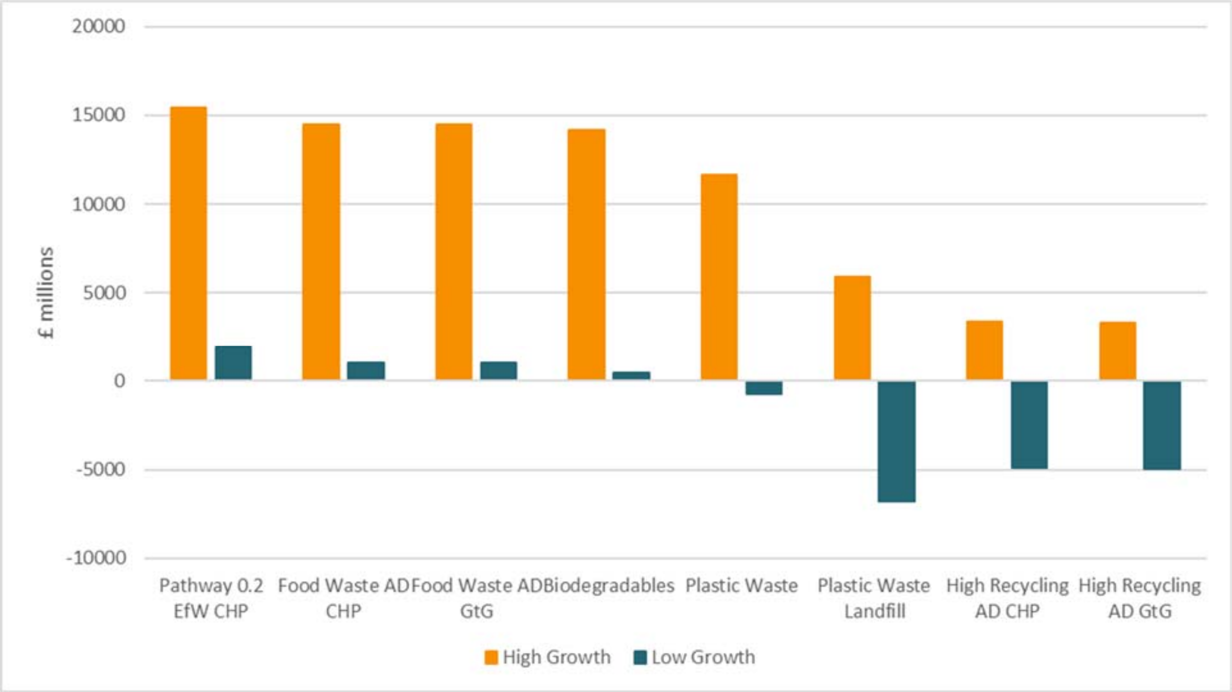
Segregation Scenario	Residual Waste Volume (Annual Average across 2020-2050) Mt	Residual Waste CV (average over 2020-2050) MJ/kg	Discounted Capital Cost (Phase 2) £ millions	NPV including residual value (Phase 2) £ millions	Residual waste infrastructure as 2020	Residual waste diversion from landfill to EfW with CHP
Baseline Residual Waste Pathway 0	23.2 to 31.5	9.8 to 9.9	0 to 0	0 to 0	✓	
Residual waste Pathway 0.2	23.2 to 31.5	~9.8	229 to 7,158	1,923 to 15,426		✓
Food waste to AD CHP	21.9 to 29.7	~10.2	193 to 290	314 to 405	✓	
	21.9 to 29.7	~10.2	193 to 6,783	1,052 to 14,512		✓
Food Waste to AD GtG	21.9 to 29.7	~10.2	205 to 318	285 to 345	✓	
	21.9 to 29.7	~10.2	205 to 6,811	1,023 to 14,452		✓
Biodegradable Waste	21.4 to 29.0	10.0 to 10.1	193 to 325	271 to 1,631	✓	
	21.4 to 29.0	10.0 to 10.1	193 to 5,585	461 to 14,179		✓
Plastics Waste to recycling	22.6 to 30.7	~9.5	0 to 12	-1,848 to -2,590	✓	
	22.6 to 30.7	~9.5	0 to 6,577	-752 to 11,622		✓
Plastics Waste to landfill	22.6 to 30.7	~8.9	3,248 to 7,572	-6,792 to 5,882		✓
High Recycling (food waste to AD CHP)	18.8 to 25.2	~9.7	430 to 485	-4,997 to -1,700	✓	
	18.8 to 25.2	~9.7	430 to 3,684	-4,914 to 3,390		✓
High Recycling (food waste to AD GtG)	18.8 to 25.2	~9.7	448 to 521	-5,037 to -1,776	✓	
	18.8 to 25.2	~9.7	448 to 3,720	-4,954 to 3,313		✓

More detail on the modelling conditions and results per segregation scenario are given in Appendix V to this report.

As shown in Table 12, those segregation scenarios using the baseline residual waste infrastructure pathway 0 i.e. 2020 infrastructure, show positive NPVs for the organic segregation scenarios (food and biodegradable wastes), as increasing volumes of organic waste are segregated at kerbside and directed to AD, reducing the volume of residual waste sent to EfW and landfill, and therefore reducing the cost of waste management operation overall whilst boosting income from energy production. Conversely, the plastics and high recycling scenarios showed negative NPVs with relatively high capital cost figures, due to the requirement for additional MRF capacity to deal with multi-material recyclate streams, plus less demand on EfW and landfill reducing energy and gate fee income, compared to baseline. Comparing those segregation scenarios using residual waste infrastructure pathway 0.2 (i.e. landfill diversion to EfW with CHP to fill the capacity gap) shows decreasing capital cost and NPV compared to pathway 0.2 alone, due to the reduction in residual waste volume and therefore need for EfW CHP capacity, at least using the high growth model. This reduction in capital costs is not repeated for the plastics to landfill scenario, however, as the increased requirement for intermediate waste treatment capacity to remove plastics from the residual waste generated, increases capital costs and relevant operating costs substantially.

Figure 13: Phase 2 NPV (Treatment/Disposal) for the range of segregation scenarios using i) baseline residual waste scenario i.e. 2020 infrastructure pathway 0, and ii) diverting residual waste from landfill to EfW with CHP pathway 0.2. In all cases, difference to baseline pathway 0 is presented.





4.6.2.4 Impact on outputs

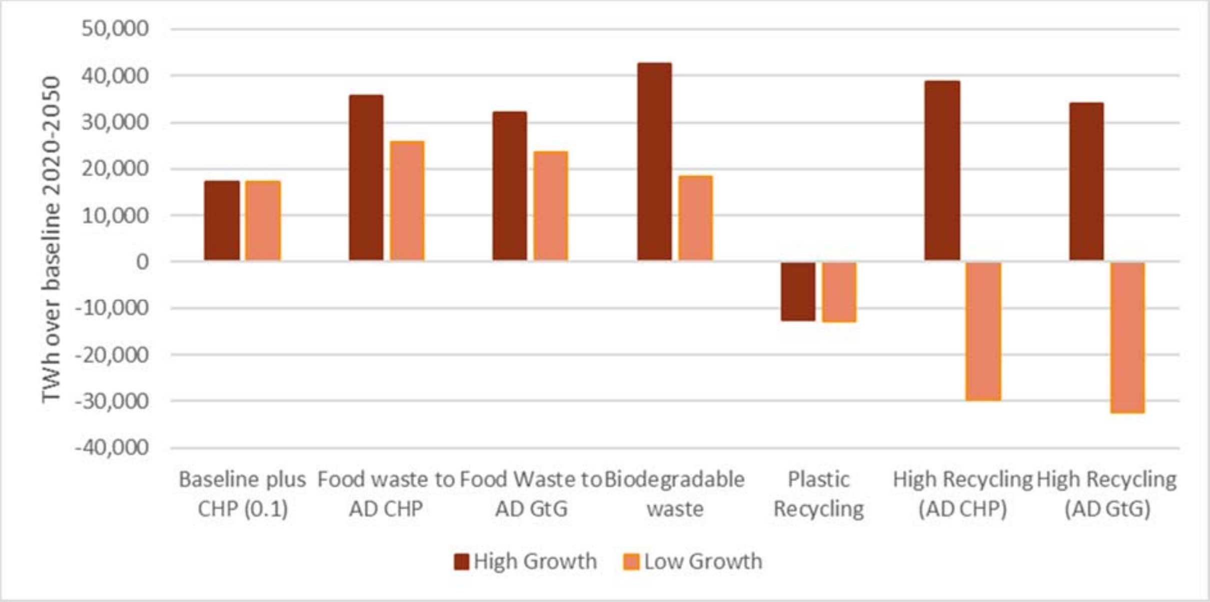
Outputs in terms of energy (heat and power) and GHG emissions were also modelled for each segregation scenario. Detail on methodology used is given in Appendix IV to this report, and more detailed results are given in Appendix V. Results are summarised in Figure 14 for energy outputs and Figure 15 for GHG outputs.

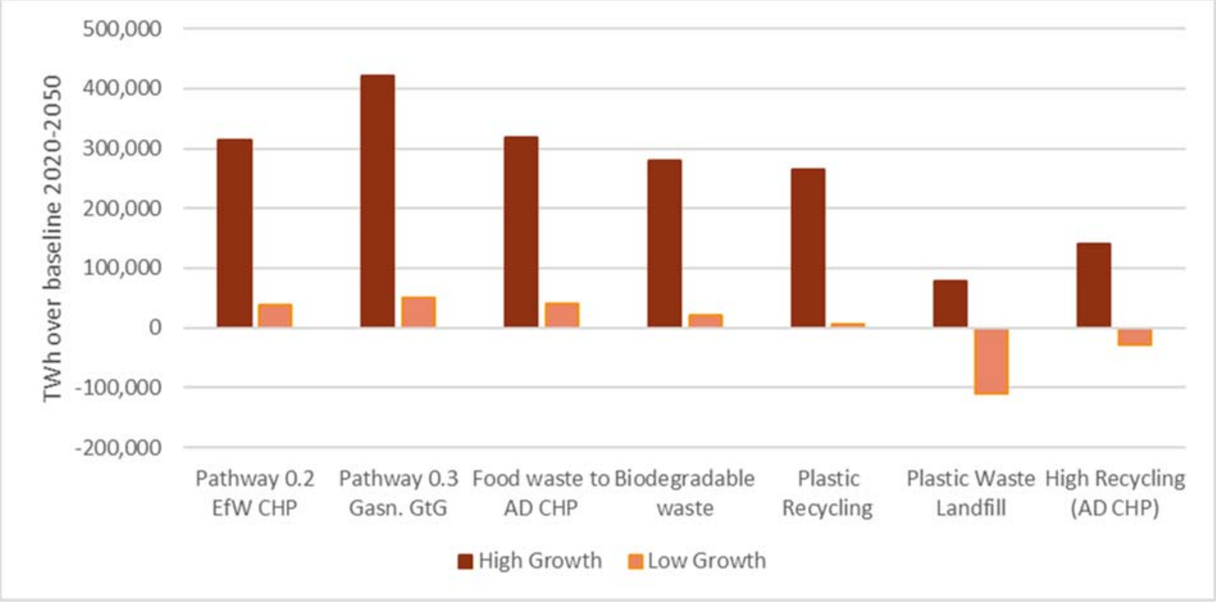
4.6.2.5 Energy

In the infrastructure modelled, key sources of heat and power are the anaerobic digestion of food waste, and the energy recovery of residual waste – in this case via residual waste infrastructure pathway 0 (established 2020 infrastructure) and pathway 0.2 (diversion from landfill to increased EfW with CHP capacity). The model forecasts CV per scenario and this is taken into account in modelled energy generation as well as infrastructure capacity assessments.

Figure 14 summarises the total energy outputs per segregation scenario compared to baseline pathway 0. For those scenarios modelled with pathway 0 (2020 residual waste infrastructure), each shows sizable increases in energy generation over the forecast period, mainly due to the diversion of food waste to AD as EfW capacity is fixed at 2020 levels. Only plastic waste segregation (at high growth) reduces energy output compared to baseline, due to the reduced volume and CV of residual waste sent for energy recovery. For those segregation scenarios modelled with residual waste recovered using increased energy recovery capacity i.e. infrastructure pathway 0.2 (with diversion from landfill to EfW with CHP), the baseline pathways with no change in collection (i.e. pathways 0.2 and 0.3) produced the most significant energy output, along with food waste and biodegradable waste scenarios where waste diverted from EfW is sent as organic waste to AD. For plastics scenarios, the reduction in CV and residual waste volume had a significant negative impact on energy produced, with the high recycling option showing a similar reduction, enhanced somewhat by increased food waste segregation to AD.

Figure 14: Total Energy Outputs for the range of segregation scenarios using i) baseline residual waste scenario i.e. 2020 infrastructure (pathway 0), and ii) diverting residual waste from landfill to EfW with CHP. In all cases, difference to baseline pathway 0 are presented. (total TWh 2020-2050)



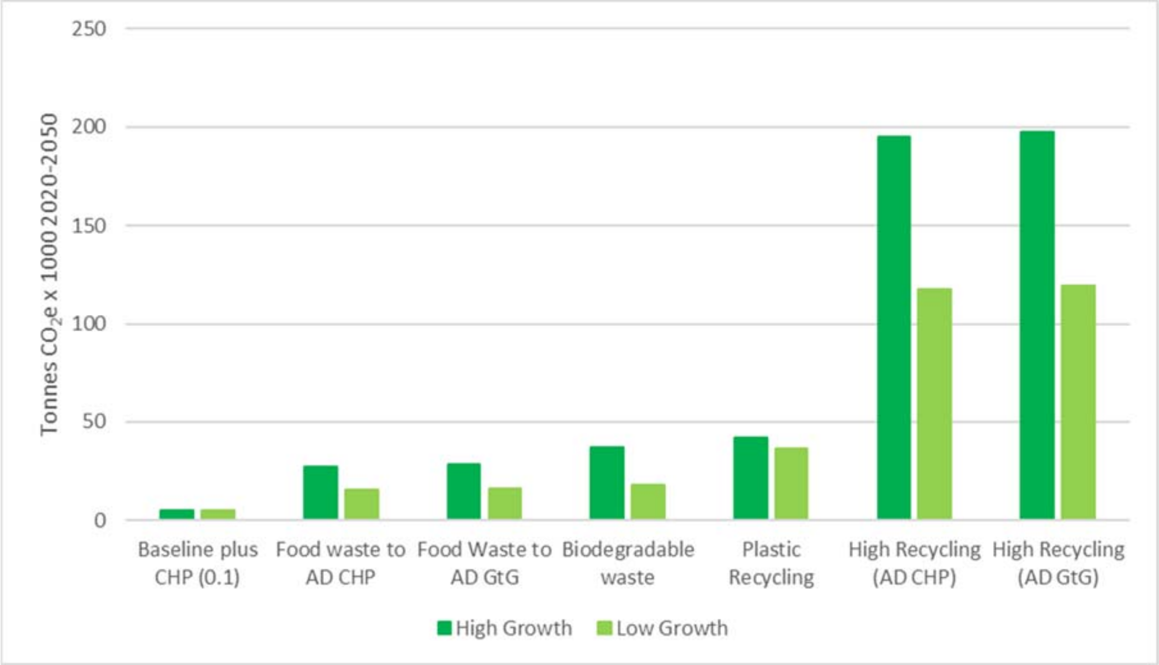


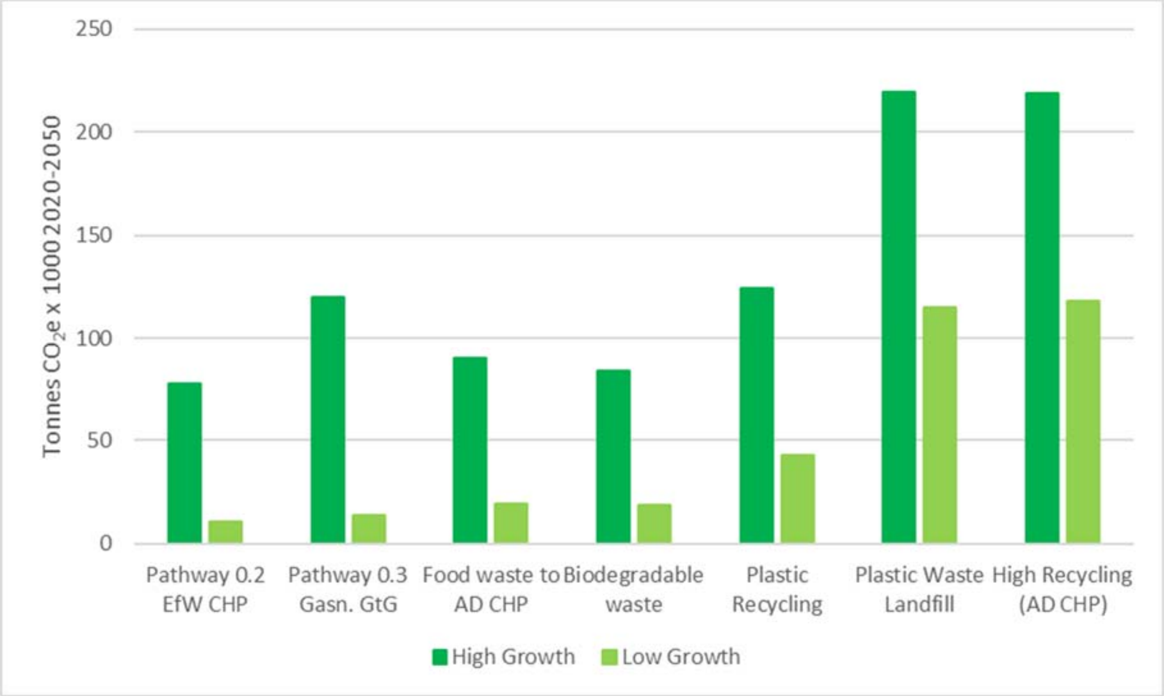
4.6.2.6 GHG Avoided

GHG emissions have been modelled for each of the segregation scenarios using WRATE. More detail on the methodology used and results obtained are given in Appendix IV and Appendix V to this report. Figure 15 shows the result of this modelling compared to baseline pathway 0. The GHG totals include those generated from collection and treatment/disposal including the impact of infrastructure, segregated materials and energy output.

Compared to baseline pathway 0 i.e. 2020 infrastructure, all scenarios deliver reduced GHG emissions, peaking for the high recycling scenarios. Similarly, for those scenarios modelled with infrastructure pathway 0.2 (i.e. full residual waste diversion to EfW with CHP), plastics to landfill and high recycling options show the greatest positive impact, although the food waste options offer advantages compared to the new EfW CHP pathway 0.2.

Figure 15: Total Avoided GHG emissions for the range of segregation scenarios using i) baseline residual waste scenario i.e. 2020 infrastructure pathway 0, and ii) diverting residual waste from landfill to EfW with CHP pathway 0.2. In all cases, difference to baseline pathway 0 is presented. (total ktonnes CO_2e 2020-2050)





4.6.2.7 Total NPV and GHG/kg NPV

Total combined Phase 1 and Phase 2 capital cost and NPV figures (including residual value) are provided in Table 13. This shows both total figures and as a measure of value for money, ratios for energy production per £ NPV and GHG avoided per £ NPV.

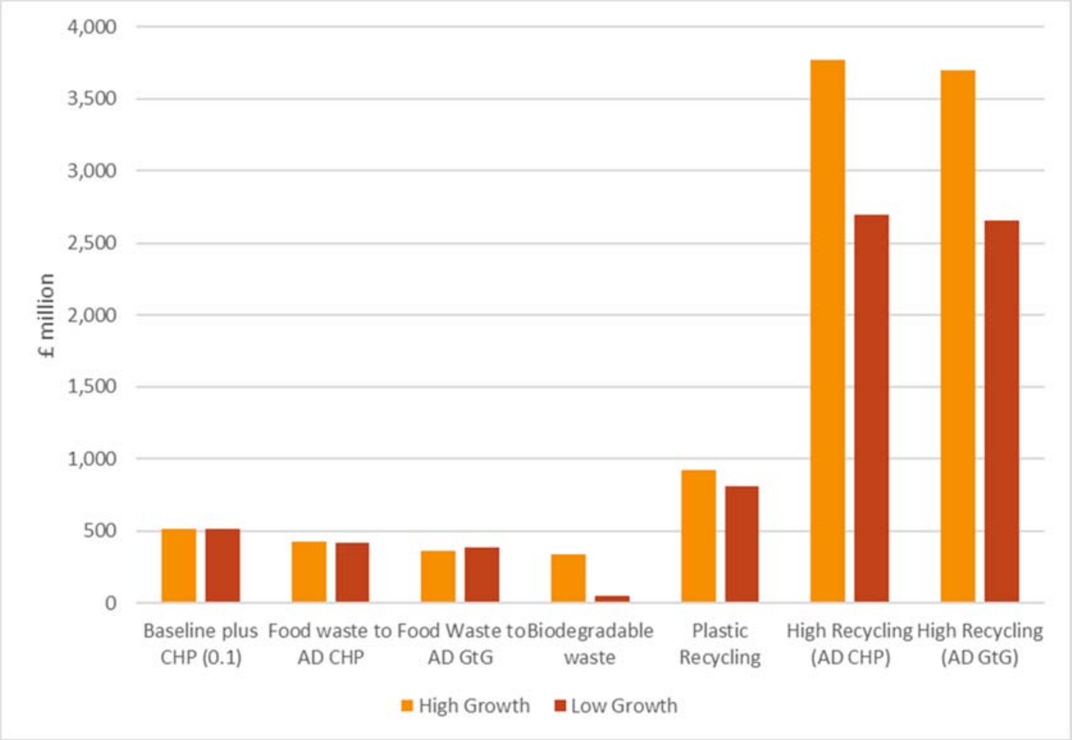
Table 13: Segregated Waste Scenarios, Outputs/£ Capital Investment and NPV (energy and GHG) - difference from baseline pathway 0

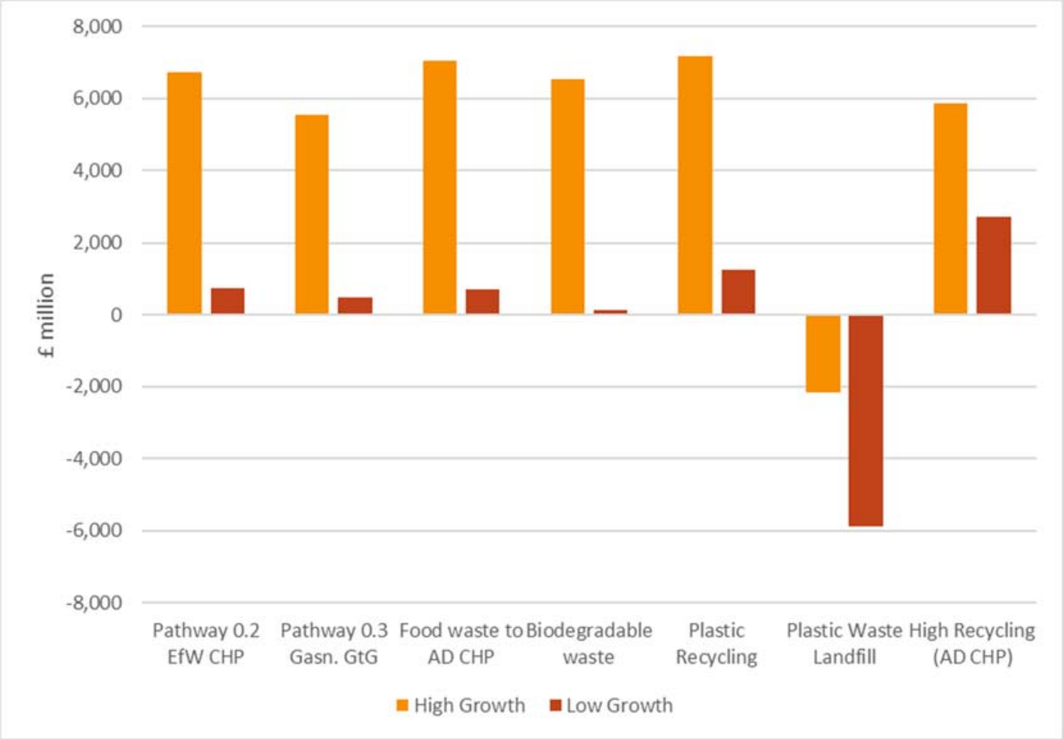
Segregation Scenario	Total Discounted capital cost (£ millions)	NPV including residual value (total, £ millions))	Energy Generation per £ NPV compared to baseline (KWh)	CO₂e avoidance/ £NPV compared to baseline (kg)	Residual waste infrastructure as 2020	Residual waste diversion from landfill to EfW with CHP
Baseline Residual waste Pathway 0	0 to 0	£0 to £0	0.0 to 0.0	0.0 to 0.0	✓	
Residual waste Pathway 0.2	229 to 7,158	£741 to £6,725	50.0 to 46.7	13.9 to 11.5		✓
Food waste to AD CHP	193 to 253	£416 to £425	62.0 to 84.2	37.5 to 63.8	✓	
	193 to 6,747	£729 to £7,056	53.3 to 45.2	26.7 to 12.7		✓
Food Waste to AD GtG	205 to 281	£387 to £365	61.0 to 87.9	42.0 to 78.7	✓	
	205 to 6,775	£700 to £6,996	52.4 to 45.1	28.7 to 13.1		✓
Biodegradable Waste	193 to 271	£53 to £338	341.0 to 125.5	333.2 to 110.0	✓	
	193 to 5,531	£132 to £6,534	156.1 to 42.8	140.2 to 12.9		✓
Plastics Waste to recycling	8 to 32	£808 to £927	-15.7 to -13.6	45.2 to 45.1	✓	
	8 to 6,597	£1,251 to £7,166	4.5 to 36.9	34.1 to 17.4		✓
Plastics Waste to landfill	3,256 to 7,591	-£5,878 to -£2,163	18.7 to -36.6	-19.6 to -101.6		✓
High Recycling (food waste to AD CHP)	436 to 411	£2,698 to £3,773	-11.0 to 10.2	43.7 to 51.7	✓	
	436 to 3,610	£2,732 to £5,878	-10.5 to 23.8	43.1 to 37.3		✓
High Recycling (food waste to AD GtG)	453 to 447	£2,658 to £3,697	-12.2 to 9.2	44.8 to 53.4	✓	
	453 to 3,646	£2,692 to £5,802	-11.7 to 23.4	44.2 to 38.2		✓

NPV results per scenario are summarised in Figure 16. For scenarios modelled with residual waste infrastructure pathway 0 (i.e. 2020 infrastructure), all waste segregation scenarios deliver NPV improvements, however best results are achieved by the plastics and high recycling options. For those modelled using pathway 0.2 (full residual waste diversion to EfW with CHP) all options deliver a reduction in NPV compared to pathway 0.2 itself (but significant positive NPV compared to baseline 0) essentially caused by increasing diversion of waste from EfW to segregation at kerbside. In contrast, the plastics to landfill scenario shows a

NPV reduction at high growth i.e. costlier than the baseline scenario due to the increased cost of intermediate treatment of residual waste to remove plastics.

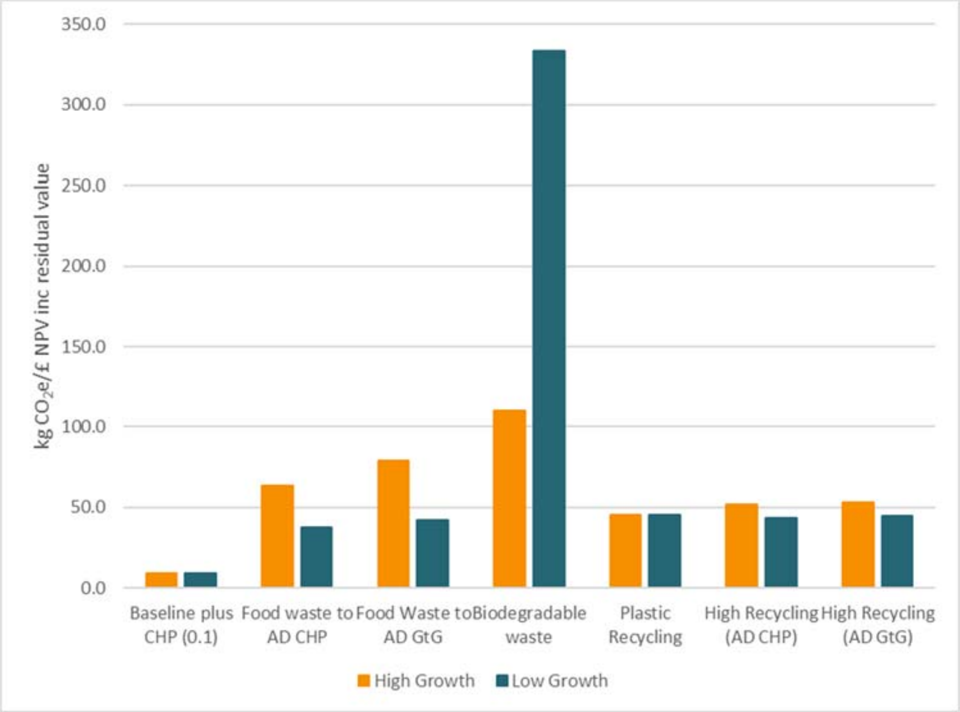
Figure 16: Total NPV (including residual value) for the range of segregation scenarios using i) baseline residual waste scenario i.e. 2020 infrastructure pathway 0, and ii) diverting residual waste from landfill to EfW with CHP pathway 0.2. In all cases, difference to baseline pathway 0 are presented. (£ millions)

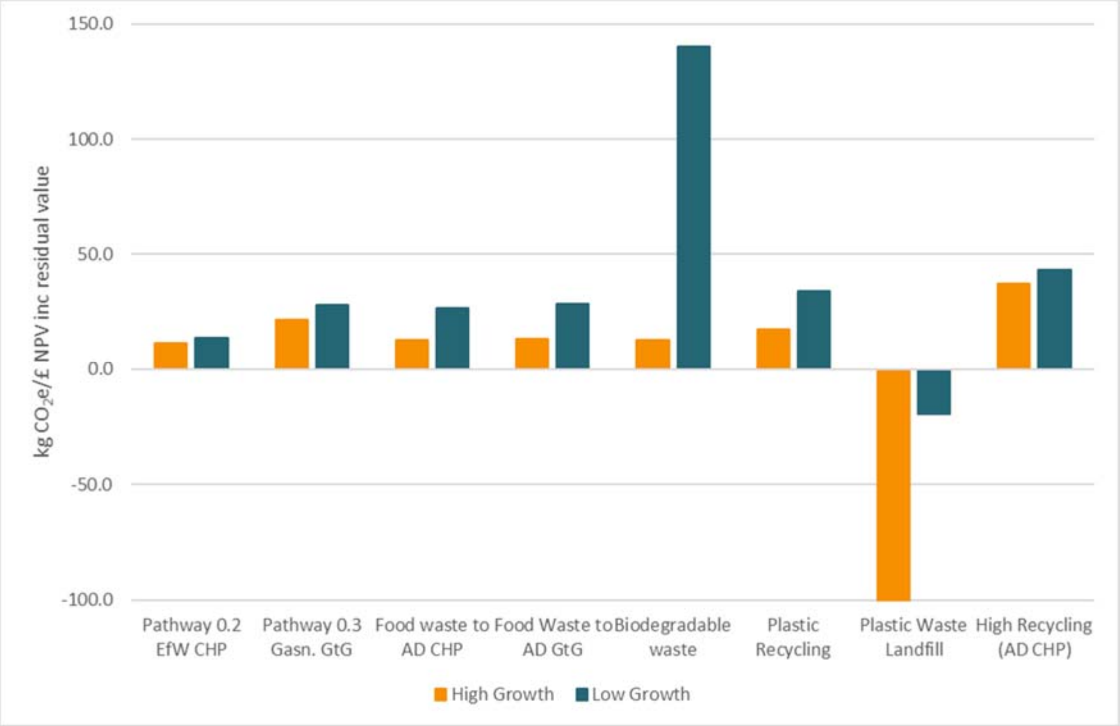




Combining model results gives some measure of the financial efficiency of the developed scenarios, particularly in terms of environmental impact and GHG avoided. Comparing GHG avoidance to NPV produces an improvement against baseline pathways for the plastic and high recycling segregation scenarios in particular. For scenarios involving residual pathway 0.2, all show positive GHG reduction against baseline per £ NPV. Only plastics to landfill shows a negative ratio. These are summarised in Figure 17.

Figure 17: kgCO$_2$e avoidance per £ NPV including residual value for the range of segregation scenarios using i) baseline residual waste scenario i.e. 2020 infrastructure, and ii) diverting residual waste from landfill to EfW with CHP. In all cases, difference to baseline pathway 0 presented. (kg CO$_2$e/£)





As previously reported, NPV including residual value figures compared to baseline, are particularly low for biodegradable waste segregation options employing the low growth model. This produces abnormally high and unrepresentative GHG avoided per £ NPV figures for this particular scenario, as clearly evident in Figure 17.

4.7 Summary of Results by Infrastructure Pathway

Baseline infrastructure modelling (i.e. with no change in collections) has shown:

- Diverting residual waste from landfill to the three infrastructure pathways modelled generates significant GHG advantages and additional energy production compared to the 'business as usual' baseline i.e. compared to the EfW infrastructure in place in 2020;
- Delivering additional infrastructure will cost up to £5.5-7.2 billion over the forecast period, but all pathways modelled deliver benefit over the forecast period, whether waste grows over that period following the "high" or "low" growth models selected;
- Closing the capacity gap between 2020 EfW infrastructure capacity and total residual waste demand delivers significant energy generation and GHG avoidance compared to baseline, with gasification and GtG delivering a greater impact than EfW with CHP. This however does not include the additional cost of a heat network. In terms of GHG avoidance per £ NPV, gasification with GtG delivers an average of 24.8 $kgCO_2e$/£ compared to 12.7 $kgCO_2e$/£ for EfW with CHP. However, this technology is not yet commercially proven and has a chequered history of success in the UK;
- Investment in EfW with CHP will generate up from 20 to 170 TWh total heat output over the forecast period 2020-2050. However, the challenge with CHP development in the past has been finding sustainable users for the heat generated and to implement the necessary distribution infrastructure. For gasification to gas to grid, additional heat (as syngas) could reach 50-423 TWh over the forecast period. Production as syngas allows a number of follow on options for use, including direct gas to grid for generation of heat or power on demand, and potentially power of vehicles or as a synthetic raw material for chemical manufacture.

4.8 Summary of results by Segregation Scenario

4.8.1 Food Waste Segregation

Increased food waste segregation produces:

- Benefits when modelled with both residual waste infrastructure pathways i.e. compared to 2020 infrastructure (pathway 0) and compared to diversion of residual waste from landfill to EfW with CHP (pathway 0.2);
- Up to 2.5 Mtpa (2050 segregated volume, high growth model, 1.25-1.76 Mt annual average over the forecast period) of additional food waste available for AD to produce heat and power, or gas to grid;
- A pro rata reduction in residual waste volume with increase in CV, reducing the effective capacity of 2020 and future EfW capacity by an estimated 5%;
- Savings to the collection authority of increased food waste segregation (when including the impact of landfill tax) giving a positive NPV to baseline of £1.5-2.2 billion. These savings come from a reduced WTS requirement (assuming food waste is delivered directly to the AD facility, giving reduced capital and operational costs compared to baseline) and cheaper gate fees from directing additional food waste to AD in comparison to landfill (including LFT) and EfW. These savings are reduced somewhat by increased collection costs in expanding the collection of food waste at kerbside;
- Positive NPV for all infrastructure pathways compared to baseline of approximately £0.3 to 0.4 billion over the forecast period using 2020 residual waste infrastructure. Diverting food waste to AD with CHP gives

slightly better NPV than for AD with GtG. Positive NPVs are influenced by increased energy income and reduced operating costs from diverting additional food waste from landfill and EfW to AD;

- Sizable increases in GHG/£ NPV and GHG/£ capital investment ratios compared to baseline, to 42-79 kg CO_2 avoided per £ NPV (residual waste infrastructure as 2020);
- In terms of GHG avoidance in particular, AD with GtG shows some advantages over AD to CHP.

However, it should be noted that:

- As with the baseline CHP scenarios, the cost of establishing heat distribution networks is not included;
- Achieving high levels of food waste segregation is likely to require policy intervention as practised in other jurisdictions which achieve the same segregation rate. This could include mandatory collections or the banning of food waste to landfill;
- The lack of land spread demand for the digestate produced by the increased application of anaerobic digestion may be a barrier to expansion.

4.8.2 Biodegradable Waste Segregation

Results of increased biodegradable waste segregation have shown:

- Segregating all biodegradable waste at kerbside separates an additional 1.9-2.7 Mtpa (average annual volume over the forecast period) of waste for AD and recycling i.e. 0.68 to 0.96 Mtpa more than food waste segregation alone;
- This leaves 21.4 to 29.0 Mt (annual average over the forecast period) of residual waste with forecast increased CV of 10.05 to 10.06;
- Savings to the collection body giving a positive NPV to baseline of £1.8-3.0 billion (using residual waste to 2020 infrastructure baseline pathway 0). As with food waste segregation alone, these savings come from reduced gate fees and WTS requirement, along with in this case, increased materials revenues from the additional segregated paper and card. As with food waste collections alone, these savings are reduced by increased collection costs;
- Positive NPV for the infrastructure pathways compared to baseline of approximated £0.3 to 1.6 billion over the forecast period using 2020 residual waste infrastructure, i.e. slightly less than for food waste alone. This is due to the reduced infrastructure requirements caused by the increased recycling of biodegradable dry recyclates, and hence reduced residual waste EfW requirement, impacting on energy revenues;
- Sizable increases in GHG/£ NPV compared to baseline, of 108-318 kg CO_2e avoided per £ NPV (residual waste infrastructure as 2020), i.e. significantly higher than for food waste alone. However, particularly for the results achieved using the low growth model, positive NPVs of close to zero exaggerate this effect, producing abnormally positive ratios.

It is also noted that:

- Although MBT is used as a method of segregating biodegradable waste from residual waste in the market today, the lower gas yields and production of a digestate for which there is no viable market apart from landfill cover, means that this option has not been modelled. The latest MBT developments have been focussed on producing an RDF material for energy recovery and currently no MBT plant in the UK is producing organic outputs for revenue generation.

4.8.3 Plastic Waste Segregation

Plastic waste segregation was modelled with both kerbside collection for increased recycling, and with subsequent separation from residual waste for landfilling, as a form of fossil carbon sequestration. Results showed:

- Additional kerbside collection segregation of 1.5 to 2.1 Mtpa of plastic recyclate (annual average over the forecast period) which is sent for reprocessing. Overall CBA benefit over baseline for the collection body was sizable at £3.7-4.8 billion using 2020 infrastructure (pathway 0). This benefit came mostly from the considerable additional income from of the sale of the additional plastics segregated and gate fee savings from reduced residual waste volumes, reduced by increased WTS requirement (in contrast to the food waste scenarios) and increased collection costs. The impact of the income from segregated plastics makes this scenario sensitive to the selling price of this recyclate, which has varied considerably in recent years;
- The impact of the removal of this material reduced residual waste CV slightly to 9.51 to 9.53. Reduced residual waste volume and CV, resulted in energy generation from EfW less than the baseline scenarios. However, diversion of this material from energy recovery increased GHG avoidance significantly, compared to food and biodegradable waste segregation and to baselines;
- As diversion of plastics from residual waste reduced demand on EfW and other residual waste treatment facilities, without delivering significant new infrastructure for plastics segregation and recycling (although some new MRF and WTS capacity was needed), overall capital cost figures were low. Contrary to the food and biodegradable waste scenarios, this delivers a negative Phase 2 NPV against baseline, primarily due to the loss of energy revenue and reduced EfW gate fee income;
- The benefits from Phase 1 collection outweigh Phase 2 infrastructure operation reductions compared to baseline, giving overall NPV totals of £0.8-0.9 billion over baseline for 2020 infrastructure. This gave GHG/£ NPV figures of between 45.1 to 45.2 kgCO_2e using 2020 infrastructure (pathway 0).

When modelling plastics segregation from residual waste in addition to that at kerbside, main impacts were:

- Up to an additional 10 Mt of plastics is segregated, directed to landfill, causing a further reduction in residual waste volumes for energy recovery and further reduction in CV to approximately 8.95 MJ/kg;
- Further significant reduction in energy generation compared to baseline, reflected in a significant increase in GHG avoidance to 115-219 MtCO_2e over the forecast period;
- An overall increase in capital costs over plastic segregation at kerbside alone, due to the requirement for additional residual waste segregation capacity, although this was balanced somewhat by a reduced EfW capacity requirement. As a result, total NPV at -£2.1 to -£5.9 billion compared to baseline pathway 0 was significantly less than for kerbside segregation alone, delivering GHG/£ NPV of between -20 to -102 kgCO_2e.

Note however that:

High GHG avoidance figures are due to the sequestration of fossil, long term carbon in landfill. If the current trend to biologically produced plastics continues, the prevalence of this short-term carbon source would reduce modelled GHG benefits.

4.8.4 High Recycling segregation

The high recycling scenarios model increased segregation at kerbside of key recyclates to achieve the specified recycling targets. As a result:

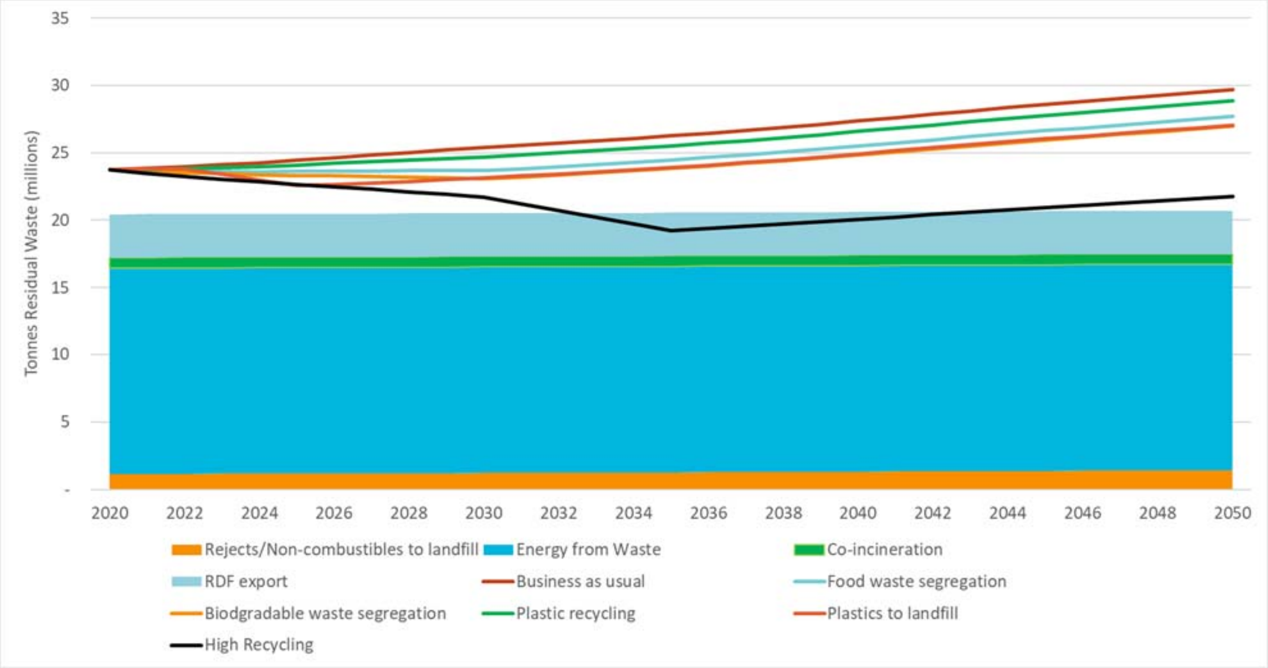
- Up to 6-8.6 Mt (annual average over the forecast period) of recyclates and organic wastes are segregated for treatment and recycling. This results in a significant amount of additional recycling and treatment infrastructure required, with up to 3.7 Mt additional AD capacity and 3.3 Mt additional MRF capacity over baseline (high growth model);
- The modelled increased segregation of key recyclates, distributed evenly over the materials concerned, has only a marginal impact on CV with a forecast figure of approximately 9.72 MJ/kg. The significant reduction in residual waste volumes, however, reduced the need for additional EfW capacity significantly, reducing need to around 0-7.35 Mt over baseline depending upon the growth model applied. This compares to 0.35-15.2 Mtpa for the infrastructure pathway 0.2, diverting waste from landfill to EfW with CHP;
- Savings in Phase 1 are significant resulting in a large positive NPV of £5.4–7.7 billion (£9.9-15.7 billion including LFT). This is driven by the value of materials segregated at kerbside, plus gate fee savings which in total more than compensate for the increased collection costs. However, this also makes the results sensitive to material prices which can be volatile;
- In operation, significant reduction in the volume of residual waste due to recyclate segregation at kerbside, reduces gate fee and energy income from EfW, the income of outputs from intermediate processing such as MBT, as well as gate fee income reduction from landfill, giving a sizable negative NPV for Phase 2 compared to baseline. As a result of reduced EfW demand, overall capital cost is also low.
- Low capital costs plus sizable savings at collection, outweighing income reduction from infrastructure operation, supporting a high overall NPV at £2.7-3.7 billion using 2020 residual infrastructure;
- Although the energy output of EfW is reduced due to the reduced residual waste volume, this is balanced somewhat by increase heat and energy output from AD to CHP or AD gas to grid.

5 Summary and conclusions

5.1 High Level Findings

- England is currently (2015 data) landfilling some 12.4 Mtpa of residual waste and exports 3.2 Mtpa (2016 data) of refuse derive fuel (RDF). With landfill void capacity declining rapidly in some parts of the country, and landfill diversion of residual waste encouraged via landfill tax, energy recovery from residual waste is growing. This study estimates that 15.3 Mtpa of energy recovery capacity will be operational by 2020, meaning that landfill will be required for between 2.8 Mtpa and 4.2 Mtpa[19] of residual waste, unless alternative infrastructure is built;
- Projections relating to future infrastructure requirements are very sensitive to waste growth within LACW and C&I streams. If waste growth is high due to the impact of population and economic growth, and if waste infrastructure, excluding landfill, in 2020 is not expanded, then the gap between available residual waste treatment capacity and amount of residual waste produced could increase to as much as 16 Mtpa by 2050[20]. If waste growth is low due to the impact of waste minimisation, such as packaging or food waste reduction, this could be as low as 2 Mtpa;
- To further diversion of residual waste from landfill, most of the segregation scenarios modelled require additional residual waste treatment infrastructure. This is summarised in the following chart, taking a central forecast of available residual waste (i.e. average of high and low growth models) against each segregation scenario, compared to 2020 EfW capacity (plus RDF export and assumed volume to co-incineration) across the forecast period (Figure 2):

Figure 18: Central forecast residual waste volume for each of the modelled segregation scenarios, compared to 2020 EfW infrastructure capacity, RDF forecast and co-incineration volume assumptions.



---

[19] assuming 3.2 Mtpa of RDF is exported and 0.8 Mtpa is recovered via co-incineration, and including losses from intermediate treatment including mechanical biological treatment (MBT)

[20] Assuming no change in recycling rate, 3.2 Mtpa of RDF is exported and 0.8 Mtpa is recovered via co-incineration

Only with the high recycling scenario is there a risk of 2020 capacity exceeding demand for part of the forecast period, although this would be mitigated by the diversion of exported refuse derived fuel to domestic capacity;

- Energy from Waste (EfW) generating both heat and power (i.e. CHP enabled) offers a prime option to fill this capacity gap because of its greater efficiency than EfW to power alone. Modelling suggests that the total output of heat and power from the expanded EfW network could be between 14 TWhpa to 32 TWhpa by 2050. However, the cost of heat distribution to respective users is outside the scope of this study and part of the national energy infrastructure assessment. Experience in the UK from the last 20 years has shown that sustainable heat demand can be difficult to find;
- Gasification with gas to grid (GtG) promises several advantages over traditional EfW in terms of cost and greenhouse gas (GHG as CO_2 equivalent) impact across a range of potential options for the synthetic natural gas (syngas) generated; however, this technology is not commercially proven and recent experience with gasification in England has been problematic[21].

5.2 Studied Segregation Scenarios and Infrastructure Pathways

Results generated are compared to a baseline consisting of the anticipated recycling rate for 2020 (50% for LACW and 55% for household like C&I) and the expected infrastructure operational in 2020. All options studied are developments from this ‘business as usual’ baseline. Note that residual waste capacities quoted assume 3.2 Mtpa of RDF is exported for energy recovery – if not exported this would add to the England EfW capacity requirement. Modelling has shown:

- Food waste segregation at kerbside requires additional anaerobic digestion (AD) capacity of 1.1 to 2.7 Mtpa. It delivers positive GHG avoidance (from 15,615 to 27,098 tCO_2e in total 2020-2050) and economic NPV benefits (from £416 to £425 million). A potential barrier to this expansion in food waste processing may be the storage and land spread demand generated by the resulting digestate;
- Segregating all biodegradable waste at kerbside will require an additional food waste AD capacity of 1.1 to 2.7 Mtpa and up to 0.6 Mtpa MRF capacity due to the segregation of other recyclates. It provides similar overall GHG (17,776 to 37,224 tCO_2e) and NPV benefits (£53 to £338 million) compared to food waste alone;
- Increased plastic waste segregation at kerbside is forecast to require additional transfer station (0.5-1.2 Mtpa) and MRF (up to 0.6 Mtpa) infrastructure. It delivers a significant GHG benefit (36,488 to 41,812 tCO_2e) and a positive NPV (£808 to £927 million). This positive financial impact is sensitive to the market value of the recycled plastics collected. These conclusions could be impacted if the use of bioplastics or renewable plastics increases over the forecast period;
- When including plastics separation for landfill, between 16.5 and 28.2 Mtpa of new residual waste separation facilities are required. GHG avoidance is significantly increased (115,134 to 219,713 tCO_2e) with landfill functioning as a carbon sink, but with a significant cost penalty (NPV -£5,878 to -£2,163 million). There are also potential degradation issues in landfilling plastics, although modern landfill design should be able to deal with this;
- High recycling requires an increase in MRF (1.5 to 3.3 Mtpa) and AD capacity (1.8 to 3.7 Mtpa). It delivers a significant GHG benefit (117,821 to 194,993 tCO_2e), and sizable cost benefits (£2,698 to £3,773 million).

---

[21] For instance, the 2016 failure to commission 0.7 Mtpa of advanced gasification capacity in Tees Valley.

However, this economic impact is influenced significantly by recyclate selling prices so market volatility can impact on this negatively.

Relative performance of the scenarios modelled, compared to baseline, is summarised in the charts below. On the basis that an optimum scenario combines high GHG avoidance and high positive NPV benefit, these show the relative good performance of high recycling and plastic recycling options over those others modelled. However, all scenarios give better results than baseline. Plastics sent to landfill is an exception, with a negative NPV compared to the baseline, but the scenario has a high environmental benefit, second only to high recycling.

Figure 19: Plot of Central Growth GHG avoided against NPV with residual value, modelled scenarios using 2020 residual waste infrastructure CHP

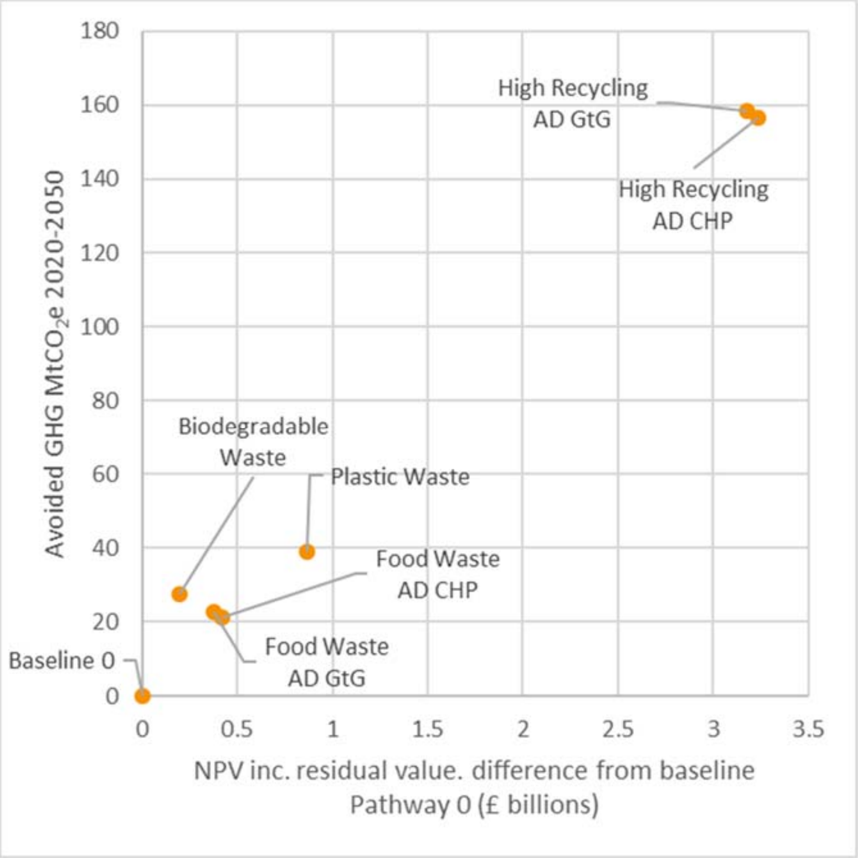
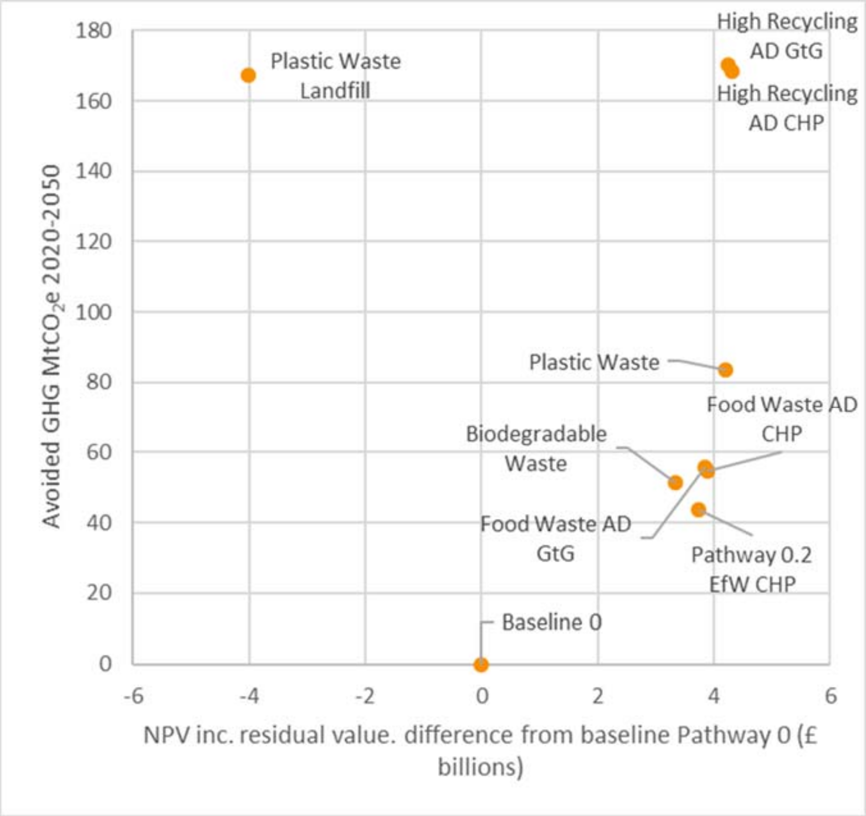


Figure 20: Plot of Central growth GHG avoided against NPV with residual value, modelled scenarios diverting residual waste from landfill to EfW with CHP (i.e. filled capacity gap)



5.3 Conclusions

Waste infrastructure in England that delivers high recycling and high GHG avoidance is predicated on a raft of government policies via taxation, subsidies and other financial interventions to produce a ‘financially net positive’ supply chain for LACW and C&I waste management services. Although a number of segregation options have been modelled which show benefits over the baseline (i.e. what is delivered now), all scenarios still deliver a negative overall NPV suggesting continued intervention in the sector is essential for its long-term viability.

This study has shown that key improvements to the existing infrastructure can be achieved by:

- Implementing collection infrastructure to increase segregation of materials for recycling, which has shown to be a key component in decarbonising the waste sector;
- Improvements in the energy efficiency of residual waste recovery, which is beneficial for all scenarios as it reduces the overall financial impact of all pathways and supports the decarbonisation of waste infrastructure.

The waste infrastructure modelling undertaken within this study needs to be considered within the wider context of national infrastructure assessments carried out for energy, transport etc., as well as in the context of the changing regulatory, economic and political framework. It should be noted that:

- Changes in residual waste composition through the increased segregation of materials at kerbside and residual waste volume can have a significant impact on energy production from residual waste. This impacts the efficiency of current energy from waste infrastructure as well as the need for new infrastructure. This impact on the use of energy from waste as an energy generation option needs to be considered carefully when developing future policy;

- The additional cost of building up England's heat distribution infrastructure to take advantage of the higher energy efficiencies possible in using combined heat and power technology, is not included in the modelling. In this context, the option for gas-to-grid energy production from residual waste should be investigated further as this energy carrier will utilise an existing network and might provide better value for money outside of any considerations related to waste infrastructure. However, this technology needs to be demonstrated both technically and commercially before such advantages can be sought;
- Separating plastics from residual waste to send to landfill appears to deliver a substantial GHG reduction from carbon storage, but at a considerable cost. However, this is a complex and evolving picture given government action on plastics and the increase in the use of biopolymers and plastics made from biogenic sources. The full GHG effect has also not been considered in this study and landfill has mainly been applied as a carbon storage option without a detailed assessment of potential future environmental implications. Therefore, the impact of future changes in how plastics are used and how they are produced, on all stages of the waste management supply chain, requires more investigation;
- The scenarios based upon creating value through recycling of dry recyclates are impacted negatively by reductions in material pricing. Volatility in material prices in the last few years makes it difficult to forecast prices going forward;
- The modelling carried out for this study has shown that, irrespective of chosen residual waste options, the most beneficial waste infrastructure pathway options include:
    - increased organic waste recycling through the segregation of food and other biodegradable waste;
    - increased plastics recycling via kerbside collection;
    - and high recycling of a variety of organic and dry recyclable materials.
- These options are preferred segregation routes, where material segregation takes place at source via single material or co-mingled kerbside collection and therefore doesn't require extensive residual waste processing infrastructure to segregate additional materials from the residual waste stream.

5.4 Considerations for Deliverability

It should be noted that the results of the modelling demonstrate what is potentially is possible, but a number of practical delivery issues should be considered if utilising the data to inform decision-making:

5.4.1 Heat Networks

Although it is clear that optimal efficiency of energy from waste facilities is achieved by providing heat from the unit as well as power, this has a number of challenges. Firstly, power is simple to generate and distribute, its demand is reasonably consistent all year round and year on year, and electricity sales represents a key income for the facility operators. Producing heat from the same unit reduces the power generated, and exposes the operator to a potentially risky seasonal market. Although there are a number of successful heat networks around England (of the 58 EfWs modelled as operational by 2020, 8 actively supply local heat users) finding a sustainable heat user or users that can take heat for the lifetime of the facility, and covering the cost of the distribution network required, can be a challenge, evidenced by the small number of successful schemes to date.

Note that although CHP has been modelled in this study, the cost of heat distribution has not been included in the financial analysis. With gas to grid, assuming network quality specifications are achieved, distribution is a much simpler prospect.

5.4.2 Landfilling Plastics

Removing plastics from energy recovery for landfill, as a form of carbon sequestration, has the potential to significantly reduce GHG emissions, as demonstrated by this study. This practise would however require additional investment in separation facilities, and plastics landfilled are likely to carry with them a degree of biogenic contamination, especially food waste. There is a move worldwide to both reduce the use of plastics and to replace fossil based plastics with biologically produced renewable plastics, which would have a considerable impact on modelled GHG emissions for EfW in particular.

It needs to be noted that there are potential environmental problems associated with the degradation of plastics in landfill (discussed in section 3.6.2) which need to be better understood.

5.4.3 RDF Exports

The residual waste forecasting in this study assumes RDF exports to Europe continue throughout the forecast period at the current level of 3.2 Mtpa, assuming available facilities in Europe are at capacity. Intermediate processing required to generate this RDF is also modelled. This practice may or may not continue as a result of tariff changes due to Brexit. Increased export costs have already been reported due to the weakening of Sterling. Therefore, for all the EfW capacity gaps reported, domestic recovery of this material could boost England capacity requirements by an additional 3.2 Mtpa.

5.4.4 Markets for recyclates

Increasing kerbside capture of dry recyclates assumes a market for this material. The recent introduction of Chinese import restrictions of key recyclates, particularly paper, card and plastics, has seen a sharp fall in material prices and the stock piling of material by MRF operators. A barrier therefore to increased recycling is a sustainable market, either locally or via export, for the materials captured.

In addition, the financial advantages of plastics and high recycling segregation options modelled in this study are based on the assumption of achieving good prices in the market. Materials markets have been particularly volatile in recent years, and any reduction in material prices in the future will negatively impact the financial advantages of these segregation scenarios.

5.4.5 Regulatory position after Brexit

The UK’s regulatory position to date has been driven by EU environmental legislation and it is not clear whether such legislation will remain in UK/English law. This needs to be considered in line with calls from some quarters to reduce the regulatory burden on UK business post-Brexit, including employment, health and safety and environmental laws. Similarly, the implementation of evolving policy such as the Circular Economy Package is unclear and although the Defra 25 year Environmental Plan[25] and the announcements made in the Clean Growth Strategy[55] in combination with the UK Industrial Strategy and the next Carbon Plan should bring some clarity.

6 References

[1] WRAP, “WRAP Statistics.” [Online]. Available: http://laportal.wrap.org.uk/Statistics.aspx. [Accessed: 04-Apr-2018].

[2] DEFRA, “Waste Duty of Care Code of Practice,” 2016.

[3] LARAC, “Waste collection services: in-house or outsourced?,” 2016. [Online]. Available: http://www.larac.org.uk/news/waste-collection-services-house-or-outsourced. [Accessed: 04-Apr-2018].

[4] APSE, “Insourcing: A guide to bringing local authority services back in house,” 2009.

[5] WRAP, “A framework for greater consistency in household recycling in England.”

[6] WRAP, “Recycling Tracking Survey 2017: Behaviours, attitudes and awareness around recycling,” 2017.

[7] WRAP, “Materials Facility Reporting Portal.” [Online]. Available: https://mfrp.wrap.org.uk/. [Accessed: 04-Apr-2018].

[8] WRAP, “Materials Facility Reporting Portal Q2 2017 - Commentary,” 2017.

[9] WRAP, “Organics Recycling industry status report 2015,” 2017. [Online]. Available: http://www.wrap.org.uk/content/organics-recycling-industry-status-report-2015-0. [Accessed: 04-Apr-2018].

[10] DEFRA, “Digest of Waste and Resource Statistics 2017 Edition,” 2017.

[11] WRAP, “Household food waste in the UK, 2015,” 2015. [Online]. Available: http://www.wrap.org.uk/content/household-food-waste-uk-2015-0. [Accessed: 04-Apr-2018].

[12] WRAP, “Overview of Waste in the UK Hospitality and Food Service Sector,” 2013.

[13] WRAP, “Quantification of food surplus, waste and related materials in the supply chain,” 2016. [Online]. Available: http://www.wrap.org.uk/content/quantification-food-surplus-waste-and-related-materials-supply-chain. [Accessed: 04-Apr-2018].

[14] WRAP, “Operational AD sites,” 2017. [Online]. Available: http://www.wrap.org.uk/content/operational-ad-sites. [Accessed: 04-Apr-2018].

[15] WRAP, “Gate Fees Report 2017: Comparing the costs of waste treatment options,” 2017.

[16] REA, “The Real Economic Benefit of Separate Biowaste Collections,” 2016.

[17] LetsRecycle.com, “Is large-scale gasification viable,” 2016. [Online]. Available: https://www.letsrecycle.com/news/latest-news/is-large-scale-gasification-viable/. [Accessed: 04-Apr-2018].

[18] LetsRecycle.com, “Global Renewables Lancashire contract terminated,” 2014. [Online]. Available: https://www.letsrecycle.com/news/latest-news/global-renewables-lancashire-contract-terminated/. [Accessed: 04-Apr-2018].

[19] MRW, “Greater Manchester contract termination confirmed,” 2017. [Online]. Available: https://www.mrw.co.uk/latest/greater-manchester-contract-termination-confirmed/10022814.article. [Accessed: 04-Apr-2018].

[20] Environment Agency, “Waste Management Information for England,” 2015.

[21] Environment Agency, “Landfill and Deposit for Recovery Sector 2016,” 2016.

[22] Environment Agency, “Waste Management Information for England,” 2016.

[23] Biffa, “The Reality Gap,” 2017.

[24] Norden, “Proposals for targets and indicators for waste prevention in four waste streams,” 2013.

[25] DEFRA, “25 Year Environment Plan,” 2018.

[26] International Synergies, “Projects: National Industrial Symbiosis Programme.” [Online]. Available: http://www.international-synergies.com/projects/national-industrial-symbiosis-programme/. [Accessed: 04-Apr-2018].

[27] WRAP, “Composition and re-use potential of household bulky waste in the UK,” 2012.

[28] AEA, “Energy from Waste Technology Landscape Review: Anaerobic Digestion,” 2011.

[29] WRAP, “Improving Anaerobic Digestion operations,” 2010.

[30] IEA Bioenergy, “Pretreatment of feedstock for enhanced biogas production,” 2014.

[31] European Commission, “Reference document on the best available techniques for waste incineration,” 2006.

[32] Hitachi Zosen Inova, “Plants in Operation.” [Online]. Available: http://www.hz-inova.com/cms/en/home?page_id=279. [Accessed: 04-Apr-2018].

[33] Biochar International, “Biochar.” [Online]. Available: http://www.biochar-international.org/. [Accessed: 04-Apr-2018].

[34] Fichtner Consulting Engineers Limited, “The viability of advanced thermal treatment of MSW in the UK,” 2004.

[35] Zero Waste Scotland, “Plastics to Oil Products,” 2013.

[36] WRAP, “Enhancement and treatment of digestates from anaerobic digestion,” 2012.

[37] BEIS, “Digest of United Kingdom energy statistics 2016,” 2016.

[38] DEFRA, “Guidance on applying the waste hierarchy,” 2011.

[39] WRAP, “Environmental benefits of recycling,” 2010.

[40] DG Environment, “Plastic Waste: Ecological and Human Health Impacts,” 2011.

[41] P. Jones, “Landfill mining: Is this the next big thing in recycling,” 2017. [Online]. Available: https://www.weforum.org/agenda/2017/06/landfill-mining-recycling-eurelco/. [Accessed: 04-Apr-2018].

[42] Ku Leuven, “EP votes yes to add ELFM to Landfill Directive,” 2017. [Online]. Available: http://kuleuven.sim2.be/ep-votes-yes-add-elfm-landfill-directive/. [Accessed: 04-Apr-2018].

[43] IRENA, “Biogas for road vehicles: Technology brief,” 2017.

[44] HM Treasury, “The Green Book,” 2018.

[45] Environment Agency, “Waste Data Interrogator, October 2016,” 2016. [Online]. Available: https://data.gov.uk/dataset/waste-data-interrogator-2015. [Accessed: 04-Apr-2018].

[46] Environment Agency, “Waste management for England 2015,” 2016. [Online]. Available: https://www.gov.uk/government/statistics/waste-management-for-england-2015. [Accessed: 04-Apr-2018].

[47] Environment Agency, “International Waste Shipments exported from England,” 2016. [Online]. Available: https://data.gov.uk/dataset/international-waste-shipments-exported-from-england.

[Accessed: 04-Apr-2018].

[48] NIC, “The impact of population change and demography on future infrastructure demand,” 2017.

[49] NIC, “Economic growth and demand for infrastructure services,” 2017.

[50] Jacobs, “Commercial and Industrial Waste Survey 2009,” 2011.

[51] Resource Futures, “Updated compositional estimates for local authority collected waste and reycling in England 2010/11,” 2013. .

[52] WRAP, “Household food waste collections guide,” 2016. [Online]. Available: http://www.wrap.org.uk/content/household-food-waste-collections-guide. [Accessed: 04-Apr-2018].

[53] WRAP Cymru, “National municipal waste compositional analysis in Wales,” 2016.

[54] Royal Dutch Waste Management Association, “Household waste seperation in NL (Presenation by Erik de Baedts),” 2014.

[55] DEFRA, “Clean Growth Strategy,” 2017.

National Infrastructure Commission

National Infrastructure Assessment: Waste Infrastructure Analysis for England

Appendices

Report prepared by: Peter Scholes, Claudia Amos, Thomas Milne

Report Approved by: Susan Harris, Debbie Hitchen

Date: May 2018

Disclaimer

Anthesis Consulting Group PLC has prepared this report for the sole use of the client and for the intended purposes as stated in the agreement between Anthesis and the client under which this report was completed. Anthesis has exercised due and customary care in preparing this report but has not, save as specifically stated, independently verified information provided by others. No other warranty, express or implied, is made in relation to the contents of this report. The use of this report, or reliance on its content, by unauthorised third parties without written permission from Anthesis shall be at their own risk, and Anthesis accepts no duty of care to such third parties. Any recommendations, opinions or findings stated in this report are based on facts and circumstances as they existed at the time the report was prepared. Any changes in such facts and circumstances may adversely affect the recommendations, opinions or findings contained in this report.

National Infrastructure Commission Disclaimer

This report was commissioned as part of the evidence base for the National Infrastructure Assessment. The views expressed and recommendations set out in this report are the authors' own and do not necessarily reflect the position of the National Infrastructure Commission.

National Infrastructure Assessment: Waste Infrastructure Analysis for England (Appendices)

National Infrastructure Commission

(Reference: CCCC17A49)

Prepared for:

National Infrastructure Commission
5th Floor,
11 Philpot Lane
London EC3M 8UD

Report written by:
Peter Scholes, Claudia Amos, Thomas Milne

Analysts:
Hannah Dick, Beth Simpson (Anthesis)
Nick Fellows (Fellows Environmental)

Quality Assurance
Analysis:
Peter Scholes, February 2018
Report:
Susan Harris, Debbie Hitchen, April 2018

Prepared by:

Anthesis Consulting Group
The Future Centre,
9 Newtec Place,
Magdalen Road,
Oxford,
OX4 1RE

E-mail: mail@anthesisgroup.com
Website: www.anthesisgroup.com

Tel: 01865 250818
Fax: 01865 794586

May 2018

Anthesis Consulting Group

Anthesis is a specialist global sustainability services and solutions provider founded on the belief that sustainable business practices are at the heart of long-term commercial success.

We develop value-driven sustainability strategy which is underpinned by technical experience and delivered by innovative, collaborative teams across the world. We not only develop solutions for clients, but act as a delivery partner too.

We combine the reach of big consultancies with the deep expertise of our practice leaders from across the globe.

Appendices

Table of contents

Table of figures

Table of Tables

Acknowledgements

The authors would like to thank Geoff Watson, Adrian Judge and Pat Wheeler for peer review of this report, and a range of industry stakeholders for their input.

A1. Technology Horizon Scan – Detailed Notes

This annex gives a detailed review of waste technology options available during the 2020-2050 forecasting period, overviewed in Chapter 3 of the main report.

A1.1 Anaerobic Digestion

Anaerobic digestion is the process by which organic matter is broken down to produce biogas and biofertiliser. This technology is applied to the digestion of organic materials such as sewage sludge, animal manure, crops, industrial waste water and food waste. Digesters for food waste tend to be more complex and expensive than other applications, as they need to recover bacteria in the effluent (e.g. using a down-flow filter bed or an up-flow sludge blanket), involve more operator training, and are also prone to acidification and failure. Increasingly, AD plants are having to handle more complex feedstocks and varying volume streams. Although requirements in terms of reliability, stability and robustness are significant, such plants can produce a high yield of biogas of a high quality.

1.1.1 Review of improvement options

The following key technical and commercial AD developments are being pursued today:

- Biogas yield is a key parameter in the economics of AD plants, and it can vary widely depending on several factors, including feedstock type, dry matter content, hydraulic retention time, solids retention time and the overall mix of the feed (which can be influenced by mixing complimentary feedstocks). These parameters also influence biogas composition (i.e. its methane content) and hence its fuel value for heat and power generation or use as Liquefied Natural Gas (LNG) or Compressed Natural Gas (CNG) in transport;
- The optimal configuration of feedstock preparation, tank conditions and digestate handling to optimise biogas yield are considered very site and feedstock specific and therefore difficult to roll-out as industry wide improvements. Owing to this complexity, key challenges with the AD technology revolve around how best to manage mixed waste streams and optimise the plant to maintain a consistent high yield of biogas of a high quality;
- The majority of AD plants are “wet” using pumpable wet feedstock streams with <10–20% total solids. However, there are a couple of dry AD systems in the UK processing drier materials without adding water with a total solids content of 20–40%;
- The current preferred approach of lower temperature (mesophilic) AD is considered unlikely to change across the industry as a whole;
- Higher temperature (thermophilic) AD technologies have been applied in continental Europe. In principle, the higher the temperature, the faster the process. However, most plants of this kind have experienced operational challenges as the higher temperatures can make the process more sensitive to changes in feedstock and operating conditions. The thermophilic process can be harder to control and requires additional energy both to heat up the substrate and to compensate for higher heat losses from the tanks;
- Single stage AD technology is relatively inefficient with respect to semi-solid waste, but will continue to be applied, with some modification, as it provides greater flexibility when feedstocks are prone to change from season to season or even daily. Multi-phase AD provides greater energy yield, but is relatively costly because of additional tankage, the quality of digestate produced, and the high level of operation and control required.

The following key improvement options have been included in the waste infrastructure pathway modelling:

Feedstock Pre-treatment:

- Various pre-treatment technologies have been developed in recent years (including milling, hot water, microbial, enzymatic, steam explosion, extrusion, acid and alkali treatments) to increase the availability for AD of sugars and other small molecules in biogas substrates, particularly in lignocellulosic material. Many methods are expensive or have a high energy demand and their efficiency is often difficult to prove. However, some pre-treatment methods can stabilise biogas plants that have stability problems (for example by adjusting the pH) and can potentially make new substrates available for anaerobic digestion;
- In particular, thermal treatments (such as steam explosion) have achieved significant improvements in biogas production and reduced residence time in the waste water (sewage) treatment industry. This may see an increased uptake in the organic waste (non-source separated) sector given the need for sanitisation and the reduced demand to get to 130°C from 70°C.

Biogas Post-Processing:

- Biogas cleaning for use in heat and/or power generation is already well established, with developments focused on the production of biomethane for vehicles or gas grid injection. Such production helps the UK meet its renewable energy targets by supporting the efforts to decarbonise heat consumption by replacing natural gas with biomethane;
- Three main biogas cleaning technologies in widespread use are water scrubbing, chemical absorption and Pressure Swing Adsorption. Two more promising further technologies, cryogenic upgrading and membrane separation, are in development but are currently expensive and unproven in the field. While the long term operational cost impact of the different biomethane upgrading technology options is not yet fully understood, the production of biomethane is a concept that enables new AD plants to efficiently produce energy. The efficiency of combined heat and power (CHP) and gas to grid (GtG) is comparable, but the distribution and use of the biomethane using an established gas network is much easier to implement.

Digestate Post-Processing:

- See later notes (for MBT)

1.1.2 Impact on Study & Modelling

Although anaerobic digestion has long been commercial, further technology optimisation and cost reduction are still possible that could improve the economic viability of the existing facilities operating under current market conditions as well as support the viability of new facilities. The main requirements are:

- to improve pre-treatment (to reduce digestion time);
- to reduce costs and to improve reliability of two-stage technologies;
- to improve biogas cleansing processes (mainly of corrosive H_2S); and
- to increase the robustness of the thermophilic process.

These are general process improvements but will have at most a 5% cost improvement impact across the industry and will mostly support the facilities to compensate for reducing industry gate fees and renewable subsidies to ensure commercial viability.

The key improvement in the past years has been the growing number of AD facilities producing biomethane for the gas grid, which has become a commercially valuable and environmentally friendly option.

Therefore, we expect AD with biogas to grid to become a key cornerstone of future waste treatment infrastructure and therefore this has been incorporated into the waste infrastructure pathway modelling.

A1.2 Thermal Processes

1.2.1 Introduction to combustion & advanced thermal conversion technologies

To date the UK thermal waste conversion infrastructure is dominated by moving grate, mass burn combustion of untreated residual wastes complemented by a handful of plants using fluidised bed combustion and/or gasification to process pre-processed residual waste streams or waste derived fuels.

1.2.2 Combustion

Most UK thermal plants are focussed on electricity production via steam boilers and turbines. This has been mainly driven by the initial incentivisation of renewable power production through the renewable energy obligation, but also by the relatively easy access to the power grid. A significantly smaller percentage of stations to-date have also generated thermal energy (CHP or otherwise) via steam and/or hot water. If produced, this thermal energy is typically utilised in local, large-scale industrial centres and/or as part of district heating systems and heat networks in the UK (see Section 1.2.5 for further details on heat utilisation).

1.2.3 Advanced thermal conversion

Gasification as a technology sector is still considered to be under development and has faced a number of technical and commercial challenges. Efforts in developing the technology for the conversion of less homogeneous feedstocks, such as waste, have been active since c. 1970-80s – with little in the way of commercial success. To date, in terms of the efficiency of standalone plants optimised for power generation, all existing gasification and pyrolysis technologies have lower efficiencies than that currently achieved by modern combustion technology. However, the innovative potential for gasification is based on the production and utilisation of syngas (i.e. synthetic gas) as a product itself either as:

- An upgraded BioSNG (synthetic natural gas) directly to grid;
- Combusting within gas engines or gas turbines to produce power more efficiently; or
- By converting the gas into chemical pre-cursors including hydrogen and other sustainable fuel options.

1.2.4 Review of Improvement Options

1.2.4.1 Combustion

Typical net efficiencies of mass burn stations utilising steam turbine plant are of the order of 14-27%. Potential improvement opportunities exist if steam temperatures can be raised within the boiler and combustion conditions improved. The incineration sector has undergone significant technological development over the last c. 15-20 years. Much of this change has been driven by legislation specific to the industry which has led to reduced emissions from individual installations. Development is ongoing, with the sector now focussing on techniques which limit costs, whilst maintaining or improving environmental performance. With potential improvement opportunities, plant efficiencies up to around 35-40% are theoretically possible if steam temperatures can be raised and combustion conditions improved at the larger sites (>20MWe)[1]–[3].

In summary, the moving grate sector has been and is still optimising their plants to improve combustion efficiency, reduce parasitic load and increase energy conversion efficiency to produce heat and power, however these are currently not expected to provide a step change, but continuous improvements over time for this technology category.

1.2.4.2 Gasification

Gasification types can be split roughly between steam raising/closed coupled and syngas focussed gasification for use in gas engines or as upgraded Bio-SNG in injection to the gas grid.

6.1.1.1 Gasification focussed on steam raising using closed- coupled combustion technology

These gasification technologies are considered relatively “bankable” but are unable to deliver complete flexibility as they rely on power and CHP production alongside, in some cases, limited syngas cleaning. The syngas cleaning is employed to improve plant life, but the gas produced is not clean enough to take advantage of better energy conversion via gas engines or turbines. Engine efficiencies currently reach about 43% on natural gas with about 35% on syngas. It the future, it should be possible to increase engine efficiencies to about 40%. At larger scales, efficiency differences can become less marked. A standalone gasification configuration that might result in a higher overall electrical efficiency than combustion technology, is based on the use of a combined cycle gas turbine (CGT) for power generation, but this configuration is currently unproven for residual waste.

It is essential to clean the syngas for use in engines and turbines due to the presence of tars, higher temperatures and other contaminants along with the associated risks of corrosion and fouling. These difficulties are not considered insurmountable, but they inevitably lead to further processing stages and give rise to additional inefficiencies, unavailability and costs. To date, the ability to achieve these levels of cleaning, especially for chemical synthesis, has not been robustly demonstrated to enable widespread commercial roll-out.

Most commercial gasification operations to date utilise a “close-coupled” gasifier and boiler (steam turbine) to avoid the gas clean-up issues. This direction has been led by ROC incentives and encouraged an increase in awareness from financiers and others that “gasification can work” within the UK, reflected by the number of active projects in development. However, it should be noted that most operating plants use homogeneous feedstocks, rather than mixed residual waste (typically wood), and the failures of major projects such as the Air Products 50 MW plasma gasification plants in Teesside means that the viability of this technology for residual waste is questioned by industry. In terms of energy efficiency of mass-burn technologies when optimised for power generation, close-coupled are less efficient than modern incineration technology.

6.1.1.2 Gasification focussed on syngas production

The focus on syngas production requires quite extensive syngas cleaning equipment to yield an ultra-clean, tar free, syngas and BioSNG for the gas grid. Once the output syngas has been cleaned, it can be used to provide a variety of end uses, many of which are not available via moving grate and other combustion technologies. Companies including Royal Dahlman[4] and APP[5] are developing technologies to sufficiently clean gases for use beyond close-coupling. High temperature based systems (such as APP) will typically include a second stage high temperature thermal treatment step at about 1200°C to crack (or split) the heavy tars into lower molecular weight components, followed by cooling and polishing/conditioning steps to remove components such as sulphur and ammonia.

Low-temperature based systems (such as Royal Dahlman) typically include a set of scrubbing stages to remove and collect tars and other contaminants. Cleaning and upgrading of syngas to form BioSNG, suitable for direct injection into existing national gas infrastructure, offers benefits of decentralised energy generation and higher conversion efficiencies (engines etc.). The BioSNG could also be compressed and used as transport fuel, similar to biomethane from AD plants.

In addition, cleaned syngas can be converted into hydrogen by conventional water gas shift to enable the production of pure hydrogen at a community scale on a competitive basis. Hydrogen is expected to have an increasing role to play as a fuel for electric vehicles and as a supplement to natural gas in the gas grid. Fuel cell power generation has the potential to be significantly more efficient than existing generation methods. Another longer term potential area for development is the use of syngas as a chemical feedstock. The majority of chemical production has been developing with virgin wood feedstocks. These applications are at various stages of research, development and demonstration which may require considerable time, effort and political will. However, if technically and commercially successful, they could lead to lower costs, lower environmental impact, and lower dependency on fossil fuel reserves. However, these option are at very early development stages for residual and mixed wastes and very limited commercial information is available to date.

1.2.4.3 Pyrolysis

In most pyrolysis reactions, a combination of gas, solid and liquid by-products are created. Effectively utilising all of these product streams is required to retain processing efficiencies. Pyrolysis within the energy generation sector is considered more as a method of feedstock preparation, carbonising and homogenising the fuel before further thermochemical conversion to energy. In this instance, a sufficient increase in process efficiency will be required to balance the additional energy inputs required.

Doing anything other than directly combusting the syngas created, holds similar issues to those seen in gasification. Producing high-value products from the generated bioliquids is being researched but similar hurdles in the upgrading of syngas is delaying industry development. In particular, the control of homogenous feedstock inputs and the commercialisation of clean outputs have been identified as major technical development hurdles to apply pyrolysis at medium to large scale to replace moving grate combustion.

The technology to pyrolyse waste plastics not suitable for recycling (i.e. end of life plastics) into oils, chemicals, carbon black and hydrogen is still under development with a number of developers trying to match operational robustness with market need. A review by Zero Waste Scotland[6] notes that the oil produced is suitable for use as a heating fuel but could be refined for other applications. With systems where refining is an integral part of the process, this is normally achieved by distillation, to produce a diesel and kerosene set of products suitable for use as a vehicle fuel, as well as a heavier residue which can be used for process heat. There are also opportunities with use of semi-refined outputs as potential chemical precursors and as carbon black, although the latter will require a consistent output milled to the required grade for uses such as paint manufacture and sewage sludge filtration. The only commissioned and operationally scaled facility in the UK was designed and is operated by Suez at Avonmouth in Bristol, converting commercial waste plastic to diesel. Little has been published regarding the effectiveness of this facility and it is understood that the facility is not in continuous operation due to fluctuations in oil price.

Therefore, this technology has not been included in the waste infrastructure pathway scenarios as the development of commercial options will need to progress further to produce sufficient data sets for potential modelling as a national solution for residual wastes, as well as for plastics.

1.2.5 Improved energy conversion efficiency – heat production & heat networks

A key way to improve the efficiency of thermal conversion technology is to focus on the type of energy produced and the increased use of heat or gas production instead of, or in addition to, power. Typical incineration facilities (including close-coupled gasification) combust the fuel to create steam in a boiler unit before driving through a steam turbine to generate electricity. Once utilised in the turbine, the remaining heat energy is often lost to a cooling plant before releasing into the atmosphere. Much higher overall efficiencies are available if a proportion of the heat is produced and used in addition to the power using combined heat and power (CHP) technology. However, it must be noted that as the heat supply rate rises, depending upon the type of steam turbine used, power production falls. Nevertheless, efficiencies of up to 78% can be achieved if suitable uses for the heat can be supplied.

Creating heat through the energy recovery of waste offers the opportunity to provide thermal energy to local users replacing natural gas and other heating sources. The amount of heat utilised depends primarily on the quantity of suitable users and their operational requirements for heat. Industrial (manufacturing) users are preferred as they typically require a year-round supply of high grade (steam) thermal energy. This type of heat customer is also beneficial as energy from waste plants are usually located in similar industrial areas, reducing the infrastructure required to supply. Connecting to residential or smaller commercial users is also possible, but this has historically proved difficult in the UK, partly because plants are usually situated far away from these users given planning constraints. Historically, the UK's focus on a world-class natural gas grid has meant there was little interest in developing the infrastructure or commercial practices to supply heat directly to users. In contrast, other European countries (particularly Scandinavian) made the decision to invest in district heat networks (DHN) which now covers large proportions of residential and commercial areas.

Recent UK Government policies on decarbonisation have identified that although solid progress has been made in the electricity generating technologies, the heat sector has lagged behind and this has increased attention on developing heat networks. Although there are over 2,000 heat networks in the UK, delivering heat from energy from waste facilities has been challenging in the past and recent government funding streams such as from the Heat Networks Investment Project (HNIP) and Heat Networks Delivery Unit (HNDU) have been made available to encourage putting pipes in the ground and connecting users to sources. From an energy from waste perspective, figures from Defra suggest that around 2Mt of current capacity already supplies local heat users, with a further 1Mt having the potential to supply local heat demand, with users being actively canvassed by developers[7].

DECC (2015)[8] suggests development costs for heat networks can be sizable, with buried pipework costs averaging at around £1000 per metre, although this ranges from £422 per metre to £1472 per metre depending upon the size and nature of the scheme. Operation costs associated with the heat network appear to be low, and not considered significant by operators. Distribution losses range widely with averages of 6% and 28% depending upon the type of network.

As an example, the award winning SELCHP Energy Recovery Facility in Deptford successfully supplies 2,500 Southwark properties on a 3.5km pipe work system with heat and hot water. This addition to the established systems already in place means that more than 60% of homes in Southwark are supplied by district heating. The network was completed in 2014, representing a £7 million investment from the operator Veolia, and saving 8,000 tonnes of CO_2 every year.

1.2.6 Residual waste composition impact

Residual waste composition will likely over the forecast period 2020-2050. In the model, this will vary between scenario. Key factors that will influence this will include:

- Existing recycling rates for dry recyclables and organics;
- Planned future measures to increase the recycling rates;
- Type of pre-treatment measure applied to the residual waste before EfW.

These parameters change the composition of the residual waste to EfW and the calorific content of the material, which determines the amount of energy produced per tonne of waste. Currently the calorific value (CV) of residual waste is expected to be around 8–10 MJ/kg. Existing EfW facilities are designed to deal with a CV range as residual waste is a fairly heterogeneous waste stream. Most mass burn incinerators will have an operational envelope to process residual waste with CVs of 6–11 MJ/kg and a design point around 9.5-10 MJ/kg when the energy production is optimised. Existing facilities are likely to only experience significant technical operational impacts if the CV of the residual waste streams falls outside their existing operational envelope. This would require a significant CV change.

Higher recycling rates alone should not lead significantly effect CV. Austria, Belgium and Germany achieved recycling rates of 64%–73% in 2013 and reported CVs of 9.4–10 MJ/kg for residual waste. Still, there may specific facilities that do suffer. The disproportionate removal of one material stream may have an impact. Existing EfWs could find the removal of plastics problematic because to increase the CV more of the remaining residual waste will be required, this in turn may require higher bunker capacity and could impact other equipment. Gasification plants would likely struggle to run at the reduced CV. The pre-treatment of waste to reduce the organic content of the material, which would also include reduction of moisture and biogenic content, could have a more significant effect. Secondary waste derived fuels, where organics have been removed, can have CVs between 12–22 MJ/kg. These prepared fuels would be more suitable for gasification and fluidised bed technologies, which rely on homogenous feedstock.

From a commercial point of view, changes to composition could also impact gate fees, risk sharing agreements and payment mechanisms linked to contractual performance. Compositional change could also impact energy production, affecting energy sales.

1.2.7 Impact on Study & Modelling

The horizon scan of thermal technologies has shown that incineration (particularly moving grate) is continuously improving and in particular the application of CHP energy conversion concepts can achieve significant improvements in energy efficiency. Therefore, this option has been included in the waste infrastructure pathways to compare residual waste options. Similarly, the gasification to BioSNG option has been modelled to evaluate the impact of improved efficiency and sustainable gas supply from residual waste. Even though the technology has not yet been technically or commercially demonstrated at scale both options have been deemed sufficiently advanced enough to be modelled. These technologies are compatible with potential changes in residual waste composition.

A1.3 Other Relevant Technologies

1.3.1 In-Vessel Composting (IVC)

In-vessel composting (IVC) can be used to treat food and garden waste mixtures. In contrast to anaerobic digestion these systems rely on aerobic decomposition of organic waste in an enclosed environment, with temperature control and monitoring. There are a number of different approaches using:

- Containers;
- Silos;
- Agitated bays;
- Tunnels;
- Rotating drums;
- Enclosed halls.

During the composting process, the organic material is broken down and the release of nutrients and bacteria increases the temperature to the 60-70°C, which is needed to kill pathogens and weed seeds. Where these systems process animal-by-products (ABP), they need to meet the relevant processing regulations.

During the process the oxygen level, moisture and temperature are carefully monitored and controlled during the composting stages to ensure the material is fully sanitised. The sanitised compost is then left to mature in an open windrow or an enclosed area for approximately 10-14 weeks to ensure full stabilisation, and then screened. This produces a range of product grades suitable for various end uses such as soil conditioning in agriculture, as well as compost use on brownfield sites, for landscaping and horticultural use.

There has been little recent innovation in composting, however different composting technology suppliers are experimenting with different time and temperature profiles to increase composting efficiency and reduce energy use. Nevertheless, the key process concept does not change and therefore in-vessel composting is expected to continue to be used in the future, mainly for green waste and food and green waste combinations to ensure peat-free compost products are produced from mixed organic waste.

1.3.2 Mechanical Biological Treatment (MBT)

MBT technologies are pre-treatment technologies which contribute to the diversion of residual (i.e. not source-separated) waste streams from landfill. They complement, but do not replace, other technologies as part of an integrated waste management system, as the outputs produced will required further treatment or landfilling.

Originating in Germany and Austria, the first MBT plants were developed with the aim of reducing the environmental impact of landfilling residual waste (both volume and biodegradability). However, due to the unsuitability of output use as a compost (as waste is not source-separated), deployment at scale of MBTs has been limited. In the UK, MBT is positioned to increase recyclable material extraction from residual (i.e. not source-separated) waste streams and separate and process an organic fraction for further use, as well as use as a pre-treatment process for RDF and SRF production. However, it is noted that due to the lower quality of recovered materials (compared to that which has been source-separated), the demand and therefore efforts in extracting anything other than metals and aggregate materials has been curtailed with the balance of material directed to fuel production.

There are a number of MBT process options:

1.3.2.1 MBT with IVC

Processing of organic fractions aerobically (In-Vessel Composting or windrows) is a relatively simple method to reduce waste volume and biological activity into a “compost like output” (CLO). MBT with IVC was initially positioned as an alternative to EfW, producing a more biologically stable product to go to land. However, Environmental regulations do not permit the agricultural spreading of non-source-separated wastes which limits markets and uses for a CLO. The latest version of the EU Fertiliser scheme does not include compost from residual mixed wastes, therefore the markets for CLO and MBT with IVC are not likely to increase, making MBT is purely a volume reduction process. The organics fraction is likely to be used for landfill engineering and similar purposes, but will not be acceptable as a comparable quality compost product.

1.3.2.2 MBT with AD

The future development of MBT technologies is considered to be driven by the progress of the AD sector. AD associated with MBT differs from AD alone, which treats a source-separated waste, as it requires increased pre-processing requirements. Source segregated collections of organics will provide a less contaminated organic stream, but may not in isolation capture a high enough percentage of relevant biogenic materials to achieve required levels of landfill diversion. Additional material is therefore separated from the residual waste stream, through a MBT process, for subsequent AD processing. As with MBT with IVC, the final organic digestate produced is likely used for landfill engineering and similar non-agricultural purposes.

1.3.2.3 RDF Production

Current demands for EfW have shifted the focus of MBT facilities to increase production of a refuse derived fuel from the waste stream. In some types of process, the entire raw waste input is first processed in a biological (non-thermal) drying stage followed by mechanical separation systems to provide an overall treatment process. However, most processes that seek to produce a ‘marketable’ bio-output, whether fully bio-stabilised or not, utilise some degree of post-biological mechanical processing to remove contaminants from the output or to change the output materials into a suitable form for their ‘end-use’ applications (e.g. for reducing the particle size, baling or pelletising). An alternative RDF production method is mechanical heat treatment (MHT), a process involving mechanical sorting before applying heat to thermally treat the waste (either drying or via autoclave). Limitations to-date have been high energy input requirements in adding steam for cooking and sterilising, to produce a fibre stream that subsequently needs drying again. However, these efficiency issues are expected to improve.

1.3.3 Feedstock pre-processing options for improvement

1.3.3.1 Enzymic Hydrolysis

In the REnescience (Ørsted) process, warm water with proprietary enzyme is added to residual waste to achieve temperatures appropriate for enzymatic hydrolysis. Through enzymatic action, biodegradable materials are liquefied (and ultimately converted to biogas via AD) which permits easy separation of non-degradable solids. Processing of residual MSW is said by the developers to be robust, with no requirement for shredding. It is suggested that this makes the process much simpler than other known processes, and it is said to have a high capture rate of the biomass and recycling of materials. Tested at pilot scale for a number of years, a first commercial unit is in commissioning in Northwich, England with a stated capacity of 120kTPa, recovering c. 95% of recyclable materials and creating feedstock for a 5MWe AD facility.

1.3.3.2 Thermal Hydrolysis

This process has widespread waste water treatment applications operating on sewage sludge, and is being developed for organic and food waste applications in Europe, particularly Norway.

The thermal hydrolysis process (THP) is a high-pressure, high-temperature steam pre-treatment application for AD feedstocks. The feedstock is heated and pressurised by steam within a reaction tank before being rapidly depressurised (flashed). This results in the breakdown of cell structure within the biomass; as the organic matter is presented to the digester in a broken-down condition, the digestion process is more effective resulting in increased gas production and improved digestate quality.

To ensure the process is thermally and economically efficient the system requires a dewatered feedstock at between 15-16% dry solids. As the thermal hydrolysis process utilises a dewatered feedstock, increased digester loading is achieved and therefore gas production is increased. The quality of the digestate is improved as the hydrolysed digestate is pasteurised, easier to dewater and achieve higher dry solids product, resulting in a product that is said to be easier to store, handle and transport.

1.3.3.3 Autoclave Systems

An autoclave can be used to pre-treat digester feedstocks in a similar manner to thermal hydrolysis. The autoclave is a pressure vessel that steam treats its contents at a constant temperature and pressure, serving to pasteurise, clean and break-down organic matter within the feedstock. As the organic matter is presented to the digester in a broken-down condition, the digestion process is more effective resulting in increased gas production and improved digestate quality. After processing, inorganic material and contaminants can be removed via mechanical separation, providing a clean, pasteurised, organic rich feedstock for anaerobic digestion.

1.3.3.4 Digestate Post-Processing

Upgrading digestate to form a revenue-earning product is particularly relevant for digestates from MBT applications, as the use of digestates derived from mixed waste materials is currently restricted to use on land restoration projects only. Options are:

- **Hydro Thermal carbonisation (HTC):** Digestates are not the ideal candidates either for heat and pressure technologies or for lignocellulosic hydrolysis, as most thermal processes typically requiring a dry solids concentration of 70% or more. But HTC is unusual in that it is designed to accept wastes with a much lower dry solids content (as low as 20%) and it is not troubled by the presence of high ash, nitrogen and other contaminants. Its main application has been in the conversion of biowaste to a carbon dense material (biochar). The process takes wet and dry biomass, heats it to 200°C, pressurizes it to 10 -20 bar and within 4 –10 hours the biomass is converted into a dry, black powder;

- **Product Synthesis:** A significantly active research area is the application of microorganisms to generate novel, high-value products. In particular, anaerobic fermentation is being studied to convert digestate and MBT residues into chemical intermediaries. A large amount of optimisation and scale-up work is required before a biorefinery process can be commercially developed.

Recent WRAP-funded reviews of alternative options for digestate enhancement suggest that the scale and throughput of commercial AD facilities are too small to warrant application of many capital-intensive enhancement and recovery technologies that can deliver digestate-derived fertiliser products. In addition, most bioeconomy and enhanced solutions required clean waste streams and are focussed on nutrients, starches and sugars within the digestate. Therefore, only a very small percentage of the total digestate could be used. The use of digestate as growing media for algae and other nutrient rich potential fertilisers seems to be more promising, but again at very early stages in the development and not sufficiently commercialised for the purpose of this project.

1.3.4 Impact on Study & Modelling

- MBT has been modelled as a pre-treatment option for residual waste to produce RDF for gasification or potential export. Some existing MBTs, generating energy via AD have been included as well in the base case modelling;
- Likely segregation efficiency was modelling for food waste separation, and recyclates e.g. plastic;
- CV of resultant refuse derived fuel-type output as calculated to assess impact of segregation on resultant energy from waste efficiency and energy output;
- IVC was included in the GHG and cost models, but will not be extensively modelled due to lack of energy or other output benefits.

A1.4 Landfill

The EU Landfill Directive (1999/31/EC) was designed to reduce reliance on landfill, to decrease the environmental impacts of landfills and to reduce the risk to human health while imposing a consistent minimum standard for landfills across the EU. The Landfill Directive therefore:

- Set minimum standards for the location, design, construction and operation of landfills;
- Set targets for the diversion of Biodegradable Municipal Waste (BMW) from landfill;
- Controlled the nature of waste accepted for landfill;
- Defined the different categories of waste (municipal waste, hazardous waste, non-hazardous waste and inert waste) and defined landfill as waste disposal sites for the deposit of waste onto or into land.

The Directive also banned a number of wastes from going to landfill, including liquids, flammable wastes, clinical wastes and other wastes which did not meet the acceptance criteria laid down in Annex II.

1.4.1 Impacts and improvement areas

The key environmental impacts of landfill are the production of leachate which has the potential to pollute local water sources, and through the release to air of methane produced from the anaerobic biodegradation of biogenic wastes. Modern landfills based upon liners, clay caps, environmental monitoring and effective gas management, capture and treat generated leachate to mitigate surface and groundwater infiltration. In addition, they capture over 80% of the methane generated. Therefore, in 2015 landfills accounted for 2.4% of total UK GHG emissions (on a CO_2 equivalent basis) compared to 8% in 2000[22]. Although some captured methane is flared, around 450 landfills in the UK capture methane for energy generation via a gas engine. Generation of electricity from landfill gas was 4.8 TWh in 2015 from an installed capacity of 1.1GW[10].

Although policies at EU, UK and England level for many years have been reducing dependency upon landfill, it is clear that there is a small proportion of material which is unrecyclable and non-combustible, for which landfill will continue to be a necessary option. Also landfill of residual waste generally is likely to continue where long-term landfill capacity exists and alternative treatment or recovery capacity is not available or is too far away from the point of generation to be a viable landfill diversion option. This should ensure the commercial viability of a small number of landfill sites.

To meet regulatory and planning requirements, landfill design will maintain minimal environmental impact through the use of leachate capture and treatment and methane capture for energy generation, although future innovations may include methods to boost methane generation and hence financial viability, such as leachate recirculation, whilst the construction of landfill “bioreactors” will allow closer control of decomposition conditions and increased capture of the methane generated. Future landfill developments are therefore likely to further reduce environmental impacts, giving landfill an extended role in the disposal of certain wastes.

1.4.2 The role of Landfill in Fossil Carbon Sequestration

Landfill also has a significant role in carbon sequestration, potentially of plastics. Although policy development appears to be focussed on reducing plastic to landfill, with increasing EU plastic recycling targets and the European plastics industry lobbying for a landfill ban, there is some support for the landfilling of plastics. The Defra publication “*Guidance on applying the Waste Hierarchy*“(2011)[11] lists landfilling plastics as an

---

[22] This compares to 0.06% from waste incineration (BEIS, 2017).

environmentally acceptable disposal option, and "*Environmental Benefits of Recycling"* WRAP (2010)[12] states "in terms of greenhouse gas emissions, sending plastics to landfill is preferable to conventional energy recovery, but is less preferable in terms of all other environmental indicators commonly considered in "Life Cycle assessment" i.e. as a form of carbon sequestration".

However, there are risks involved in landfilling plastics, which need to be understood and managed. The impacts of plastic waste on public health and the environment are only just becoming apparent. Most current knowledge is based around plastic waste in the marine environment, although there is research that indicates that plastic waste in landfill and in badly managed recycling systems could be having a local negative environmental impact, mainly from the chemicals contained in plastic. Microplastics are a significant issue in plastic waste, partly because they are more difficult to monitor, and partly because they may have greater impacts at a chemical and physical level on ecosystems and human health, owing to their size and large volume-to-surface area ratio. Although there is little research on the specific impacts of plastic waste on land-based wildlife, there is concern that incorrectly managed landfills could lead to either the escape of plastic waste or the escape of landfill leachate containing the chemicals associated with plastic. Leachate acidity and chemicals can break down plastics[13].

A review by Talsness et al. (2009)[14] has identified several studies that demonstrate that the industrial chemical 'Bisphenol A' (BPA)[23] is leaching from products that have been thrown into landfills and entering groundwater, contaminating rivers, streams and drinking water. Teuten et al., (2009) suggested that the migration of additives from plastic to the landfill leachate depends on several factors, including the pore size of the plastic, the molecular size of the additive and the nature of the leachate, in terms of its acidity and organic content.

There is also increasing recognition of the opportunity presented by the mining of historic landfill, for the separation of valuable materials, such as rare earth metals used in electronics, for energy generation from combustible materials, and the recovery of land for construction particularly in areas with high land prices. Such landfill recovery would also allow the mitigation of the environmental impacts of old landfill constructed without liners or methane capture. Although this is not a new concept, there are few examples worldwide of its successful application, and there are many technical challenges in its implementation. The European Enhanced Landfill Mining Consortium (EURELCO) states that 'where higher added value outputs are targeted, the net economic balance of the combined remediation-landfill mining activity can even become positive, which is especially the case for larger landfills where economies of scale become relevant. As such, remediation combined with enhanced landfill mining can generate an income for public waste agencies, and this can then be used to cover the costs of remediating and mining smaller, less economic landfills that pose short-term environmental and health risks.'[15] The enhanced landfill mining approach is currently being demonstrated in two flagship projects funded by the European Commission's Horizon 2020 Programme, ETN NEW-MINE (for municipal solid waste) and METGROW+ (for industrial waste) and is also being considered as part of the 'Waste Package', the latest revision of the European Policy.

This states that "The Commission shall further examine the feasibility of proposing a regulatory framework for enhanced landfill mining so as to permit the retrieval of secondary raw materials that are present in existing landfills. By 31 December 2025 Member States shall map existing landfills and indicate their potential for enhanced landfill mining and share information." The consideration for this change is that Enhanced Landfill Mining does not only enable the recovery of valuable materials which can be brought back into the cycle, but also allows for recovering land area, taking into account that a large part of the EU's 0.5 million historic

---

[23] BPA is bisphenol A. BPA is an industrial chemical that has been used to make certain plastics and resins since the 1960s. BPA is one of a large number of substances that have the potential to interact with our hormone systems, i.e. a potential 'endocrine disruptor'.

landfills are situated in a (semi-) urban environment, which could be made available for other economic use[16].

1.4.3 Impact on Study & Modelling

- The modelling has assumed that landfill capacity is maintained at 2020 levels. The scenario modelling has focussed on providing treatment and recovery capacity for wastes rather than using landfill as a sustainable option, and therefore landfill has mainly been provided as a disposal option for pre-treated residues;
- Landfilling of plastic waste was modelled, along with impact on CV of residual waste when plastics are removed;
- Assessment included estimating typical bulk density of landfilled plastics and their impact on overall remaining landfill void in England

A1.5 The potential for bio-fuel and biogas for heat and HGVs

Biogas is a key product of the anaerobic decomposition of organic waste, either in landfill or via anaerobic digestion facilities. Biogas can be used for process heat, or for heat and electricity generation using a combined heat and power unit. Alternatively, the biogas can be upgraded by the removal of CO_2 and other contaminants into biomethane (this technology is reliable and mature), for injection into the natural gas grid or for use in transport applications.

The majority of the biogas currently captured is used to generate electricity – DUKES (2016)[10] reports 4.07 TWh generated from landfill gas (446 sites) and 1.43 TWh from anaerobic digestion (351 sites) in the UK as a whole in 2015. However, a growing trend in anaerobic digestion is the supply of biomethane to the natural gas grid, encouraged by Renewable Heat Incentives, with more than 80 biomethane to grid projects completed by the end of 2015, injecting 2.5TWh/year of biomethane (100,000 homes worth). The REA predict that there will be 40TWh/year of biomethane from AD injected into the grid by 2035 (5% of total UK gas demand)[17].

An opportunity yet to be fully exploited in the UK is the use of natural gas or biomethane as a transport fuel. This market is growing significantly worldwide. The following statistics give some indication of the scale[24],:

- **Worldwide:** 19 million natural gas vehicles (NGVs) worldwide [18];
- **UK:** currently 700 NGVs that are all HGVs. There are 15 dedicated filling sites currently within the UK, 5 with public access [19]. The UK is the 3rd largest country in terms of biomethane production in Europe. Since 2014 there has been a big increase due to the RHI [20]. Projected UK growth = 10,000 buses & HGV’s by 2020, 207,000 Buses & HGVs by 2050 that use gas [19];
- **USA:** currently operates 130,000 NGVs, expected to be 16m by 2035 [19];
- **Europe:** 32 countries have a combined total of 3,400 CNG filling stations [19]. 1.2m vehicles (0.7% of market) ran on natural gas and biomethane in Europe in 2014 [20];
- **Germany:** Produces 75% of total biomethane in Europe. Most gets injected into the gas grid. Currently have 165 fuelling stations offering biomethane. Feedstock is 91.5% waste [20]. In total 900 CNG

---

[24] Distribution options for gas for transport include via the existing natural gas pipeline network; road transport of CNG (compressed natural gas) or CBM (Compressed Biomethane) stored at high pressure as other commercially available gases; and road transport of LNG (liquefied natural gas) or LBM (Liquefied Biomethane) stored at low pressure.

stations [21]. Produces the most upgraded biogas in the world, with 7.2TWh in 2013, although only 1.4% used in vehicle fuel [22];

- **Sweden:** 2nd largest producer of biomethane in Europe, with 59 upgrading plants (1/3 of Germany). 73% of all gas is biomethane. 100% is produced from waste (organic/sewage) [20]. 44,000 NGVs the end of 2012, 138 public and 57 private filling stations [21]. 97% of biomethane production is used in vehicle fuel [22];
- **Netherlands:** 4th largest producer in Europe. 21 upgrading plants and an extensive gas grid. 141 CNG filling stations and 6700 NGVs [20];
- **Austria:** 14 plants that produce biomethane, over half of that produced is used in transport. 180 filling stations [20];
- **Italy:** 5 biomethane plants as of 2014, 2nd biggest producer of biogas in Europe, with 1391 plants, and is by far the European leader in biogas powered transport, with over 885,300 NGVs [21]. 810 CNG refuelling stations [21];
- **France:** 2,400 buses, 800 refuse trucks, 10,000 cars fuelled by CNG. 260 refuelling stations [21].

The main environmental advantage of biomethane as a vehicle fuel is that it can substantially reduce greenhouse gas (GHG) emissions in the transport sector (typically between 60% and 80% compared to diesel). The main challenge for biomethane as a fuel solution is the cost of the product. The product cost mainly depends on the cost of the feedstock used. Purification and upgrading (from biogas to biomethane) costs depend partially on trace gases resulting from the feedstock being used and mainly on the size of the biogas upgrading unit[22]

To encourage the use of biofuels in transport, the Renewable Transport Fuel Obligation (RTFO) was set up in the UK in 2007 and has been amended 4 times, most recently in 2015. It places an obligation on suppliers of fossil fuels in the UK to ensure that certain amounts of sustainable biofuel are supplied. It considers fuels such as biodiesel, bioethanol and biomethane – in 2015/16 biomethane only represented <1% of the biofuels market. The obligation can be met by redeeming renewable transport fuel certificates (RTFCs). These are awarded to biofuel suppliers when sustainability criteria are met. RTFCs are traded between producers and suppliers and the value of RTFCs is determined by the market. New targets were announced in 2017, with an obligation level of 9.75% biofuel in 2020, rising to 12.4% in 2032. The Department for Transport (DfT) has also published changes to the RTFO which will now include sustainable jet fuel[25] within the incentive scheme.

There is already a small supply sector in the UK. For example, CNG Fuels operates CNG refuelling infrastructure. They produce RTFO approved biomethane from food waste. Similarly, GasRec, a landfill gas and AD biogas producer, produces 5 million litres of LBM for transport at Albury, Surrey. They fuel more than 60% of duel-fuel gas powered HGVs on UK roads. They also own 11 out of the 15 refuelling stations across the UK and have clients such as Tesco, Sainsburys, Waitrose, and B&Q.

In a trial run by Leeds City Council, they demonstrated biomethane performance, using Mercedes Benz Econic vehicles. The average distance covered by their 33 vehicles in a year was 16,226km; on average these vehicles used 0.79 kg/km of gas, which amounted to 12,859 kg of biomethane per year. Despite the potential issues of

---

[25] Examples: British Airways has teamed up with Velocys to convert household waste which usually goes to landfill into sustainable aviation fuel. Current plan is to fuel all BA 787 dreamliner flights from London to San Jose and New Orleans for a whole year. Velocys claim the fuel will offer a 60% GHG reduction and 90% in particulate matter emissions in comparison to conventional fossil fuels and 60,000 tonnes of CO_2 saving every year. Similarly, Virgin Atlantic are working with US company LanzaTech, to produce aviation fuel from waste industrial gases from steel mills, claimed to be 65% cleaner than conventional jet fuel.

manufacture and scale, biomethane can be cheaper than diesel. To compare usage costs to traditional fossil fuels, Sweden is one of the most reliable sources of cost data due to being one of the most developed biomethane transport markets in Europe. Cost of biomethane here is €0.65-€0.75 per kg, excluding taxes. On an energy basis this is equal to €0.47-0.57 per litre diesel. This compares to a (at the time) price of €0.75/litre of diesel without tax.

Impact on Study & Modelling

- Opportunities were modelled using AD and gasification as likely biomethane generators. Gas efficiencies and outputs were modelled to produce a gross gas output in terms of TWh.

A2. Country Case Studies

To review the impact of different national policy regimes on waste management sector performance, four European nations were selected for review, two within the United Kingdom and two within the wider EU. This review also served to inform the development of the waste flow model, and key parameters such as kerbside collection capture rates at high recycling rates.

A2.1 Wales

What policies have Wales implemented?

The Welsh Government has a range of policies to deliver zero waste via high waste management recycling rate targets, with a focus on food waste. The key policy document "Towards Zero Waste" (2010) is supported by sector management plans for: the Collections; Infrastructure and Markets Sector; the Municipal Sector; the Industrial and Commercial Sector; the Construction and Demolition Sector; the Food, Manufacture, Services and Retail Sectors; plus the Waste Prevention Programme.

Municipal Waste targets established are:

- a minimum of 70% of waste being reused, recycled or composted by 2024/25;
- a maximum of 30% energy being created from waste by 2024/25;
- a maximum of 5% of waste being landfilled by 2024/25; and
- Wales to achieve zero waste (i.e. 100% recycling) by 2050.

As part of the Municipal Sector Plan, the Welsh Government also introduced the Collections Blueprint, which local authorities were encouraged, but not mandated, to follow. The plan was designed to achieve a degree of consistency across Wales, whilst allowing for flexibility for the specific circumstances of each local authority. Its purpose was to help local authorities comply with the targets laid out in the "Towards Zero Waste" policy document. Some local authorities were supported under the Collaborative Change Programme to evaluate their waste management performance, which helped identify savings from moving towards the model identified in the Blueprint.

These municipal initiatives are complimented by commercial and industrial (C&I) waste targets of:

- for industrial waste, a reduction of 1.4% each year;
- for commercial waste, a reduction of 1.2% each year;
- 70% of I&C waste to be recycled by 2025;
- zero waste to landfill by 2025; and
- Wales to achieve zero waste (100% recycling) by 2050.

A focus for the Welsh Government has been to reduce the landfilling of biodegradable municipal waste by significantly increasing recycling and composting/AD rates without a major reliance on energy from waste (EfW). All recyclate/compost/AD digestate generated in Wales is reprocessed and used in Wales as far as possible and energy from waste caps have been established. In 2018 the Welsh Government has the right to set local Landfill Disposal Tax rates, proposed initially in line with English rates.

The Welsh Government is also considering implementing mandatory segregation of food waste for businesses, after successful implementation in both Scotland and Northern Ireland. Both countries introduced these changes in two phases, targeting large food waste producers (over 50kg per week) first, before extending the legislation to smaller food waste producers (between 5kg and 50kg of food waste per week).

What has this policy intervention delivered?

In terms of collection provision, 99% of households have food waste collections, which is one of the aspects of the Collections Blueprint. Separate food waste collections deliver 7% of 64% recycling in Wales and the average capture rate for food is 41% (i.e. Quantity collected compared to the quantity arising). Wrap Cymru also reported that avoidable food waste was reduced by 210,000 to 188,000 tonnes in Wales between 2003-2015; this reduction was valued by WRAP at £550m and avoided 105,000 tonnes of carbon dioxide emissions.

In 2015/16 the Welsh Government set the municipal recycling target at 58%, which 19 of Wales' 22 councils met or exceeded, with Wales as a whole recycling 60.2% of waste. The Government has powers to impose a discretionary penalty on councils of £200 per tonne that the target was missed by. However, most authorities that have failed to meet the targets so far have had their fees waived, and instead have been referred to the Collaborative Change Programme to help support them. Blaenau Gwent council said it would have been fined £573,000 while Torfaen council said its fine would have been £49,800. Wales is reported to be second only to Germany in world-wide recycling rate performance[23].

In 2015, the Welsh Government published a Progress Report[24] which reported the following:

- Household waste decreased by an average rate of 2% annually between 2006/07 to 2013/14, exceeding the target reduction of 1.2% per year;
- 68% of commercial waste was reused, recycled or composted, compared to 37% achieved in 2007;
- Waste sent to landfill has continued to decrease, and met the EU target of sending no more than 643,000 tonnes of biodegradable municipal waste by 2020, eight years early;
- Greenhouse gas emissions from the waste sector have reduced every year since 2009 to 2012 – a 6% reduction per year, exceeding the Welsh Government Climate Change target of 3% year on year.

There is a projected need to ensure between 320-396kt of market demand for the products arising from food waste treatment (i.e. compost or anaerobic digestate) in Wales by 2024-25 (including the current demand). Current indications are that potential demand will significantly exceed supply, with >2MT identified.

The Waste Infrastructure Procurement Programme, established in 2008 and delivered through public private partnerships, supported local authorities to deliver sufficient treatment capacity to meet EU landfill diversion and statutory national recycling targets. Both food waste and residual waste treatment infrastructure has been delivered under this programme.

What learning can be applied to this study?

High recycling rates are clearly possible but need support from strong central policy and legislation, targets (in this case, with the potential of charging authorities for not achieving targets) and funding commitments from the government.

It has been widely reported by WRAP, that separate weekly food waste collections yield more capture of food waste than combined organic waste collections (particularly when partnered with less frequent residual waste collections, householders supplied with biodegradable liners and effective communications such as reminder on containers). This is supported by evidence from Wales as all authorities in Wales now collect food waste separately, helping to achieve the high recycling rates. However, it should be noted that the additional cost of separate collections is not always negated by the reduction in treatment costs.

The Welsh Government advocates the kerbside sort system, which provides households with two or more boxes per household for some segregation, with additional segregation delivered at kerbside by the collection crews. High capture rates have been achieved across the full suite of dry recyclates, as well as lower rates of contamination than co-mingled collections. The effectiveness of this system should also be considered with the other factors such as provision of this service weekly, whilst reducing residual waste frequency of collections.

Through the sector plans, Collaborative Change Programme and Waste Infrastructure Procurement Programme, in terms of policy a holistic approach of waste management has been taken, so both improvements in collections and the associated treatment infrastructure have been delivered, and markets for by-products (such as compost) have also been considered with programmes put in place to enhance where necessary.

A2.2 Scotland

What policies have Scotland implemented?

Scotland has a range of zero waste policies which are significantly different to those in England, with focus on the use of greenhouse gas (GHG) based metrics to prioritise material selection for recycling, mandatory food waste collection and low reliance on energy from waste. The Circular Economy concept is central to many of the Scottish Government’s policies in this area. Relevant Scottish policy and legislation can be summarised as follows:

Zero Waste Plan (2010):

- Working towards a more circular economy;
- Development of a Waste Prevention Programme;
- Landfill bans for specific waste types;
- Separate collections of specific waste types;
- Two new targets that will apply to all waste: 70 per cent target recycled, and maximum 5 per cent sent to landfill, both by 2025;
- Restrictions on the input to all energy from waste facilities;
- Encouraging local authorities and the resource management sector to establish good practice commitments and work together to create consistent waste management services, benefitting businesses and the public;

- Improved information on different waste sources, types and management highlighting further economic and environmental opportunities; and
- Measurement of the carbon impacts of waste to prioritise the recycling of resources which offer the greatest environmental and climate change outcomes, through the Carbon Metric. These policies were expected to reduce Scotland's annual waste carbon impact by 22% below 2011 levels, or 3.1 $MtCO_2e$, by 2025.

The Waste (Scotland) Regulations 2012:

- Local authorities to provide a basic recycling service to all households by 1 January 2014;
- Local authorities to offer a food waste recycling service in non-rural areas from 1 January 2016;
- A ban on material collected for recycling going to landfill or incineration (from 1 January 2014);
- A ban on municipal biodegradable waste going to landfill by 1 January 2021;
- All businesses and organisations to present key recyclable material for collection from 1 January 2014;
- Food waste businesses producing over 50kg of food waste per week to present it for separate collection from 1 January 2014;
- Food waste businesses producing over 5kg of food waste a week to present it for separate collection from 1 January 2016;
- A ban on the use of macerators to discharge food waste into the public sewer from 1 January 2016; and
- All new incinerators must ensure that metals and dense plastics have been removed from residual municipal waste prior to incineration plus a ban on biodegradable municipal waste going to landfill from 1 January 2021.

Scotland aims to have an energy from waste infrastructure that effectively manages the "leakage" from a more circular approach to the economy in Scotland, without creating demand for materials that could otherwise be kept in higher value use. There is an understanding that thermal treatment facilities have a role in addressing the demand for energy during transition to a more circular economy. Where thermal treatment plants are used, only high quality combined heat and power schemes will be developed.

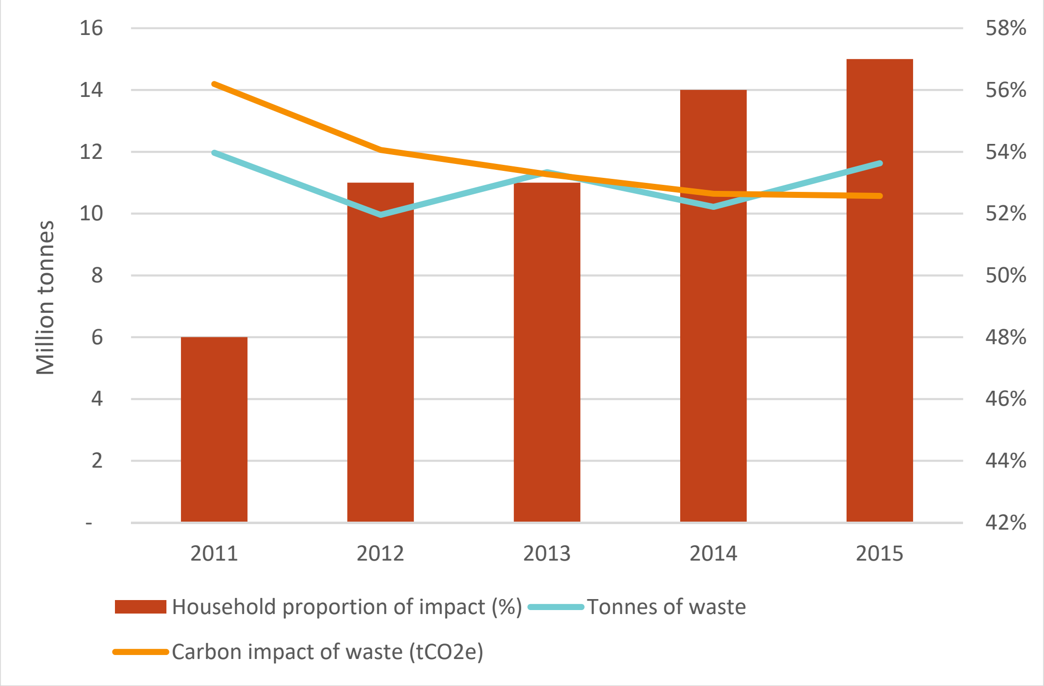
In addition, in 2015 Scotland gained control of its own landfill tax - Scottish Landfill Tax (SLfT) (which replaces UK Landfill Tax).

The Scottish Carbon Metric

The Scottish Carbon Metric measures the carbon impacts of Scotland's waste using a carbon accounting approach which measures the whole life carbon impacts of waste, regardless of where in the world those emissions occur. Traditionally, measurements of waste emissions are limited to end-of-life emissions occurring within a country's borders, meaning decision-makers do not have a complete understanding of the impacts associated with these materials and how their impacts may be reduced most effectively. The Carbon Metric addresses this by including the production emissions from materials which then becomes waste, giving a fuller understanding of the climate change impacts of waste and the potential to reduce these impacts through waste prevention and management measures.

The carbon impact of producing waste material is far greater than the carbon impacts of managing waste, making waste prevention the most effective means of reducing waste carbon impacts. However, despite annual waste tonnage fluctuating significantly between 2011 and 2015, due primarily to large variations in construction and demolition waste arisings, the carbon impact of Scotland's waste has fallen every year over the same period, culminating in a 26% reduction below 2011 baseline levels. As Scotland's waste carbon impacts have declined, the relative share attributable to household waste has steadily increased, with a net change of 9%.

Figure 21: Tonnage and carbon impact of Scottish waste 2011-2015



Source: ZWS September 2012 - The Carbon Footprint of Scotland's Waste - 2014 and 2015 Carbon Metric: Annual Report and Biennial Technical Update

The five most carbon intensive waste materials make up just 6% of Scotland's waste by weight, but nearly a third of associated carbon impacts. Food waste is the most carbon intensive waste material, generating 15% of carbon impacts in 2014, and 17% in 2015[25]. The most recently created target aims to reduce food waste arisings specifically. Since food waste has a higher carbon impact than any other homogeneous waste stream, this should be an effective driver in reducing environmental impact of waste overall.

What has this policy intervention delivered?

Benefits from this range of policy interventions have included:

- Investment of £25m to enable 80% of Scots access to separate food waste collections compared with less than 50% in England;
- "Good to Go" – a Scottish Government funded campaign to reduce food waste in restaurants (branded doggy bags);
- Electricity Market Reform (EMR) policies have resulted in a large number of investments in anaerobic digestion (AD) plants;
- MRF code of practice and reporting requirements have been put in place to guide best practice and operating standards to achieve high quality material recovery;

- Recycling targets based upon the Carbon Metric i.e. encouraging local authority collection of recyclates based upon their life cycle GHG impact. As of 2015, waste carbon impacts had already declined by 26% (3.6MtCO_2e) below 2011 levels (exceeding the 22% expectation);
- Renewable energy targets 11% of all heat from renewable energy by 2020, and 50% of all electricity;
- Various food waste collection trials and results (ZWS).

The Scottish landfill ban on food waste seems to have a strong precedent in the 9 EU countries that have a high recovery rate for food waste. France and Italy appear to lead the way with their rules on business food waste being donated or financial incentives to local authorities that donate or re-direct food that would otherwise have gone to landfill. However, when considered generally against landfill bans, Zero Waste Europe [26] highlights the risk that waste is potentially simply pushed to EfW rather than recycling.

What learning can be applied to this study?

- Mandatory local authority food waste collections are a positive factor, and similarly for C&I food waste to be separately collected;
- With the Regulatory change only reaching full Scottish coverage in the last 12-18 months, there is little reliable data to measure if mandatory food waste collection has had a material effect on food waste production. Data from the Scottish Environmental Protection Agency (SEPA) suggests that it isn't a silver bullet to resolve the problem, but there has probably been a greater impact through mandatory collection containers and services made available by Local Authorities;
- AD feedstock quality should improve and volumes increase with statutory food waste collections giving green energy and possible animal feed supplies from C&I sources. The AD market in Scotland is more buoyant (with more financially sustainable gate fees chargeable) than in England, partially due to a ready and secure supply of food waste;
- Savings from separate food waste collections (v. cost of disposal in mixed waste) will impact through GHG reductions (<14%) as well as lower general waste costs if rolled out to businesses. WRAP do quote £10-20 per household saving for food waste;
- It is possibly too early to assess the full impact on recycling rates, but since the ZWP was adopted in 2010, the household recycling rate has increased from 40% in 2011 to 46% in 2016;
- The Carbon Metric methodology has allowed for the assessment of which materials have the highest carbon impact, and therefore inform policy;
- Scotland has only been able to achieve what it has with Government and some EU funding, in contrast to WRAP (England) that has seen significant cuts to public funding, Zero Waste Scotland has seen increasing budgets;
- Scotland is still in the early years of food waste reduction. As more is being collected, there is an apparent increase in food waste arising. Glasgow studies shows complete coverage has only just been achieved, but is having the desired effect in the urban areas which produce the greatest amount of waste;
- Public communication and ambitious targets seem to back up the 'why' message to public and business to encourage behavioral change.

A2.3 Netherlands

What policies have the Netherlands implemented?

The Netherlands has managed over the last few years to divert more than half of the municipal solid waste (MSW) generated to recycling. Out of the 8.9 million tonnes of MSW generated in 2014, 4.5 million tonnes were recycled, 4.2 million tonnes were incinerated and only 128 000 tonnes ended up in landfills. A landfill ban covering 35 waste categories and a landfill tax, both introduced in 1995, considerably reduced the amounts of MSW landfilled. The subsequent increases in the landfill tax in 2002–2010 made the tax in the Netherlands the highest in Europe in 2010. In 2012, the tax was repealed due to the very low level of landfilling[27].

The first National Waste Management Plan (NWMP), which covered the period 2003-2009, set the framework for future waste management in the Netherlands and introduced the control of waste policies under a national perspective. The second NWMP (2009) introduced a target to increase the recycling of household waste to 60 % by 2015, plus other objectives:

- to limit growth in waste generation, decoupling it from economic growth;
- to reduce the environmental impact of waste, optimising recovery and re-use;
- to minimise the environmental impacts from product chains – raw material extraction, production, use and waste management including reuse.

The third NWMP (covering the period 2016-2022) introduced a new target for the collection of household waste in 2020. At least 75% should be separately collected for recycling, with a maximum of 100 kg residual household waste generated per person per year. Waste generation is 527kg/capita all waste (2014), 192kg/capita mixed (residual) household waste, 82kg/capita organic, kitchen and garden waste.

Reflecting the needs of the NWMP, waste collection in the Netherlands is characterised as follows:

- Kerbside collection of household waste is funded by local taxation and from fees paid by producer-responsibility organisations for packaging waste;
- Kerbside collection includes the collection of a range of recyclables such as paper/cardboard, plastic bottles, textiles, food and garden waste which are collected either source separated or comingled;
- Municipalities decide how waste is collected – either by local authority cleansing departments or private waste collection companies;
- There are more than 400 civic amenity sites nationwide; these are typically focused on collecting bulky waste such as furniture, and waste electrical and electronic waste (WEEE);
- Around 41% of municipalities by 2015 had introduced pay-as-you-throw (PAYT) schemes. Schemes differ from region to region (per kg of waste offered; by size of the bin, by frequency of collection or combinations of the above) as municipalities operate their own waste collection system;
- There is a deposit refund system in place for single use and refillable glass and polyethylene terephthalate (PET) containers for soft drinks and water.

Commercial waste collection varies from municipality to municipality. Waste is collected by local authority cleansing departments or private waste collection companies; however, most waste from offices and services is collected by commercial collectors.

The Dutch Government launched a Government-wide programme for a Circular Economy in 2016. The programme is aimed at developing a circular economy by 2050 with the ambition of achieving a 50% reduction in the use of primary raw materials (minerals, fossil and metals) by 2030. The Government has selected 5 economic sectors and value chains that will be the first to switch to a circular economy. They are:

- biomass and food;
- plastics;
- manufacturing industry;
- construction sector;
- consumer goods.

What has the policy intervention delivered?

The Netherlands has achieved high recycling rates and reduced waste to landfill significantly, through introducing landfill bans, landfill tax and through the implementation of successive and regularly updated NWMPs, which has introduced new targets to drive the sector forward and provide clear policy direction. MSW recycling reached 50% in 2014 being at that time the 5th highest performer in Europe after Germany (64%), Austria (56%), Belgium (55%) and Switzerland (54%)[28].

Regarding food waste, 7.7Mt is generated annually. Capture rates of biowaste of 48% have been reported, and stakeholders anecdotally report (there is no quantitative evidence), this increased consciousness of food wasting behaviours can lead to prevention at source.

Since 2010 municipalities have been required by law to collect plastic packaging separately. It has been reported that the infrastructure costs for the collection and separation of household plastic currently outweigh the revenues that are generated from the sale of recycled plastic. Currently capture rates of only 20% are being reported of plastic packaging. However, municipalities are financially compensated by the packaging industry under the producer responsibility legislation, and gets a contribution of 670 € per tonne of collected household plastic.

Infrastructure

In the mid-2000s, the Netherlands made considerable investment to increase its waste incineration capacity, which was due in part to the EU landfill directive. Currently the Netherlands operates some 7.7Mtpa of energy from waste capacity, generating 4,000GWh of electricity and 3,890 GWh of heat production, in 12 major facilities[29].

In January 2007, the Dutch government further opened its borders for the incineration of waste (both household and commercial/industrial) from abroad to stimulate the expansion of further incineration capacity in the Netherlands. Coupled with the successful implementation of national waste management plans which resulted in declining availability of waste, the Dutch waste incineration plants have been left with a net overcapacity since 2010. As such, waste companies have been importing waste from other countries, such as the United Kingdom, Ireland and Italy, to make full use of the excess incineration capacity. For example, in 2016 of the 3.2Mt RDF exported from England, 1.5MT, i.e. around half, was energy recovered in the Netherlands (data from the Environment Agency). In the Netherlands, EfW accounts for 20% of all the sustainable energy produced.

What learning can be applied to this study?

- Incineration capacity was built based upon capacity shortfalls some 20 years ago, but has since been impacted by more recent changes in government policy;
- Policies now look to wean the waste sector off incineration with a push towards greater separation at source or post collection separation;

- Due to their overcapacity of waste incinerators and recent history of imports from the UK, it is possible that they may be a significant long-term receiver of UK waste for recovery. However, the impact Brexit may have on current levels of export to the Netherlands is yet to be seen;
- Capture rates for food and other wastes[30] have been published and are used for benchmarking capture rates employed for this study – some factors cited as reasons for higher capture rates are the use of PAYT schemes, as well as reductions in collections of residual waste.

A2.4 Germany

What policies have been implemented?

Germany is one of the largest producers of waste in Europe generating 402Mt[26] annually. This total includes 320Mt of hazardous and non-hazardous waste from households, commercial and industrial, construction and demolition sources as well as 31Mt of mining spoils and 51Mt of waste processing residues.

The responsibility for waste management is shared between the national Government, the Federal States and local authorities. The National Ministry of Environment sets priorities, drafts national legislation, oversees any strategic planning and information, and defines requirements for waste infrastructure at a national level. In line with national legislation, waste management plans are produced at the regional level by Federal States. Local authorities (mostly districts and towns) have responsibility for household waste under the Recycling Management and Waste Act. Municipalities (mostly part of a district) provide sites for waste collection.

The Waste Management Act transposes Directive 2008/98/EC into German law. This includes collecting, transporting waste, measures to promote waste prevention and recovery, and the construction and operation of waste disposal facilities. The Waste Management Act is supplemented and fleshed out by a number of other regulations including individual producer responsibility regulations for individual waste streams. The Act contains new provision concerning the distinction between waste on the one hand, and by-products or product or substances no longer regarded as wastes on the other hand, i.e. that do not fall within the scope of the law (Article 4)[31].

Therefore, waste management practices in Germany aim to minimise waste generation and maximise recycling, while ensuring that any leftover waste is disposed of appropriately[31]. The sharing of responsibilities between federal states and the national government has led to the development of Germany’s significant waste infrastructure and recovery rates in the past ten years.

According to the European Environment Agency (2013), Germany was one of the first European countries to introduce landfill limiting policies in the 1990s and this led to Germany becoming one of the European countries with the highest waste recovery and treatment rates, with 79% being recovered including 68% recycling and 11% energy recovery leaving only 21% going to landfill (not including waste processing residues) in 2014 [32]. Germany’s waste recovery rates are the highest in the world and therefore the waste industry contributes to sustainable economic production by saving raw materials and primary energy. However, there is an ongoing discussion regarding the best way to recover value from waste resources i.e. material vs energy recovery.

Until June 2017, Germany put material and energy recovery at par or as ‘ecologically equal’ approaches for any materials with a heating value above 11 MJ/kg, requiring recycling or energy recovery unless the materials were required to be recovered or disposed of in a different way. However, this approach was found to be

---

[26] This compares to 203Mt of waste generated in the UK in 2014 (Defra, UK Statistics on Waste, February 2018), although the UK figure excludes mining, quarrying and agriculture.

contradictory to the European waste hierarchy and European waste framework directive after a complaint was filed to the European Commission that the clause was ‘not compliant with the directive, as it meant the flat-rate heating value threshold had overridden the hierarchy.’ It is estimated that additional 100,000 tonnes of hazardous chemical waste, 80,000 tonnes of bulky waste and tyres and unknown quantities of C&I waste collected by municipalities, combustible construction and demolition wastes and sewage sludge could be recycled in future, as these were prime wastes with heating values above the CV threshold for energy recovery[33].

Since the introduction of the German landfill ban, biologically active or organic waste is no longer permitted to be landfilled and all waste has to undergo some form of treatment, including mechanic-biological or thermal treatment to render it inert. This helps to reduce leakages and releases of landfill gas at landfills and reduce the environmental impact of waste management in general.

One of the latest introductions in Germany has been the separate collection of biowaste since 2015 under the Bio-waste Ordinance. This goes beyond the requirements of the Waste Framework Directive (WFD), of which Article 22 only requires measures to “encourage” the separate collection of bio-waste[34]. Under the Ordinance, bio-bins must be provided to all German households for the separate collection of garden and food waste. This ensures that only biodegradable waste with a low pollutant content is utilised as a source material for fertilisers or soil improvers, for example, after composting or fermentation. The aim is to recycle organic material and to avoid the accumulation of pollutants in the soil. The National Ministry of Environment states that composts from separately collected bio-waste bins contain 95% less contaminants than composts produced from mixed household waste.

The German Government has also set an ambitious target for recycling, in essence they aim for Germany to achieve almost complete high-quality recovery, at least of municipal waste, by 2020.[35]

What has this policy intervention delivered?

- Around 70 waste incineration facilities with a capacity of 20Mt are available in Germany for the treatment of residual waste. Moreover, a further 4.6Mt of incineration capacity is available in 30 refuse-derived fuel power plants. For the mechanical-biological treatment of waste, 44 facilities with a capacity of around 5.5Mt are available to pre-treat residual waste from households and businesses to reduce volume, biological activity and recover recyclables;
- The turbulent market conditions in the German incineration sector seemed to have calmed down in 2017 and the German Energy from waste trade association ITAD says Germany’s capacity for processing waste is close to 100% and that the majority of plant operators are at the "upper limit" of treatment capacity. At the same time the amount of waste imported into Germany is estimated at around 1.2Mt per year. Germany’s mergers and monopolies body, also ruled in 2017 that there was no evidence of over-capacity in the country. However, this is regularly disputed by Germany’s recycling sector, arguing that over-capacity is damaging for its sector as potentially reusable waste is swallowed up by plants needing feedstock and therefore offering very low prices for recovery of wastes, which makes recycling uncompetitive in many cases and with plastics wastes in particular;
- There are some concerns that the prices, which slightly increased for commercial wastes in 2016 and stabilised in 2017, might fall again. These concerns are mainly aimed at municipal residual waste as there are a number of regions in Germany still developing new incineration capacity despite the publicised market balance[36]. The key drivers for these additional facilities are the increasing waste volumes in Germany driven by population growth and good economic conditions, but also by the demand for waste capacity from abroad, including the UK, which cannot be influenced by Germany;

- Germany has had targets and regulations for collecting packaging waste, bio-waste and waste paper separately since the introduction of the landfill ban and the producer responsibility policies in the Waste Management Act, which led to the introduction of the German dual packaging collection system (i.e. separate packaging collections in parallel with municipal waste collection) and a sharp increase in recycling. Companies that put packaging on the market pay into the dual system to help fund the collection and their recovery. Since its enforcement, the Act ensured that producers and distributors design their products in such a way that increases their service life, reduces waste occurrence during their production and use and allows for the environmentally sound recovery and disposal of any residual substances[37]. Every citizen is estimated to separate on average more than 30 kg of packaging waste into separate bins, which keep plastic packaging separate from other municipal waste. Glass and paper packaging are also collected separately;
- The initial growth in recycling slowed by the latter part of the 2000s and the initial decoupling of waste growth from economic GDP was not sustained;
- For municipal waste recycling rates increased to 62% in 2010 (well beyond the EU 2020 target of 50%), landfilling was almost 0% and incineration 37%. This recycling rate fluctuated a % or two since then to remain at 64% in 2014[38]. Eurostat data for 2014 shows that Germany has the highest recycling and compost rate for municipal waste of all EU Member States, at 64% and even when removing composting from the equation, Germany's material recycling rate alone is 47%. An estimated 18.2Mt of packaging waste was generated in Germany in 2015, an all-time high associated with the change in living styles and consequently behaviour. An estimated 97% of packaging waste is recovered of which 69% is recycled[39];
- An estimated 12 Mt of biodegradable waste is treated yearly in composting and digestion plants (biogas installations) in Germany (mainly waste from the bio bin, biodegradable garden and park waste, market waste and other biodegradable waste of diverse origins). Around 9Mt were collected separately, either via the bio bin (4.5Mt) or as separately collected garden and park waste (4.5Mt); this is equivalent to an average annual collection rate of 107 kg per citizen. Of the total bio waste volume, around 8 Mt were processed in 924 composting facilities and around 4.3Mt were consigned to around 1,000 digestion plants. Around 3.55Mt of compost and approximately 2.96Mt of fermentation products for various purposes were produced from the collected bio waste[40];
- Future projections by the EEA indicate that efforts will need to be continued to maintain and increase Germany's already high recycling rates. This will need to take into account the impact of the latest changes to align Germany's recycling and recovery definitions to European standards as well as the growing trend of increased packaging production. In addition, Germany will also have to react the potential reduction in Chinese material exports as currently est. 20Mt of waste derived materials are exported and about 16Mt are imported, therefore leaving Germany as a net exporter[41].

What learning can be applied to this study?

Waste management in Germany is characterised by effective waste regulations and infrastructure development in the last 40 years, but it is not without concerns regarding the availability and utilisation of the recycling and recovery infrastructure at a regional and national level. The German market has had to react to a number of regulatory changes and requirements to be fully aligned with the European waste framework directive, and further amendments are expected as a result of the European Circular Economy Package. While reporting very successful recovery and recycling rates, Germany will need to continue to increase actual material recycling volumes in line with the waste growth as well as through sorting, separation and recycling as well as composting and anaerobic digestion, in particular for materials which might have benefited from the heating value exemptions, which set energy recovery and material recycling as equal waste management options. The ‘balance’ in the energy recovery market is mainly maintained through waste imports from the UK and other countries, therefore increasing UK recovery capacity might have a negative impact on the German market and potential recycling rates.

The key learnings are:

- Many EfW facilities in Germany were built, owned and partially operated by the public sector, with many municipalities having their regional and local incineration facility as well as district heating network to utilise the energy and retain added value. Therefore, the waste and energy infrastructure is far more integrated than in England, providing a direct link between waste management and decentralised energy provision;
- While more and more facilities are being privatised, the original planning and construction of waste management capacity was supervised at national and regional level to ensure sufficient capacity was assigned throughout the country. However, not only the early adoption and lead on recovery and recycling, but also the cultural buy in from the German population has supported the high recycling and recovery rates in Germany;
- High recycling performance is clearly driven by policy at federal and local levels, including focus on separate collection of waste including bio-waste, and long-standing requirements for producer responsibility (including funding of the collections), are key for high recycling rates in Germany. This is also reflected in a consistent approach across the nation to collections and kerbside infrastructure.

A3. Relevant Policy and Regulation

The waste sector and waste infrastructure developments have been influenced and shaped by government policy and regulations. To provide insight into how future policies and regulation could influence waste infrastructure developments in terms of technology choice, outputs or sizing, a high-level policy and regulation horizon scan has been developed. The horizon scan focused on new and upcoming regulations, policy and strategies in the UK and Europe as well as UK consultation documents, all relevant to the situation in England. These regulations, policies and strategies will be critical to the implementation of the pathway scenarios and could provide the political framework to support the scenario delivery.

A3.1 EU policies and regulations

3.1.1 'Clean energy for all Europeans' package

The 'Clean Energy for All Europeans' package[42] is relevant to this project because it incorporates policies such as the Renewable Energy Directive and is trying to encourage further improvement of frameworks for the transition to renewable energy. The package is made up of nine legislative proposals and seven non-legislative documents, covering energy efficiency, renewable energy, electricity market redesign, governance rules for the Energy Union, energy security and eco-design. Additionally, the Commission outlines how it wishes to support innovation in the clean energy sector, and how to accelerate building renovation.

The measures outlined look at both the uptake of existing technology, as well as how to support innovation to advance new technologies. The initiatives intend to encourage businesses to invest in new technologies, whilst also setting the framework to allow citizens to benefit from decentralised energy production. The Commission aims to put consumers at the centre of the new energy system, making it easier for them to become energy producers and sell excess energy into the market, "without being subject to disproportionate procedures and charges that are not cost-reflective". The proposals come in response to new technologies for decentralised production, as well as expected development and uptake of energy storage and smart metering. The package also includes a legislative proposal on the revised Energy Performance of Buildings Directive (EPBD), a binding 30% energy efficiency target, clarified Ecodesign framework and measures, policies to improve skills in the construction sector and smarter finance to help Europe grow while meeting its climate goals.

3.1.2 European Renewable Energy Directive (RED and RED 2)

The existing 2009 European Renewable Energy Directive has targets to source 15% of all energy and 10% of transport fuels from renewables by 2020[43]. In support of this overarching target, each Member State has taken on binding national targets for raising the share of renewables in their energy consumption. The UK's National Renewable Energy Action Plan, sets out the following targets; 30% Renewable electricity, 12% renewable heat and 10% renewable transport.

To date the UK has been successful in decarbonising the electricity network however, the heat and transport fuel sectors are still heavily reliant on fossil fuels. The government is addressing this through the revision of the Renewable Heat Incentive (RHI) regime and the revised Road Transport Fuel Obligation (RTFO) regulations. On its current course, the UK will need to increase its renewable energy performance significantly if it is to meet the 2020 renewable energy targets.

The Renewable Energy Directive is under review. The goal of revised RED (RED II) is to increase the proportion of renewable energy in Europe to 27% by 2030. It will also provide longer-term visibility and investment security to companies engaging in RES projects in the EU, including avoiding negative retroactive implications for existing installations. The commissions favoured approach to reducing emissions from transport is by using renewable fuels produced from wastes and residues[44]. With regard to transport, the RED II focuses on phasing down food and feed based biofuels and encouraging new fuels to the market. The proposals include a lowering of the current cap on food and feed based fuels from 7% in 2021 to 3.8% in 2030. It also aims to establish a blending mandate of 6.8% for fuels that are deemed to bring GHG reductions to the transport sector, including renewable electricity. In addition, the document defines a set of sustainability criteria that biofuels, bioliquids and biomass fuels, except from municipal and industrial waste and residues, must fulfil to be eligible for financial support or count towards renewable energy target[45].

3.1.3 Circular Economy Package

EU institutions have reached a provisional agreement with member states on waste laws to accelerate the transition to a circular economy in Europe. This provisional deal amends numerous directives including Waste Framework Directive (considered the umbrella legislative act of the package), the Packaging Waste Directive and the Landfill Directive.

The agreed waste legislative proposals establish binding waste reduction targets and updated rules to "decrease waste generation, ensure a better control of waste management, encourage the reuse of products and improve recycling in all EU countries", according to the European Council. Key targets include member states being required to recycle at least 55% of their municipal waste by 2025, 60% by 2030 and 65% by 2035. The agreement also includes a 10% cap on landfill by 2035 and provisions for countries to restrict the use of single-use plastics. These new targets and rules aim to promote a more circular economy and will also set out to boost growth and jobs, protect the environment, encourage sustainability[46].

Key elements of the agreed text include:

- Clearer definitions of key waste concepts;
- New binding targets at EU level for waste reduction to be met by 2025 and 2030, and 2035. These targets cover the share of municipal waste and packaging waste recycling (with specific targets for various packaging materials), plus a target for municipal waste landfilled by 2035;
- Stricter methods and rules to calculate the progress made towards those targets;
- Stricter requirements for the separate collection of waste, reinforced implementation of the waste hierarchy through economic instruments and additional measures for member states to prevent waste generation;
- Minimum requirements for extended producer responsibility schemes. Producers under these schemes are responsible for the collection of used goods, sorting and treatment for their recycling. Producers will be required to pay a financial contribution for that purpose calculated on the basis of the treatment costs;
- As part of the action plan for a circular economy released as part of the package in 2015, the European Commission is currently developing a European Strategy for Plastics, which was released in early 2018.

3.1.4 European fertilizer regulation

A draft fertiliser regulation has been developed as part of the EU Circular Economy package. The main elements of the proposal include recovery rules for bio-waste transformed into composts and digestates. If these products are incorporated in CE marked fertilisers, they are no longer considered to be waste within the meaning of the Waste Framework Directive. However, the latest version very clearly states that only source segregated MSW will produce a product and MBT CLO (compost like output) will not be accepted. This has been taken into consideration in the scenario modelling and as such CLO produced by MBT (covered by the intimidate residual waste treatment facilities) is not included in the results.

A3.2 UK policies and regulations

3.2.1 Clean growth strategy

The UK's 2008 Climate Change Act sets a framework for legally binding five-year carbon budgets. These are staging posts towards a long-term goal of cutting greenhouse emissions to 80% below 1990 levels by 2050. The governments Clean Growth Strategy (CGS) [47] released in October 2017 commits to delivering action towards the fourth (2023-2027) and fifth (2028-2032) carbon budgets[48].

Key aim of the Clean Growth Strategy that could have an impact the delivery on the pathway scenarios for this study are [49]:

- A 20% reduction in food and drink waste arising in the UK, and other environmental impacts of food and drink consumption through the delivery of the Courtauld Commitment 2025;
- Work towards no food waste entering landfill by 2030;
- Ambition for the UK to produce zero avoidable waste by 2050;
- Increase recycling, reuse, repair and remanufacturing levels;
- Extend producer responsibility schemes;
- Develop resource efficiency and "industrial symbiosis" with local enterprise partnerships;
- Manage emissions from landfill and research landfill gas capture; and
- Support anaerobic digestate used as fertiliser.

The key specific elements of the strategy looking at heat generation relevant to the study are:

- It is recognised in the strategy that there will need to be a combination of locality-specific options across a range of technologies, including biogas, hydrogen, electric and district heating, alongside measures to improve energy efficiency to decarbonising heat. The Strategy leaves all the longer-term options open, saying that decisions on approach will be made in the 'first half of the next decade';
- the Renewable Heat Incentive is already being reformed to focus more on long-term decarbonisation via technologies such as heat pumps and biogas. It will spend £4.5bn to support innovative low-carbon heat technologies in homes and businesses between 2016 and 2021.

The key specific elements of the strategy looking at power/electricity generation relevant to the study are:

- The end of coal generation will be part of plans to drive substantial further cuts in power sector emissions;
- The government hopes low-carbon sources of power will account for more than 80% of supplies by 2030, up from around 50% today. Beyond the Hinkley C nuclear plant, the government says further new reactors would have to be cheaper;

- It was confirmed in the strategy that offshore wind will compete for up to £557m in low-carbon support, with onshore wind on Scottish islands also allowed to compete, subject to state aid approval from the European Commission. The next auction will be held in spring 2019;
- The strategy repeats a 10 gigawatt target for new offshore wind in the 2020s and says it will consider going even further “if this is cost-effective and deliverable”.

Carbon capture storage:

- The strategy sets out plans to invest up to £100m in carbon capture usage and storage (CCUS) and industrial innovation;
- This sum includes up to £20m for a carbon capture and utilisation demonstration for new technologies and an extra £10m for the UK’s £60m international CCS programme, which has been running since 2012.

3.2.2 Industrial Strategy

The UK Industrial Strategy was released in November 2017[50]. It includes a commitment to move towards a circular strategy and also pledges to raise “the resource productivity of businesses, including through the promotion of recycling and strong secondary materials markets where products are designed with efficiency and recyclability in mind.” The strategy looks to be aligned with the European Commission’s circular economy proposals.

3.2.3 UK Government 25 Year Environment Plan

Announced in January 2018, the 25 Year Environment Plan covers various environmental concerns. In the Plan the UK government commits to:

- Making sure that resources are used more efficiently and kept in use for longer to minimise waste and reduce its environmental impacts by promoting reuse, remanufacturing and recycling;
- Working towards eliminating all avoidable waste by 2050 and all avoidable plastic waste by end of 2042, (although this term is not defined); and
- Reducing pollution by tackling air pollution in the Clean Air Strategy and reducing the impact of chemicals.

This Plan looks at the role of the tax system to reduce the amount of single use plastic waste, working with industry to reduce complexity in packaging to allow easier recycling, looking at potential future bans in line with the recent microbeads ban, and looking to support future innovation. Practical measures to make recycling easier for consumers are also highlighted along with actions to reduce food waste. These initiatives are all aimed at increasing levels of recycling and composting and reducing residual waste. The waste sorting, treatment and disposal infrastructure in England will need to respond to these potential changes in waste flows.

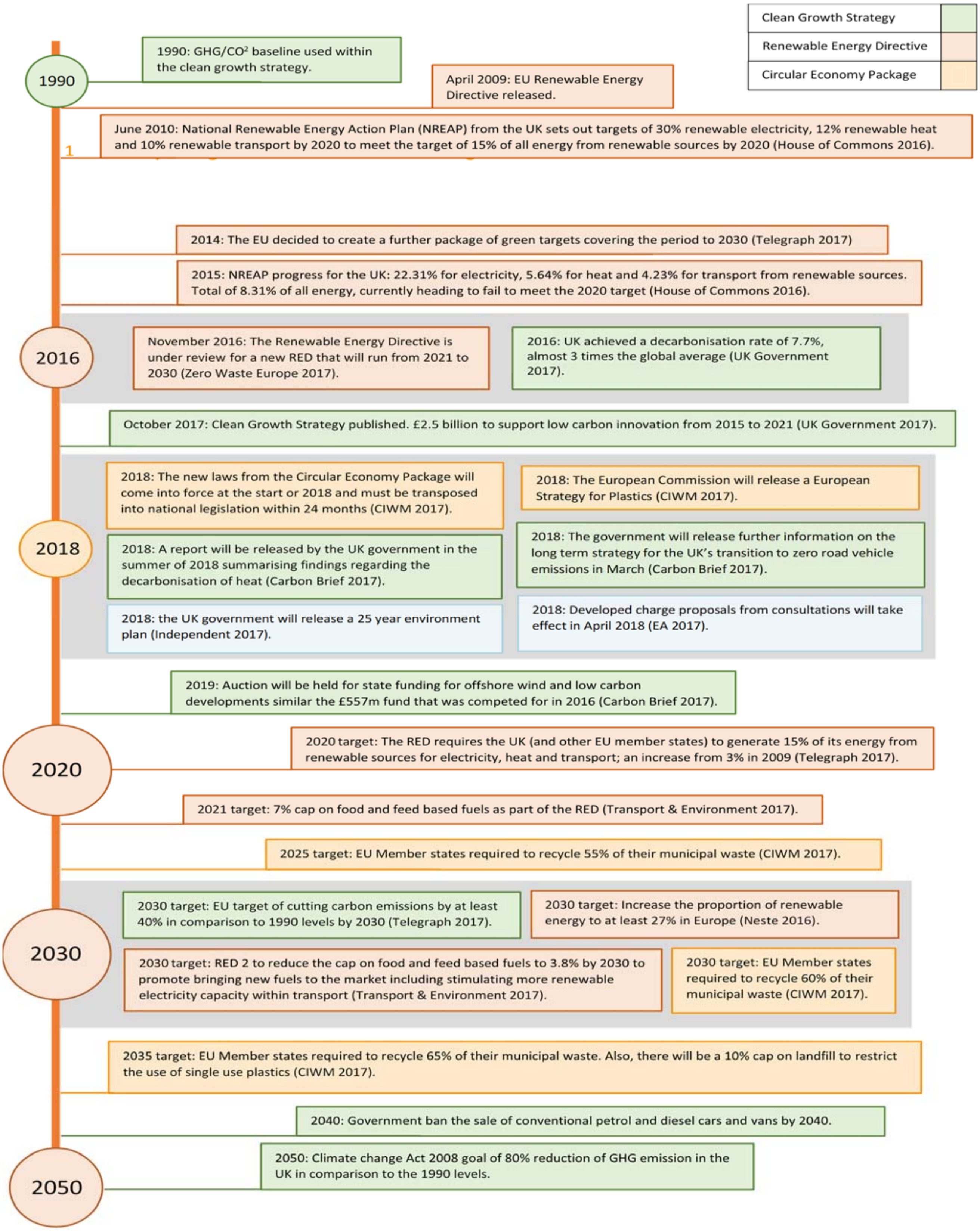
The Plan also commits to publishing the new Resources and Waste strategy.

3.2.4 Environment Agency revised permit charging consultation

The Environment agency is revising the way it charges for waste permits. The new charges will be based on a modular approach, the “risk-based charging model”, no longer dependent upon the operational risk assessment (OPRA) profile for EPR installations and waste operations. The new scheme also replaces the ‘charges for discharges’ approach for surface water and groundwater discharges and the different charging provisions for Tier 2 activities, radioactive substances permits and flood risk activity permits. Applicants will pay for assessments depending on the permit required and any further assessments charges as additional components.

This will affect all permitted waste facilities. For example the proposed charges might triple the cost of current permits for non-PAS110 digestate disposal, whereas well run operations producing PAS compliant materials could also reduce charges. The consultations period closed in January 2018, and the developments will take effect in England in April 2018[51].

Figure 22 : Timeline of related policies and regulations for the horizon scan (Source: Anthesis)



Clean Growth Strategy	🟩
Renewable Energy Directive	🟥
Circular Economy Package	🟧

1990: GHG/CO² baseline used within the clean growth strategy.

April 2009: EU Renewable Energy Directive released.

June 2010: National Renewable Energy Action Plan (NREAP) from the UK sets out targets of 30% renewable electricity, 12% renewable heat and 10% renewable transport by 2020 to meet the target of 15% of all energy from renewable sources by 2020 (House of Commons 2016).

2014: The EU decided to create a further package of green targets covering the period to 2030 (Telegraph 2017)

2015: NREAP progress for the UK: 22.31% for electricity, 5.64% for heat and 4.23% for transport from renewable sources. Total of 8.31% of all energy, currently heading to fail to meet the 2020 target (House of Commons 2016).

November 2016: The Renewable Energy Directive is under review for a new RED that will run from 2021 to 2030 (Zero Waste Europe 2017).

2016: UK achieved a decarbonisation rate of 7.7%, almost 3 times the global average (UK Government 2017).

October 2017: Clean Growth Strategy published. £2.5 billion to support low carbon innovation from 2015 to 2021 (UK Government 2017).

2018: The new laws from the Circular Economy Package will come into force at the start or 2018 and must be transposed into national legislation within 24 months (CIWM 2017).

2018: The European Commission will release a European Strategy for Plastics (CIWM 2017).

2018: A report will be released by the UK government in the summer of 2018 summarising findings regarding the decarbonisation of heat (Carbon Brief 2017).

2018: The government will release further information on the long term strategy for the UK's transition to zero road vehicle emissions in March (Carbon Brief 2017).

2018: the UK government will release a 25 year environment plan (Independent 2017).

2018: Developed charge proposals from consultations will take effect in April 2018 (EA 2017).

2019: Auction will be held for state funding for offshore wind and low carbon developments similar the £557m fund that was competed for in 2016 (Carbon Brief 2017).

2020 target: The RED requires the UK (and other EU member states) to generate 15% of its energy from renewable sources for electricity, heat and transport; an increase from 3% in 2009 (Telegraph 2017).

2021 target: 7% cap on food and feed based fuels as part of the RED (Transport & Environment 2017).

2025 target: EU Member states required to recycle 55% of their municipal waste (CIWM 2017).

2030 target: EU target of cutting carbon emissions by at least 40% in comparison to 1990 levels by 2030 (Telegraph 2017).

2030 target: Increase the proportion of renewable energy to at least 27% in Europe (Neste 2016).

2030 target: RED 2 to reduce the cap on food and feed based fuels to 3.8% by 2030 to promote bringing new fuels to the market including stimulating more renewable electricity capacity within transport (Transport & Environment 2017).

2030 target: EU Member states required to recycle 60% of their municipal waste (CIWM 2017).

2035 target: EU Member states required to recycle 65% of their municipal waste. Also, there will be a 10% cap on landfill to restrict the use of single use plastics (CIWM 2017).

2040: Government ban the sale of conventional petrol and diesel cars and vans by 2040.

2050: Climate change Act 2008 goal of 80% reduction of GHG emission in the UK in comparison to the 1990 levels.

A4. Methodologies and assumptions applied

The modelling methodologies used, the key assumptions made and data applied in development of these models, are explained in this Appendix. Note that this has been subject to a peer review process as well as stakeholder engagement.

A4.1 Waste flow model

The waste flow model develops forecasts of waste arisings from local authority collected waste (LACW) and commercial and industrial (C&I) waste sources for England for each year between 2020 and 2050. In generating these forecasts, flow of waste from collection through key infrastructure types to final waste management destinations (or fates), is also modelled, to allow:

- variation in capture rates of individual materials in the waste streams;
- modelling of calorific value changes in the residual waste forecast;
- modelling different infrastructure pathways;
- generation of waste flow data required to adequately cost and model the GHG impact of the infrastructure pathways developed.

4.1.1 LACW arisings

The prime source of data for estimating LACW arisings for the baseline year is Defra's WasteDataFlow database (at http://www.wastedataflow.org/). Using data supplied directly by local authorities, this source is generally accepted in the sector as a robust dataset.

LACW data is reported on a financial year basis rather than calendar year. In order to align with other datasets such as the Environment Agency's "Waste Data Interrogator" (WDI - with waste returns reported by permitted waste sites, of all types of wastes), quarterly data downloadable from WasteDataFlow (WDF) has been collated for the calendar year 2015. Although WDI was available for 2016, not all quarters of WDF data was available at the time of creating the model, and therefore 2015 was used as baseline.

Total LACW has been calculated using WDF 2015 Performance Indicators (PI) summary report totals from unitary (UA) and waste disposal authorities (WDA) for England. This has been cross checked against the total figure for 2015/16.7

Other LACW flows have been modelled using both the WDF collection questions and Question 100, which was designed to replace a number of questions in WDF covering the management of waste (treatment, disposal and transfer to reprocessors) and to allow greater detail of reporting. Question 100 only became mandatory for authorities to complete from April 2015 and therefore some extrapolation had to be undertaken for the first quarter to factor up to the whole 2015 figure. Also, in analysing the data, it was clear that some authorities may have completed this in different ways and it was quite challenging to interpret the waste flows. The user survey from 2017[52] indicates that respondents felt that Question 100 had been poorly implemented and would benefit from simpler data entry processes. However, this was still deemed to be the best data available and useful for understanding the complete waste flows.

It is noted that LACW figures, include both wastes collected from households, and that collected from businesses ("trade waste"), where such a local authority service operates.

4.1.2 C&I arisings

C&I waste arisings are notoriously difficult to estimate, given the severe lack of historical and current data. A review of previous work carried out in this area is summarised later in this Appendix. The estimate for this study has focussed upon the "household like" fraction of C&I waste i.e. that C&I waste with a similar composition to LACW, which uses similar waste facilities to LACW for processing i.e. non-hazardous landfill, EfW, MBT, and dirty MRF etc. Depending upon the data used, this appears to be between 50% to 70% of total C&I waste. This will therefore exclude the more industrial parts of C&I waste i.e. mineral wastes, inert wastes, agricultural wastes, construction and demolition wastes, industrial wastes with particular waste treatment technologies, hazardous waste, sludges, chemical manufacturing wastes etc.

There have been no surveys of C&I waste arisings in England since 2010, when 2009 data was collected[53]. This was deemed too old to be robust for this study.

As a consequence, the key source of data from which C&I arisings can be derived, and waste flow estimated, is the Environment Agency's "Waste Data Interrogator" (WDI)[54] with waste returns reported by permitted waste sites, of all types of wastes. Although there are issues with returns data (i.e. it does not cover all types of waste facility e.g. reprocessors, facilities regulated by local authorities, those facilities exempt from permitting; and for some facility types, up to 15% of operators do not submit data), for the key facilities involved in this study e.g. landfill and EfW, returns data is robust.

In WDI, input tonnage into key facilities are a combination of LACW and C&I wastes with no way of differentiating the two waste sources (the WDI describes these as HIC wastes i.e. household, industrial and commercial). Note that data for 2015 was used although 2016 data was available at the time the model was developed, to ensure compatibility with the WDF 2015 figures.

Therefore C&I waste flow calculations have been based, where possible, upon:

C&I arisings = (Total volume through key waste management types from EA returns) – (LACW inputs through same key waste management types from WasteDataFlow)

Total residual LACW plus "household like" C&I arisings have been calculated using:

- Returns data for non-hazardous landfill (WDI data, household like materials only);
- EfW inputs (from EA returns data[55]);
- Co-Incineration (from EA returns data); and
- RDF exports (from EA/HMRC data[56]).

Discussions with the EA have shown this to be robust data with high participation rates in annual reporting. This mirrors the methodologies used in most recent studies. The household like C&I residual waste total can then be estimated by removing from this total LACW residual waste volumes from WDF. By calculating arisings in this way, any possible double counting due to local authority trade waste collections, is eliminated.

A baseline recycling rate of 55% has been used. The latest known recycling rate was 52% in the 2009 survey, and this accounted for recycling of all C&I waste arisings. There is no other data available since this survey, on which a more up to date recycling rate could be based, and this reflects assumptions used in other published studies. In order to then calculate the recycling total, the residual waste total and the 55% recycling rate are used.

One drawback with WDI returns data, is that it does not contain a robust set of recycling data, as many of the reprocessors handing segregated recyclates are not regulated under Environmental Permits, or are regulated by local authorities rather than the Environment Agency. To fill this gap, data from the Environment Agency "National Packaging Waste Database" (NPWD)[57] for England (gross weights received by registered reprocessors) was used, with LACW recycling removed, to estimate C&I recycling rates and therefore capture rates per key material. Although it is recognised that not all reprocessors are registered under this scheme, and that not all key recyclates are covered by the packaging regulations, it has been used as a proxy for recycling in the light of no other robust data sources on waste material recycling being available. However, packaging recycling data still left volume of recyclables unaccounted for (assuming 55% recycling rate) so it did not completely fill the data gap. This data gap therefore has been included in the total C&I waste figure, but removed from the detailed modelling.

4.1.3 Waste Compositions

So that waste flows can be modelled, along with capture rates of individual components of LACW and C&I waste, waste compositions have been assumed based upon those published in the review by Resource Futures (2013)[58].

Waste compositions are presented in terms of primary and secondary category materials. Primary categories are overall material types such as paper, glass; secondary categories are the constituent material types for the primary categories – so for the primary category "paper", secondary categories are: "newspapers", "magazines", "recyclable paper (excluding news and mags)", "other paper"; and for "glass" are: "packaging glass", "green bottles", "clear bottles", "brown bottles", "jars", "non-packaging glass". Some adjustments were made to the secondary categories in particular to ensure they matched with the input material composition requirements of WRATE.

It has been assumed for this study that this baseline waste composition does not change during the forecast period. However, this is unlikely to be true over the 30-year horizon for this study.

4.1.4 Waste Arisings Growth rates

Economic and population growth rates to 2050 have been supplied by the NIC from relevant studies NIC[59], [60]. Both factors have been used for LACW and C&I waste arisings and for both growth scenarios as follows:

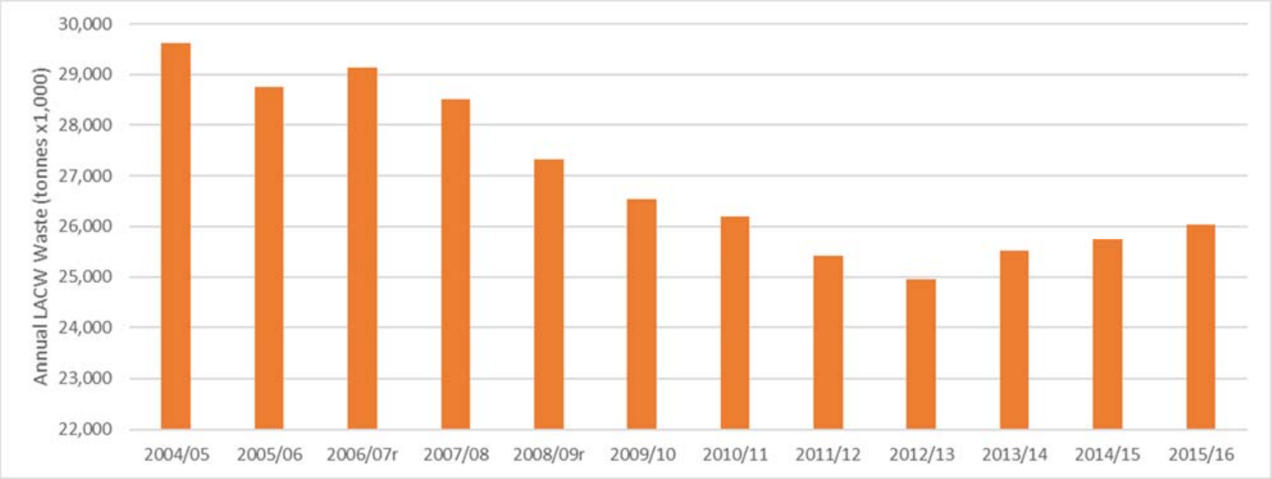
Total Waste Arisings = (arisings from previous year) x (1+% change in population since previous year) x

(1+% economic growth as output per capita) x (1-d)

where d = decoupling factor.

The difference between the two growth scenarios is a difference in decoupling rate. For the higher growth scenario, a decoupling rate of 1% was applied (to give average annual growth of +1.4% from 2020-2050) and for the lower growth scenario a rate of 2.5% applied (average overall growth -0.1% 2020-2050). This results in a growth in waste annually for the higher growth scenario and a small annual decrease for the lower growth scenario. The lower rate is based on actual LACW performance in the last 10 years, as shown in Figure 23 where a long standing downward trend has started to increase again in recent years, although there are a number of external factors which may also have impacted upon reported LACW annual totals. There is no such annual data for C&I waste upon which growth forecasts could be benchmarked. The figures chosen do however mirror growth rates applied in other recent studies.

Figure 23: Total local authority collected waste trends 2004/5 to 2015/16 (Source: Defra)



Most recent studies have built in waste growth into their forecasting horizons as a "worst case" scenario. With the evidence of LACW totals in recent years, the modelling of a low growth option ensures this possibility is robustly reviewed. It could be argued that the low growth rate assumes the application of waste minimisation initiatives, packaging de-weighting, food waste and avoidable plastic waste minimisation and other programmes which have not been costed for in the CBA, or the impact of a declining economy. The high growth model could be seen as the impact of a growing economy and consumer behaviour in receipt of growing incomes. The true growth between 2020 and 2050 is likely to be somewhere between these extremes.

This growth rate is applied to each material individually at the primary category level – with the exception of organic waste streams, which need to be amended at the secondary category level (i.e. garden, good(s) etc.). In the model itself, this overall growth rate can be overwritten for individual material types, if for example, certain waste materials were expected to go against the overall trends anticipated. The total arisings is then calculated annually on the basis of growth rates set for individual materials.

Total waste arisings are presented by secondary category level, but are only presented by primary category throughout the rest of the model (with the exception of the organic waste).

4.1.5 Collection

For both LACW and C&I wastes, the tonnes collected for recycling are forecast. For the baseline year, these tonnages are based on actual data, and drive the capture rates per material type. LACW recycling capture rates are derived from WDF Q100 data; C&I recycling rates are based upon adjusted data from the NPWD. However, beyond the baseline year, capture rates drive the tonnages captured at collection stage, and so the model is designed so that capture rate for individual materials can be increased / decreased, allowing the modelling of changed recycling rates, and material segregation options. This in turn, drives forecast residual waste tonnage, residual waste composition and calorific value (CV) estimates.

The capture rate for each material is capped at 100%.

4.1.6 Treatment

Flows are modelled through key waste management types to allow WRATE and cost modelling. LACW and C&I wastes are modelled separately.

4.1.7 Dry Recyclates Management

Assumptions for LACW and C&I waste are slightly different for this element. For both waste streams, it has been assumed that 45% of dry recyclates are collected co-mingled and separated at a MRF, and 55% of dry recyclates are collected segregated and therefore go directly for reprocessing. These assumptions were derived using 2015 WasteDataFlow data (i.e. for LACW).

More detailed data is available for LACW through WasteDataFlow (Q100) and so the LACW flows through MRFs are able to be modelled in greater detail than C&I. Q100 was used to estimate input, output and contamination compositions and quantities (contamination estimated at 11%). Source segregated dry recyclates were estimated by subtracting the dry recyclates collected co-mingled from the total dry recyclates collected.

Much less is known about C&I waste arisings in general, but dry recyclates are particularly uncertain, due to the potential for some materials to go directly to unpermitted sites, particularly if they are segregated for recycling at source, which means they are not captured in waste returns data (WDI). The National Packaging Database captures some data for dry recyclates, both packaging and non-packaging materials, from reprocessors accredited to be able to supply Producer Responsibility Notes (PRNs). This data has been used to estimate an overall dry recyclables composition.

4.1.8 Organic waste

For LACW, WDF collection questions (2015) were used to calculate how much green, food and other organic waste was collected. A WRAP report[61] and WRAP LA portal[28] data were used to estimate the proportion of food and garden waste in mixed collections. It was assumed that all segregated garden waste (and other organic) was sent to windrow composting (OAW), all separately collected food waste was sent to anaerobic digestion (AD) and all mixed organics (e.g. food plus garden) was sent to in-vessel composting (IVC).

For C&I waste, WDI was used to estimate the waste going to each type of organic treatment facility and the same assumption was applied (i.e. all waste going to AD was food waste etc.).

No rejects for any of the waste streams have been factored in. It has also been assumed that all digestate and compost produced meets the necessary requirements to meet recycling targets i.e. total tonnage received at these facilities counts as recycling.

Assumptions with regard to outputs from organic treatment facilities have been estimated using WRAP's ASORI 2012[62] (the last detailed survey undertaken which included composting) and Anthesis knowledge of the processes.

4.1.9 Residual waste management

Residual waste volume and composition was estimated from overall composition and estimated capture rates for recycling, including any rejects.

For LACW, 2015/16 WDF data was used to estimate how much residual waste went to each treatment type. These are destinations for which residual waste is sent directly i.e. that collected as residual or those as rejects from other materials. Onward flows to EfW (e.g. of RDF) or landfill are in addition.

For C&I waste, WDI data has been used to estimate the destinations of residual waste treatment. Waste inputs coded to EWC Chapter 19 (i.e. outputs from waste facilities) have been taken into account to estimate a proportion of waste inputs which are likely to be direct, and those which may have come from another treatment facility, such as an MBT or a dirty MRF etc.

A challenge of establishing the waste flows for C&I is that environmental permits, as recorded in WDI (waste returns), are quite wide ranging and are not necessarily consistent given the length of time some of these have been in place, changes from waste management licences and the nature of bespoke / standard permits.

Given the relatively small number of MBT facilities in England, an estimate for the total waste being treated through MBTs was estimated. However, other interim residual waste treatment, such as dirty MRF / RDF production, was calculated as the difference between what was estimated to be treated directly by other facility types and the total residual waste.

4.1.10 Interim Residual Waste Management

For simplicity, but to enable a level of appropriate detail to be captured in the environmental assessment, this category has been split into four different processes. Compositions going into each process type were assumed to be the same as overall residual waste calculated. Each of the processes has been set up with the same output types, to allow for flexibility to amend the assumptions if necessary.

The four types of interim residual waste management facilities were:

- MBT with bio drying (MBT/BMT);
- MBT with AD (MBT/AD);
- MBT with IVC (MBT/IVC); and
- Dirty MRF / RDF Production.

For both LACW and C&I waste, the proportion of residual waste going to MBT facilities was estimated. MBT facility capacity was derived from a number of sources including the DWIR dataset and EA permitted facility list. An estimate of the proportion of waste being sent to the different types of MBT facility was made using the total capacity of each type of facility (e.g. 46% of the capacity of MBT facilities uses AD technology and therefore 46% of the waste streams assigned as going to MBT facilities, as a whole, were assumed to go to MBT/AD facilities).

The remaining residual waste (that was not sent directly to EfW, landfill or MBT) was assumed to go via Dirty MRF / RDF Production facility types.

For each of the four facility types, WRATE in-built assumptions were used to estimate the waste flows. The WRATE generic technologies were used for both MBT/AD and MBT/IVC, the EcoDeco for the MBT/BMT and a WRATE MRF process with V screens with a residual waste ingoing composition, were all modelled and helped generate some broad assumptions for the waste flows for these facilities.

Capture rates of different materials were set, and so although there were some overall broad high-level assumptions with regards to what the outputs were, in reality this changed as the incoming composition changed.

4.1.11 Energy recovery

The inputs to EfW were split into two flows – that which was sent directly to the EfW without pre-processing (and therefore not a refused derived fuel (RDF)) and that which was an RDF and had been through one of the interim residual waste management processes. These two flows were also totalled. These flows were modelled separately to calculate and demonstrate the difference in calorific values of the RDF and the residual wastes.

4.1.12 Landfill

The model was designed to break down what waste was sent directly to landfill and what was sent from the other residual waste processes (i.e. rejects from interim processes, and incinerator bottom ash (IBA) and fly ash from EfW – a distinction between hazardous and non-hazardous was not made). CLO[27]/digestate from interim residual waste facilities was also anticipated as going to landfill but had been separated out and was not included within the landfill total.

4.1.13 Modelling Change in Residual Waste Calorific Value

By taking into account composition of the waste type (LACW or C&I) and modelled capture rates for recycling for individual material types (primary and secondary categories) a residual waste composition was modelled for each year of the forecast period. By using calorific values for individual material types (taken from sources such as WRATE and Defra (2014) *“Energy recovery for residual waste - A carbon based modelling approach*”, February 2014[63], calorific value of the forecast residual waste was estimated in MJ/Kg.

4.1.14 Segregation Scenario Modelling

Several segregation scenarios have been modelled, to account for varying potential policy outcomes.

For each of the key materials, a ‘maximum’ feasible capture rate was ascertained through reviewing WRAP’s 2016 composition report for Wales[64] (Wales having a higher recycling rate than England and being considered a useful comparator), and through engagement with colleagues at WRAP to discuss particular materials, particularly food waste. A summary of the proposed 2030 capture rates for each material (depending on the scenario) used in modelling is in Table 14.

---

[27] CLO=Compost Like Output

Table 14: Material capture rates

Material	**Existing capture rate (2015)**	**Proposed 2030 capture rate**	**Wales (2015) – kerbside**	**Capture rate for overall MSW**
Paper & card	54%	64%	64%*	60%
Dense Plastics	21%	46%	66%	46%
Plastic film	11%	16%	N/A	16%
Wood	68%	75%	N/A	N/A
Garden waste	79%	85%	N/A	85%
Food waste	11%	42%	47%	41%
Glass	67%	79%	87%	79%
Ferrous metals	54%	63%	74%	63%
Non-ferrous metals	47%	55%	49%	55%

These capture rates were also benchmarked against those achieved in the Netherlands, which is also a high recycling rate nation.

These capture rates for the relevant materials were applied to the scenarios as per the table below. The capture rates were increased annually up until 2030 (also 2035 for the high recycling scenario), to reach the target rates. The modelled recycling rates are also presented below.

Table 15: Segregation scenarios, resulting recycling and explanation of capture rates used

Scenario	**LACW / C&I**	**Recycling Rates**				**Capture rates**
		2020	**2030**	**2035**	**2050**	
Business as Usual (Baseline)	LACW	50%	50%	50%	50%	Capture rates for materials increase proportionally across all materials
	C&I	56%	56%	56%	56%	
Food waste	LACW	50%	55%	55%	55%	Food waste capture increased to 42% in 2030
	C&I	56%	58%	58%	58%	
Biodegradable	LACW	50%	55%	55%	55%	Food waste capture increased to 42% in 2030 Other biodegradable wastes capture increased to proposed 2030 rates (unless already exceeded)
	C&I	56%	60%	60%	60%	
Plastics	LACW	50%	52%	52%	52%	Both dense and film plastic capture rates increased to 46% and 16% respectively in 2030 (unless already exceeded)
	C&I	56%	57%	57%	57%	
High Recycling	Both	LACW: 50%	Overall: 60%	Overall: 65%	Overall: 65%	Material capture rates increased to their proposed 2030 rates

Scenario	LACW / C&I	Recycling Rates 2020	2030	2035	2050	Capture rates
		C&I: 56%				(including metals) in 2030 to meet 60% overall EU Circular Economy recycling target. Increased beyond 2030 (including combustibles) to reach 65% overall target in 2035.

Overall Recycling Rates

All the segregation scenarios are increases in recycling from the baseline of 50% LACW and 55% C&I in 2020. All scenarios build capture rate from their 2020 baseline to the defined maximum by 2030, apart for high recycling which reaches maximum by 2035. Although the capture rate for the particular target material(s) are increased, that for all other waste recyclates stays constant.

How these increased capture rates translate into increased overall recycling rates is summarised in the following table, with biodegradable wastes and plastics kerbside and from residual waste, approaching 60% for these materials alone:

Table 16: Resulting recycling rates, all segregation scenarios

Segregation Scenario	2030 Recycling Rates			2035 Recycling Rates		
	LACW	C&I	Overall	LACW	C&I	Overall
Baseline	50%	56%	53%	same as 2030		
Food segregation	55%	58%	56%	same as 2030		
Biodegradable segregation	55%	60%	58%	same as 2030		
Plastics segregation from kerbside	52%	57%	54%	same as 2030		
Plastics segregation from kerbside and from residual waste	58%	59%	58%	same as 2030		
High Recycling	57%	64%	60%	60%	64%	65%

4.1.15 Capacity Forecasts and Modelling of Infrastructure Pathways

Key infrastructure types were added to the model, to represent available capacity in place at the start of the forecast period (2020).

Starting capacity was based upon data from a number of sources, including EA Permit Data, Defra WIDP, and other published sources plus Anthesis' own infrastructure databases. Capacity figures include that already operational (as of 2017, estimated as 10.2Mt) and that in construction and commissioning in 2017 (estimated as 3.9Mt), plus other infrastructure deemed highly likely e.g. that gaining support in the recent Contracting for Difference (CfD) round (estimated as 1.2Mt). In addition, there is an estimated 7.6Mt of projects (3.4Mt of these gasification) which have planning approved but have not reached financial close. Due to the lack of information on their likelihood of delivery, these were excluded from the 2020 capacity total.

Therefore, for baseline modelling for this study it has been assumed that 5.1 Mt (3.9Mt plus 1.2Mt) of additional EfW capacity will be delivered and operational by 2020, giving an overall operating capacity in

England of 15.3 Mt (excluding co-incineration). Although 7.6Mt has been left out given the considerations above, some of this may be delivered post 2020 further reducing the capacity gap between available EfW capacity and the total volume of residual waste produced.

Starting capacity data was supplied for energy from waste (including co-incineration). For other facility types, it was assumed that the existing infrastructure would accommodate waste growth up until 2020 but beyond that, new infrastructure would be required.

How available capacity was developed from 2020 depended upon the infrastructure pathway being modelled.

Some assumptions were made across all pathways:

- 3.2M tonnes of RDF annually was assumed exported for use in overseas EfW facilities and therefore not available for UK capacity (this value was used after examination of EA RDF export data[56]);
- Approximately 780,000 tonnes each year of RDF was also assumed to go to co-incineration facilities within the UK, and therefore not available for UK EfW capacity (value derived from EA dataset[65]);
- Mass burn incinerators operate optimally when treated waste within a certain range of CVs. Therefore, changes in CV of the residual waste beyond this range were assumed to have a proportional impact on the capacity of the facility i.e. an increase in CV means less waste can be treated, and a decrease means more can be treated. This impact was determined using the following assumptions:

Table 17: Assumed residual waste calorific valve v. EfW capacity (central CV baseline 9.7MJ/kg)

CV range		Assumed Capacity factor (where 100% = nominal capacity at baseline CV)
min	max	
7.7	8.2	115%
8.2	8.7	110%
8.7	9.2	105%
9.2	10.2	100%
10.2	10.7	95%
10.7	11.2	90%

- Remaining RDF (after export and that to co-incineration) was assumed to go to existing gasification facilities before mass burn incineration facilities. If there was more RDF than capacity at existing gasification facilities, it was assumed to go to mass burn – power only post-2000 facilities, prior to facilities of other types;
- When EfW capacity was not available, the cheapest alternative treatment operation (i.e. landfill) was used.

4.1.16 Outputs

The key outputs from the waste flow model are:

- Total waste arisings for each year 2020-2050 based upon high/low growth scenarios;
- Input tonnage of each key material type into key waste infrastructure types, for:
    - Each segregation scenario and infrastructure pathway modelled;

  - For each year of the forecast period 2020-2050;
  - LACW, C&I and total waste;
- Residual Waste and RDF composition and Calorific Value estimates for each segregation scenario, for each year of the forecast period 2020-2050.

A4.2 Modelling Environmental Impact (using WRATE[28])

Using outputs from the waste flow model, environmental impact was modelled for each segregation scenario and associated infrastructure pathway, using the WRATE software version 4.0.1.0.

A standard / average technology was selected for each of the different treatment or disposal options within WRATE. Where a flexible or generic process existed within WRATE this was utilised. No collection or transport was included within the scope of the study and only additional transfer stations required for different options where included.

The WRATE calculations were driven by the waste composition and tonnages outputs from the waste flow model. To allow multiple growth and pathways within each scenario to be modelled, and sensitivity carried out on results, WRATE factors for each component of the analysis were calculated. These factors were based on growth rate and waste composition and were calculated every 5 years from 2020 to 2050. These factors were then integrated into the waste flow model to enable the total impact to be calculated (tonnage multiplied by factor).

A number of complex assumptions were made around energy generation and therefore to make sure the environmental impact analysis used the same assumptions and information as the rest of the project, the energy generation was stripped out of WRATE for the calculation of the factors. The electricity and heat generation from each of the scenarios were then calculated and inputted into the waste flow models. This ensured that the cost benefit analysis outcomes were consistent.

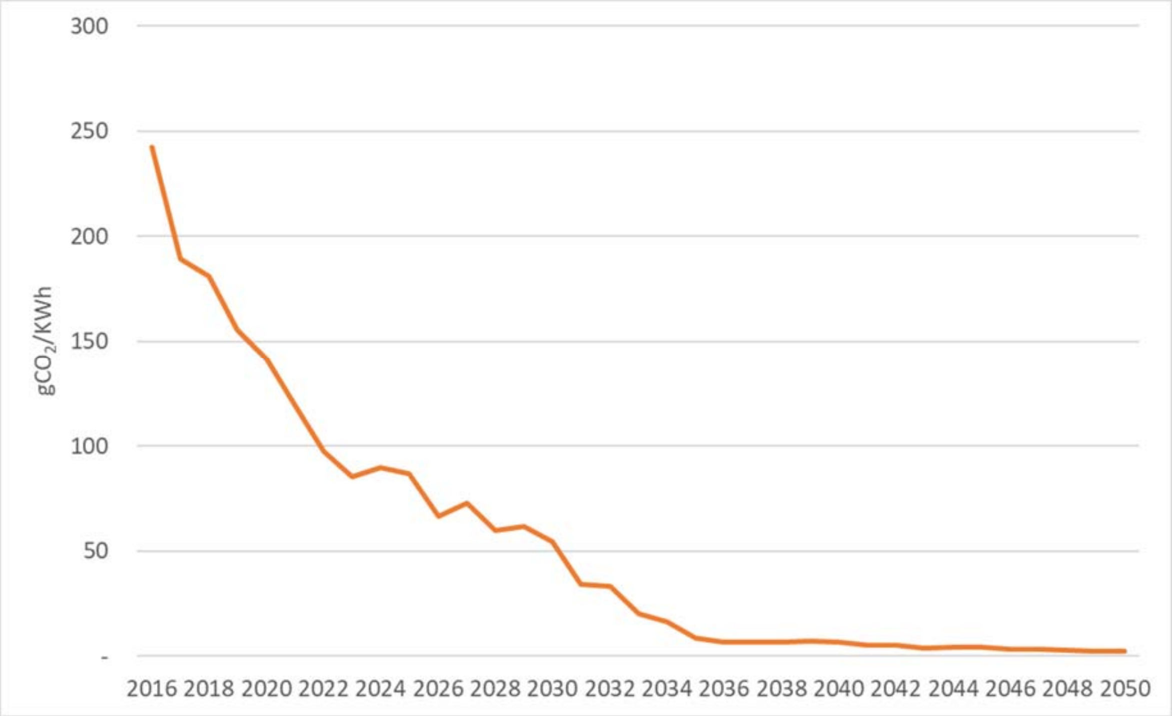
The only exceptions to this were landfill and co-incineration. The landfill impact factor included an assumption of 50% gas capture and the co-incineration internally offsets against coal and electricity (these were not double counted within the final results). The electricity and heat factors were calculated in WRATE and included in the waste flow model. The heat factor used an estimated average of 60% efficiency (consistent with the project assumptions) whereas the electricity factor was calculated for each modelling year on the basis of the electricity mix.

WRATE modelling compared GHG impact of the energy generated to the following forecast energy mix, which shows increasing use of renewable energy sources by 2050 (renewable from 38% in 2020 to 67% in 2050) mirroring the National Grid energy sector carbon intensity forecasts[66] presented in Figure 24. This will mean for all EfW based scenarios, EfW is mostly offsetting renewables by 2050.

Figure 24: Carbon Intensity of power generation 2016-2050 (Source: National Grid)

---

[28] Waste and Resources Assessment Tool for the Environment



To calculate the final environmental results the totals were exported from the waste flow models and the results for the intervening years were calculated as a linear regression between the two points. The final results were then inputted into the cost benefit analysis model.

A4.3 Cost Benefit Model

A cost benefit model was constructed to take inputs from both the waste flow and environmental impact models, to calculate the value of costs and benefits of each segregation scenario and infrastructure pathway across the forecast period.

4.3.1 Approach and Adjustments

The overall approach to undertaking the CBA was in line with the HM Treasury Green Book[67]. The costs and benefits outlined in Table 18 are included in the CBA assessment.

Table 18: Costs and benefits included in the CBA model

Included in CBA	Not included	Further details
Capital costs of constructing a new facility	Depreciation and capital charges	in line with the HM Treasury Green Book
	Refurbishment cost for existing facilities	It has been assumed that all the pre- 2000 mass burn facilities will be refurbished / upgraded before 2020 and brought in line with the operational capabilities of the post 2000 facilities. The capital investment associated with these refurbishments are considered sunk costs and therefore not included. Any other refurbishment of existing facilities that take place within the time horizon of the CBA will occur in all scenarios and pathways and therefore, as the CBA results will look at comparisons across the results these costs

Included in CBA	Not included	Further details
		are not considered. This only applies to the mass burn facility technologies. As these assumptions are common over all the pathways, this assumption will have no impact on the overall results.
	Capital costs of existing facilities (i.e. at 2020)	These are considered sunk costs and therefore not included in the CBA.
	Decommissioning costs / benefits of existing facilities	The assumption in the model is that all facilities last until a minimum of 2051 and therefore any decommissioning costs occur after the time horizon of the CBA. There are a number of reasons for setting this assumption: 1) decommissioning costs are difficult to access; 2) decommissioning costs vary within the facility types included in the CBA depending on the actual technologies used. For example, the decommissioning costs of the AD plants will depend on if the facility utilised steel or concrete digesters.
Existing facilities operation cost / benefits that occur during the time horizon of the CBA	Existing facilities capital cost	Assumed spent outside of the forecast period.
Residual value	-	The assumption used is that after 2050, each facility is operating (i.e. giving operational benefits and costs) until it reaches its end of life (i.e. has been operating for 30 years) and that there are no new facilities built after 2050. It is recognized that in reality new facilities will be built after 2050, however for the purpose of the modelling this will be the boundary for the analysis. For the purpose of the modelling the annual operational benefits and costs associated with each facility that has a life beyond 2050 is equal to the operational benefits and costs experienced by that facility in 2050. The annual net cost of these facilities is discounted by the appropriate annual discount rate.
Variable cost / benefits associated with material inputs	Landfill tax	In general taxes and subsidies are neither a cost nor a benefit in a CBA, because taxes and subsidies are rather ways to transfer money between the state and actors. For this reason, taxes and subsidies are not include in the

Included in CBA	Not included	Further details
to and from the facilities		CBA (in line with HM Treasury Green Book recommendations).
Variable cost / benefits associated with energy and heat outputs from facilities	Renewable energy subsidies	These are excluded in line with HM Treasury Green Book recommendations, as with landfill tax. Assumptions on the income generated from sale of energy, gas and / or heat will be accounted for in the model.
	Fixed costs / benefits associated with operating (existing and new) the facility	The availability of accurate fixed and variable operational costs information was very limited and therefore it was decided that the operational costs available would be presented as a cost per tonne based on design capacity of the facilities. This was then used to derive variable operational costs for the facilities. This ensures a fair and comparable approach across facility types and pathways. This approach to fixed and variable cost does not favour any particular pathway being considered.

The HM Treasury Green Book[67] lists a number of adjustments that can be made to the costs and benefits used in the CBA. Table 19 lists these adjustments and provides details as to whether, or not, these adjustments were undertaken in this CBA. Reasoning for undertaking the adjustment, or not, is also provided.

Table 19: CBA adjustments (based upon recommendations from the (in line with HM Treasury Green Book)

Adjustments	Inclusion in the CBA?
Distributional impacts	Adjustments for distributional impacts across different actors were not undertaken. This analysis is at national level and therefore there is no benefit of looking at the distributional impacts.
Relative price movements	It is an accepted practice to assume constant relative prices when doing a CBA. All costs / revenues (including capital, operational, gate fees and sales revenue) are as is in 2017. These have been inflated using RPI forecasts to 2020 and then the 2020 values have been kept static throughout the model (and then discounted). Collection costs are at 2015 values and have been inflated to 2020 values. For the purpose of the modelling the gate fees and material sales values have been kept static over the CBA time horizon. For material sales values, it is expected that market forces have a higher impact on the values than inflation. For this reason, the maximum and minimum values for each materials stream over the last 3 years (December 2014 to December 2017, inflated to 2020 values) have been used in the sensitivity testing undertaken on the model. Review of the WRAP data back to 2004 (when data collection started) has shown these figures to be representative of historical variations, and it has therefore been assumed that these are representative of likely material price movements over the forecast period. The impact of gate fee variations has been viewed through the sensitivity testing undertaken on the model.
Discounting to obtain present value	NPV is calculated, using the standard real discount rate as specified in the Green Book. Year 0 in the NPV calculations has been taken as 2020 as this is the first year in the CBA time horizon.
Adjust for material differences in tax	Landfill Tax and renewable energy subsidies are not included in the CBA. The general rule is that taxes and subsidies are neither a cost nor a benefit in a CBA, because taxes and subsidies are rather ways to transfer money between the state and actors. The CBA will look at the costs and benefits outside of the current policy position.
Risk and optimism	Adjustments were not made for risks and optimism. The risks within the different pathways (i.e. the facilities that the waste will be diverted down) include looking at the risks associated with the different technologies therefore the assessment risk element is built into the modelling.

Note that the implicit behavioural costs of households having to separate their waste has not been included in this analysis.

4.3.2 Fundamental principles - Material and facility types

The facilities types listed in Table 20 were included in the CBA scope (i.e. are part of at least one of the scenario pathways). These facility types consist of existing facilities (E) and new facilities (N). Technical assumptions were developed based on research, engagement with industry and Anthesis internal knowledge for each of these facility types. These technical assumptions were presented in the CBA in technical sheets set up for each facility type which cover assumptions on design capacity, available capacity, capital costs[29], processing costs and energy efficiency. Assumptions on gate fees and material sales values were recorded in the overarching assumptions tabs in the model.

A number of the pathways required the construction of new facilities using the same technology as existing ones. For example, the construction of new Wet AD – CHP facilities (where CHP is combined heat and power). In these cases, the operating and cost assumptions behind the CBA for the new and existing facilities are the same. In other pathways the cost and benefits of totally new technologies are tested. In these cases, technical sheets for the new technology were developed. For example, in the pathways that utilise gasification technologies to produce Bio Synthetic gas (Gasification (BioSNG) (N)).

Table 20: CBA facility types

Input material stream	facility type	Technical sheet present
Residual waste	Landfill (E)	Yes
Residual waste	Mass burn – power only (E): pre 2000	Yes
Residual waste	Mass burn – power only (E): post 2000	Yes
Residual waste	Mass burn – CHP (E)	Yes
Residual waste	Gasification (power only, steam cycle) (E)	Yes
Residual waste	Intermediate residual WM facilities (E)	Yes - one technical sheet based on a RDF production facility
Food waste	Wet AD – CHP (E)	Yes
Food and garden waste	IVC (E)	Yes
Garden waste	OAW (E)	Yes
Commingled dry recycling	MRF (E)	Yes
All materials	WTS (E)	Yes
Residual waste	Mass burn – power only (N)	Use technical sheet for existing facilities 90% of existing mass burn - power only infrastructure has been built in the last 5 years. The efficiency of new facilities and therefore operating costs are assumed to be the same as existing facilities

---

[29] Note that capital costs built into the model do not include additional project costs such as interest during construction, capitalised lifecycle, funding costs, SPV costs during construction and development costs

Input material stream	facility type	Technical sheet present
Residual waste	Mass burn – CHP (N)	Use technical sheet for existing facilities
Residual waste	Gasification (BioSNG) (N)	Yes
Residual waste	Intermediate residual WM facilities (N)	Use technical sheet for existing facilities
Food waste	Wet AD – CHP (N)	Use technical sheet for existing facilities
Food waste	Wet AD – gas to grid (N)	Use technical sheet for existing facilities
Food and garden waste	IVC (N)	Use technical sheet for existing facilities
Garden waste	OAW (N)	Use technical sheet for existing facilities
Commingled dry recycling	MRF (N)	Use technical sheet for existing facilities
All materials	WTS (N)	Use technical sheet for existing facilities

The CBA was set up to enable the cost and benefits of two different categories of facility capacities to be tested; strategic facilities (i.e. large scale facilities) and decentralised facilities (small scale facilities).

4.3.3 Fundamental principles - Dry recycling materials

The following dry recyclables are included in the CBA model:

- Mixed paper and card;
- Plastic film;
- Dense plastics;
- Mixed glass;
- Clear glass;
- Amber glass;
- Green glass;
- Non-ferrous metal;
- Ferrous metal;
- Wood.

Where segregated dry recyclates were generated by the waste flow model, these were valued at a market material price i.e. the net processing cost, cost and benefits or construction of new reprocessing capacity were not taken into account and were out of the CBA scope.

4.3.4 Fundamental principles - Cost benefit analyses

The CBA model calculates the following:

- The CBA of increased separation/collection as Net Present Value (termed in this report “Phase 1” of the CBA analysis). This is the costs and benefits to the collectors i.e. the cost of collecting the material(s) from where it is initially generated and the income from the recyclates collected. The collection costs (cost per tonne) were developed using WRAP’s Indicative Costs and Performance Online Tool[68]. Although the tool’s outputs do not completely align with the requirements of the project[30], this was the most

---

[30] The main points where the tool outputs do not align with the requirements of the project: (i) Provide costs per household rather than costs per tonne. The costs were therefore converted to cost per tonne; (ii) Provide costs for collections delivered by local

appropriate and robust source of collection data available and, with the adjustments made, considered to be an adequate proxy for actual collection costs. These costs include maintenance, overheads and depreciation of vehicles purchased for the collections. Transfer station costs are added separately, assuming transfer stations are employed for residual waste collections and dry recyclate collection (single stream or multi-material), but not for organic wastes;

- The CBA as Net Present Value of directing the new separated waste streams to different treatment/disposal pathways (termed in this report “Phase 2” of the CBA analysis). This is the cost and benefits of treating the waste post collection, includes gate fees from collectors (as an income), gates fee to onward treatment (as a cost) e.g. bottom ash to landfill and revenue from material and energy sales as an income. The model does not include costs of transporting waste materials between facilities; and
- A combined CBA for each pathway, which covers the two above bullets.

Inputs into the CBA model:

The following tonnage and carbon data from the waste flow model for each pathway were inputted into the CBA model.

- Tonnages collected (tonnes) broken down by material stream and treatment / disposal facility it was being delivered to. Where the materials were delivered to a WTS initially this tonnage was allocated to the treatment / disposal facility that the material was then transported to. This was used in the phase 1 CBA calculations.
- Tonnage input into facilities (tonnes) broken down by material. This included the materials collected and directly delivered to the facilities or via WTS as well as residual waste (either untreated or as a RDF) that came out of treatment facilities e.g. the intermediate facilities or MRFs. This was used in the phase 2 CBA calculations to model the number of new facilities needed and the operational costs and benefits of operating all the required facilities.
- Calorific values for the residual waste and food waste input (MJ/kg) into the residual waste treatment facilities and the AD plants. These were used to calculate the energy output of the facilities and the associated revenue.
- Tonnage of material outputs (tonnes) from the different facilities. The outputs from each facility are listed below:
    - All mass burn, CHP, gasification facilities: fly ash, incinerator bottom ash landfilled, incinerator bottom ash recycled, non-ferrous metal and ferrous metal;
    - Intermediate residual WM facilities: RDF - domestic treatment, RDF – export, RDF - co incineration, mixed paper and card, film, dense plastics, mixed glass, non-ferrous metal and ferrous metal;
    - All AD facilities: digestate;
    - All IVC facilities: compost; and

---

authorities from kerbside rounds and does not include collections from flats or C&I collections. In the absence of robust collection costs from these sources these costs were applied to all the tonnage in the CBA; and (iii) Does not include the costs of collection of garden waste or the collection of mixed food and garden waste. It was assumed that the costs per tonne of collecting dry recycling and food waste could also be applied to these collection services.

- MRF: residual, mixed paper and card, film, dense plastics, mixed glass, non-ferrous metal and ferrous metal.

Main outputs from the CBA model were:

1. Total number of new facilities

The number of new facilities needed for each pathway was modelled after a “trigger point” was reached. This trigger point assumed that the current infrastructure could handle additional tonnages (by for instance upping throughput rates, extending shift patterns) to compensate for small increases before investment in a new facility was required. For the purpose of this model it was assumed that this trigger point was reached at 300% of the capacity of a new facility, at which point a new facility was deemed built. This ratio is commonly used by investors in assessing need. The CBA model therefore triggered the need for a new facility when there was enough additional tonnage within the market to actually fill three new facilities.

2. Energy Outputs and Incomes

For both heat and power, energy outputs were calculated using the calorific value of the waste stream and the efficiency of the appropriate waste management facility concerned.

3. Total non-discounted and discounted capital and operational net cash inflow

For each pathway the CBA model calculated the total non-discounted capital and operational net cash inflow (where net cash inflow = cash inflows (such as revenue from energy and material sales) minus cash outflow (such as operational costs). These were then discounted using the real discount rate of 3.5% for the first 30 years of the model and 3.0% beyond 30 years (required for the residual value calculations, explained below) as specified in the Green Book.

4. Net present values (NPV)

For each pathway the CBA model uses the discounted capital and net operational cash inflow to calculate a net present value over the CBA time horizon. The following formula is used:

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_0$$

Where C_t = net cash inflow during the period t

C_o = total initial investments cost

r = discount rate

t = number of time periods

where Net cash inflow = inflow cash items (such as income from revenue items such as material sales, energy sales, gate fees to operators) minus outflow cash items (costs such as operating costs, disposal costs, gate fees to collectors)

5. Residual value

The modelling assumed that after 2050, each facility constructed within the CBA time horizon continued to operate until it reached its end of life (i.e. this was assumed as operating for 30 years). During the operating period post 2050, the facility continues giving operational benefits and costs. Since the capital cost of constructing the facility occurred within the CBA time horizon and was used in the NPV calculations, it is important to include these benefits and costs that occur post the time horizon. For the purpose of the modelling, the annual operational benefits and costs associated with each facility that had a life beyond 2050 was equal to the operational benefits and costs experienced by that facility in 2050. The annual net cost of each facility for each year that the facility operated beyond 2050 was then added together to give the total residual value of that facility.

The annual net cost of each facility was then discounted by the appropriate annual discount rate for each year that it operated beyond 2050 and added together to give the total discounted residual value.

6. GHG Output and the Cost of Carbon

The environmental model took the tonnage of materials passing through each facility and applied a carbon factor to calculate the kg CO_2 equivalent for each facility. These values were then summed and multiplied annually by a cost of carbon factor. The cost of carbon factor used followed the approach stipulated in the Carbon valuation for policy appraisal based upon DECC's Carbon Valuation in UK Policy Appraisal: A Revised Approach, (2009). It was therefore assumed that all relevant installations to 2030 were not subject EU Emission Trading System (EU ETS) in accordance with Annex I of the European Directive 2003/87/EC.

Note that the cost of carbon is not included in the NPV values reported.

4.3.5 Summary – what is included in and excluded from the financial model

Inclusions and exclusions are summarised in the following table:

Table 21: Inclusions and exclusions from the financial model

CBA Phase	Included/ Excluded in CBA	Costs & Revenues	Capital Costs
Phase 1 Collection – CBA for collection body, usually the local authority	Included	- Collection costs per tonne all waste streams (including food - from WRAP data) - Operating costs of waste transfer/bulking stations - Gate fee paid by collecting body for treatment/disposal (based on WRAP data) - Revenue from sales of segregated recyclates (based upon WRAP material prices data) - Inflation and discounting	- Cost of new waste transfer stations - Residual value i.e. value of new waste transfer stations at 2050 to end of life
	Excluded	- Transport costs of materials to transfer stations and on to reprocessing or treatment - Cost of recyclate reprocessing/use in new products - Landfill tax - Cost of communications/waste education/central staffing - the implicit behavioural costs of households having to separate their waste has not been included in this analysis.	- Development, planning and permitting costs - Financing costs - Cost of bins, vehicles and depots
Phase 2 Treatment/ Disposal – CBA for the infrastructure operators, usually private sector companies	Included	- Gate fee income for facilities used (based on WRAP data) - Operating costs of facilities used - Energy income (heat and power) - Costs of disposal of outputs/rejects (e.g. AD digestate, MRF rejects) - Income from saleable outputs e.g. recyclates (based on WRAP materials price data) - Inflation and discounting	- Cost of new infrastructure including MRF, AD, IVC, composting, EfW, gasification - Residual value i.e. value of facilities at 2050 to end of life
	Excluded	- Income from renewable energy incentives - Landfill tax - Transport costs of materials to/from relevant infrastructure	- Development, planning and permitting costs - Vehicle costs - Costs of heat networks, power distribution and other ancillary equipment - Financing costs
Total		Total Phase 1 + Phase 2	Total Phase 1 + Phase 2

A4.4 Recent Residual Waste Infrastructure Studies

There have been a number of reports in recent years looking at the requirement for residual waste infrastructure in the UK, largely to 2030, from a number of sources including from commercial waste management companies. These are summarised following. These studies assessed capacity requirements based on a range of source data and assumptions, and exclusively look at the UK as a whole. These reports have been used to benchmark the estimates generated in this study, and test assumptions such as waste growth rates and recycling rates which are key to the arisings and capacity modelling.

Green Investment Bank[69]

The purpose of the Green report was to highlight any investment opportunity in the UK waste market, focusing on the shift to processing C&I waste. The report identified 5.2 Mt of existing energy from waste facilities currently operating in the UK and estimated this would reach 11.9 Mt by 2020. There was 27.7 Mt of residual waste in 2012; the Bank's projections suggest that there will be between 22.4 to 26.5 Mt of residual waste in 2020. Taking into account RDF export, pre-treatment and that a proportion will always go to landfill, they estimated that there is a market for between 4.0 and 7.7 Mt of merchant capacity. This represents a potential investment of approximately £5 billion.

Eunomia[70]

Eunomia releases a biannual Residual Waste Infrastructure Review to compare the balance between arisings of residual waste and the facilities available to treat it within the UK and Northern Europe. In the 12th issue they examined the degree to which recycling rates were being constrained as residual waste infrastructure continued to be developed. Eunomia made the point that residual waste treatment capacity in the UK has increased from 6.3 Mt to 13.5 Mt since 2009/10, but the quantity of residual waste has fallen from an estimated 29.9 Mt to 26 Mt. A further 4.8 Mt capacity is currently under construction or committed, totalling 18.3 Mt to capacity. They calculated the current capacity gap as 7 Mt, which was down on their estimate from Issue 11 which estimated it as 10.2 Mt. One of their scenarios suggested that the UK's capacity will exceed the available residual waste in 2020/21, with the level of excess demand rising to 9.5 Mt in 2030/31.

Biffa[71]

Biffa produced the report *Reality Gap* in 2015 to highlight the capacity gap within the UK. In 2017 they released an updated report, utilising newer data and further insight into the development of residual waste treatment facilities. Biffa has concluded that the current EfW capacity gap is over 13 Mt and predict it will reduce to 6 Mt by 2025 but think it is unlikely to drop further. They also focussed on landfill void, and estimate that the UK will run out within the next ten years, with parts of England already having exhausted their capacity. Biffa also concludes that although recycling levels have been growing rapidly, they have now plateaued and further gains are likely to be limited, and that the recycling sector is beginning to mature but more needs to be done to share commodity price movements.

Suez[72]

Suez released the report *Mind the Gap* in 2014 that assessed residual waste infrastructure requirements from 2015 to 2025. A new report was released in 2017 which updated the forecasts from 2014, given changes in the market landscape, including uncertainty around export of RDF and SDF and future landfill provision; it also considers capacity on a regional basis. It concluded that the total residual treatment capacity will rise by 9 Mt, from 18.6 Mt in 2017 to 28 Mt in 2030. Taking into account the estimated waste growth and the projections of new waste infrastructure, there will be a net capacity gap of around 4.6 million tonnes in 2025 and 2.4 million tonnes in 2030 nationally, assuming no UK consumption of RDF and SRF currently exported. However, within the fourteen zones in the UK considered in the report, there was significant variation in the need for residual waste treatment. In 2017, all zones required more treatment than is currently in place, but in the future, there is the potential that some zones will have surplus capacity. The report also said that landfill capacity is declining faster than anticipated, so much so that zones such as the South East face the virtual elimination of local landfill site access by 2025. As many as eight modelled trading zones were forecast to still be in capacity deficit by 2030. The forecasts suggested that he UK will still need landfill capacity for 2.4 million tonnes per year for residual waste in 2030.

ESA[73]

Delivered by Tolvik, the ESA report took published data from Suez, Biffa and Eunomia, as well as unpublished analysis from Viridor, FCC and SLR to generate normalised forecasts for residual waste arisings from household and C&I sources. By taking into account the expected infrastructure development and delivery, the treatment capacity gap at 2030 could be calculated. The six reports that are reviewed within this report were all prepared with varying purposes, so this report attempts to identify areas of common ground and differences in methodology. The ESA's review estimated capacity in the UK which is currently operational or in construction as 16.6 Mt, and the residual waste in 2030 is modelled between 17.3 Mt (high recycling) and 29.5 Mt. The estimated capacity gap therefore varied between 13 Mt (no change scenario) and -0.7 Mt (high recycling – 71% overall). It therefore concluded that the UK is heading for under-capacity for residual waste treatment for all but the most ambitious recycling rates. The report also said that landfill has a role to play in the future for wastes where there is no alternative treatment and should continue to play a crucial role in 2030. The review demonstrated the sensitivity of the market to the assumptions made about recycling and highlighted that policy uncertainty in England increases the risk of a mismatch between residual waste tonnages and available treatment capacity. This sensitivity and policy uncertainty can influence capital investment into the sector.

A4.5 Estimating Commercial and Industrial Waste Arisings – A Review

There is a dearth of data on the production of commercial and industrial (C&I) which results in a problem in producing robust arisings estimates and forecasts.

The last survey of C&I waste in England was in 2010-11, collecting data for the 2009 calendar year (Jacobs (2011)). By collecting data from over 6,000 businesses, by a variety of methods, this survey estimated total C&I arisings to be 47.9 Mt (23. 8 Mt commercial, 24.1 Mt industrial). Previous surveys were carried out in 2002-3 and 1998-9 and hence there is little data upon which trends could be identified. In delivery of such surveys, C&I waste is considered to exclude that generated by construction and demolition activities, by mineral and quarrying activities, and agricultural practices.

In 2014 Defra commissioned Jacobs (2014) to develop a new methodology for estimating C&I arisings for biannual reporting to the EU (known as the “Reconcile” study). The requirements of the work included “[The] estimates need to be consistent with Defra’s estimates of waste disposal at landfill and incinerator sites based on administrative permit data. Consistency must take into account levels of recycling and reuse, and imports and exports of waste. The estimates must be based on evidence and show a clear audit trail from final estimate back to evidence sources.” The developed methodology was therefore based upon data reported by permitted waste facilities, with other data derived from import/export records. Double counting waste was eliminated by a number of methods including removal of LACW volumes from totals. Application of this methodology reassessed 2009 arisings as 37.8 Mt, and reported 43.8 Mt total arisings for 2012.

A number of previous and subsequent studies have attempted to estimate C&I arisings as part of a residual waste infrastructure assessment:

- Defra (2011) – forecasted arisings and capacity to 2020. Of 47.9 Mt arisings from the 2009 survey, Defra estimated the “municipal component” of this C&I waste to be 24.7 Mt[31]. Economic impact was used to drive C&I forecasts, giving 43.9 Mt by 2020;
- Nera (2012) – reviewed methods of forecasting arisings and capacities. For C&I waste, the report confirms the Defra model to be based upon work delivered by ADAS in 2009, which translated data from an Urban Mines (now part of Anthesis) survey of North West England in 2006, to the rest of the UK. A number of modifications to the methodology were recommended;
- Ricardo-AEA (2013) – critiqued data from various sources; C&I estimates prepared based upon permit returns data (EA);
- Imperial College (2014) – reviewed the Defra (2013) methodology and applied estimate of “household like” wastes based upon selected waste types in the 2009 survey data[32] The total arising for C&I similar to household waste used in this study was 25.4 Mt, being very close to the relevant arising used by Defra (24.7 Mt). This report reviewed a number of assumptions used in the Defra model including: 84% of commercial waste and 19% of industrial waste was defined as “household like”; assumed biodegradable content of LACW and municipal component of C&I waste as 68%, treating the 2 streams as a single waste;

---

[31] where the municipal component of C&I waste is defined as that which is similar in nature and composition to household waste;

[32] these are Animal and vegetable waste, Non-metallic wastes and discarded equipment

- Green Investment Bank (2014) - used target recycling rates varying between 50% and 64% depending upon UK nation. Estimated residual waste (2012) as 27.7 Mt (UK) using permit returns data. Report defined "suitable waste" as local authority collected waste (LACW) plus an estimated 63% of the total C&I waste stream which is readily combustible[33] est. 64.8Mt in 2012. It should be noted that the definition of suitable waste is marginally wider than that for municipal waste used by DEFRA in its 2013 analysis of potential compliance with the Landfill Directive. Assumed 5% of suitable waste continues to be landfilled for geographic/market reasons;
- Biffa – used the "Reconcile" 2012 figure as total C&I arisings, and applied 84% municipal like from Defra (2013). This figure has also been used by Tolvik for work delivered for them, which Biffa have also benchmarked against their own collected material. Residual waste volume was calculated from the recycling assumptions;
- Suez – used ADAS (2009) for total estimates. The study filled gaps with estimates from their own internal data. Used growth predictions per sector, some by population, some by GVA;
- Eunomia (2017) – this study used returns data in both calculating arisings and benchmarking results. It used recycling rates for MSW of 50% in 2020 and 65% in 2030, for C&I 75% by 2030 for commercial waste and 80% by 2030 for industrial waste. It also used a definition of "other wastes" i.e. that spread to land, used for landfill engineering purposes (e.g. daily cover), used in specialist treatment or non-combustibles as a portion of the waste not included in the analysis. This is thought equivalent to "non-household C&I" in other analyses;
- Defra (2018) – recognising problems with the application of the Reconcile methodology, and working with the RWM sponsored "Waste and Resource Sectors Working Group on Data", a revised methodology was developed leading to newly published results in Defra's "UK Statistics on Waste" (22nd February 2018). This gave a 2016 C&I waste estimate for England of 32.2 Mt, whilst qualifying this figure with the statement "all figures will remain provisional until they have been approved by Eurostat following the submission of the 2016 Waste Statistics Regulation return in June 2018". These estimates were published after the modelling had been completed for this study.

---

[33] i.e. excluding inert wastes, hazardous wastes and industrial waste streams such as sludges, metals, chemical and mineral wastes

Figure 25: Results summary C&I waste and residual waste estimations

Estimate Source (Published date)	Prime data source	Total C&I arisings Estimate	Total Residual Waste Estimate	Modelled recycling rates
Defra Survey (Jacobs, 2009 data)	Survey	47.9Mt 2009		52% (2009)
Defra (2013)	Survey	43.9Mt by 2020 (24.7mt household like C&I wastes).		
Nera (2014)	Survey	39.8Mt by 2020		
Imperial College (2014)	Survey	25.4 Mt household like C&I wastes		
Jacobs "Reconcile" Project	Permitted Sites Returns Data plus other sources	37.8Mt 2009 43.8Mt 2012		n/a
Green Investment Bank (2014)		64.8Mt in 2012 ("suitable waste" from LACW plus C&I household like)		50% to 64%
Richardo AEA/CIWM	Permitted sites returns	47.7Mt 2011		
Biffa (2027)	Permitted sites returns		24-27Mt (UK)	LACW 44% to 60% scenarios C&I 62% (2030)
Suez (2017)	Survey results (regional level) Permitted Sites Returns Data plus other sources		32Mt (includes illegally landfilled wastes)	LACW 56% C&I 65% (2030)
Eunomia (2017)	Permitted sites returns		26-27.5Mt UK	LACW 50-65% C&I to 80%
Defra (2018)	Permitted site returns plus waste packaging and other recyclate market data.	32.2Mt	N/a	N/a

A5. Waste infrastructure Analysis – Detailed Results

A summary of the modelling results for this study is given in the main report. This section of the appendices gives more detail on the individual scenarios modelled, breakdown of the results obtained, and the conclusions developed.

Note that in this section, modelled changes in collection practices are termed 'Segregation Scenarios'; different waste management infrastructure combinations used to manage the waste collected are 'Infrastructure Pathways'.

A5.1 Baseline Residual Waste Infrastructure Pathways Modelling

A number of baseline infrastructure pathways were developed, based upon the current collection system (i.e. no change in waste material capture for recycling from 2020), with three alternative residual waste treatment infrastructure options.

Modelled baselines were:

Baseline (Pathway 0)	Based upon 2020 residual waste infrastructure assuming no new infrastructure delivered in the forecast period 2020-2050. Recycling rate assumed 50% LACW and 55% C&I ("household like") with no change over forecast period. Existing EfW CHP capacity is included in the energy output calculations.
Baseline with existing EfW Infrastructure with CHP Improvement (Pathway 0.1)	As Pathway 0 but delivering CHP in the 2020 EfW infrastructure where the potential exists i.e. taking into account the potential upgrading of existing power only EfW to more efficient CHP plants producing heat and power (based upon the selection identified by Defra of existing facilities where there are potential local heat users[7]).
Diversion from landfill to new EfW with CHP (Pathway 0.2)	The capacity gap between 2020 capacity and residual waste demand is assumed taken up with new CHP enabled EfW (capacity increased to take all available waste (less non-combustibles) from 2025). This includes current EfW plants using CHP today and the upgrading of existing plants as per Pathway 0.1. EfW with CHP has been selected because of its higher energy efficiency compared to EfW for power alone and the opportunity to 'upgrade' the UK infrastructure from being disposal facilities to become R1 recovery plants in line with many European EfW facilities.
Diversion from landfill to new GtG enabled Gasification (Pathway 0.3)	As Pathway 0.2 but new capacity delivered using gasification to syn-gas to grid (GtG) including preparation of the relevant residual waste feedstock to evaluate the direct conversion of residual waste to bio-sng to replace natural gas and decarbonise the UK heat grid.

These baseline pathways are explained in more detail, in terms of key assumptions and impact on energy production, with a summary of the GHG impact and CBA results, in the following sections.

5.1.1 Baseline Infrastructure Pathway (Pathway 0)

The baseline pathway (Pathway 0) assumed a fixed recycling rate across the forecast period 2020 to 2050; therefore the:

- proportion of residual waste from collections therefore remains constant;

- and the availability of dry recyclates, organic waste for recycling and residual waste are only driven by waste growth.

Baseline Pathway 0 also assumed a constant export of RDF of 3.2 Mtpa throughout the forecast period, and a constant 0.78 Mtpa to co-incineration. Figure 26 summarises this pathway in terms of forecast residual waste fate, for both the high growth and low growth scenarios (growth rates explained in Appendix A4).

Figure 26 indicates for this pathway the need for landfill disposal of residual waste of 5.3 to 18.0 Mtpa (high growth model) and 2.8 to 3.6 Mtpa (low growth model) over the forecast period, in addition to the available energy recovery capacity, to provide an outlet for the anticipated growth in residual waste arisings.

5.1.1.1 Residual Waste Calorific Value

Calorific value (CV) of the residual waste produced by this baseline pathway was forecast by modelling the composition of the input waste and removing key materials from this composition based upon the rate at which they are captured at kerbside (and other facilities) for recycling. The energy value of the resulting residual waste was then estimated by applying selected known CVs for the individual materials to the estimated waste composition. The CV for the residual waste from Pathway 0 was therefore estimated at approximately 9.8 MJ/kg (average across the forecast period 2020-2050) for residual waste to energy recovery, and approximately 10.1 MJ/kg for RDF for export and gasification.

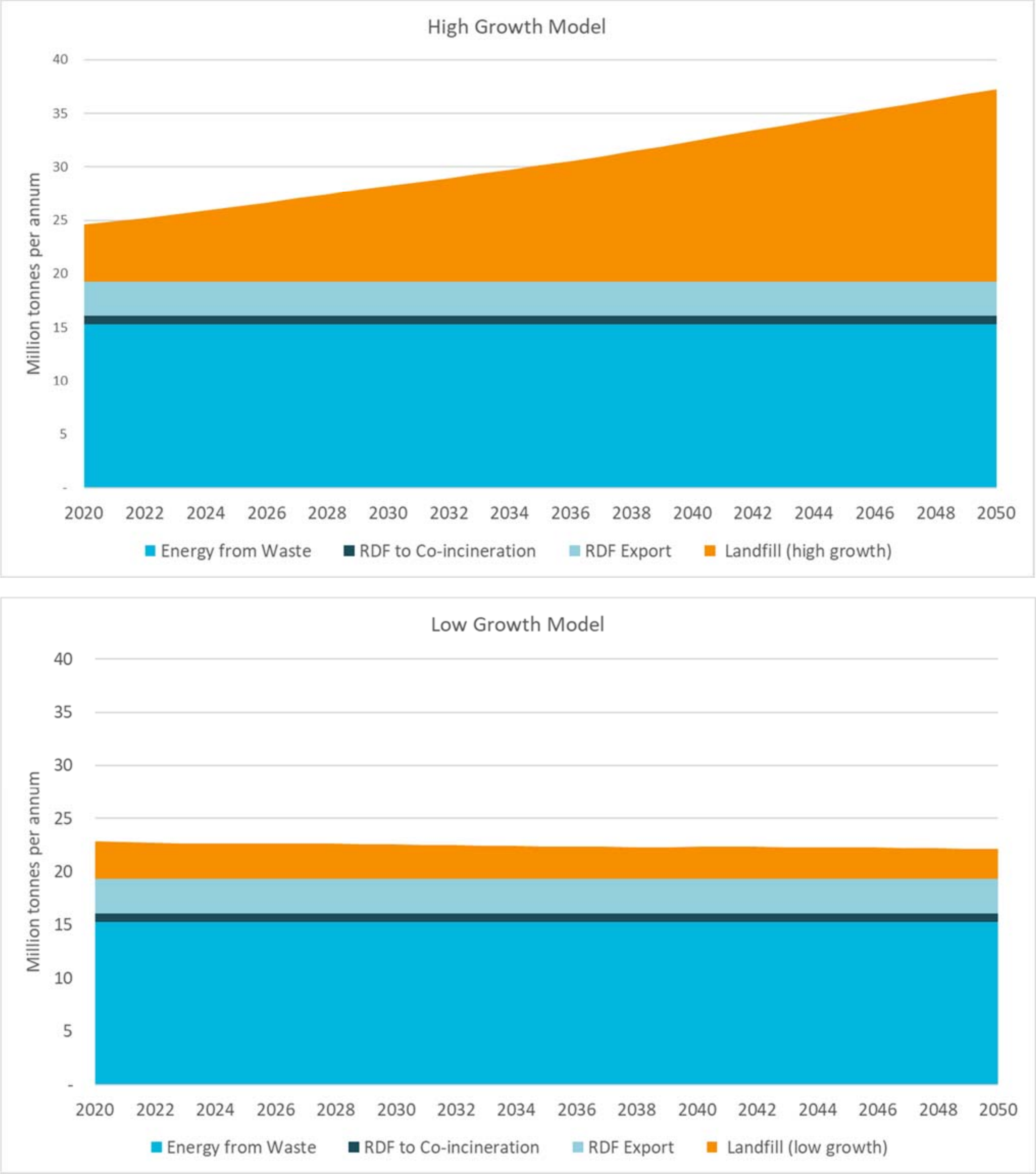
5.1.1.2 Energy Outputs

For Pathway 0, energy in the form of heat and power generated from the following two waste streams was quantified:

- organic waste to CHP anaerobic digestion; and
- residual waste to EfW facilities.

Note that although methane capture from landfill was modelled, it was not translated into power grid output. Therefore, power production from landfill gas is not included in these figures. The modelled energy outputs for Pathway 0, reported in Table 22 and Table 23 following, are based upon the forecast waste volume throughputs of relevant facilities, and show a total energy output from 13.1 TWh (low growth model) to 13.8 TWh (high growth model) in 2050. Note that while these power figures include a reduction for parasitic load (i.e. net on-site power consumption), the heat figures provided are total heat output without any additional losses or reductions for on-site use.

Figure 26: Modelled residual waste treatments (High growth and low growth models) - baseline Pathway 0



These results are aligned with the Digest of UK Energy Statistics (DUKES - 2017) [74] analysis, which reports 8.9 TWh of EfW power generating capacity in the UK in 2016, including tyres and clinical waste. The additional modelled energy is produced by the additional EfW facilities scheduled to come on-line in the period 2016-2020. Although the EfW capacity is the same for both the high growth and low growth models using this baseline, energy output from the high growth model is slightly higher due to increasing food waste volumes processed in the AD sector. It has been assumed that the existing AD capacity is available for additional food waste, potentially displacing lower or non-gate fee materials such as manures, energy crops etc.

Table 22: Energy Outputs Baseline Pathway 0 (in GWh) – high growth model

Output	2020	2025	2030	2035	2040	2045	2050	Total 2020-2050
Power	11,277	11,314	11,358	11,401	11,452	11,508	11,562	353,672
Heat	1,954	1,984	2,023	2,061	2,106	2,155	2,203	64,105
Total	13,231	13,298	13,380	13,463	13,558	13,663	13,765	417,776

Table 23: Energy Outputs Baseline Pathway 0 (in GWh) – low growth model

Output	2020	2025	2030	2035	2040	2045	2050	Total 2020-2050
Power	11,238	11,232	11,231	11,227	11,226	11,225	11,221	348,082
Heat	1,920	1,916	1,914	1,911	1,910	1,909	1,906	59,278
Total	13,158	13,148	13,145	13,138	13,136	13,135	13,128	407,360

5.1.2 Infrastructure Pathway 0.1 - improved efficiency of 2020 infrastructure

Infrastructure Pathway 0.1 was the same as Pathway 0 in terms of applied waste growth rates, assumed waste processing capacities and recycling rates, but with an improved EfW infrastructure from 2020 onwards. A proportion of the baseline 2020 energy from waste capacity infrastructure, defined in Pathway 0 as power only, was now assumed to produce heat and power via CHP[34]. These outputs assumed all of the CHP capacity met the minimum requirement for R1.

This change was based upon figures provided by Defra WIDP which report 2,081ktpa of existing capacity (28 facilities) already delivering CHP, and 1,070 ktpa of power only capacity (8 facilities) with "existing nearby heat load and developer actively seeking opportunity" (supplied October 2017[7]).

The main impact of this change was in the forecast energy output, as shown in Table 24, and resultant GHG impact. The slight improvement in existing infrastructure resulted in an increased heat output of between 2.6 TWh (by 2050, low growth) and 2.9 TWh (by 2050, high growth), with a slight reduction in power production compared to baseline.

Table 24: Energy Outputs Pathway 0.1 (in GWh) – high and low growth model

---

[34] Assumed efficiencies are 27% for power alone, 21% power and 25% heat for CHP

Output	2020	2025	2030	2035	2040	2045	2050	Total 2020-2050
Power (high growth)	11,102	11,138	11,182	11,226	11,276	11,331	11,385	348,220
Heat (high growth)	2,684	2,715	2,754	2,794	2,840	2,890	2,939	86,819
Total Energy Output (high growth)	13,786	13,854	13,936	14,019	14,116	14,221	14,324	435,039
Power (low growth)	11,062	11,057	11,056	11,052	11,050	11,050	11,046	342,645
Heat (low growth)	2,651	2,646	2,645	2,642	2,641	2,640	2,637	81,932
Total Energy Output (low growth)	13,713	13,703	13,701	13,693	13,691	13,690	13,683	424,577

5.1.3 Infrastructure Pathway 0.2 - CHP enabled EfW to fill the capacity gap

Infrastructure Pathway 0.2 took the same waste growth and recycling assumptions as Pathways 0 and 0.1, but was aimed at moving residual waste up the waste hierarchy by reducing landfill disposal and increasing energy recovery capacity to divert residual waste from landfill to CHP enabled EfW. To this end, the potential CHP in the current EfW infrastructure was modelled as in pathway 0.1, plus from 2020 onwards EfW capacity was increased by employing EfW with CHP to improve energy efficiency throughout the EfW infrastructure (increased in stages from 2020) to take all available residual waste after recycling. Only non-combustibles and rejects from interim processes were landfilled from 2025.

The model assumed that any increase in the volume of residual waste less than 300% of the capacity of a single new facility, could be absorbed by the current EfW infrastructure because most facilities are able to process up to 110% of their nominal design capacity. This cover ratio has been used by investors to ensure new facilities have sufficient feedstock in an attempt to reduce the risk of overcapacity in the market.

Figure 27 shows how this increase in energy recovery capacity for residual waste reduces landfill requirements in both growth models. It needs to be noted that this pathway assumes RDF export was able to continue at current levels and therefore support landfill diversion.

Figure 27: Residual waste fates v demand, Pathway 0.2, High and Low Growth model 2020-2050

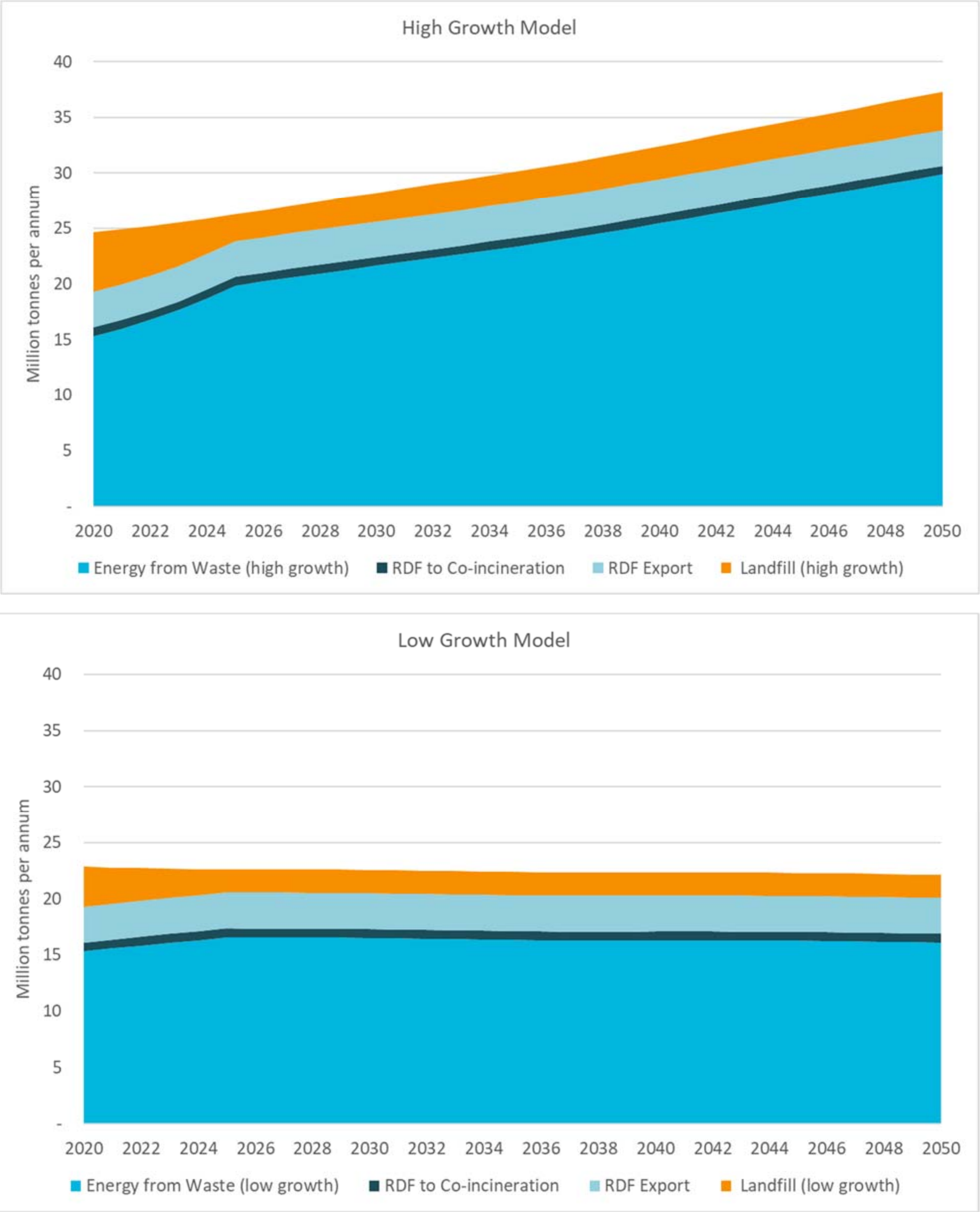


Table 25 summarises the additional volumes going to EfW CHP in this pathway. This increase in capacity would either be delivered by 45 new strategic EfW CHP facilities over the forecast period (of 350,000 tpa throughput each) following the requirements of the high growth model, or alternatively just 1 following the requirements of the low growth model. This pathway also assumed that 3.2 Mt of residual waste in the form of RDF was exported throughout the forecast period, which would require an additional 9 strategic EfW facilities if there was a preference to recovery the energy domestically or if the export market was not economically accessible in the future.

Table 25: Pathway 0.2 Residual Waste Volumes directed to new EfW CHP capacity 2020-2050 (in ktpa)

Growth Model	2020	2025	2030	2035	2040	2045	2050
High Growth	0	4,558	6,329	8,091	10,141	12,375	14,563
Low Growth	0	1,247	1,188	1,024	978	951	795

This significant increase in CHP enabled EfW capacity is reflected in the increased energy output as summarised in Table 26. These outputs assume all of the CHP capacity meets the minimum requirement for R1 in terms of efficiency and therefore represent a considerable performance improvement compared to EfW with power capability only. Table 26 shows the forecast total energy output amounts to between 12 TWh (low growth) and 19.9 TWh (high growth) annual power production by 2050 and between 2.5 TWh (low growth) and 12.1 TWh (high growth) heat production by 2050. (i.e. in total energy output between 1.0 TWh and 18.3 TWh greater than baseline Pathway 0). The reduced GHG impact compared to baseline Pathway 0) is available in appendices section 5.1.5 along with CBA impacts.

Table 26: Energy Output of modelled EfW CHP capacity as Pathway 0.2 (GWh) – based on assumed minimum R1 power and thermal efficiencies

Output	2020	2025	2030	2035	2040	2045	2050	Total 2020-2050
Power (high growth)	11,277	13,929	14,988	16,042	17,267	18,602	19,910	496,817
Heat (high growth)	1,954	5,097	6,347	7,594	9,045	10,627	12,179	234,892
Total Energy Output (high growth)	13,231	19,026	21,335	23,635	26,312	29,230	32,089	731,709
Power (low growth)	11,238	11,948	11,913	11,814	11,787	11,771	11,677	364,980
Heat (low growth)	1,920	2,767	2,726	2,610	2,578	2,559	2,449	79,395
Total Energy Output (low growth)	13,158	14,715	14,639	14,425	14,364	14,330	14,127	444,374

In addition, greater energy efficiencies can be achieved by increasing the proportion of heat offtake to power, to meet the minimum requirements of CHPQA[35], which assume that a larger proportion of heat to power is generated than is usual at current EfW CHP facilities[36]. Based on running at these efficiencies, absolute energy output would increase to 16 TWh (low growth) to 46 TWh (high growth) per annum by 2050, up to 43% higher than only meeting R1 minimum requirements as shown in Table 27. It needs to be noted that the subsequent GHG impacts and CBA analysis assume minimum R1 efficiencies are delivered and does not include the additional impact expected from CHPQA. This is due to commercial considerations as power sales are more common in the market, whereas heat sales require new distribution infrastructure, which is not consistently available or easily delivered in England.

Table 27: Energy Output of modelled EfW CHP capacity as Pathway 0.2 (GWh) – based on minimum CHPQA efficiencies

Output	2020	2025	2030	2035	2040	2045	2050	Total 2020-2050
Power (high growth)	10,801	12,456	13,127	13,794	14,569	15,412	16,238	427,356
Heat (high growth)	4,276	12,276	15,418	18,552	22,201	26,180	30,080	573,513
Total Energy Output (high growth)	15,077	24,732	28,546	32,346	36,769	41,592	46,318	1,000,869
Power (low growth)	10,761	11,199	11,177	11,114	11,097	11,087	11,027	343,773
Heat (low growth)	4,243	6,418	6,315	6,024	5,942	5,895	5,619	182,776
Total Energy Output (low growth)	15,004	17,617	17,491	17,138	17,038	16,981	16,646	526,550

5.1.4 Infrastructure Pathway 0.3 - ATT GtG to fill the capacity gap

Pathway 0.3 is as Pathway 0.2. However, the additional EfW capacity is delivered via an advanced thermal conversion technology, namely gasification coupled with extensive gas cleaning technology to produce syn-gas clean enough to be fed into the gas grid (GtG).

It should be noted that although this technology is being modelled it has not been proven technically and commercially at the time of writing. However, the government funded technology is currently under

---

[35] Combined heat and power quality assurance; The CHP Quality Assurance programme (CHPQA) is a government initiative providing a practical, determinate method for assessing all types and sizes of Combined Heat and Power (CHP) schemes throughout the UK. CHPQA aims to monitor, assess and improve the quality of UK Combined Heat and Power. More information at: https://www.gov.uk/guidance/combined-heat-power-quality-assurance-programme

[36] For CHPQA an efficiency of power production of 13% has been assumed, and of heat 64% assuming 50% of the heat offtake is steam. This is compared to an assumed efficiency of 27% for power alone and 21% power plus 25% heat for minimum R1 CHP.

development to be evaluated for its future potential and could provide significant carbon reduction potential in comparison to existing combustion and gasification technologies by producing gas for the grid[75].

This type of EfW technology is expected to require pre-processing of the relevant residual waste feedstock and this has been modelled accordingly. This delivers 44 (high growth) or 1 (low growth) new gasification facilities during the forecast period (at 315 ktpa per facility). Due to the higher efficiencies associated with gasification to GtG (62% assumed, based upon recommendation by the technology developer) annual energy outputs reach 14 TWh (low growth) to 38 TWh (high growth) by 2050, up to 6 TWh per annum (18%) greater than EfW at R1 efficiencies.

Table 28: Energy Output of modelled EfW + Gasification capacity as Pathway 0.3 (GWh) – GtG included in heat total

Output	2020	2025	2030	2035	2040	2045	2050	Total 2020-2050
Power (high growth)	11,277	11,281	11,312	11,343	11,378	11,417	11,455	351,831
Heat (high growth)	1,954	9,704	12,741	15,762	19,277	23,107	26,860	486,809
Total Energy Output (high growth)	13,231	20,986	24,053	27,105	30,655	34,524	38,315	838,640
Power (low growth)	11,238	11,224	11,223	11,220	11,219	11,219	11,216	347,871
Heat (low growth)	1,920	4,027	3,927	3,645	3,566	3,520	3,253	109,167
Total Energy Output (low growth)	13,158	15,251	15,150	14,865	14,785	14,739	14,469	457,038

5.1.5 Infrastructure Pathway Summaries

5.1.5.1 Climate Change Impact

GHG figures for all Infrastructure pathways are summarised in Table 29 and Table 30. Pathways 0.2 (increased waste recovery through CHP enabled EfW) and 0.3 (increase waste recovery through gasification with GtG) have the most significant impact on greenhouse gas emissions compared to the baseline Pathway 0, the efficiency of the gasifier to bio-SNG conversion having a particularly positive impact.

Table 29: Greenhouse Gas Impact baseline pathways (reported as difference from baseline Pathway 0) in tCO_2e x1000 (High Growth)

Pathway	2025	2030	2035	2040	2045	2050	Total 2020-2050
Pathway 0.1 (improved efficiency 2020 infrastructure)	-98.1	-98.2	-195.9	-196.3	-197.2	-197.7	-4,816.0
Pathway 0.2 (CHP enabled EfW to fill capacity gap)	-2,184.2	-3,026.9	-2,146.5	-2,666.0	-3,213.2	-3,744.9	-77,418.4
Pathway 0.3 (ATT GtG to fill capacity gap)	-1,947.3	-2,639.7	-3,989.2	-5,000.3	-6,105.7	-7,189.0	-119,978.2

(note: positive figures = GHG impact greater than baseline, negative figures GHG impact less than baseline)

Table 30: Greenhouse Gas Impact baseline pathways (reported as difference from baseline Pathway 0) in tCO_2e x1000 (Low Growth)

Pathway	2025	2030	2035	2040	2045	2050	Total 2020-2050
Pathway 0.1 (improved efficiency 2020 infrastructure)	-98.1	-98.1	-195.4	-195.6	-196.1	-196.3	-4,800.0
Pathway 0.2 (CHP enabled EfW to fill capacity gap)	-597.5	-568.3	-271.5	-256.8	-246.6	-204.1	-10,316.0
Pathway 0.3 (ATT GtG to fill capacity gap)	-532.7	-495.7	-505.0	-482.2	-469.4	-392.6	-13,603.2

(note: positive figures = GHG impact greater than baseline, negative figures GHG impact less than baseline)

5.1.5.2 Cost Benefit Analysis - Phase 1 Collection

Phase 1 (collection) CBA results are presented (as difference from baseline Pathway 0 i.e. 2020 waste management capacities) in Table 31 (high growth model) and in Table 32 (low growth model)

Table 31: Cost benefit Analysis Results Baseline Pathways – reported as difference from baseline Pathway 0 (Collections Phase 1) - in £ millions (High Growth Model)

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV – excl. residual value	Residual value	NPV - including residual value
Pathway 0.1 (improved efficiency 2020 infrastructure)	£0.0	£0.0	£0.0	£0.0	£0.0
Pathway 0.2 (CHP enabled EfW to fill capacity gap)	£0.0	-£8,701.4	-£8,701.4	£0.0	-£8,701.4
Pathway 0.3 (ATT GtG to fill capacity gap)	£0.0	-£11,601.9	-£11,601.9	£0.0	-£11,601.9

Note: for NPV and operational cash inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

Table 32: Cost benefit Analysis Results Baseline Pathways - reported as difference from baseline Pathway 0 (Collections Phase 1) - in £ millions (Low Growth Model)

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV – excl. residual value	Residual value	NPV - including residual value
Pathway 0.1 (improved efficiency 2020 infrastructure)	£0.0	£0.0	£0.0	£0.0	£0.0
Pathway 0.2 (CHP enabled EfW to fill capacity gap)	£0.0	-£1,182.3	-£1,182.3	£0.0	-£1,182.3
Pathway 0.3 (ATT GtG to fill capacity gap)	£0.0	-£1,576.4	-£1,576.4	£0.0	-£1,576.4

Note: for NPV and operational cash inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

Although the collection regime modelled in the three infrastructure pathway variations 0.1 to 0.3 is the same as the baseline Pathway 0, resulting in no change in capital costs, there is an impact on NPV for Pathways 0.2 and 0.3 due to the diversion of waste away from landfill to EfW with CHP, due to the change in gate fees charged. In the CBA for Phase 1 this results in a negative NPV compared to baseline, as the modelled gate fee cost of EfW exceeds that of landfill when landfill tax (LFT) is excluded. Following HM Treasury Green Book[67] guidance to exclude taxes from CBA assessments, these figures are carried through to the final CBA calculation.

However, presenting the same figures including LFT in Table 33 and Table 34 shows a more realistic view of the impact of the infrastructure changes on the collection body, with positive NPVs reflecting the actual reduction in cost in collection, from the diversion of the waste away from high gate fee landfill to lower gate fee EfW.

Table 33: Cost benefit Analysis Results Baseline Pathways – reported as difference from baseline Pathway 0 (Collections Phase 1 including landfill tax) - in £ millions (High Growth Model)

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV - excl. residual value	Residual value	NPV - including residual value
Pathway 0.1 (improved efficiency 2020 infrastructure)	£0.0	£453.5	£453.5	£0.0	£453.5
Pathway 0.2 (CHP enabled EfW to fill capacity gap)	£0.0	£6,721.8	£6,721.8	£0.0	£6,721.8
Pathway 0.3 (ATT GtG to fill capacity gap)	£0.0	£3,821.4	£3,821.4	£0.0	£3,821.4

Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

Table 34: Cost benefit Analysis Results Baseline Pathways – reported ass difference from baseline Pathway 0 (Collections Phase 1 including landfill tax) - in £ millions (Low Growth Model)

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV - excl. residual value	Residual value	NPV - including residual value
Pathway 0.1 (improved efficiency 2020 infrastructure)	£0.0	£453.5	£453.5	£0.0	£453.5
Pathway 0.2 (CHP enabled EfW to fill capacity gap)	£0.0	£913.3	£913.3	£0.0	£913.3
Pathway 0.3 (ATT GtG to fill capacity gap)	£0.0	£519.2	£519.2	£0.0	£519.2

Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

5.1.5.3 Cost Benefit Analysis - Phase 2 Treatment CBA

The CBA results for Phase 2 of the infrastructure pathways are given in Table 35 (high growth model) and Table 36 (low growth model). These show a sizable increase in capital costs for pathways 0.2 and 0.3 compared to baseline due to the cost of delivering new EfW and gasification infrastructure and capacity. This is also reflected in a large positive residual value representing the value of the new infrastructure at the end of the forecasting period.

This new infrastructure generates revenue through the sale of generated power and heat, and through gate fee income, generating a cash surplus over operating costs and hence a sizable positive net cash inflow compared to baseline pathway 0. Combining the capital and cash elements therefore gives an overall positive NPV over baseline.

Table 35: Cost benefit Analysis Results Baseline Pathways – reported as difference from baseline Pathway 0 (Treatment Phase 2 CBA) - in £ millions (High Growth Model)

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV - excl. residual value	Residual value	NPV - including residual value
Pathway 0.1 (improved efficiency 2020 infrastructure)	£0.0	£62.4	£62.4	£0.0	£62.4
Pathway 0.2 (CHP enabled EfW to fill capacity gap)	£7,157.6	£14,758.6	£7,601.0	£7,825.4	£15,426.4
Pathway 0.3 (ATT GtG to fill capacity gap)	£5,495.7	£15,478.4	£9,982.7	£7,156.3	£17,139.0

Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

Table 36: Cost benefit Analysis Results Baseline Pathways – reported as difference from baseline Pathway 0 (Treatment Phase 2 CBA) - in £ millions (Low Growth Model)

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV - excl. residual value	Residual value	NPV - including residual value
Pathway 0.1 (improved efficiency 2020 infrastructure)	£0.0	£61.6	£61.6	£0.0	£61.6
Pathway 0.2 (CHP enabled EfW to fill capacity gap)	£228.5	£2,004.7	£1,776.2	£146.7	£1,922.8
Pathway 0.3 (ATT GtG to fill capacity gap)	£172.8	£2,087.1	£1,914.2	£149.1	£2,063.3

Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

5.1.5.4 Cost benefit Analysis - Overall CBA

Adding Phase 1 and Phase 2 results give the overall CBA outputs. These are presented in Table 37 (high growth model) and Table 38 (low growth model).

As anticipated, as Pathways 0.2 and 0.3 involve the most significant infrastructure investments, this is reflected in overall sizable capital costs and residual values when phase 1 and phase 2 capital spends are added together. For net operational cash inflow, the cash surplus from phase 2 operation of the new infrastructure outweighs the increased collection costs reflected in negative cash inflows from phase 1. This gives an overall sizable positive cash inflow surplus and positive NPV for these two pathways over baseline, once the residual value of these new facilities at the end of the forecast period is taken into account, and therefore an overall sizable financial benefit over baseline.

Table 37: Cost benefit Analysis Results Baseline Pathways – reported as difference from baseline Pathway 0 (total Phase 1 plus Phase 2 CBA) - in £ millions (High Growth Model)

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV - excl. residual value	Residual value	NPV - including residual value
Pathway 0.1 (improved efficiency 2020 infrastructure)	£0.0	£515.8	£515.8	£0.0	£515.8
Pathway 0.2 (CHP enabled EfW to fill capacity gap)	£7,157.6	£6,057.1	-£1,100.5	£7,825.4	£6,725.0
Pathway 0.3 (ATT GtG to fill capacity gap)	£5,495.7	£3,876.5	-£1,619.2	£7,156.3	£5,537.1

Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

Table 38: Cost benefit Analysis Results Baseline Pathways - reported as difference from baseline Pathway 0 (total Phase 1 plus Phase 2 CBA) - in £ millions (Low Growth Model)

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV - excl. residual value	Residual value	NPV - including residual value
Pathway 0.1 (improved efficiency 2020 infrastructure)	£0.0	£515.1	£515.1	£0.0	£515.1
Pathway 0.2 (CHP enabled EfW to fill capacity gap)	£228.5	£822.4	£593.9	£146.7	£740.6
Pathway 0.3 (ATT GtG to fill capacity gap)	£172.8	£510.7	£337.9	£149.1	£486.9

Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

5.1.5.5 Environmental Impact per £ NPV

Table 39 shows a measure of the added value generated by these different pathways in form of the GHG impact per £ using the CBA outputs, which represents the net environmental benefits for the different investments into each pathway:

Table 39: Value for money - GHG impacts compared to CBA £ outputs (reported as difference from baseline Pathway 0)) (as Kg CO_2e/£ and KWh/£)

Pathway	**High Growth Model**	**Low Growth Model**
	kg CO_2e/£ NPV inc residual value	kg CO_2e/£ NPV inc residual value
Pathway 0.1 (improved efficiency 2020 infrastructure)	9.3	9.32
Pathway 0.2 (CHP enabled EfW to fill capacity gap)	11.5	13.93
Pathway 0.3 (ATT GtG to fill capacity gap)	21.7	27.94

Although from these figures the gasification to GtG appears to be generating the best value for money in terms of environmental impact, the fact that this technology is not commercially proven means that it will not be used for comparison against segregation scenarios in the following sections of the report.

5.1.5.6 Absolute NPVs

As the CBA results are presented as difference from baseline Pathway 0, Table 40 gives the absolute outputs from the CBA model for the infrastructure pathways in £ billions for comparison. This is not intended as an absolute measure of the economic impact of the waste sector in England on the economy, due to the model limitations. This shows that collections present a high negative NPV representing a cost to the collection body, and treatment a positive NPV denoting a revenue generator for the operator. In this model, the collection costs outweigh the treatment revenues, giving an overall negative NPV. This trend is seen over all the segregation scenarios modelled.

Table 40: Infrastructure Pathway CBA including residual value - NPV (absolute values, £ billions)

Pathway	Baseline Pathway 0	Pathway 0.1 existing EfW improvement	Pathway 0.2 landfill to new CHP	Pathway 0.3 landfill to new Gasification GtG
Phase 1 Collection - High Growth	-84.3	-83.9	-93.0	-95.9
Phase 2 Treatment - High Growth	64.7	64.7	80.1	81.8
Overall CBA - High Growth	-19.6	-19.1	-12.9	-14.1
Phase 1 Collection - Low Growth	-71.4	-70.9	-72.6	-73.0
Phase 2 Treatment - Low Growth	54.7	54.7	56.6	56.8
Overall CBA - Low Growth	-16.7	-16.2	-16.0	-16.2

Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

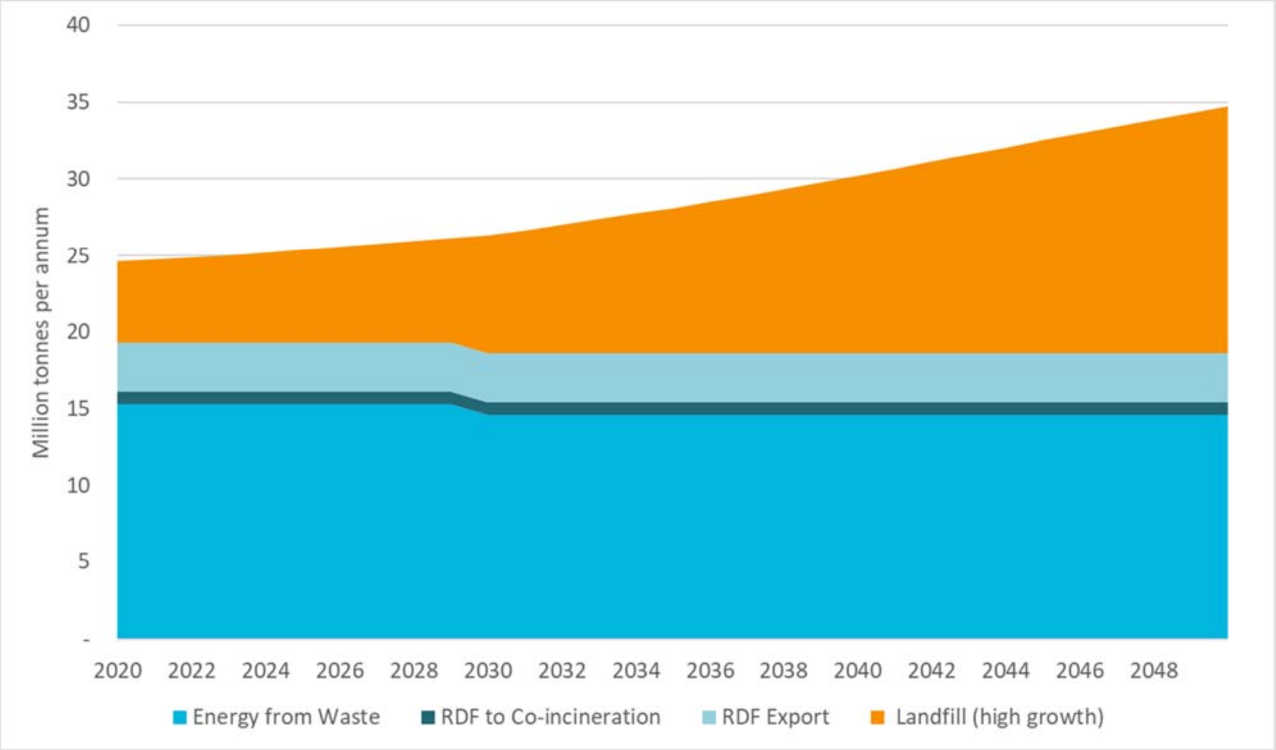
A5.2 Waste Segregation Scenarios

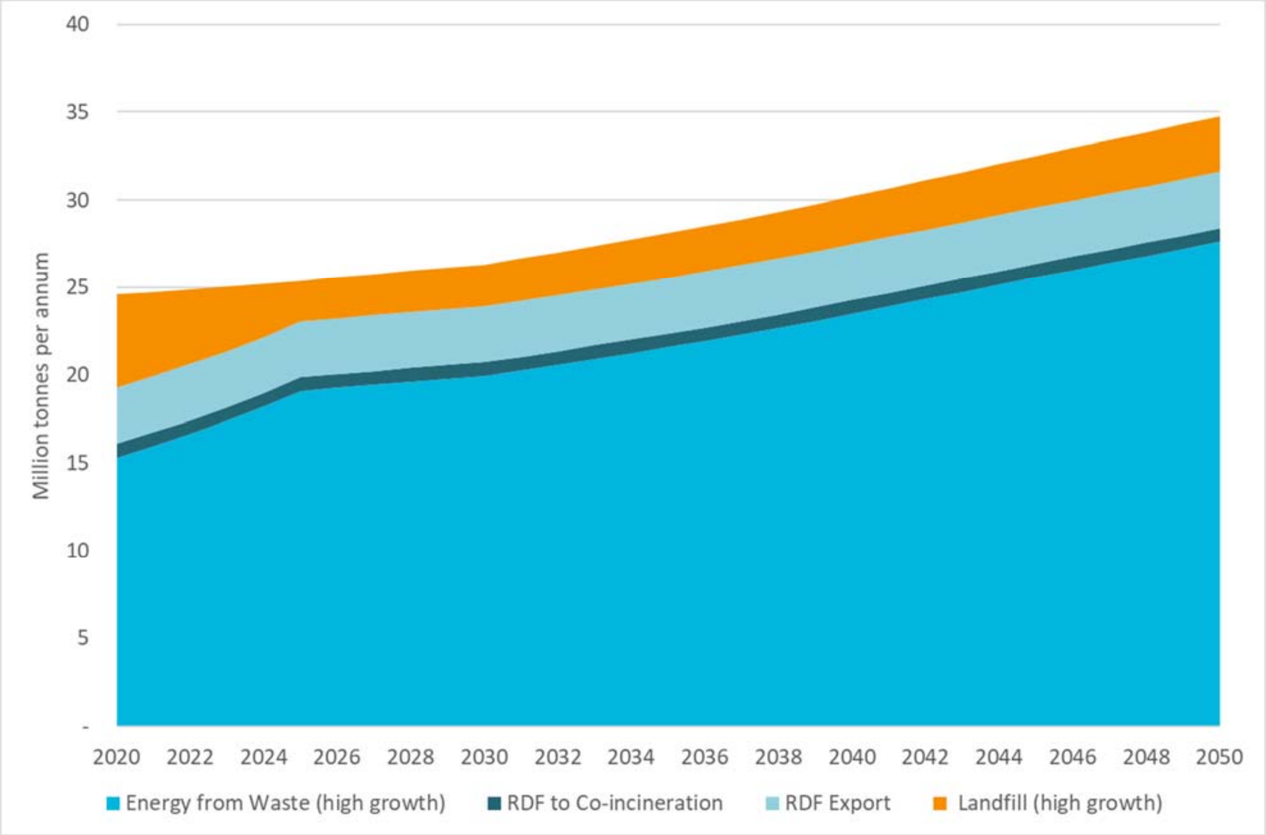
Having modelled residual waste infrastructure pathway options, based upon no change in collection or segregation practises, a range of segregation scenarios were modelled. By comparing the results of these changes in collection practices (as segregation scenarios) against the infrastructure baselines results already produced, this allowed the environmental and economic impacts of the individual segregation changes to be isolated and compared. These are reported in detail in the next report sections.

A5.3 Food Waste Segregation

This segregation option looked at maximising food waste collection at source i.e. at kerbside from households and from the private sector e.g. from restaurants, food manufacturers and catering businesses, for increased recycling, and the impact on residual waste infrastructure requirements caused by this diversion of food waste. In this respect, two organic waste infrastructure pathways were modelled i.e. segregated food waste to anaerobic digestion with CHP (organic pathway 1), and anaerobic digestion with gas upgrading and biomethane to grid (organic pathway 2). These organic processing options have in turn been modelled against residual pathways Pathway 0 (i.e. 2020 infrastructure) and Pathway 0.2 (i.e. 2020 infrastructure plus energy recovery capacity gap taken up with EfW with CHP). Essentially, therefore, modelling residual waste Pathway 0 diverts segregated food waste from a mixture of EfW and landfill, Pathway 0.2 from EfW power only and EfW with CHP, as indicated in the residual waste infrastructure profiles shown in Figure 28.

Figure 28: Residual waste from food waste segregation scenarios - infrastructure pathways Pathway 0 and Pathway 0.2 (High Growth Model)





Modelled capture rate of food waste segregation at kerbside was based upon recommendations from WRAP in terms of practical maximum per household, and delivered capture rates in high recycling jurisdictions such as Wales and the Netherlands (as described in Appendix III). Baseline tonnages are built up with data from Waste Data Flow for municipal wastes, and Environmental Agency waste returns data for all food wastes processed through permitted facilities.

Modelled infrastructure pathways are therefore:

Food Waste to AD CHP (Organic Pathway 1)	Increased food waste segregation to average 42% (from baseline of 13% for LACW and 31% for C&I) with segregated food waste directed to AD CHP producing heat and power.
Food Waste to AD GtG (Organic Pathway 2)	As above, with all new AD upgrading the biogas to biomethane, which can then be provided directly as gas to the grid to replace natural gas (and potentially could be compressed into vehicle gas, however this has not been modelled).

In total four food pathways have been modelled as each food waste pathway assumes:

- the same residual waste infrastructure pathway as Baseline Residual Waste Infrastructure Pathway 0, i.e. using current EfW infrastructure as the increased food waste segregation will reduce residual waste amounts and therefore the need for additional recovery infrastructure;
- the same residual waste infrastructure pathway as Residual Waste Infrastructure Pathway 0.2, i.e. increased landfill diversion of residual waste via EfW CHP.

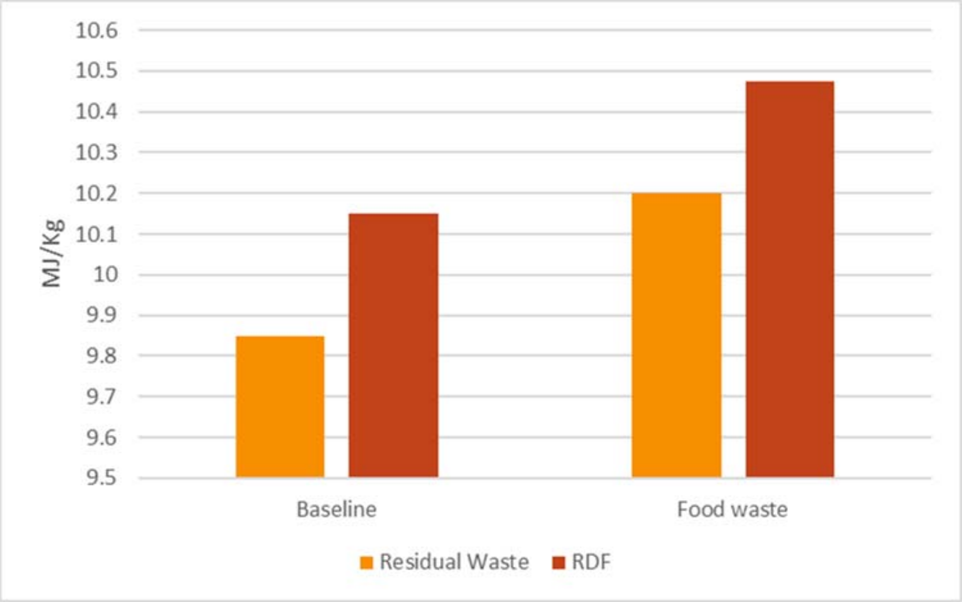
Compared to baseline (Pathway 0), the increase in food waste collection from household and commercial industrial sources will require between 1.5 Mt (low growth model) and 2.5 Mt (high growth model) of additional recycling capacity by 2050 (between 38.7 Mt and 54.6 Mt in total over the forecast period) which is assumed to be provided using existing and new anaerobic digestion facilities in England. This would require an additional 9.5 – 16 additional strategic AD facilities or 33 – 55 decentralised AD facilities in England.

Table 41: Increase in segregated food waste (compared to baseline) in tonnes per annum

Segregated food waste v baseline (tonnes)	2025	2030	2035	2040	2045	2050	Total 2020-2050
Food waste to AD CHP (High Growth)	891,625	1,915,683	2,047,430	2,200,698	2,367,717	2,531,336	54,590,626
Food waste to AD CHP (Low Growth)	767,846	1,531,323	1,519,044	1,515,572	1,513,587	1,501,922	38,749,434
Food Waste to AD GtG (High Growth)	891,625	1,915,683	2,047,430	2,200,698	2,367,717	2,531,336	54,590,626
Food Waste to AD GtG (Low Growth)	767,846	1,531,323	1,519,044	1,515,572	1,513,587	1,501,922	38,749,434

The reduction of food waste in the composition of the resultant residual waste was forecast to increase residual waste CV to ~10.2 MJ/kg (average 2020-2050, v 9.8 MJ/kg baseline), and ~10.45 MJ/kg (average 2020-2050, from 10.15 MJ/kg baseline) for RDF, as shown in Figure 29. Both CVs are expected to be within the operational envelope of existing EfW plants, but will be very much at the higher end of acceptable residual waste. Therefore, it has been assumed that the increase in CV will lead to a reduced throughput equivalent to 95% of the EfW capacity available at baseline CV. This then has an impact on the gate fee and energy revenues at the energy from facilities.

Figure 29: CV for residual waste after increased food waste segregation, compared to baseline



5.3.1 Outputs – Energy generation

Organic Pathway 2 assumes this waste is directed to anaerobic digestion producing biomethane to grid to replace natural gas for heating (described as gas to grid or GtG for this report). In each case, the energy created by the increase in segregated food waste volume sent to AD is off-set by the reduction in residual waste volume and hence a reduced energy output from EfW energy recovery.

Net energy output for the four food waste pathways compared to their respective baseline is summarised in Table 42 (difference from residual waste Pathway 0) and Table 43 (difference from Pathway 0.2). The diversion of food waste away from residual waste reduces the need for additional EfW capacity from 43 (Pathway 0.2 baseline) over the forecast period to 40 (at 350ktpa per facility) in the high growth model, and from 1 to zero in the low growth model (assuming continued RDF export). This also shows an increase in energy output in most cases compared to baseline, although slightly reduced from organic pathway 1 i.e. AD CHP.

Table 42: Total Energy (Power + Heat) Outputs (GWh) Food Waste Segregation Pathway 1 Segregated Food Waste to AD CHP and Pathway 2 Segregated Food Waste to AD GtG – reported as difference to residual waste baseline Pathway 0 (2020 infrastructure)

Pathway	2025	2030	2035	2040	2045	2050	Total 2020-2050
Segregated Food Waste to AD CHP (High growth)	826	1,159	1,241	1,338	1,444	1,547	35,779
Segregated Food Waste to AD CHP (Low growth)	748	918	910	908	906	899	25,810
Segregated Food Waste to AD GtG (High growth)	769	1,037	1,106	1,187	1,275	1,361	32,061
Segregated Food Waste to AD GtG (Low growth)	704	830	824	822	821	815	23,616

Note positive figures have energy output greater than baseline, negative figures less than baseline

Table 43: Total Energy (Power + Heat) Outputs (GWh) Food Waste Segregation Pathway 1 Segregated Food Waste to AD CHP and Pathway 2 Segregated Food Waste to AD GtG – reported as difference to Pathway 0.2 (2020 infrastructure plus EfW CHP to fill residual waste capacity gap)

Pathway	2025	2030	2035	2040	2045	2050	Total 2020-2050
Segregated Food Waste to AD CHP (High growth)	-72	180	205	237	271	304	5,074
Segregated Food Waste to AD CHP (Low growth)	-98	103	100	100	99	97	1,875
Segregated Food Waste to AD GtG (High growth)	-128	58	70	85	102	119	1,356
Segregated Food Waste to AD GtG (Low growth)	-141	16	14	14	14	13	-319

Note positive figures have energy output greater than baseline, negative figures less than baseline

5.3.2 Cost Benefit Analysis

5.3.2.1 Phase 1 Collection

The cost model for increased food segregation assumes that:

- segregated dry recyclates and residual wastes are bulked at waste transfer stations (WTS) before transport to the next waste processing phase;
- and that the mixed recyclate sent to a MRF, and organic wastes sent to an organic recycling facility are assumed to be delivered directly to the relevant facility and not bulked at a transfer station.

Therefore, impacts on phase 1 capital cost and operation cash inflow compared to baseline are a combination of:

- Reduced WTS requirement: both food waste scenarios require less transfer station capacity than the baseline, resulting in reduced (negative) capital cost over the forecast period. This reduced requirement for WTS would also reduce operation costs for WTS overall impacting positively on the net operational cash inflow. This reduced requirement is significantly more in the high growth model compared to the low growth model;
- Changes in gate fee: using residual waste pathway 0, food waste diversion from a combination of EfW and landfill to AD, and for pathway 0.2 from all EfW to AD, gives an overall saving for the collection authority in AD gate fees compared to EfW and landfill, when landfill tax is excluded, for pathway 0, and a greater saving compared to all EfW for pathway 0.2;
- Increased collection costs: collection costs for all food waste scenarios are greater than baseline due to food waste collections being more expensive than residual waste collection as smaller vehicles are required at higher collection frequencies, which will need to be emptied more often during collection rounds;

Combining these effects, for the scenarios modelled with residual waste infrastructure as 2020 i.e. baseline pathway 0, high growth scenarios give a negative operational cash inflow i.e. overall increased cost, while low growth gives an overall positive operational cash inflow i.e. increased revenue. This is because of the magnitude of the competing impacts. For the high growth model, the increased collection cost (£2.03bn non-discounted) totalled over the forecast period, exceeds the savings from reduced WTS requirement (0.5bn non-discounted) and gate fees (£1.44bn non-discounted). For the low growth model, the lower volumes reduce the increased collection cost (to £1.44bn non-discounted) which in this case is exceeded by the savings from less WTS operation (£0.35 bn non-discounted) and gate fees (£1.38 bn non-discounted) giving an overall positive operational cash inflow. In both high and low growth models, the impact of the residual value of the new AD facilities constructed, gives an overall positive NPV (including residual value) i.e. financial benefit over baseline.

For the scenarios modelled with residual waste diversion from landfill to EfW, i.e. baseline Pathway 0.2, diverting food waste from EfW to AD gives a significant saving, mirrored in the increased net operational cash inflow, for both high and low growth models due to the increased gate fee savings benefit. Results are summarised in Table 44 (compared to baseline Pathway 0) and Table 45 (compared to Pathway 0.2).

Table 44: Cost Benefit Analysis (£ million) Food Waste Segregation Pathway 1 Segregated Food Waste to AD CHP and Pathway 2 Segregated Food Waste to AD GtG – Collection Phase 1 – reported as difference from baseline Pathway 0 (2020 infrastructure)

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV - excl. residual value	Residual value	NPV - including residual value
Segregated Food Waste to AD CHP (High growth)	-£36.2	-£93.1	-£56.9	£76.6	£19.8
Segregated Food Waste to AD CHP (Low growth)	£0.0	£101.8	£101.8	£0.0	£101.8
Segregated Food Waste to AD GtG (High growth)	-£36.2	-£93.1	-£56.9	£76.6	£19.8
Segregated Food Waste to AD GtG (Low growth)	£0.0	£101.8	£101.8	£0.0	£101.8

Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

Table 45: Cost Benefit Analysis (£ million) Food Waste Segregation Pathway 1 Segregated Food Waste to AD CHP and Pathway 2 Segregated Food Waste to AD GtG – Collection Phase 1 – reported as difference from Pathway 0.2 (EfW CHP)

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV - excl. residual value	Residual value	NPV - including residual value
Segregated Food Waste to AD CHP (High growth)	-£36.2	£1,133.0	£1,169.2	£76.6	£1,245.8
Segregated Food Waste to AD CHP (Low growth)	£0.0	£859.9	£859.9	£0.0	£859.9
Segregated Food Waste to AD GtG (High growth)	-£36.2	£1,133.0	£1,169.2	£76.6	£1,245.8
Segregated Food Waste to AD GtG (Low growth)	£0.0	£859.9	£859.9	£0.0	£859.9

Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

However, excluding LFT can show reduced cost saving advantages to the collection body, diminishing the benefits of a change in collection scenario. For completeness, the CBA results including LFT are presented as Table 46 and Table 47. These show results compared to both baselines, and show significantly improved NPVs from maximising food waste segregation at kerbside, due to diversion from EfW and landfill (compared to Pathway 0) or EfW alone (compared to Pathway 0.2).

Table 46: Cost Benefit Analysis (£ million) Food Waste Segregation Pathway 1 Segregated Food Waste to AD CHP and Pathway 2 Segregated Food Waste to AD GtG – Collection Phase 1 – reported as difference from baseline Pathway 0 (2020 infrastructure) – including LFT

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV - excl. residual value	Residual value	NPV - including residual value
Segregated Food Waste to AD CHP (High growth)	-£36.2	£2,145.6	£2,181.8	£76.6	£2,258.5
Segregated Food Waste to AD CHP (Low growth)	£0.0	£1,504.2	£1,504.2	£0.0	£1,504.2
Segregated Food Waste to AD GtG (High growth)	-£36.2	£2,145.6	£2,181.8	£76.6	£2,258.5
Segregated Food Waste to AD GtG (Low growth)	£0.0	£1,504.2	£1,504.2	£0.0	£1,504.2

Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

Table 47: Cost Benefit Analysis (£ million) Food Waste Segregation Pathway 1 Segregated Food Waste to AD CHP and Pathway 2 Segregated Food Waste to AD GtG – Collection Phase 1 – reported as difference from Pathway 0.2 (EfW CHP) – including LFT

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV - excl. residual value	Residual value	NPV - including residual value
Segregated Food Waste to AD CHP (High growth)	-£36.2	£1,198.5	£1,234.7	£76.6	£1,311.4
Segregated Food Waste to AD CHP (Low growth)	£0.0	£918.5	£918.5	£0.0	£918.5
Segregated Food Waste to AD GtG (High growth)	-£36.2	£1,198.5	£1,234.7	£76.6	£1,311.4
Segregated Food Waste to AD GtG (Low growth)	£0.0	£918.5	£918.5	£0.0	£918.5

Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

5.3.2.2 Phase 2 Treatment

Processing of the segregated food waste in anaerobic digestion is reflected in an increased capital cost compared to baseline (Pathway 0), essentially for the delivery of this additional capacity. Due to the additional AD capacity there is a slight reduction in net operational cash inflow over baseline for the high growth model and a slight increase in the low growth model.

It is assumed that the 2020 AD capacity is unable to accommodate this additional volume as the market is currently relatively balanced (at a national level) with sufficient capacity for food waste, agricultural and sewage sludge residues and energy crops. Although capacity does outstrip demand in some geographic areas and there is a good level of competition for food waste to increase gate fee revenue.

For the residual waste pathway 0, net operational cash inflow compared to baseline show a significant surplus, as these figures include revenue from gate fees and energy sales, as well as facility operating costs and cost of disposal of digestate.

Digestate for soil improvement has have been modelled at cost in the CBA as most operators are paying a fee for collection and spreading of it. Increasing food waste processing via AD by up to 1.5-2.5 Mtpa will increase the volume of digestate produced also, and hence demand for land spread. In some geographic areas this could potentially be a barrier to expansion because digestate is only permitted during certain periods in the year and on certain soils, therefore requiring digestate storage outside these periods.

For those scenarios maximising diversion from landfill to EfW i.e. against Pathway 0.2, net operation cash inflows are negative, showing reduced revenues from diverting food waste from EfW to AD, with modelled AD gate fees giving lower overall margins per tonne processed than EfW. Conversely, capital costs are reduced in replacing EfW capacity with AD capacity for the segregated food wastes, giving a slightly negative NPV and therefore comparing less well against this base line.

Outputs are summarised in Table 48 and Table 49.

Table 48: Cost Benefit Analysis (£ million) Food Waste Segregation Pathway 1 Segregated Food Waste to AD CHP and Pathway 2 Segregated Food Waste to AD GtG – Treatment Phase 2 – reported as difference from baseline Pathway 0 (2020 infrastructure)

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV - excl. residual value	Residual value	NPV - including residual value
Segregated Food Waste to AD CHP (High growth)	£289.7	£618.7	£329.1	£76.0	£405.1
Segregated Food Waste to AD CHP (Low growth)	£192.8	£381.9	£189.0	£125.4	£314.5
Segregated Food Waste to AD GtG (High growth)	£317.7	£595.3	£277.7	£67.4	£345.1
Segregated Food Waste to AD GtG (Low growth)	£204.9	£367.5	£162.6	£122.9	£285.5

Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

Table 49: Cost Benefit Analysis (£ million) Food Waste Segregation Pathway 1 Segregated Food Waste to AD CHP and Pathway 2 Segregated Food Waste to AD GtG – Treatment Phase 2 – reported as difference from Pathway 0.2 (EfW CHP)

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV - excl. residual value	Residual value	NPV - including residual value
Segregated Food Waste to AD CHP (High growth)	-£374.3	-£1,067.2	-£692.9	-£221.8	-£914.7
Segregated Food Waste to AD CHP (Low growth)	-£35.7	-£885.7	-£850.1	-£21.3	-£871.3
Segregated Food Waste to AD GtG (High growth)	-£346.3	-£1,090.6	-£744.3	-£230.4	-£974.7
Segregated Food Waste to AD GtG (Low growth)	-£23.6	-£900.2	-£876.5	-£23.7	-£900.3

Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

5.3.2.3 Overall CBA

Adding phase 1 to phase 2 gives the overall CBA compared to baseline as follows in tables Table 50 and Table 50

Table 50: Cost Benefit Analysis (£ million) Food Waste Segregation Pathway 1 Segregated Food Waste to AD CHP and Pathway 2 Segregated Food Waste to AD GtG – Total Phase 1 + Phase 2 – reported as difference to baseline Pathway 0 (2020 infrastructure)

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV - excl. residual value	Residual value	NPV - including residual value
Segregated Food Waste to AD CHP (High growth)	£253.5	£525.7	£272.2	£152.7	£424.9
Segregated Food Waste to AD CHP (Low growth)	£192.8	£483.7	£290.9	£125.4	£416.3
Segregated Food Waste to AD GtG (High growth)	£281.5	£502.3	£220.8	£144.1	£364.9
Segregated Food Waste to AD GtG (Low growth)	£204.9	£469.3	£264.4	£122.9	£387.3

Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

Table 51: Cost Benefit Analysis (£ million) Food Waste Segregation Pathway 1 Segregated Food Waste to AD CHP and Pathway 2 Segregated Food Waste to AD GtG – Total Phase 1 + Phase 2 – reported as difference from Pathway 0.2 (EfW CHP)

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV - excl. residual value	Residual value	NPV - including residual value
Segregated Food Waste to AD CHP (High growth)	-£410.5	£65.8	£476.2	-£145.1	£331.1
Segregated Food Waste to AD CHP (Low growth)	-£35.7	-£25.9	£9.8	-£21.3	-£11.4
Segregated Food Waste to AD GtG (High growth)	-£382.5	£42.4	£424.8	-£153.7	£271.1
Segregated Food Waste to AD GtG (Low growth)	-£23.6	-£40.3	-£16.6	-£23.7	-£40.4

Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

Compared to residual waste baseline Pathway 0 (using 2020 infrastructure) both food waste segregation pathways show an increased capital spend due to the construction of new AD capacity (note with Pathway 0 segregated food waste is essentially diverted from a combination of EfW and landfill). However, the comparison to Pathway 0.2 (segregated food waste diverted from EfW CHP) shows that when this AD capacity replaces EfW capacity, this gives an overall reduction in capital required. For operational cash inflow, overall impact depends upon the competing influences of increased collection costs and the range of operational costs and revenues involved in operating WTS, AD and EfW (combining phase 1 and phase 2 results eliminates any impact of gate fees). For high growth options this results in positive operational cash inflow, for low growth negative. Overall, taking into account the operational cash inflows reported, and the capital cost and residual value of new AD capacity, all options deliver a significant positive NPV benefit for food waste segregation against baseline, apart from low growth Pathway 0.2 where there is a small negative NPV i.e. cost increase over the forecast period as in the low growth the positive costs impacts of reduced transfer station requirement are not sufficiently large to counteract the reduced revenues in treatment for this pathway described in phase 2.

5.3.3 Greenhouse Gas Impact

Modelling the greenhouse gas impact of this segregation scenario compared to baseline, shows a positive impact from 2025 i.e. reduction in GHG generation, reaching 0.5Mt CO_2e (low growth) to 1.4Mt CO_2e (high growth) by 2050. The main impact is likely to be the reduced GHG impact of anaerobic digestion compared to landfill and EfW. Modelled GHG forecasts are given in Table 52 (difference from Pathway 0) and Table 53 (difference from Pathway 0.2).

Table 52: GHG Impact (t CO_2e x 1000) Food Waste Segregation Pathway 1 Segregated Food Waste to AD CHP and Pathway 2 Segregated Food Waste to AD GtG – reported as difference from baseline Pathway 0 (2020 infrastructure)

Pathway	2025	2030	2035	2040	2045	2050	Total 2020-2050
Segregated Food Waste to AD CHP (High growth)	-579.9	-995.5	-919.5	-1,027.4	-1,142.4	-1,258.3	-27,098.4
Segregated Food Waste to AD CHP (Low growth)	-482.1	-692.2	-545.9	-543.7	-540.2	-531.4	-15,614.6
Segregated Food Waste to AD GtG (High growth)	-502.7	-829.3	-1,053.8	-1,178.1	-1,312.4	-1,446.6	-28,720.5
Segregated Food Waste to AD GtG (Low growth)	-422.7	-572.9	-631.2	-629.0	-626.3	-616.9	-16,261.3

(note positive figures = GHG impact greater than baseline, negative figures GHG impact less than baseline)

Table 53: GHG Impact (t CO_2e x1000) Food Waste Segregation Pathway 1 Segregated Food Waste to AD CHP and Pathway 2 Segregated Food Waste to AD GtG – reported as difference from Pathway 0.2 (2020 infrastructure plus EfW CHP to fill residual waste capacity gap)

Pathway	2025	2030	2035	2040	2045	2050	Total 2020-2050
Segregated Food Waste to AD CHP (High growth)	-177.2	-451.4	-467.5	-500.7	-533.3	-567.3	-12,352.2
Segregated Food Waste to AD CHP (Low growth)	-150.7	-365.4	-362.9	-364.1	-363.7	-362.5	-9,122.1
Segregated Food Waste to AD GtG (High growth)	-100.0	-285.2	-601.8	-651.3	-703.3	-755.5	-13,974.4
Segregated Food Waste to AD GtG (Low growth)	-91.3	-246.1	-448.3	-449.5	-449.9	-447.9	-9,768.8

(note positive figures = GHG impact greater than baseline, negative figures GHG impact less than baseline)

A5.4 Biodegradable Waste Segregation

The biodegradable waste segregation scenario is an extension of the food waste scenario, and includes the collection of other biodegradable waste including paper & card, garden waste and wood, which are further segregated at kerbside (and other collection facilities such as HWRC, bring banks etc). In each case, capture rates were used as summarised in Appendix A4 based upon that achieved in high recycling jurisdictions such as Wales and the Netherlands, modelled to be achieved in 2030. Because 2020 capture rates of paper & card and garden waste were already relatively high in England, this only had a sizable impact upon the volumes of food waste and wood waste collected.

Modelled pathway is:

Biodegradables with residual waste Pathway 0 (baseline, 2020 infrastructure)	Separate collection of biodegradable wastes including food, paper, card, wood, garden wastes; residual waste modelled as baseline pathway 0 i.e. 2020 infrastructure
Biodegradables with residual waste pathway 0.2 (Diversion from landfill to new EfW with CHP)	Separate collection of biodegradable wastes including food, paper, card, wood, garden wastes; residual waste modelled as pathway 0.2 i.e. 2020 infrastructure plus EfW CHP to fill residual waste capacity gap

Table 54 compares the additional organic waste collected to baseline (Pathway 0), which adds up to between 2.0 Mt (low growth model, 2050) and 3.4 Mt (high growth model, 2050) of additional segregated organic waste (between 52.3 and 73.7 Mt in total over the forecast period).

Modelling assumed all segregated food waste is processed using anaerobic digestion CHP (as food waste segregation pathway 1), segregated paper and card is recycled, garden waste is processed using open air windrow composting, mixed garden and food will need to be processed by in-vessel composting as per animal by-product regulation and wood is either recycled or goes to energy recovery depending on the quality of the wood waste (note the energy impact of this segregated wood waste is not modelled).

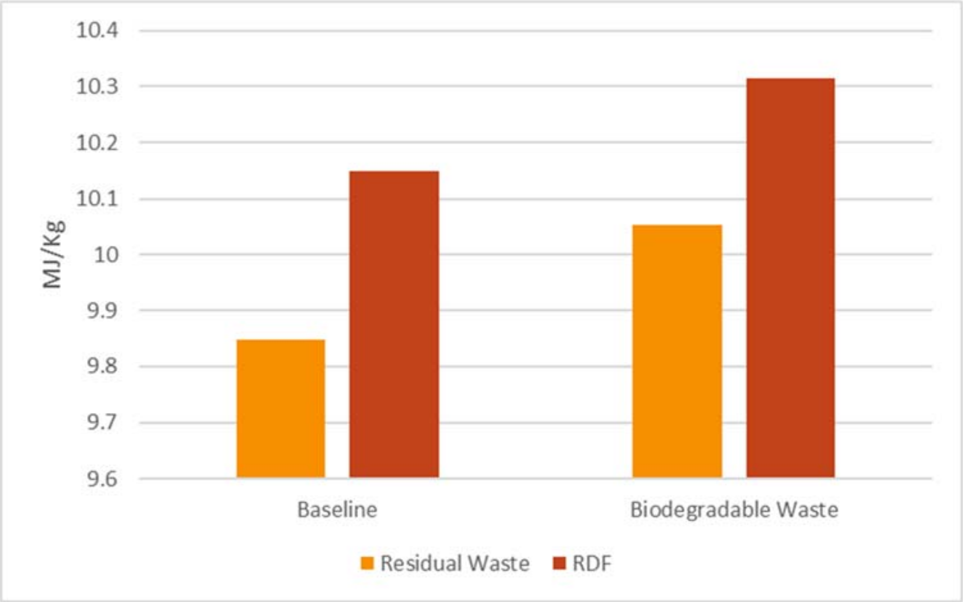
Table 54: Increase in segregated biodegradable waste (reported as difference from baseline Pathway 0 and 0.2) in tonnes per annum

Segregated biodegradable waste v baseline (tonnes)	2025	2030	2035	2040	2045	2050	Total 2020-2050
Biodegradable waste (High Growth)	1,204,083	2,587,008	2,764,924	2,971,903	3,197,452	3,418,408	73,721,173
Biodegradable waste (Low Growth)	1,036,927	2,067,954	2,051,372	2,046,684	2,044,004	2,028,251	52,328,650

As with the food waste segregation scenario, the increased segregation of food waste produces sufficient feedstock for 17 (high growth model) or 7 (low growth model) new AD facilities (at 160 ktpa per facility), plus up to 3 (high growth) additional clean MRFs for material separation.

The reduction of biodegradable waste in the residual waste, produces an estimated increase to ~10 MJ/kg (average v 9.8 MJ/kg baseline) for residual waste modelled for energy from waste recovery, and ~10.26 MJ/kg (from ~10.15 MJ/kg baseline) for RDF prepared for export.

Figure 30: CV for residual waste after increased biodegradable waste segregation, compared to baseline



5.4.1 Outputs – Energy generation

The infrastructure pathway modelled assumes the additional segregated food waste is directed to CHP anaerobic digesters, therefore delivering both heat and power outputs, which are used on site or sold into the market. The energy impact of wood waste directed to biomass energy plants is not modelled in this total as the volumes involved were relatively low, and this impacted on a set of energy facilities out of scope for this particular study. Energy output compared to baseline is therefore summarised in Table 55 and Table 56.

Against baseline residual pathway 0 modelling shows an energy generation increase to 0.5TWh – 1.9TWh per annum (2050). However, the diversion of up to 3.5Mtpa of waste away from the residual stream has a significant impact on EfW energy (power and heat) outputs in pathway 0.2, showing an overall reduction by up to 0.5-1.6TWh per annum by 2050.

Table 55: Total Energy (Power + Heat) Outputs (GWh) Biodegradable Waste Segregation – reported as difference from baseline Pathway 0 (2020 infrastructure)

Pathway	2025	2030	2035	2040	2045	2050	Total 2020-2050
Biodegradables Segregation (High Growth)	715	1,527	1,608	1,705	1,811	1,914	42,485
Biodegradables Segregation (Low Growth)	637	771	650	616	596	482	18,191

Note: positive figures show energy output greater than baseline, negative figures less than baseline

Table 56: Total Energy (Power + Heat) Outputs (GWh) Biodegradable Waste Segregation – reported as difference from Pathway 0.2 (2020 infrastructure plus EfW CHP to fill residual waste capacity gap)

Pathway	2025	2030	2035	2040	2045	2050	Total 2020-2050
Biodegradables Segregation (High Growth)	-597	-1,279	-1,349	-1,427	-1,511	-1,594	-34,512
Biodegradables Segregation (Low Growth)	-536	-722	-637	-613	-599	-517	-16,428

Note: positive figures show energy output greater than baseline, negative figures less than baseline

5.4.2 Cost Benefit Analysis

5.4.2.1 Phase 1 Collection

The cost model for increased biodegradable waste segregation assumes that:

- both segregated dry recyclates (including paper & card) and residual (black bin) wastes are bulked at waste transfer stations before transport to the next processing site;
- mixed recyclates are sent to a MRF;
- and it is assumed that organic wastes (including food and garden wastes) sent to an organic recycling facility are delivered directly and are not bulked at a transfer station.

Therefore, both food waste and garden waste require less transfer station capacity than the baseline, resulting in lower capital cost over the forecast period than the baseline, and negative residual value at the end of the forecast period, mirroring the results for food waste alone.

The model shows a decrease in net operational cash inflow (i.e. increased cost) over baseline (made up of collection cost, gate fees charged for processing, revenue from any dry recyclates and operating costs of any waste transfer stations involved) due to a number of factors:

- Collection costs have increased over baseline due to a higher unit collection cost for recyclates and organic wastes exceeding that of residual waste;

- sole gate fee costs for anaerobic digestion and open-air windrow are expected to exceed landfill gate fees without landfill tax (the model does not impose landfill tax in the costs of residual waste and other residues sent to landfill, in line with Green Book recommendations).

Outputs are summarised in Table 57 and Table 58 and outputs results including LFT are summarised in Table 59 and

Table 60 to better quantify the full impact to the collection body. This shows positive operational cash inflows and NPV benefits for all scenarios compared to baseline.

Table 57: Cost Benefit Analysis (£ million) Biodegradable Waste Segregation – Collection Phase 1 – reported as difference from baseline Pathway 0 (2020 infrastructure)

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV - excl. residual value	Residual value	NPV - including residual value
Biodegradables Segregation (High Growth)	-£54.3	-£1,461.4	-£1,407.1	£114.6	-£1,292.5
Biodegradables Segregation (Low Growth)	£0.0	-£217.8	-£217.8	£0.0	-£217.8

Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

Table 58: Cost Benefit Analysis (£ million) Biodegradable Waste Segregation – Collection phase 1 – reported as difference from Pathway 0.2 (2020 infrastructure plus EfW CHP to fill residual waste capacity gap)

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV - excl. residual value	Residual value	NPV - including residual value
Biodegradables Segregation (High Growth)	-£54.3	£887.5	£941.8	£114.6	£1,056.4
Biodegradables Segregation (Low Growth)	£0.0	£853.6	£853.6	£0.0	£853.6

Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

Table 59: Cost Benefit Analysis (£ million) Biodegradable Waste Segregation – Collection Phase 1 inc LFT – reported as difference from baseline Pathway 0 (2020 infrastructure)

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV - excl. residual value	Residual value	NPV - including residual value
Biodegradables Segregation (High Growth)	£54.3	£1,046.0	£1,316.8	£276.1	£1,592.9

Biodegradables Segregation (Low Growth)	£0.0	£585.4	£778.2	£125.4	£903.6

Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

Table 60: Cost Benefit Analysis (£ million) Biodegradable Waste Segregation –Collection Phase 1 inc LFT - reported as difference from Pathway 0.2 (2020 infrastructure plus EfW CHP to fill residual waste capacity gap)

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV - excl. residual value	Residual value	NPV - including residual value
Biodegradables Segregation (High Growth)	-£54.3	£977.2	£1,031.5	£114.6	£1,146.1
Biodegradables Segregation (Low Growth)	£0.0	£933.8	£933.8	£0.0	£933.8

Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

5.4.2.2 Phase 2 Treatment

Processing of the segregated biodegradable wastes in anaerobic digestion, clean MRF and other infrastructure (such as open-air windrow, in-vessel composting) is reflected in an increased capital cost compared to baseline. For all these facility types, it is assumed that the current (2020) capacity is unable to accommodate this additional volume and new facilities will need to be built.

Net operational cash inflow compared to baseline shows a significant revenue increase against baseline pathway 0, as these figures include revenue from gate fees and energy sales, as well as facility operating costs and cost of disposal of outputs. As per the food waste pathways, the digestate spreading to land has been modelled at costs, while composting production was modelled creating a small revenue. When considering the scenario with pathway 0.2 i.e. residual waste diversion from landfill to EfW with CHP, due to the diversion of waste from EfW to AD and other recycle options, capital cost reduces significantly along with operational cash inflow, reflecting the results for food waste alone. Results are summarised in Table 61 and Table 62.

Table 61: Cost Benefit Analysis (£ million) Biodegradable Waste Segregation – Treatment Phase 2 – reported as difference from baseline Pathway 0 (2020 infrastructure)

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV - excl. residual value	Residual value	NPV - including residual value
Biodegradables Segregation (High Growth)	£325.2	£1,794.6	£1,469.5	£161.5	£1,631.0

Biodegradables Segregation (Low Growth)	£192.8	£338.6	£145.8	£125.4	£271.2

Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

Table 62: Cost Benefit Analysis (£ million) Biodegradable Waste Segregation – Treatment Phase 2 - reported as difference from Pathway 0.2 (2020 infrastructure plus EfW CHP to fill residual waste capacity gap))

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV - excl. residual value	Residual value	NPV - including residual value
Biodegradables Segregation (High Growth)	-£1,572.4	-£1,947.5	-£375.1	-£872.1	-£1,247.2
Biodegradables Segregation (Low Growth)	-£35.7	-£1,476.7	-£1,441.0	-£21.3	-£1,462.3

Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

5.4.2.3 Overall CBA

Adding phase 1 to phase 2 gives the overall CBA compared to baseline as displayed in Table 63 and Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

Table 64. The overall CBA compared to baseline show that the collection NPV is lower than in the food waste only pathways, resulting in a lower overall NPV also. The results following residual waste pathway 0.2 delivers a negative NPV including residual value, as the collection cost impact is not significant enough to compensate for additional capital costs.

Table 63: Cost Benefit Analysis (£ million) Biodegradable Waste Segregation – Total Phase 1+ Phase 2 – reported as difference from baseline Pathway 0 (2020 infrastructure)

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV - excl. residual value	Residual value	NPV - including residual value
Biodegradables Segregation (High Growth)	£270.8	£333.2	£62.4	£276.1	£338.5
Biodegradables Segregation (Low Growth)	£192.8	£120.8	-£72.1	£125.4	£53.3

Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

Table 64: Cost Benefit Analysis (£ million) Biodegradable Waste Segregation – Total Phase 1 + Phase 2- reported as difference from Pathway 0.2 (2020 infrastructure plus EfW CHP to fill residual waste capacity gap)

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV - excl. residual value	Residual value	NPV - including residual value
Biodegradables Segregation (High Growth)	-£1,626.7	-£1,060.0	£566.7	-£757.5	-£190.8
Biodegradables Segregation (Low Growth)	-£35.7	-£623.1	-£587.4	-£21.3	-£608.7

Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

Using residual waste baseline pathway 0, the increased collection costs are more than compensated by the net gains in operation of these additional facilities, giving an overall NPV benefit against baseline for both high and low growth models. For residual pathway 0.2, the reduction in requirement for new EfW CHP results in a significant reduction in capital spend compared to baseline, and an overall small negative NPV for the high growth model and higher negative for the low growth model.

5.4.3 Greenhouse Gas Impact

Modelling the greenhouse gas impact of this segregation scenario compared to baseline, shows a positive impact from 2025 i.e. reduction in GHG generation. Residual waste pathways show GHG impact benefits to baseline, of between 18 and 37 Mtpa CO_2e for pathway 0 and 7-8 Mtpa CO_2e for pathway 0.2 totalled over the forecast period 2020-2050.

Modelled GHG forecasts are given in Table 65 and Table 66.

Table 65: GHG Impact (t CO_2e x1000) Biodegradable Waste Segregation – reported as difference from baseline Pathway 0 (2020 infrastructure)

Pathway	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**Total 2020-2050**
Biodegradables Segregation (High Growth)	-632.0	-1,387.8	-1,272.0	-1,441.8	-1,626.0	-1,808.8	-37,224.2
Biodegradables Segregation (Low Growth)	-486.1	-707.0	-660.7	-657.8	-657.1	-644.1	-17,775.7

(note positive figures = GHG impact greater than baseline, negative figures GHG impact less than baseline)

Table 66: GHG Impact (t CO_2e x1000) Biodegradable Waste Segregation – reported as difference from Pathway 0.2 (2020 infrastructure plus EfW CHP to fill residual waste capacity gap)

Pathway	2025	2030	2035	2040	2045	2050	Total 2020-2050
Biodegradables Segregation (High Growth)	-29.3	-77.3	-300.6	-326.4	-355.7	-384.7	-6,600.3
Biodegradables Segregation (Low Growth)	-29.8	-138.7	-389.2	-401.0	-410.5	-440.0	-8,166.1

(note positive figures = GHG impact greater than baseline, negative figures GHG impact less than baseline)

A5.5 Plastics Waste Segregation

Two scenarios have been modelled to examine the impact of the increased separation of plastic waste:

- Pathway 1 increases plastics segregation at kerbside (additionally segregated material goes for recycling) and the residual waste follows the infrastructure pathway modelled in the baseline pathway 0. Plastics capture rates follow those explained in Appendix A4, which are based upon those achieved in high recycling rate jurisdictions such as Wales and the Netherlands. To assess the result of this change in collection, results are compared to those obtained using baseline 0, infrastructure at 2020 levels, and pathway 0.2 i.e. filling the capacity gap with CHP enabled EfW;
- Pathway 2 is a significant change from the baseline as plastics are not only segregated at kerbside as plastics pathway 1 and go for recycling, but additional plastics waste is also removed from the residual waste. In this pathway the residual waste is passed through intermediate treatment (e.g. residual waste MRFs) to specifically remove the plastics and additional other recyclates such as metals. These contaminated and lower grade plastics are sent to landfill (food waste contamination in particular is likely on flexible plastics packaging, non-PET/PP bottles etc.). The remainder of the residual waste is sent for energy recovery (including the biodegradable fraction) as pathway 0.2 using increasing EfW CHP.

Modelled pathways are therefore:

Plastics Pathway 1 Residual Waste baseline Pathway 0 (i.e. 2020 infrastructure)	Increased capture of plastics at collection; compared to residual waste baseline pathway 0 i.e. no change in residual waste infrastructure
Plastics Pathway 1 Residual Waste Pathway 0.2 (i.e. CHP enabled EfW to fill the capacity gap)	Increased capture of plastics at collection; compared to residual waste pathway 0.2 i.e. new EfW CHP delivered to fill the capacity gap
Plastics Pathway 2, Residual waste pathway 0.2 (residual waste plastics to landfill)	Increased capture of plastics at collection, with additional interim residual waste facilities to remove further plastics from residual waste, prior to going to EfW (plastics landfilled). Kerbside segregated plastics go for recycling. Plastics separated from residual waste go to landfill. Residual waste (including biodegradable waste) goes to EfW. Any landfill capacity for this material is replaced with new EfW capacity as pathway 0.2.

The kerbside collection regimes are the same for both scenarios. Compared to the baseline, the increase in plastic waste collection in the plastics pathway 1 adds between 0.3 Mt (low growth model, 2050) and 0.5 Mt (high growth model, 2050) of additional segregated material (between 8 Mt and 12 Mt in total over the forecast period) from higher capture kerbside collections.

In addition, pathway 2 separates an additional 7 to 10 Mt of plastics waste from residual waste over the forecast period 2020 to 2050, which is sent to landfill for this scenario. The removal of plastics from residual waste is carried out using so-called “dirty MRF” capacities without organic waste separation – a separation efficiency of 49% was assumed; the residual waste or RDF type material from this treatment is sent to energy recovery, including the biodegradable fraction, and this scenario does not have additional organic material separation, neither at kerbside nor for the residual waste.

Table 67: Plastics segregation scenarios – additional plastics segregated per pathway (tonnes)

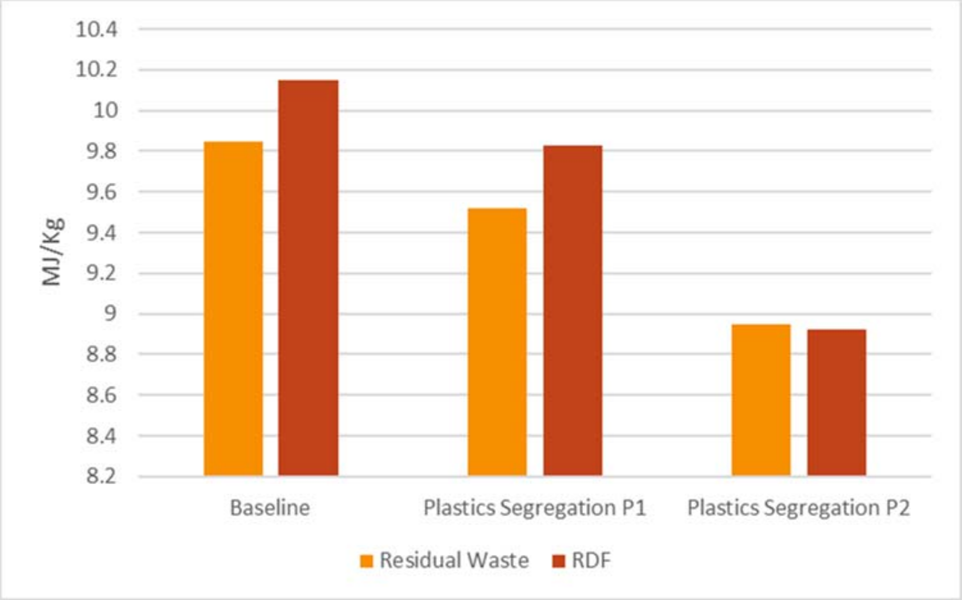
Segregated recyclates v baseline (tonnes)	2025	2030	2035	2040	2045	2050	Total 2020-2050
Plastics (High Growth) Pathway 1	190,897	410,148	438,355	471,170	506,929	541,959	11,687,865
Plastics (Low Growth) Pathway 1	164,396	327,856	325,228	324,484	324,059	321,562	8,296,262
Plastics (High Growth)[a] Pathway 2	1,706,220	1,857,807	1,985,574	2,134,211	2,296,185	2,454,859	21,563,263
Plastics (Low Growth)[a] Pathway 2	1,469,355	1,485,058	1,473,151	1,469,784	1,467,859	1,456,547	15,330,432

[a] *includes kerbside separated plastics for recycling and plastics separated from residual waste for landfill.*

Segregating plastics at kerbside in plastics pathway 1 slightly reduces the volume of plastics in the residual waste, although maximum practical capture rates are such that there is still a significant plastic component in the remaining residual waste. Pathway 1 reduces the CV in residual waste to EfW to ~9.5 MJ/kg (average 2020-2050 v. ~9.8 MJ/kg residual waste baseline pathway 0) and ~9.75 MJ/kg for RDF (average 2020-2050 v. 10.15 MJ/kg baseline pathway 0).

In plastics pathway 2 a proportion of the plastics remaining in the residual waste are also separated and the resultant contaminated plastics landfilled, therefore having a significant additional impact on the residual waste composition, reducing the CV to 8.95 MJ/kg for residual waste and 8.92 MJ/kg for RDF. These CV forecasts are summarised in Figure 31.

Figure 31: Change in residual waste CV, plastics pathways 1 and 2, in MJ/kg



For plastics pathway 1, this reduction of plastics in the residual waste and subsequent reduction of calorific value of the waste results in a reduction in energy output of the modelled residual waste pathway, of up to 0.5 TWhpa (in 2050) compared to baseline pathway 0. Compared to residual waste pathway 0.2, with an increased

EfW capacity over that of pathway 0.2, this energy output is more strikingly reduced to up to 1.2-2.4 TWhpa (in 2050).

For plastics pathway 2 modelling the residual waste pathway 0.2 i.e. sending residual waste to EfW CHP, amplifies this effect in tandem with a considerable reduction in residual waste CV caused by the separation and landfilling of much of the residual plastics. As a result, overall energy output is reduced compared to pathway 0.2, by as much as 5-10 TWh (in 2050).

Table 68: Total Energy (Power + Heat) Outputs (GWh) Plastics Segregation Pathway 1 – reported as difference from baseline Pathway 0 (2020 infrastructure)

Pathway	2025	2030	2035	2040	2045	2050	Total 2020-2050
Plastic segregation (High Growth)	-245	-498	-497	-496	-495	-494	-12,627
Plastic segregation (Low Growth)	-246	-499	-499	-499	-499	-499	-12,690

Note positive figures have energy output greater than baseline, negative figures less than baseline

Table 69: Total Energy (Power + Heat) Outputs (GWh) Plastics Segregation Pathway 1 and Pathway 2 (plastics to landfill) – reported as difference from residual waste Pathway 0.2 (2020 infrastructure plus EfW CHP to fill residual waste capacity gap)

Pathway	2025	2030	2035	2040	2045	2050	Total 2020-2050
Plastic segregation Pathway 1 (High Growth)	-773	-1,691	-1,840	-2,012	-2,200	-2,384	-49,206
Plastic segregation Pathway 1 (Low Growth)	-634	-1,257	-1,243	-1,239	-1,237	-1,224	-31,414
Plastic segregation Pathway 2 (High Growth)	-6,332	-7,736	-8,349	-9,064	-9,843	-10,607	-234,816
Plastic segregation Pathway 2 (Low Growth)	-5,288	-5,508	-5,389	-5,356	-5,337	-5,224	-146,692

Note positive figures have energy output greater than baseline, negative figures less than baseline

Removal of plastics from EfW also has a considerable impact on greenhouse gas impact of these scenarios, showing benefits against baseline pathway 0 for plastics pathway 1, and baseline pathway 0.2 for plastics pathway 2, as summarised in Table 70 and Table 71.

Table 70: GHG Impact (t CO_2e x1000) Plastic Waste Segregation pathway 1 – reported as difference from baseline Pathway 0 (2020 infrastructure)

Pathway	2025	2030	2035	2040	2045	2050	Total 2020-2050

Plastic segregation (High Growth)	-571.6	-1,363.7	-1,671.8	-1,753.9	-1,843.3	-1,930.2	-41,812.1
Plastic segregation (Low Growth)	-542.0	-1,237.6	-1,493.0	-1,522.1	-1,554.4	-1,580.8	-36,488.3

(note positive figures = GHG impact greater than baseline, negative figures GHG impact less than baseline)

Table 71: GHG Impact (t CO_2e x1000) Plastic Waste Segregation pathway 1 and Pathway 2 (residual plastics to landfill) – reported as difference from Pathway 0.2 (2020 infrastructure plus EfW CHP to fill residual waste capacity gap)

Pathway	2025	2030	2035	2040	2045	2050	Total 2020-2050
Plastic segregation Pathway 1 (High Growth)	-493.2	-1,243.6	-1,853.2	-2,047.4	-2,269.5	-2,493.1	-47,013.7
Plastic segregation Pathway 1 (Low Growth)	-421.8	-985.4	-1,364.6	-1,393.9	-1,427.8	-1,448.6	-32,313.4
Plastic segregation Pathway 2 (High Growth)	-2,676.0	-3,469.4	-5,547.8	-6,009.7	-6,528.9	-7,040.3	-142,294.9
Plastic segregation Pathway 2 (Low Growth)	-2,345.0	-2,892.0	-4,322.5	-4,354.5	-4,394.7	-4,419.7	-104,817.9

(note positive figures = GHG impact greater than baseline, negative figures GHG impact less than baseline)

5.5.1 Cost Benefit Analysis

5.5.1.1 Phase 1 Collection

Increased volumes of segregated plastics, which will need to be bulked at transfer stations, produces an increase capital cost with both high and low growth scenarios. For all scenarios excluding landfill, net operating cash inflow increases, supported by increase in revenue from recyclate sales which considerably exceeds the cost of operating more transfer stations, giving overall sizable positive NPVs. It has been assumed that the plastics removed at kerbside are of sufficient quality to be recycled and have a value in the market. These have been valued at typical market prices reflecting the real benefit to the collection authority – any further costs and benefits in transforming these recycled plastics into saleable products by reprocessors, is not included. When including the impact of landfill tax, the comparison to baseline pathway 0 delivers increased positive operational cost inflows and increased positive NPV.

For the scenarios using the residual waste pathway 0.2 i.e. residual waste diversion from landfill to EfW with CHP, significant increases in operational cash inflow are seen, although reduced for plastics to landfill due to the increased cost of intermediate segregation of plastics from residual waste at dirty MRFs.

Outputs summarised in Table 72 and Table 73 excluding LFT, Table 74 and Table 75 including LFT.

Table 72: Cost Benefit Analysis (£ million) Plastic Waste Segregation Pathway 1 – Collection Phase 1 – reported as difference from baseline Pathway 0 (2020 infrastructure)

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV - excl. residual value	Residual value	NPV - including residual value
Plastic segregation (High Growth)	£19.6	£3,549.8	£3,530.2	-£13.2	£3,517.0
Plastic segregation (Low Growth)	£7.9	£2,665.4	£2,657.5	-£1.6	£2,655.9

Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

Table 73: Cost Benefit Analysis (£ million) Plastic Waste Segregation Pathway 1 and Pathway 2 (residual plastics to landfill) – Collection Phase 1 – reported as difference from Pathway 0.2 (2020 infrastructure plus EfW CHP to fill residual waste capacity gap)

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV - excl. residual value	Residual value	NPV - including residual value
Plastic segregation Pathway 1 (High Growth)	£19.6	£4,277.6	£4,257.9	-£13.2	£4,244.8
Plastic segregation Pathway 1 (Low Growth)	£7.9	£3,195.1	£3,187.2	-£1.6	£3,185.6
Plastic segregation Pathway 2 (High Growth)	£19.6	£689.5	£669.9	-£13.2	£656.7
Plastic segregation Pathway 2 (Low Growth)	£7.9	£2,105.7	£2,097.8	-£1.6	£2,096.2

Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

Table 74: Cost Benefit Analysis (£ million) Plastic Waste Segregation Pathway 1 – Collection Phase 1 inc LFT – reported as difference from baseline Pathway 0 (2020 infrastructure)

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV - excl. residual value	Residual value	NPV - including residual value
Plastic segregation (High Growth)	£19.6	£4,867.5	£4,847.9	-£13.2	£4,834.7
Plastic segregation (Low Growth)	£7.9	£3,629.2	£3,621.2	-£1.6	£3,619.6

Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

Table 75: Cost Benefit Analysis (£ million) Plastic Waste Segregation Pathway 1 and Pathway 2 (residual plastics to landfill) – Collection Phase 1 inc LFT – reported as difference from Pathway 0.2 (2020 infrastructure plus EfW CHP to fill residual waste capacity gap)

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV - excl. residual value	Residual value	NPV - including residual value
Plastic segregation Pathway 1 (High Growth)	£19.6	£4,305.4	£4,285.7	-£13.2	£4,272.5
Plastic segregation Pathway 1 (Low Growth)	£7.9	£3,220.0	£3,212.0	-£1.6	£3,210.5
Plastic segregation Pathway 2 (High Growth)	£19.6	£1,076.2	£1,056.6	-£13.2	£1,043.4
Plastic segregation Pathway 2 (Low Growth)	£7.9	£2,347.9	£2,339.9	-£1.6	£2,338.4

Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

5.5.1.2 Phase 2 Treatment

For the scenario using the residual waste pathway 0 i.e. 2020 infrastructure, capital cost is low, as the key additional infrastructure consists of additional MRF capacity to sort comingled recyclates collections. As biodegradable waste segregation is as baseline, there is no new AD capacity included in this figure. Net operational cash inflow is sizably negative, showing increased operational costs in line with increased sorting and separation, but also reflecting reduced EfW and landfill requirements from reduced residual waste volumes and CV.

For scenarios using the residual waste pathway 0.2 i.e. residual diversion to EfW, plastics pathway 1 shows a significant capital cost reduction due to the reduced requirement for EfW capacity, similarly reflected in net operational cash inflow figures. For the plastics to landfill option pathway 2, a significant capital cost increase is explained by a significant increase in the need for intermediate treatment facilities. CBA outputs are summarised in Table 76 and Table 77:

Table 76: Cost Benefit Analysis (£ million) Plastic Waste Segregation Pathway 1 - Treatment Phase 2 – reported as difference from baseline Pathway 0 (2020 infrastructure)

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV - excl. residual value	Residual value	NPV - including residual value
Plastic segregation (High Growth)	£12.0	-£2,342.9	-£2,354.8	-£235.6	-£2,590.5
Plastic segregation (Low Growth)	£0.0	-£1,848.1	-£1,848.1	£0.0	-£1,848.1

Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

Table 77: Cost Benefit Analysis (£ million) Plastic Waste Segregation Pathway 1 and Pathway 2 (residual plastics to landfill) – Treatment Phase 2 – reported as difference from Pathway 0.2 (2020 infrastructure plus EfW CHP to fill residual waste capacity gap)

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV - excl. residual value	Residual value	NPV - including residual value
Plastic segregation Pathway 1 (High Growth)	-£580.2	-£3,731.6	-£3,151.4	-£652.7	-£3,804.1
Plastic segregation Pathway 1 (Low Growth)	-£228.5	-£2,756.6	-£2,528.0	-£146.7	-£2,674.7
Plastic segregation Pathway 2 (High Growth)	£414.1	-£8,280.5	-£8,694.7	-£849.9	-£9,544.6
Plastic segregation Pathway 2 (Low Growth)	£3,019.3	-£7,064.7	-£10,084.1	£1,368.8	-£8,715.2

Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

5.5.1.3 Overall CBA

The overall CBA (i.e. phase 1 and phase 2 analysis) shows, for plastics pathway 1, NPV is positive compared to baseline, although somewhat reduced for residual waste pathway 0.2 where the drop in residual waste volume is reflected in a reduced need for EfW capacity and therefore lower capital spend compared to baseline. Results are presented in Table 78 and Table 79.

Table 78: Cost Benefit Analysis (£ million) Plastic Waste Segregation Pathway 1 – Total Phase 1 + Phase 2 – reported as difference from baseline Pathway 0 (2020 infrastructure)

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV - excl. residual value	Residual value	NPV - including residual value
Plastic segregation (High Growth)	£31.6	£1,206.9	£1,175.4	-£248.8	£926.5
Plastic segregation (Low Growth)	£7.9	£817.3	£809.4	-£1.6	£807.8

Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

For plastics pathway 2 i.e. residual plastics to landfill, a significant additional capital cost compared to baseline is driven by the need for additional residual waste segregation capacity, despite the reduced capacity requirements for the lower volumes of residual waste for energy recovery produced. This, plus the additional cost of running these facilities, generated an overall sizable cost increase (i.e. NPV decrease) over baseline. Results are summarised in Table 79.

Table 79: Cost Benefit Analysis (£ million) Plastic Waste Segregation Pathway 1 and Pathway 2 (residual plastics to landfill) – Total Phase 1 & Phase 2 – reported as difference from Pathway 0.2 (2020 infrastructure plus EfW CHP to fill residual waste capacity gap)

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV - excl. residual value	Residual value	NPV - including residual value
Plastic segregation Pathway 1 (High Growth)	-£560.6	£546.0	£1,106.6	-£665.9	£440.7
Plastic segregation Pathway 1 (Low Growth)	-£220.6	£438.6	£659.2	-£148.3	£510.9
Plastic segregation Pathway 2 (High Growth)	£433.8	-£7,591.0	-£8,024.8	-£863.1	-£8,887.9
Plastic segregation Pathway 2 (Low Growth)	£3,027.3	-£4,959.0	-£7,986.3	£1,367.2	-£6,619.1

Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

Note that for plastics pathway 2 the cost of landfill tax has not been taken into account (following guidance from HM Treasury Green Book). Over the forecast period this could potentially cost between £748 million and £1,050 million in additional disposal costs (assuming the landfilled plastics attract full rate landfill tax, and based upon an assumed landfill tax rate for 2020), reducing the net operational cash inflow and overall NPV even further, by the same amount.

A5.6 High Recycling Waste Segregation

The high recycling segregation scenarios are designed to reflect more ambitious recycling targets and are aligned to the EU Circular Economy targets of 60% recycling in 2030 and 65% by 2035. These recycling rates were applied to both LACW and C&I (household like) wastes. Two infrastructure pathways have been modelled, based upon increased segregation of a range of key recyclables, including metals, and collection at kerbside. Modelled capture rates of recyclates at kerbside has been based upon delivered capture rates in high recycling nations such as Wales and the Netherlands, with in some cases capture extended over these levels to deliver the required recycling rate targets. The two infrastructure pathways differ in how food waste is being processed; pathway 1 assumes AD to CHP as the baseline; Pathway 2 assumes AD gas to grid.

Modelled pathways are:

High Recycling Pathway 1, residual baseline pathway 0	Capture rates increased in 2030 to hit 60% overall recycling and 65% by 2035; compared to baseline pathway 0; organic AD CHP.

High Recycling Pathway 1, residual pathway 0.2	Capture rates increased in 2030 to hit 60% overall recycling and 65% by 2035; compared to baseline pathway 0.2; organic AD CHP.
High Recycling Pathway 2, residual pathway 0	Capture rates increased in 2030 to hit 60% overall recycling and 65% by 2035; compared to baseline pathway 0; organic AD gas to grid.
High Recycling Pathway 2, residual pathway 0.2	Capture rates increased in 2030 to hit 60% overall recycling and 65% by 2035; compared to baseline pathway 0.2; organic AD gas to grid.

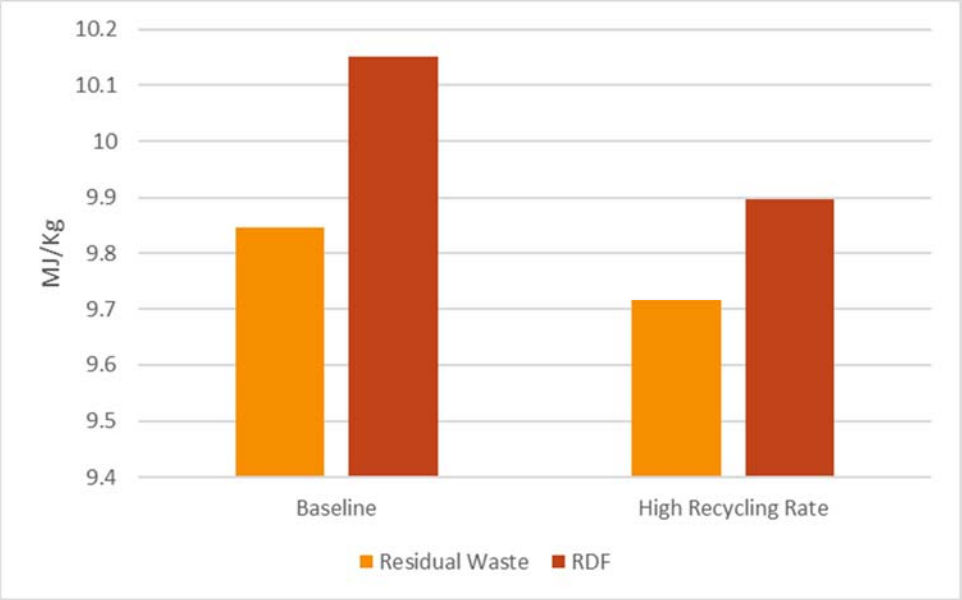
Compared to baseline (pathway 0 and pathway 0.2), the increase in dry recyclates and organic waste collection adds between 5.9 Mt (low growth model, 2050) and 10.0 Mt (high growth model, 2050) of additional segregated material (between 132 Mt and 190 Mt in total over the forecast period). This segregation scenario is a significant change from baseline and will require significant investment in additional collection and processing infrastructure.

Table 80: Increase in High Recycling segregated recyclates (compared to baseline pathway 0) in tonnes per annum, for high recycling pathways P1 and P2

Segregated recyclates v baseline (tonnes)	2025	2030	2035	2040	2045	2050	Total 2020-2050
High Recycling (High Growth) Pathway 1	1,916,573	4,117,811	8,056,062	8,659,127	9,316,302	9,960,094	189,732,646
High Recycling (Low Growth) Pathway 1	1,650,505	3,291,619	5,977,010	5,963,351	5,955,541	5,909,642	131,946,497
High Recycling (High Growth) Pathway 2	1,916,573	4,117,811	8,056,062	8,659,127	9,316,302	9,960,094	189,732,646
High Recycling (Low Growth) Pathway 2	1,650,505	3,291,619	5,977,010	5,963,351	5,955,541	5,909,642	131,946,497

As with previous scenarios, the modelling assumes all additionally segregated dry recyclates go to recycling (some via a dry MRF), and organic waste are processed via AD or OAW. The reduction of a range of recyclates and organics in the composition of the resultant residual waste, has only a small impact on overall impact on the forecast CV of the residual waste generated, reducing figures slightly to 9.7 MJ/kg (average 2020-2050 v ~9.8 MJ/kg baseline) for residual waste modelled for energy from waste recovery as materials are proportionally removed from the waste stream, and ~9.9 MJ/kg (average 2020-2050 v ~10.15 MJ/kg baseline) for RDF prepared for export.

Figure 32: CV for residual waste after increased high recycling recyclates segregation, compared to baseline



5.6.1 Outputs – Energy generation

High Recycling Pathway 1 assumes the additional segregated organic waste (particularly food) is directed to anaerobic digesters using CHP to deliver both heat and power outputs, as modelled in the baseline. Pathway 2 assumes this waste is directed to gas to grid anaerobic digestion. In each case, the energy created by the increase in segregated food waste volume sent to AD is compensated somewhat by the reduction in residual waste volume overall and hence a reduced energy output from EfW energy recovery.

Compared to residual waste baseline pathway 0 (i.e. no change in residual waste infrastructure from 2020) this diversion of various recyclates to recycling (including food waste to AD) does show some increase in energy generation to 1.8 TWh by 2050 (high growth model), although conversely a significant decrease using the low growth model (to 2 TWh reduction in 2050) due to the relatively lower residual waste volumes.

When compared to residual waste baseline pathway 0.2, where any additionally recycled material results in lower volumes through new EfW CHP capacity, a significant reduction in energy output of between 2.7 TWh and 9.5 TWh is noted depending upon the growth model applied (2050 figures).

Energy output compared to baseline is therefore summarised in Table 80 and Table 82.

Table 81: Total Energy (Power + Heat) Outputs (GWh) High Recycling Pathway 1 Segregated Food Waste to AD CHP and Pathway 2 Segregated Food Waste to AD GtG – reported as difference from baseline Pathway 0 (2020 infrastructure)

Pathway	2025	2030	2035	2040	2045	2050	Total 2020-2050
High Recycling (High Growth) Pathway 1	616	1,323	1,435	1,563	1,703	1,841	38,664
High Recycling (Low Growth) Pathway 1	367	-190	-1,680	-1,702	-1,714	-1,787	-29,655
High Recycling (High Growth) Pathway 2	559	1,202	1,254	1,363	1,481	1,599	34,043
High Recycling (Low Growth) Pathway 2	324	-278	-1,800	-1,821	-1,833	-1,905	-32,456

Note positive figures have energy output greater than baseline, negative figures less than baseline

Table 82: Total Energy (Power + Heat) Outputs (GWh) High Recycling Pathway 1 Segregated Food Waste to AD CHP and Pathway 2 Segregated Food Waste to AD GtG – reported as difference from Pathway 0.2 (2020 infrastructure plus EfW CHP to fill residual waste capacity gap)

Pathway	2025	2030	2035	2040	2045	2050	Total 2020-2050
High Recycling (High Growth) Pathway 1	-1,524	-3,279	-7,608	-8,208	-8,862	-9,500	-173,818
High Recycling (Low Growth) Pathway 1	-1,200	-1,683	-2,967	-2,930	-2,909	-2,786	-65,653
High Recycling (High Growth) Pathway 2	-1,581	-3,401	-7,789	-8,408	-9,083	-9,742	-178,440
High Recycling (Low Growth) Pathway 2	-1,243	-1,771	-3,087	-3,050	-3,029	-2,904	-68,454

Note positive figures have energy output greater than baseline, negative figures less than baseline

5.6.2 Cost Benefit Analysis

5.6.2.1 Phase 1 Collection

The cost model for increased recyclate and organic waste segregation assumes that both segregated dry recyclates and residual (black bin) wastes are bulked at a waste transfer stations before transport to the next processing site; mixed recyclate is sent to a MRF, and organic wastes sent to an organic recycling facility are delivered directly and are not bulked at a transfer station. Therefore, using the high growth model for both pathways requires less transfer station capacity than the baseline for residual waste bulking as residual volumes reduce significantly, and more transfer station capacity for the additional dry recyclates collected.

For the low growth model, the increase in recyclate and the transfer station requirement from this, outweighs the reduction from lower residual waste volume, giving a small increase in capital cost, and a more positive operation cash inflow supported by the sales value of the recyclates collected. Comparing the results with landfill tax included shows a significant increase in pathway 1 operational cash inflow, showing the impact of the significant diversion from landfill of the increased recycling. Outputs are summarised in Table 83 and Table 84 excluding LFT, and Table 85 and Table 86 including LFT.

Table 83: Cost Benefit Analysis (£ million) High Recycling Pathway 1 Segregated Food Waste to AD CHP and Pathway 2 Segregated Food Waste to AD GtG – Collection Phase 1 – reported as difference from baseline Pathway 0 (2020 infrastructure)

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV - excl. residual value	Residual value	NPV - including residual value
High Recycling (High Growth) Pathway 1	-£73.7	£5,157.1	£5,230.8	£242.4	£5,473.2
High Recycling (Low Growth) Pathway 1	£5.3	£7,701.4	£7,696.2	-£1.1	£7,695.1
High Recycling (High Growth) Pathway 2	-£73.7	£5,157.1	£5,230.8	£242.4	£5,473.2
High Recycling (Low Growth) Pathway 2	£5.3	£7,701.4	£7,696.2	-£1.1	£7,695.1

Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

Table 84: Cost Benefit Analysis (£ million) High Recycling Pathway 1 Segregated Food Waste to AD CHP and Pathway 2 Segregated Food Waste to AD GtG – Collection Phase 1 – reported as difference from Pathway 0.2 (2020 infrastructure plus EfW CHP to fill residual waste capacity gap)

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV - excl. residual value	Residual value	NPV - including residual value
High Recycling (High Growth) Pathway 1	-£73.7	£10,873.8	£10,947.6	£242.4	£11,190.0
High Recycling (Low Growth) Pathway 1	£5.3	£8,834.6	£8,829.3	-£1.1	£8,828.3
High Recycling (High Growth) Pathway 2	-£73.7	£10,873.8	£10,947.6	£242.4	£11,190.0
High Recycling (Low Growth) Pathway 2	£5.3	£8,834.6	£8,829.3	-£1.1	£8,828.3

Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

Table 85: Cost Benefit Analysis (£ million) High Recycling Pathway 1 Segregated Food Waste to AD CHP and Pathway 2 Segregated Food Waste to AD GtG – Collection Phase 1 inc LFT – reported as difference from baseline Pathway 0 (2020 infrastructure)

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV - excl. residual value	Residual value	NPV - including residual value
High Recycling (High Growth) Pathway 1	-£73.7	£15,431.7	£15,505.4	£242.4	£15,747.8
High Recycling (Low Growth) Pathway 1	£5.3	£9,836.7	£9,831.4	-£1.1	£9,830.3
High Recycling (High Growth) Pathway 2	-£73.7	£15,431.7	£15,505.4	£242.4	£15,747.8
High Recycling (Low Growth) Pathway 2	£5.3	£9,836.7	£9,831.4	-£1.1	£9,830.3

Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

Table 86: Cost Benefit Analysis (£ million) High Recycling Pathway 1 Segregated Food Waste to AD CHP and Pathway 2 Segregated Food Waste to AD GtG – Collection Phase 1 inc LFT – reported as difference from Pathway 0.2 (2020 infrastructure plus EfW CHP to fill residual waste capacity gap)

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV - excl. residual value	Residual value	NPV - including residual value
High Recycling (High Growth) Pathway 1	-£73.7	£11,015.5	£11,089.2	£242.4	£11,331.6
High Recycling (Low Growth) Pathway 1	£5.3	£8,961.3	£8,956.0	-£1.1	£8,954.9
High Recycling (High Growth) Pathway 2	-£73.7	£11,015.5	£11,089.2	£242.4	£11,331.6
High Recycling (Low Growth) Pathway 2	£5.3	£8,961.3	£8,956.0	-£1.1	£8,954.9

Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

5.6.2.2 Phase 2 Treatment

Processing of the segregated organic waste in anaerobic digestion and open-air windrow as well as the additional separation of mixed recyclate in clean MRFs increases capital cost compared to baseline. As with previous scenarios, it is assumed that the current (2020) facility capacity is unable to accommodate this additional volume. Net operational cash inflow compared to baseline show a reduction i.e. cost increase, as these figures include revenue from gate fees and energy sales, both of which are impacted by significant residual waste volume reductions, as well as facility operating costs and cost of disposal of, or revenue from, outputs. Outputs summarised in Table 87 and Table 88.

.

Table 87: Cost Benefit Analysis (£ million) High Recycling Pathway 1 Segregated Food Waste to AD CHP and Pathway 2 Segregated Food Waste to AD GtG – Treatment Phase 2 – reported as difference from baseline Pathway 0 (2020 infrastructure)

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV - excl. residual value	Residual value	NPV - including residual value
High Recycling (High Growth) Pathway 1	£484.9	-£1,077.6	-£1,562.5	-£137.5	-£1,700.0
High Recycling (Low Growth) Pathway 1	£430.5	-£5,419.4	-£5,849.9	£853.2	-£4,996.7
High Recycling (High Growth) Pathway 2	£521.0	-£1,106.1	-£1,627.1	-£149.1	-£1,776.2
High Recycling (Low Growth) Pathway 2	£448.2	-£5,437.3	-£5,885.5	£848.8	-£5,036.6

Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

Table 88: Cost Benefit Analysis (£ million) High Recycling Pathway 1 Segregated Food Waste to AD CHP and Pathway 2 Segregated Food Waste to AD GtG – Treatment Phase 2 – reported as difference from Pathway 0.2 (2020 infrastructure plus EfW CHP to fill residual waste capacity gap)

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV - excl. residual value	Residual value	NPV - including residual value
High Recycling (High Growth) Pathway 1	-£3,474.0	-£10,939.1	-£7,465.1	-£4,571.7	-£12,036.8
High Recycling (Low Growth) Pathway 1	£202.0	-£7,341.2	-£7,543.1	£706.5	-£6,836.6
High Recycling (High Growth) Pathway 2	-£3,437.9	-£10,967.5	-£7,529.6	-£4,583.4	-£12,113.0
High Recycling (Low Growth) Pathway 2	£219.6	-£7,359.0	-£7,578.7	£702.2	-£6,876.5

Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

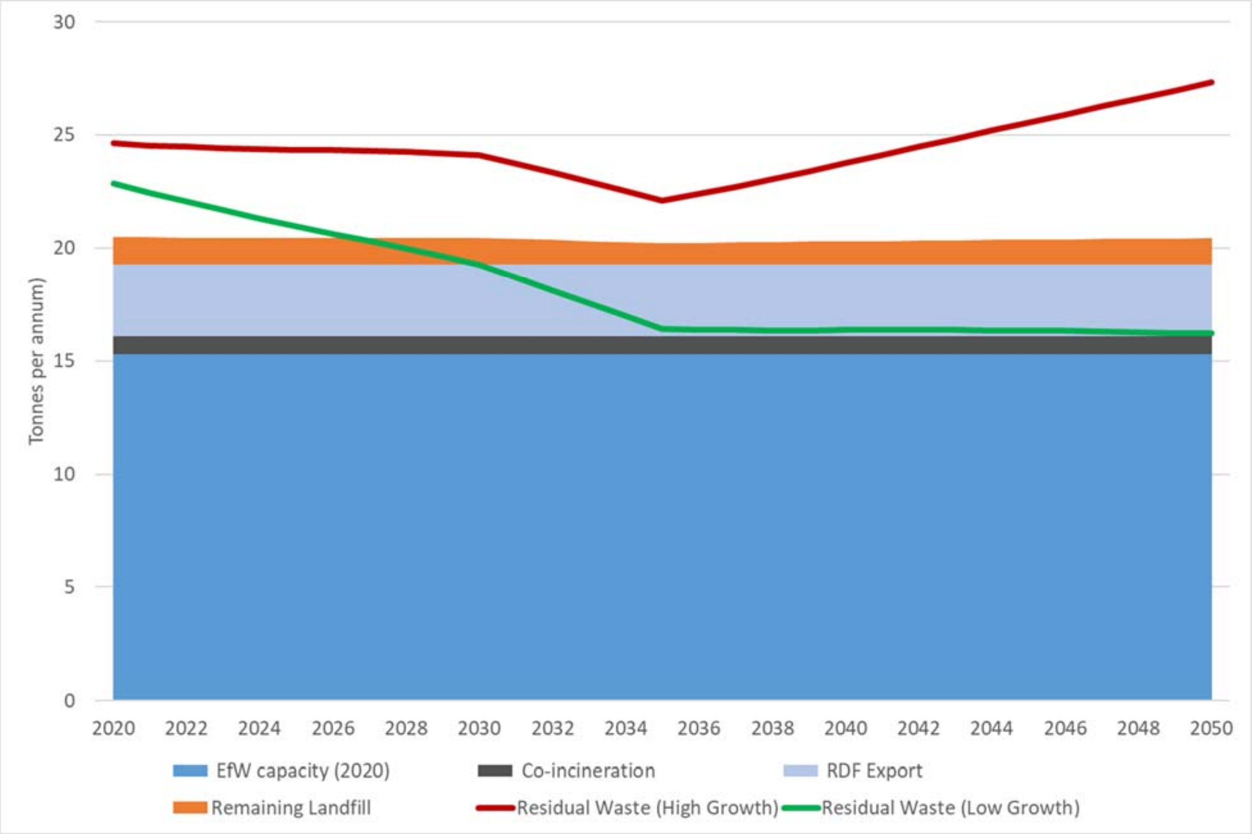
5.6.2.3 Residual Waste Capacity

The residual waste volumes are impacted by both overall waste growth and increase in recycling, with the annual increase in recycling rates having a more significant impact on residual waste volumes than the annual growth assumed for the modelling. Therefore, this scenario increases recycling rates substantially which in turn reduces the amount of residual waste requiring landfill disposal or energy recovery:

- For the high growth model between 2.8 Mt and 8.0 Mt of residual waste volume will need to be landfilled as shown in Figure 33;
- In contrast, in the low growth model, diversion from residual waste to recycling produces an overall decline in residual waste volume, with arisings falling below available capacity by 2030 and potentially creating as much as 3 Mtpa overcapacity based on baseline capacity (4Mt including continued landfilling of non-combustibles).

However, baseline capacity includes an assumption of 3.2 Mtpa RDF to export; making this material available for energy recovery within England would therefore fill the available 2020 capacity with a small excess necessary to accommodate annual plant maintenance and unexpected outages etc. Therefore, export would mainly be used to balance capacity where landfill is not available.

Figure 33: Residual waste capacity (baseline Pathway 0) compared to modelled residual waste arisings - high recycling scenario (showing both high growth and low growth models)



5.6.2.4 Overall CBA

Adding phase 1 to phase 2 gives the overall CBA compared to baseline as follows in Table 89 and Table 90. These show an overall substantial increase in NPV compared to baseline for most pathways, driven by cost savings/revenue increases to the collection authority.

Table 89: Cost Benefit Analysis (£ million) High Recycling Pathway 1 Segregated Food Waste to AD CHP and Pathway 2 Segregated Food Waste to AD GtG – Total Phase 1 + Phase 2 – reported as difference from baseline Pathway 0 (2020 infrastructure)

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV - excl. residual value	Residual value	NPV - including residual value

High Recycling (High Growth) Pathway 1	£411.2	£4,079.4	£3,668.3	£104.9	£3,773.2
High Recycling (Low Growth) Pathway 1	£435.8	£2,282.0	£1,846.2	£852.1	£2,698.4
High Recycling (High Growth) Pathway 2	£447.3	£4,051.0	£3,603.7	£93.3	£3,697.0
High Recycling (Low Growth) Pathway 2	£453.5	£2,264.2	£1,810.7	£847.8	£2,658.5

Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

Table 90: Cost Benefit Analysis (£ million) High Recycling Pathway 1 Segregated Food Waste to AD CHP and Pathway 2 Segregated Food Waste to AD GtG – Total Phase 1 + Phase 2 – reported as difference from Pathway 0.2 (2020 infrastructure plus EfW CHP to fill residual waste capacity gap)

Pathway	Discounted capital cost	Discounted net operational cash inflow	NPV - excl. residual value	Residual value	NPV - including residual value
High Recycling (High Growth) Pathway 1	-£3,547.8	-£65.3	£3,482.5	-£4,329.3	-£846.8
High Recycling (Low Growth) Pathway 1	£207.2	£1,493.5	£1,286.2	£705.5	£1,991.7
High Recycling (High Growth) Pathway 2	-£3,511.6	-£93.7	£3,417.9	-£4,341.0	-£923.0
High Recycling (Low Growth) Pathway 2	£224.9	£1,475.6	£1,250.7	£701.1	£1,951.8

Note: for NPV and Operational Cash Inflow, +ive figures represent increased revenue/reduced cost; -ive reduced revenue/increased cost

5.6.3 Greenhouse Gas Impact

Modelling the greenhouse gas impact of this segregation scenario compared to baseline, shows from 2025 a significant positive impact, including:

- a reduction in GHG generation, reaching 10.8 Mt CO_2e (high growth) to 5.5 Mt CO_2e (low growth) by 2050 (compared to baseline Pathway 0);
- and 8.2 Mt CO_2e (high growth) to 5.3 Mt CO_2e (low growth) by 2050 (compared to Pathway 0.2), which is significantly more than other scenarios.

The main impact is from the reduced GHG impact of dry recyclate recycling and organic waste recycling compared to energy from waste and landfill. Modelled GHG forecasts are given in Table 91 and Table 92.

Table 91: GHG Impact (t CO_2e x1000) High Recycling Pathway 1 Segregated Food Waste to AD CHP and Pathway 2 Segregated Food Waste to AD GtG – reported as difference from baseline Pathway 0 (2020 infrastructure)

Pathway	2025	2030	2035	2040	2045	2050	Total 2020-2050
High Recycling (High Growth) Pathway 1	-1,646.9	-3,719.2	-8,370.9	-9,071.2	-9,840.9	-10,582.3	-194,992.8
High Recycling (Low Growth) Pathway 1	-1,305.0	-2,249.0	-5,573.3	-5,561.7	-5,570.1	-5,508.4	-117,820.5
High Recycling (High Growth) Pathway 2	-1,569.7	-3,553.0	-8,550.5	-9,270.7	-10,064.1	-10,827.7	-197,522.5
High Recycling (Low Growth) Pathway 2	-1,245.6	-2,129.7	-5,692.2	-5,680.7	-5,690.2	-5,627.7	-119,074.9

(note positive figures = GHG impact greater than baseline, negative figures GHG impact less than baseline)

Table 92: GHG Impact (t CO_2e x1000) High Recycling Pathway 1 Segregated Food Waste to AD CHP and Pathway 2 Segregated Food Waste to AD GtG – reported as difference from Pathway 0.2 (2020 infrastructure plus EfW CHP to fill residual waste capacity gap)

Pathway	2025	2030	2035	2040	2045	2050	Total 2020-2050
High Recycling (High Growth) Pathway 1	-793.4	-1,895.5	-6,416.4	-6,916.6	-7,484.0	-8,022.8	-141,598.3
High Recycling (Low Growth) Pathway 1	-707.5	-1,680.7	-5,301.7	-5,304.9	-5,323.5	-5,304.3	-107,504.5
High Recycling (High Growth) Pathway 2	-716.2	-1,729.3	-6,595.9	-7,116.1	-7,707.1	-8,268.2	-144,128.1
High Recycling (Low Growth) Pathway 2	-648.1	-1,561.4	-5,420.7	-5,423.9	-5,443.6	-5,423.6	-108,758.9

(note positive figures = GHG impact greater than baseline, negative figures GHG impact less than baseline)

A5.7 Summary of Results

The modelling of specific segregation pathways has generated some detailed insights into the impact of increased material segregation and subsequent recycling on the overall waste infrastructure in England. In the following the key results have been presented, by

1. comparing the relevant pathway results against ‘Business as Usual’ (Pathway 0), which represents today’s infrastructure mix, and
2. then against Pathway 0.2, which assumes energy recovery infrastructure using more efficient CHP technology is replacing landfill.

Pathway 0.3 models the same increase in EfW infrastructure as pathway 0.2, but assumes future EfW are applying gasification technology to produce renewable gas for the gas grid. This pathway has not been presented for comparison as the technology is currently being commercialised and would not be applicable to the high recycling and plastics to landfill scenarios as gasification is mostly aimed at higher CV waste streams created by removal of organics and non-combustibles.

In the following we are presenting how the individual pathway scenarios compare against the initial baseline of ‘business as usual’ in all key variable modelled for this waste infrastructure option assessment to establish ‘best in class’ for each measure and draw conclusions on the preferred options for future waste infrastructure in the England.

5.7.1 Greenhouse Gas Impact

Figure 34 shows that in comparison to baseline Pathway 0 (i.e. 2020 infrastructure with no change over the forecast period) all of the modelled scenarios show environmental benefits in terms of tCO_2e avoided, with the high recycling segregation scenarios having the most impact.

The modelling also suggests that the environmental impact can be increased if residual plastics are sent to landfill (Plastic Waste P2). However, the long term environmental effects of landfilling plastics and the potential to mine and utilise the carbon content of these plastics as resources in the future has not been covered in this study.

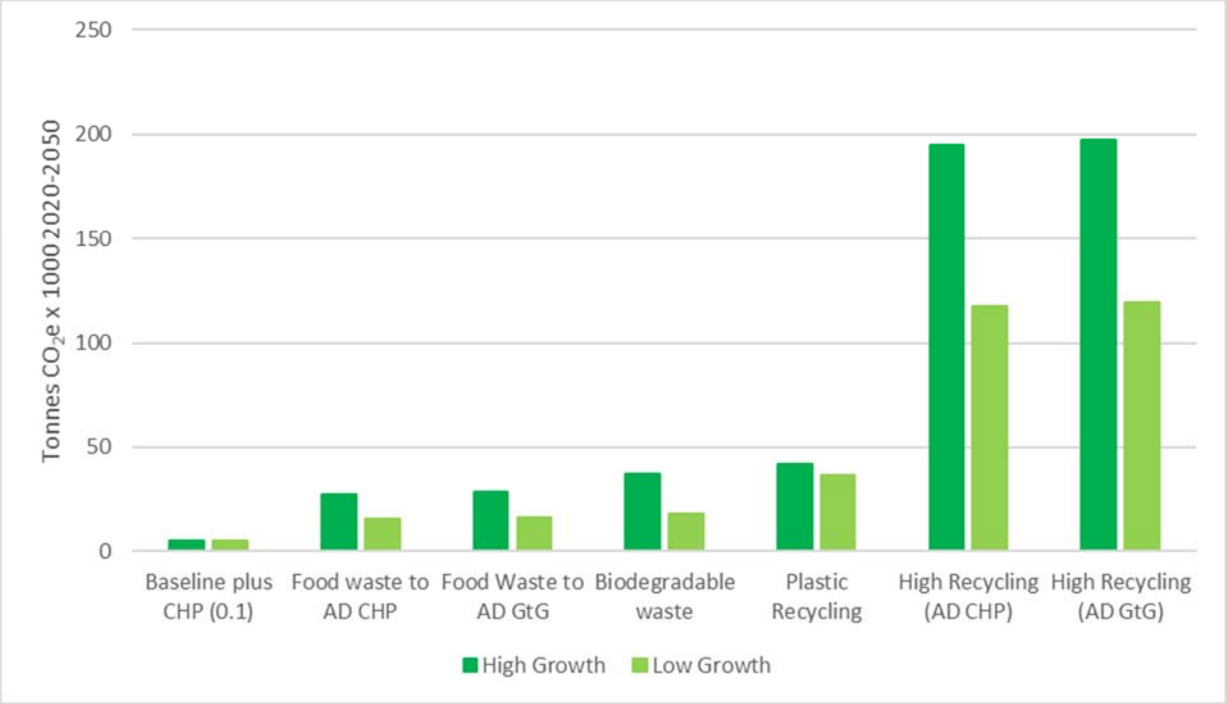
Therefore, the modelling suggests that implementing collection infrastructure to increase segregation of materials for recycling is a key component to decarbonise the waste industry.

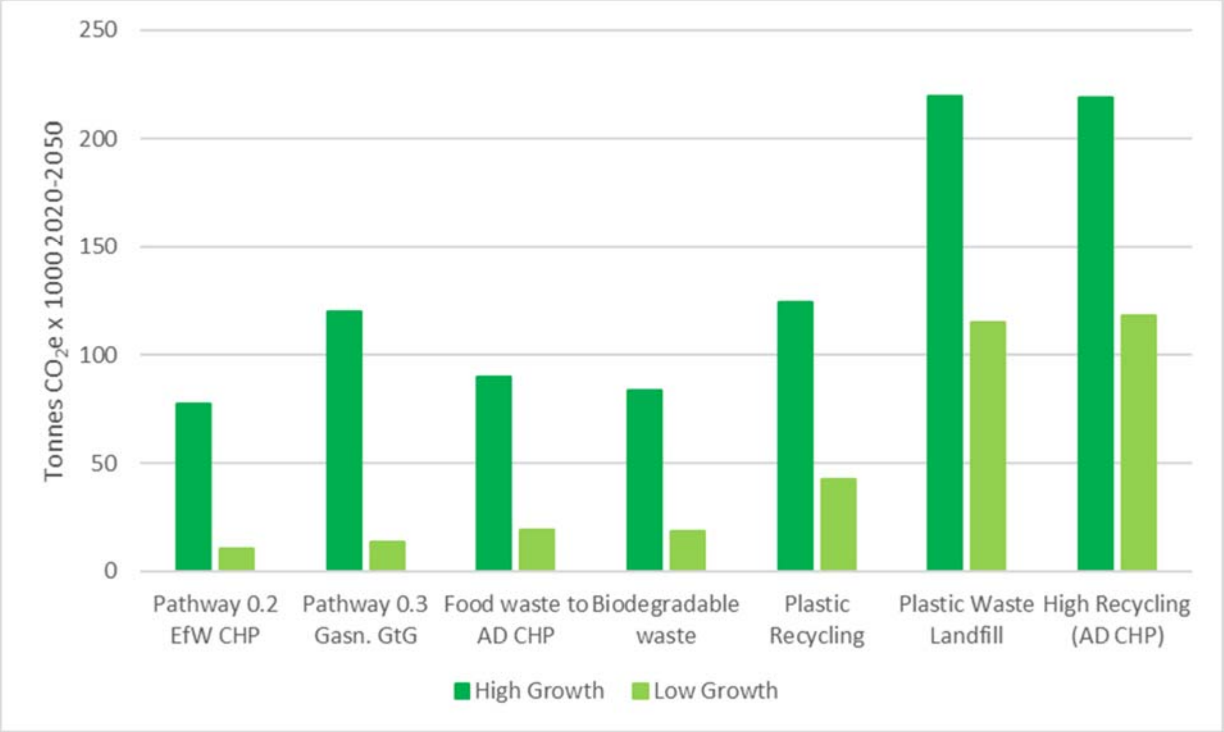
5.7.2 Energy Production

Figure 35 illustrates that energy generation from waste is one of the factors contributing to carbon savings, but it is not the dominant element. The energy generation of specific segregation scenarios shows that the amount of energy generated in each scenario is mainly driven by the energy produced via residual waste recovery. The amount of additional energy recovered depends on:

- energy recovery capacity from segregated materials, such as food waste to AD;
- and the impact of the material segregation on the CV in the residual waste i.e. plastics removal.

Figure 34: Difference in GHG impact (as t CO_2e) for segregation scenarios modelled against baseline Pathway 0 i) for those segregation scenarios modelled with residual pathway 0 i.e. 2020 infrastructure ii) for those segregation scenarios modelled against residual waste pathway diversion from landfill to EfW CHP i.e. Pathway 0.2

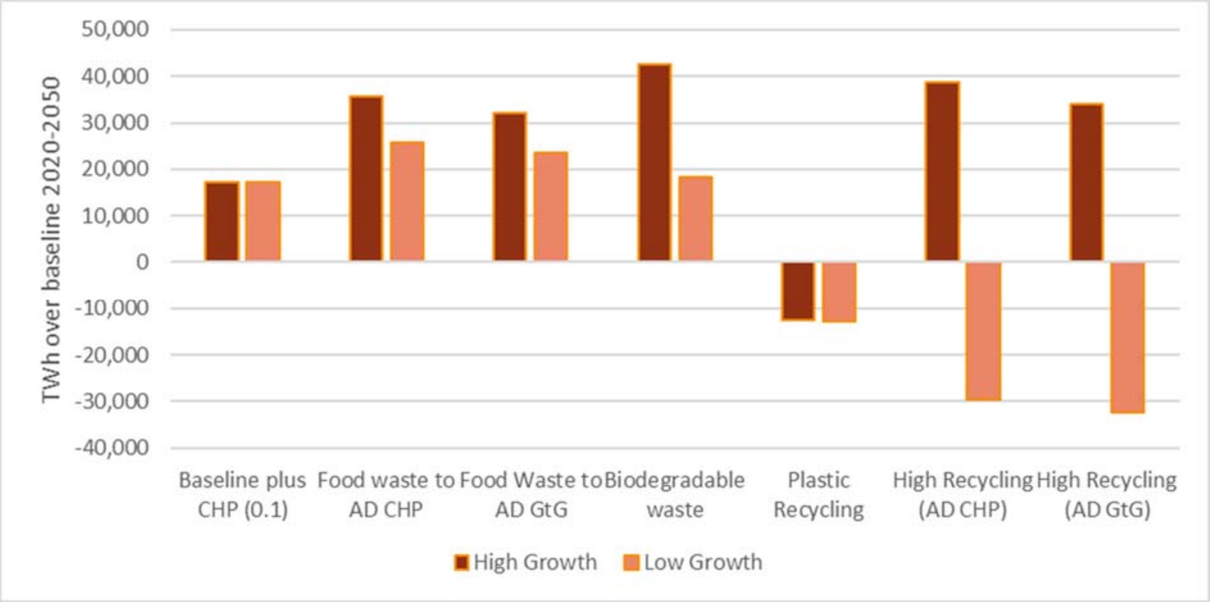


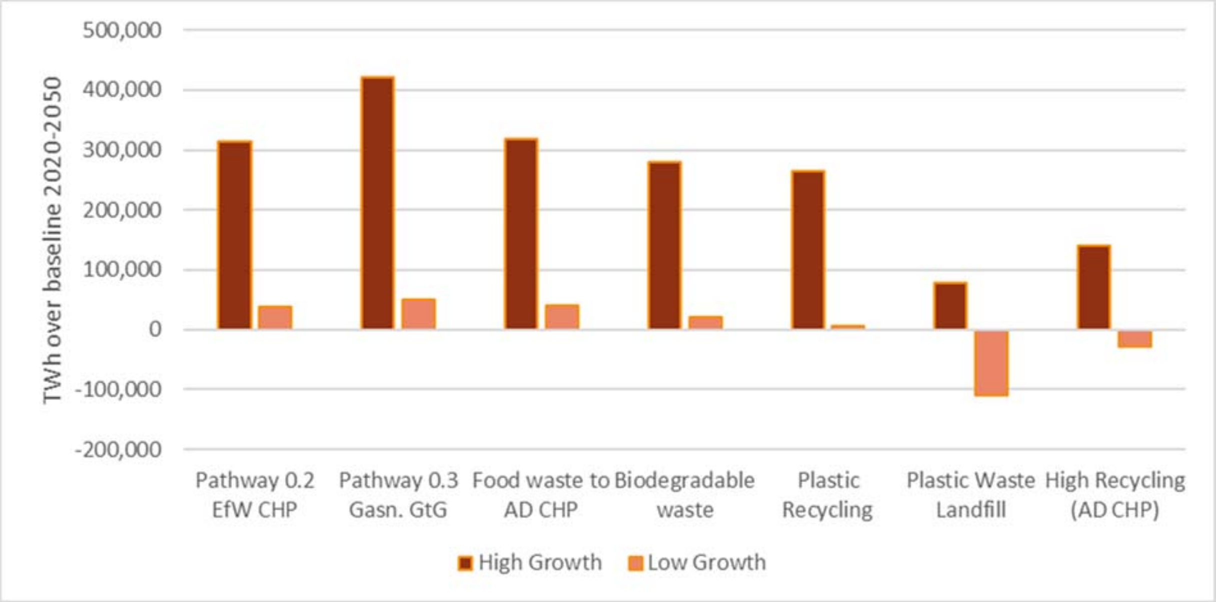


The results show that with today's EfW infrastructure, the pathways focussing on organic material segregation at source have the most significant potential for energy generation depending on waste growth and composition.

In addition, the reduction in residual waste volume and change in CV for all pathways, has a pronounced impact on energy production, showing largest reductions to baseline where both these factors take effect. The removal of plastics from the residual stream as well as increasing overall recycling can have a significant impact on energy from waste as a renewable energy generation option.

Figure 35: Difference in Energy production (as GWh) for segregation scenarios modelled against baseline Pathway 0 i) for those segregation scenarios modelled with residual Pathway 0 i.e. 2020 infrastructure ii) for those segregation scenarios modelled against residual waste pathway diversion from landfill to EfW CHP i.e. Pathway 0.2

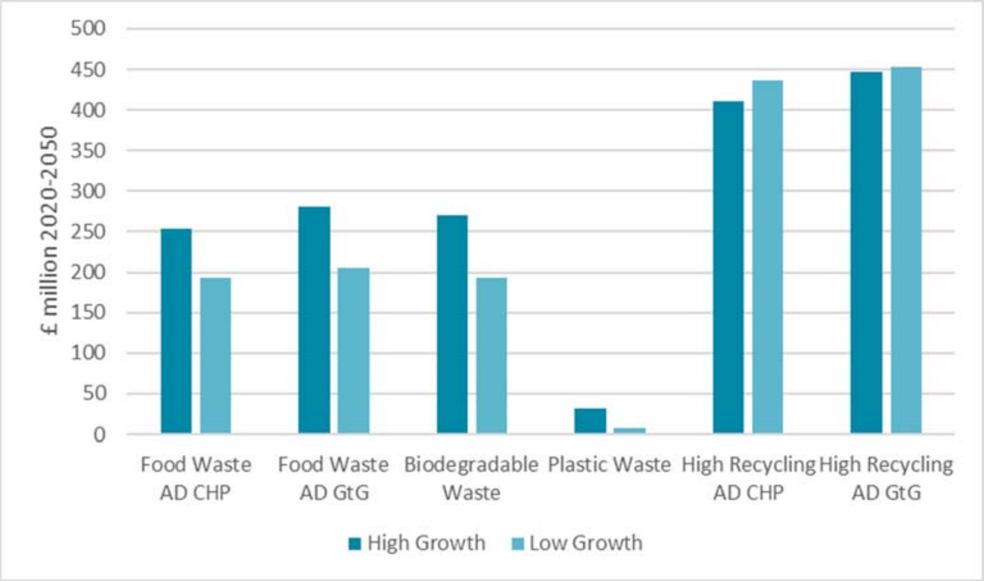


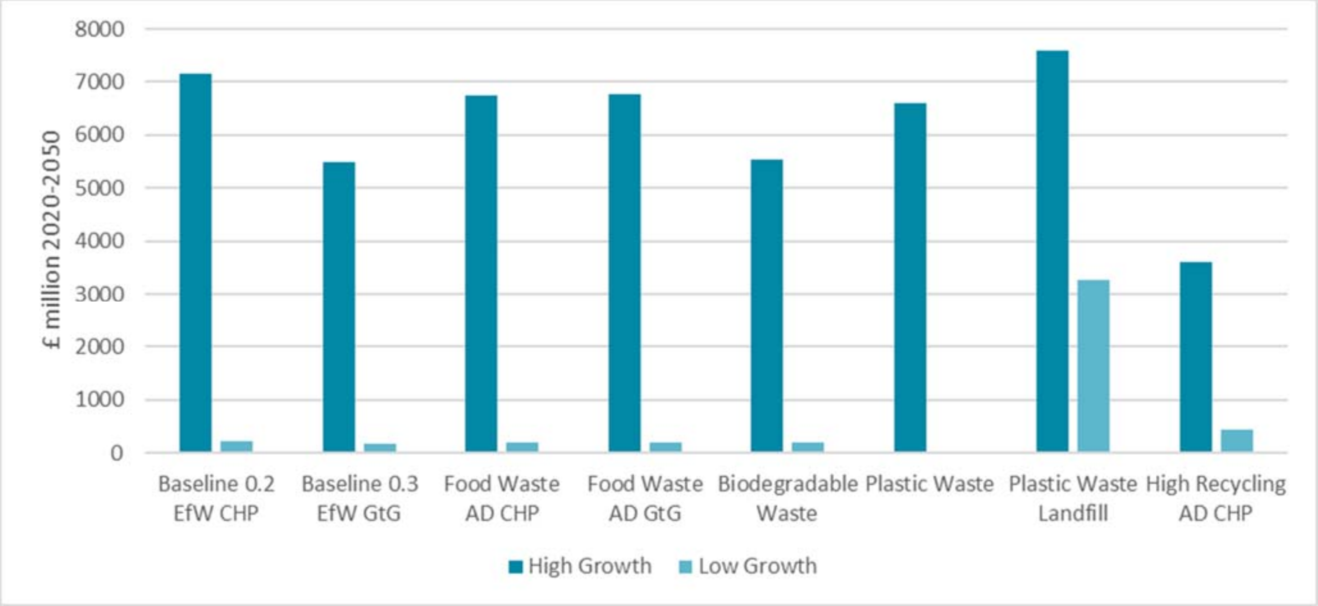


5.7.3 Capital Cost

For each segregation scenario and modelled infrastructure pathway, volumes of key wastes generated have been converted into the number of new facilities required to process that waste. The additional infrastructure requirement for each pathway are driven by increased segregation volumes of particular waste streams, or by overall waste growth as well as by changes in waste composition and energy content of waste (CV). Figure 36 summarises the overall discounted capital cost figures generated for the 2020-2050 forecast period. These are based on today's average capital cost figures per facility type in England, where representative data could be sourced through research and discussions with operators and technology providers. However, the actual capital cost will very for individual facilities and in different geographies.

Figure 36: capital cost per scenario difference from baseline Pathway 0 i) for those segregation scenarios modelled with residual Pathway 0 i.e. 2020 infrastructure ii) for those segregation scenarios modelled against residual waste pathway diversion from landfill to EfW CHP i.e. Pathway 0.2





Compared to baseline Pathway 0, most segregation options using the 2020 baseline infrastructure (Pathway 0) to treat the residual waste generated, show capital spend over the forecast period of up to £450 million, primarily due to the need for AD capacity for organic waste segregation options, and AD and MRF capacity for the high recycling option. In addition, most segregation options using diversion from landfill to EfW with CHP for residual waste treatment (Pathway0.2) peak with capital sped at around £7 billion, with segregation scenarios requiring reduced capital spend as the residual waste volume reduces compared to Pathway 0.2.

Only the plastics waste to landfill scenario shows significantly different results, in that although residual waste recovery volume is significantly reduced, considerable investment in intermediate processing is required to remove the plastics from residual waste for subsequent landfilling.

It needs to be noted that the need for new capacity has been driven by market need i.e. the modelling has assumed that new plants are only being built when the national capacity gap is more than three times the plant capacity. This assumption is commonly used by investors to avoid over-capacity and accommodates the fact that the existing infrastructure and export market together could absorb up to 10% more waste than normally processed in the facilities when waste is available at economic gate fees.

5.7.4 Net Present Value

Net Present Value (NPV) is calculated from net operational cash inflow (made up from operational incomes such as that from energy sales and gate fees, minus costs) minus the discounted capital cost of the new infrastructure required. For the figures presented, residual value of the infrastructure operational at the end of the forecast period is added. Figure 37 shows the CBA modelling results per scenario as NPV including residual value.

The NPV results show that:

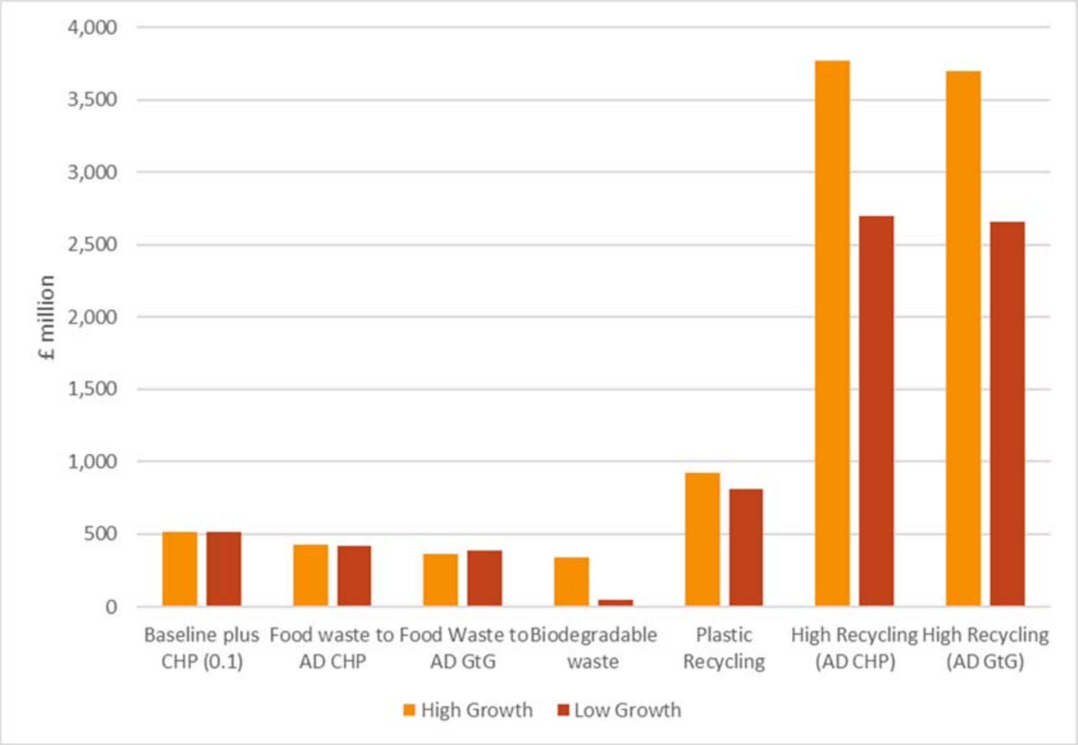
- All segregation scenarios show positive financial against baseline Pathway 0, peaking with high recycling and plastic waste segregation at kerbside;
- This pattern is replicated against the landfill diversion of EfW CHP pathway (Pathway 0.2) except for plastic waste to landfill, which for the high growth model generates a negative NPV.

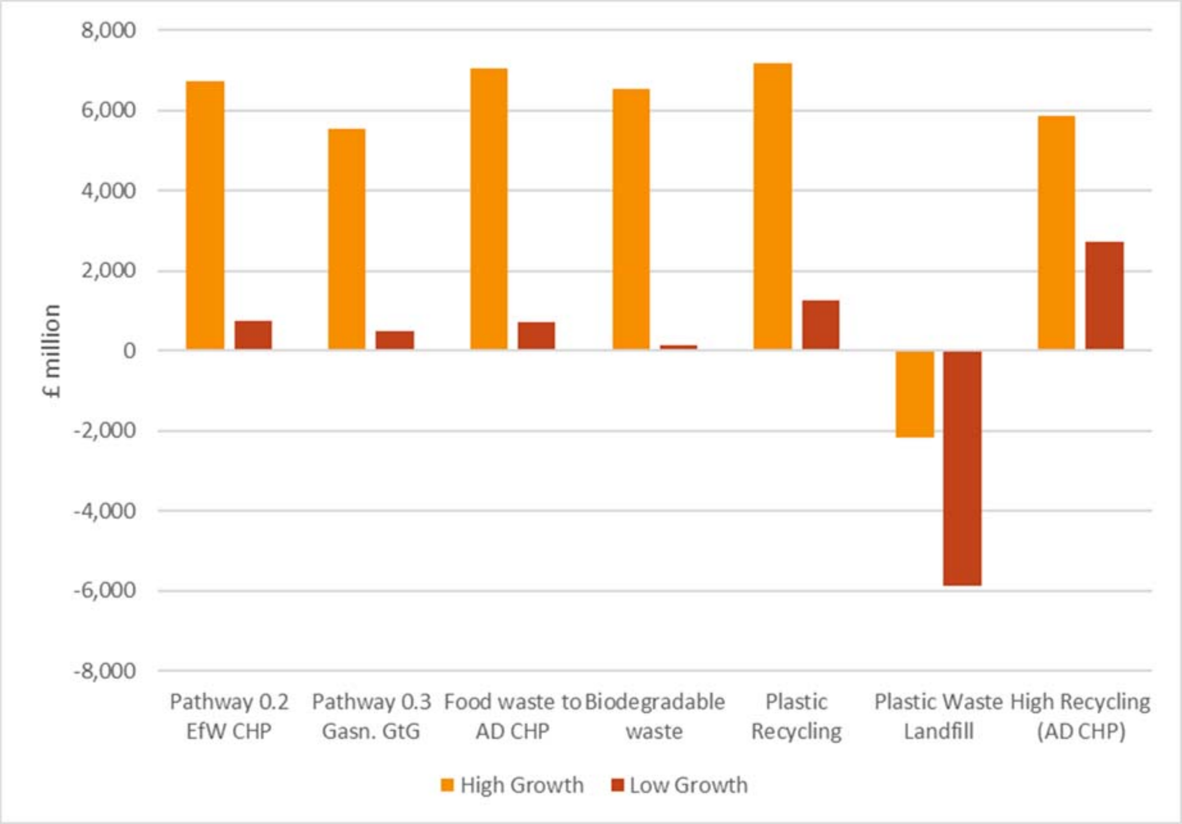
To reiterate, the modelling has not included the costs of industrial re-processing to produce a saleable product i.e. the re-use of plastics, glass, metals etc in industrial processes as secondary materials.

Comparing segregation scenarios using residual waste Pathway 0.2 i.e. diversion from landfill to EfW with CHP, only the residual plastics to landfill pathway provides a negative NPV compared to baseline Pathway 0. This is due to the need for intermediate treatment to remove plastics from residual waste, which increases the capital spend and negates the savings made by reducing energy from waste infrastructure spending.

Therefore, the financially advantages pathways are promoting recycling and lower energy from waste infrastructure, when material segregation takes place at source and doesn’t require extensive residual waste processing infrastructure.

Figure 37: Difference in Net Present value (as £ million) for segregation scenarios modelled against baseline Pathway 0 i) for those segregation scenarios modelled with residual Pathway 0 i.e. 2020 infrastructure ii) for those segregation scenarios modelled against residual waste pathway diversion from landfill to EfW CHP i.e. Pathway 0.2





5.7.5 GHG impact per £ NPV

The modelling has shown that each of the selected waste infrastructure pathways requires investment in new waste infrastructure to deliver the pathways scenarios. Therefore, to measure value for money, the environmental impact of difference pathways has been calculated per £ of NPV (including residual value) and compared to the respective baselines. Figure 39 shows that all segregation options show beneficial results for those scenarios modelled against baseline Pathway 0, with organic waste segregation showing the best CO_2e

to £ efficiency. Similarly, for those options modelled with residual pathway with diversion from landfill to EfW with CHP (i.e. Pathway 0.2), the high recycling options offer significant GHG impact per £ NPV with only plastics to landfill giving a negative ratio.

As indicated in section 5.7.4, NPV including residual value figures compared to baseline, are particularly low for biodegradable waste segregation options employing the low growth model. This produces abnormally high and unrepresentative GHG avoided per £ NPV figures in Figure 39 for this particular scenario.

This impact is also shown in the charts in Figure 38 presenting GHG avoided in relation to NPV including residual value. Working on the basis that high GHG avoided and high positive NPV difference gives the best return, the high recycling scenarios give best results with both pathways, then plastic waste then organic waste options. Although plastics to landfill does give a significant GHG benefit, its higher cost compared to baseline detracts from this options in terms of return on environmental impact.

Figure 38: Central growth (i.e. average high growth and low grow) Avoided CO_2e against NPV inc residual value, difference to baseline Pathway 0 i) for those segregation scenarios modelled with residual Pathway 0 i.e. 2020 infrastructure ii) for those segregation scenarios modelled against residual waste pathway diversion from landfill to EfW CHP i.e. Pathway 0.2

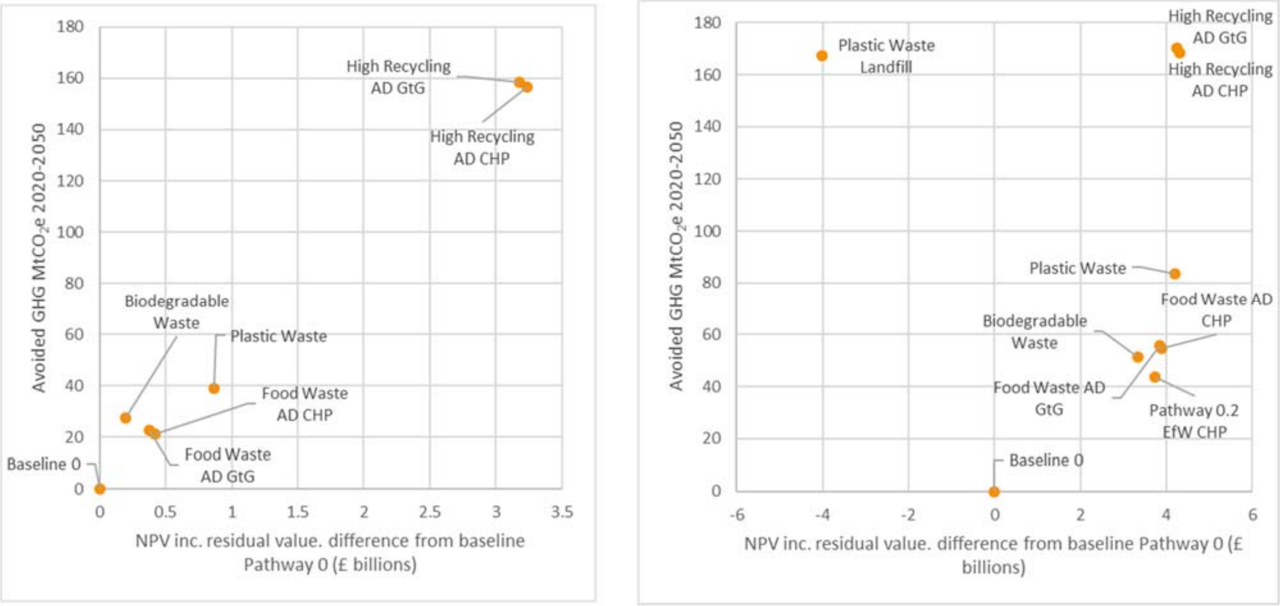
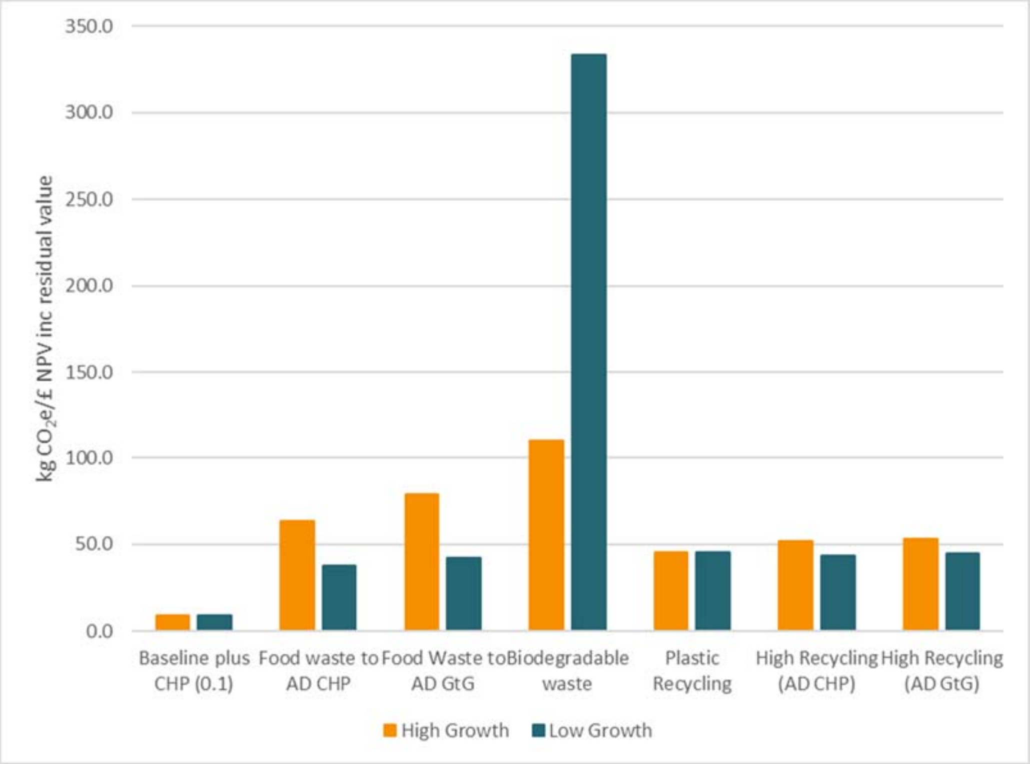
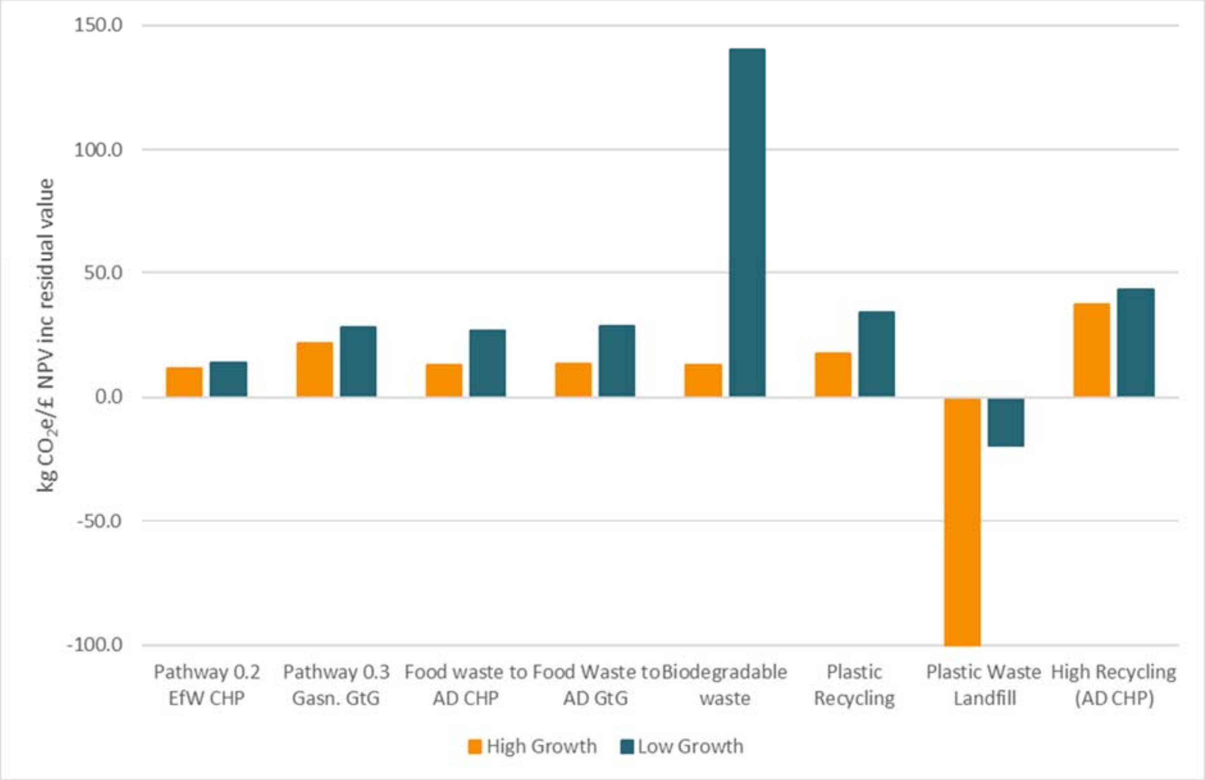


Figure 39: Difference in kg CO_2e/£ million for segregation scenarios modelled against baseline Pathway 0 i) for those segregation scenarios modelled with residual Pathway 0 i.e. 2020 infrastructure ii) for those segregation scenarios modelled against residual waste pathway diversion from landfill to EfW CHP i.e. Pathway 0.2





A6. Model Sensitivities

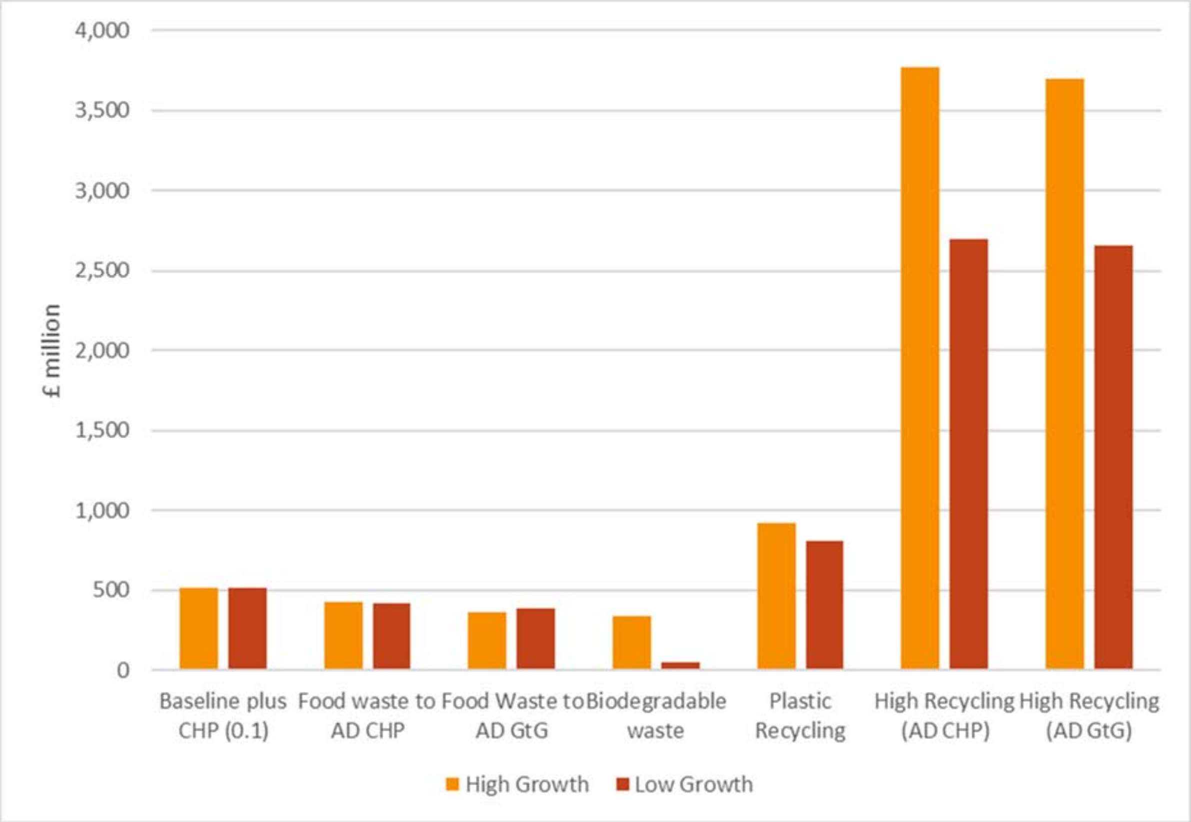
To ascertain the sensitivity of the waste flow and CBA models to changes in key model variables, a range were tested to measure how these changes were likely to impact on the overall results and conclusions of this study. NPV including residual value, was selected as the key output upon which sensitivities were measured.

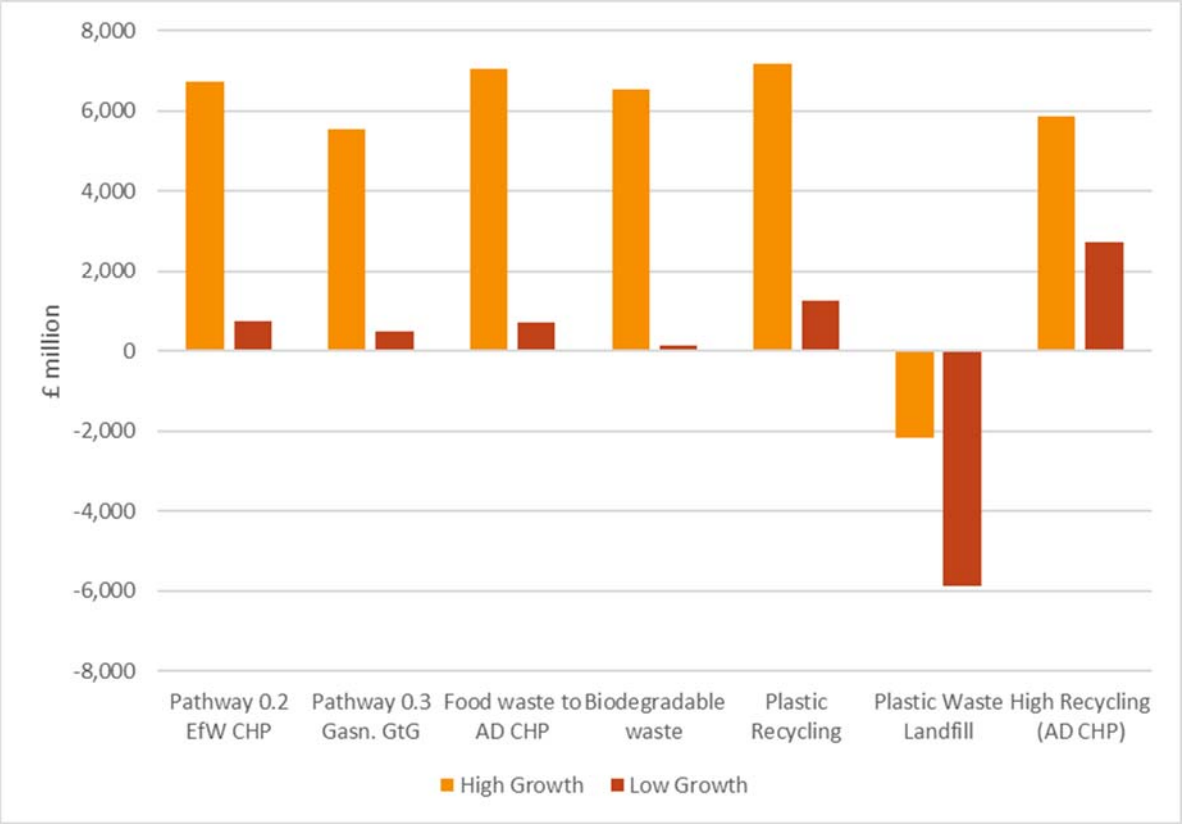
A6.1 Waste Growth

In terms of the waste flow model, the variable expected to have the most significant impact on the overall results is waste growth. As explained in Appendix A4, there is little data upon which waste growth for 2020-2050 can be forecast, particularly for commercial and industrial waste. Decoupling rates to mitigate population and economic growth factors, were selected to provide low (i.e. waste minimisation scenario) and high (economic growth scenario) growth options, with actual expected growth to lie somewhere between the two. Results for both models have been presented extensively in this report.

Focusing on NPV including residual value as a key output, Figure 40 compares NPV results for all scenarios, and each residual waste pathway tested. Although there are differences in absolute value between the two growth models, the ranking of best/worst scenarios for high and low growth models produces very similar results, particularly against baseline pathway 0. It is only in plastic to landfill that the low growth model result shows a significant divergence to the high growth.

Figure 40: NPV including residual value, all scenarios, comparing high and low growth i) residual waste pathway as 2020 infrastructure, ii) residual waste scenario with landfill diversion to EfW with CHP





A6.2 CBA sensitivities

A range of key variables were tested to identify significant differences in the output NPV including residual value, as listed in Table 93. Differences in a number of variables such as modelled operational costs and capital costs, appeared to have little overall impact on final results. However, three key variables showed significant impact – recyclate material prices, kerbside collection costs and selection of decentralised as opposed to strategic infrastructure types.

Table 93: Variation in NPV including residual value, on adjustment of key CBA variables

Tested Variable	**Variation**	**Deviation from Reported Results (*)**	
		High Growth	**Low Growth**
Reported results	0%	100%	100%
Max to Min collection costs	See below	22%	36%
Higher C&I collection costs	+10%	106%	105%
Lower C&I collection costs	-10%	94%	95%
Increased capital cost	+10%	101%	100%
Decreased capital cost	-10%	99%	100%
Increased operations cost	+10%	110%	108%
Decreased operations cost	-10%	90%	92%
Increased gate fees	+10%	98%	100%
Decreased gate fees	-10%	102%	100%

Tested Variable	Variation	Deviation from Reported Results (*)	
		High Growth	Low Growth
Max to Min Materials Prices	See below	197%	173%
Increased energy Revenue	+10%	95%	96%
Decreased energy Revenue	-10%	105%	104%
Decentralised capacities	See below	139%	126%

(*) averaged across all scenarios

The results obtained for sensitive variables are explained in more detail:

6.2.1 Materials Prices

Modelled material prices were based upon minimum and maximum prices over the last 3 years as reported in WRAPs Material Price Index. There has been considerable volatility in the market for recyclates in the last few years, and with a high dependence upon overseas markets, this is likely to continue into the forecast period unless significant home markets are developed, and until supply and demand is more in balance. As shown in Table 94, there has been considerable variation in material prices over the last 3 years giving an average over all the materials modelled of over 100%. As shown originally in Table 93, variation in recyclate pricing appears to have a significant impact on the resulting NPV figure of around 1.7 to 1.9% per 1% change in the material pricing. Such price variations have most impact on those scenarios where income from recyclates has most positive impact, for instance plastics recycling and high recycling scenarios.

Table 94: Material sales value (2017 values) Source: WRAP

	Max price	Min price	Difference Max to Min	Difference as % max
Mixed paper and card	£120	£25	£95	79%
Film	£380	£160	£220	58%
Dense plastics	£150	£35	£115	77%
Mixed glass	£25	-£25	£50	200%
Clear glass	£30	-£5	£35	117%
Amber glass	£20	-£5	£25	125%
Green glass	£20	£0	£20	100%
Non-ferrous metal	£1,200	£450	£750	63%
Ferrous metal	£175	£5	£170	97%
Average change				102%

6.2.2 Collection Costs

WRAP published collection costs vary considerably depending upon the material collected, the frequency of collection, the number of recyclate streams collected and whether they are collected separately or co-mingled (and whether the co-mingled streams contain glass or not). Other factors include whether garden waste and food are collected separately, which materials are co-collected by a single vehicle, and finally whether the collections are undertaken in an urban or rural environment.

In modelling collection costs, producing an accurate model reflecting collection practises for England as a whole, taking into account the above possible variations, was out of scope and not attempted. A range of costs taken from the WRAP data were applied, building maximum and minimum values for each.

As shown in Table 93, variation of collection cost from the maximum to minimum per material type, has a considerable impact on the resultant NPV. Modelled maximum and minimum collection costs varied by 56% for dry recyclates and food waste, whether or not food waste was also collected separately, and residual waste collection by 31% on average. Therefore 1% change in collection costs produced around -1.6% change in NPV including residual value

6.2.3 Decentralised facilities

The model was constructed with a range of facility sizes, classed as either strategic (centralised) or decentralised, the main difference being the centralised facilities usually had a higher capacity. Costs, gate fees and energy efficiencies were specified per facility and facility type, as summarised in Table 95. In general, centralised facilities were modelled with better energy, capital and operational cost efficiencies than decentralised facilities.

Table 95: Assumed capacities, centralised and decentralised facilities

Facility Type	Centralised Facility: capacity	Decentralised facility: capacity
Landfill	600,000	40,000
Energy from Waste	350,000	100,000
Gasification	350,000	150,000
Interim Residual	300,000	100,000
Wet AD	160,000	45,000
MRF	150,000	150,000
WTS	150,000	150,000

The results shown in this report assume centralised facilities are used. As shown in Table 93, selecting decentralised facilities instead has a moderate impact on overall NPV.

6.2.4 Other variables

Other variables modelled had only small impacts on the overall NPV

A6.3 Relative Results and Ranking

Despite the significant impact of key variables (material prices, collection costs and the use of decentralised facilities) on overall NPV including residual value, these changes had only minor impact on the relative results of the scenarios modelled, and of their ranking from lowest NPV to highest NPV, and therefore are anticipated to have a low impact on the conclusions of this study (figures presented for high growth model only). This is shown in Table 96. For instance, in all sensitivity tests, plastics to landfill was the most expensive option, irrespective of the actual NPV reported. In terms of cheapest options, plastics and high recycling options appear to be ranked least expensive in all sensitivity tests, although absolute ranking did vary from one sensitivity to the next. Only with low recyclate prices did the high recycling options become less advantageous, with, in this case, organic waste options showing the highest ranking in terms of optimum NPV.

Table 96: Ranking (ranked from 1=lowest to 17=highest where the higher the NPV, the better the investment potential) of NPV including residual value results with changes in key variables (high growth outputs)

Pathway	Reported Results	min material prices	min collection costs	decentralised facilities	Reported Results Low Growth
Baseline Pathway 0	2	5	2	5	2
Pathway 0.1	6	11	3	9	8
Pathway 0.2	14	15	11	2	11
Pathway 0.3	12	12	8	4	7
Food Segregation Residual Pathway 0 Organic Pathway 1	5	10	5	12	6
Food Segregation Residual Pathway 0.2 Organic Pathway 1	16	17	17	7	10
Food Segregation Residual Pathway 0 Organic Pathway 2	4	8	4	11	5
Food Segregation Residual Pathway 0.2 Organic Pathway 2	15	16	16	6	9
Biodegradables Segregation Residual Pathway 0	3	6	7	10	3
Biodegradables Segregation Residual Pathway 0.2	13	14	13	8	4
Plastic Segregation Residual Pathway 0 Plastics pathway 1	7	4	6	13	12
Plastic Segregation Pathway 0.2 Plastics Pathway 1	17	13	12	3	13
Plastic Segregation Residual Pathway 0.2 Plastics Pathway 2	1	1	1	1	1
High Recycling Residual Pathway 0 Organic Pathway 1	9	3	10	17	16
High Recycling Residual Pathway 0.2 Organic Pathway 1	11	9	15	15	17
High Recycling Residual Pathway 0 Organic Pathway 2	8	2	9	16	14
High Recycling Residual Pathway 0.2 Organic Pathway 2	10	7	14	14	15

Unfortunately, future recyclate prices are very difficult to predict. The market has been volatile in recent years, and the impact of the Chinese import restrictions is likely to push prices of key recyclates down in the short to medium term, particularly for plastics and paper, which is likely to reduce the NPV advantages of the plastics and high recycling scenarios compared to those segregating organic wastes.

A7. References

[1] A. Sigg, "'Mass Burn' is Advanced Conversion Technology," 2014.

[2] DEFRA, "Incineration of Municipal Solid Waste," 2013.

[3] A. Main and T. Maghon, "Concepts and experiences for higher plant efficiency with modern advanced boiler and incineration technology," 2010.

[4] "Royal Dahlman." [Online]. Available: http://www.royaldahlman.com/renewable/home/gasification/.

[5] "Advanced Plasma Power." [Online]. Available: http://advancedplasmapower.com/.

[6] Zero Waste Scotland, "Plastics to Oil Products," 2013.

[7] Defra WIDP, "Email (31-10-18)." 2017.

[8] DECC, "Assessment of the Costs, Performance, and Characteristics of UK Heat Networks," 2015.

[9] Waste 2 Go, "Waste Profiling," 2014.

[10] BEIS, "Digest of United Kingdom energy statistics 2016," 2016.

[11] DEFRA, "Guidance on applying the waste hierarchy," 2011.

[12] WRAP, "Environmental benefits of recycling," 2010.

[13] DG Environment, "Plastic Waste: Ecological and Human Health Impacts," 2011.

[14] D. R. . et al. Teuten, E.L., Saquing, J.M., Knappe, "Transport and release of chemicals from plastics to the environment and to wildlife," *Philos. Trans. R. Soc. B 3642027-2045*, 2009.

[15] P. Jones, "Landfill mining: Is this the next big thing in recycling," 2017. [Online]. Available: https://www.weforum.org/agenda/2017/06/landfill-mining-recycling-eurelco/. [Accessed: 04-Apr-2018].

[16] Ku Leuven, "EP votes yes to add ELFM to Landfill Directive," 2017. [Online]. Available: http://kuleuven.sim2.be/ep-votes-yes-add-elfm-landfill-directive/. [Accessed: 04-Apr-2018].

[17] K. Zennaro, "Review 2016: Biomethane-to-grid is heating up," 2016. [Online]. Available: https://www.r-e-a.net/blog/review-2016-biomethane-to-grid-is-heating-up-14-06-2016. [Accessed: 05-Apr-2018].

[18] Gas Networks Ireland, "Natural gas in transport," 2016.

[19] National Grid, "The future of gas," 2016.

[20] European Biogas Association, "Biomethane in transport," 2016.

[21] University of Oxford, "The prospects for natural gas as a transport fuel in Europe," 2014.

[22] IRENA, "Biogas for road vehicles: Technology brief," 2017.

[23] LetsRecycle.com, "Welsh recycling rate 52%, finds Eunomia," 2017. [Online]. Available: https://www.letsrecycle.com/news/latest-news/welsh-recycling-rate-52-finds-eunomia/. [Accessed: 05-Apr-2018].

[24] Welsh Government, "Towards Zero Waste," 2015.

[25] Zero Waste Scotland, "Zero Waste Scotland welcomes recycling progress," 2017. .

[26] Zero Waste Europe, "Zero waste to landfill and/or landfill bans: false paths to a circular economy," 2015.

[27] European Environment Agency, “Municipal Waste Management in the Netherlands,” 2016.

[28] WRAP, “Local Authority Waste and Recycling Information Portal.” [Online]. Available: http://laportal.wrap.org.uk/. [Accessed: 04-Apr-2018].

[29] Guus van den Berghe, “Presentation: Expected Energy from Waste Capacity in the Netherlands,” 2014.

[30] Royal Dutch Waste Management Association, “Household waste seperation in NL (Presenation by Erik de Baedts),” 2014.

[31] Umwelt Bundesamt, “Waste Regulations,” 2014. [Online]. Available: https://www.umweltbundesamt.de/en/topics/waste-resources/waste-management/waste-regulations. [Accessed: 05-Apr-2018].

[32] Umwelt Bundesamt, “Recycling rates of the most important types of waste,” 2017. [Online]. Available: https://www.umweltbundesamt.de/daten/ressourcen-abfall/verwertungsquoten-der-wichtigsten-abfallarten. [Accessed: 05-Apr-2018].

[33] Wohindamit, “Abfall - Recycling statt Verbrennung,” 2017. [Online]. Available: http://www.wohindamit.de/recycling-statt-verbrennen/. [Accessed: 05-Apr-2018].

[34] S. Cave, “Recycling in Germany,” 2017.

[35] Federal Ministry for the Environment Nature Conservation and Nuclear Safety, “General information waste management.” [Online]. Available: www.bmub.bund.de/en/topics/water-waste-soil/waste-management/general-information/. [Accessed: 05-Apr-2018].

[36] Recycling und Entsorgung, “The pressure will come from the East,” 2017. [Online]. Available: https://www.euwid-recycling.de/news/maerkte/einzelansicht/Artikel/der-druck-wird-vom-osten-kommen.html. [Accessed: 05-Apr-2018].

[37] UN Sustainable Development Commission, “National Report: Germany - Waste,” 2010.

[38] European Environment Agency, “Municipal waste management in Germany,” 2013.

[39] Umwelt Bundesamt, “Packaging waste,” 2017. [Online]. Available: https://www.umweltbundesamt.de/daten/ressourcen-abfall/verwertung-entsorgung-ausgewaehlter-abfallarten/verpackungsabfaelle#textpart-1. [Accessed: 05-Apr-2018].

[40] M. Nelles, J. Grunes, and G. Morscheck, “Waste Management in Germany - Development to a Sustainable Circular Economy,” 2016.

[41] “Grenzuberschreitende Abfallverbringung,” 2017. [Online]. Available: http://www.bmub.bund.de/fileadmin/Daten_BMU/Bilder_Infografiken/abfallverbringung_ausland.jpg. [Accessed: 05-Apr-2018].

[42] European Commission, “Clean Energy For All Europeans,” 2016.

[43] UK Parliament, “The 2020 Targets.” [Online]. Available: https://publications.parliament.uk/pa/cm201617/cmselect/cmenergy/173/17305.htm. [Accessed: 05-Apr-2018].

[44] Neste, “The proposed Renewable Energy Directive for 2021 through 2030 by the European Commission introduces aviation and marine sectors to contribute to the climate effort,” 2016. [Online]. Available: https://www.neste.com/en/proposed-renewable-energy-directive-2021-through-2030-european-commission-introduces-aviation-and. [Accessed: 05-Apr-2018].

[45] Zero Waste Europe, “Why the current Renewable Energy proposal is flawed, and how to fix it,” 2017. [Online]. Available: https://www.zerowasteeurope.eu/2017/08/why-the-current-renewable-energy-

proposal-is-flawed-and-how-to-fix-it/. [Accessed: 05-Apr-2018].

[46] CIWM, “Circular Economy Package: Council Agrees 55% Recycling Target by 2025,” 2017. [Online]. Available: https://ciwm-journal.co.uk/circular-economy-package-council-agrees-55-recycling-target-2025/. [Accessed: 05-Apr-2018].

[47] DEFRA, “Clean Growth Strategy,” 2017.

[48] Carbon Brief, “In-depth: How the ‘Clean Growth Strategy’ hopes to deliver UK climate goals,” 2017. [Online]. Available: https://www.carbonbrief.org/in-depth-how-the-clean-growth-strategy-hopes-to-deliver-uk-climate-goals. [Accessed: 05-Apr-2018].

[49] MRW, “Government waste strategy to ’make the UK a world leader,” 2017. [Online]. Available: https://www.mrw.co.uk/latest/government-waste-strategy-to-make-the-uk-a-world-leader/10024329.article. [Accessed: 05-Apr-2018].

[50] HM Government, “Industrial Strategy,” 2017.

[51] Environment Agency, “Environment Agency charge proposals from April 2018,” 2017. [Online]. Available: https://consult.environment-agency.gov.uk/engagement/environmentagency-charging-proposals-fromapril2018/. [Accessed: 05-Apr-2018].

[52] DEFRA, “WasteDataFlow user survey in England - results,” 2017.

[53] Jacobs, “Commercial and Industrial Waste Survey 2009,” 2011.

[54] Environment Agency, “Waste Data Interrogator, October 2016,” 2016. [Online]. Available: https://data.gov.uk/dataset/waste-data-interrogator-2015. [Accessed: 04-Apr-2018].

[55] Environment Agency, “Waste Management Information for England,” 2016.

[56] Environment Agency, “International Waste Shipments exported from England,” 2016. [Online]. Available: https://data.gov.uk/dataset/international-waste-shipments-exported-from-england. [Accessed: 04-Apr-2018].

[57] Environment Agency, “National Packaging Waste Database,” 2016. [Online]. Available: https://npwd.environment-agency.gov.uk/Public/PublicSummaryData.aspx. [Accessed: 04-Apr-2018].

[58] Resource Futures, “Updated compositional estimates for local authority collected waste and reycling in England 2010/11,” 2013. .

[59] NIC, “Economic growth and demand for infrastructure services,” 2017.

[60] NIC, “The impact of population change and demography on future infrastructure demand,” 2017.

[61] WRAP, “Performance analysis of mixed food and garden waste collection,” 2010.

[62] WRAP, “A Survey of the UK organics recycling industry in 2012,” 2013.

[63] DEFRA, “Energy recovery for residual waste - a carbon based modelling approach - WR1910,” 2014. [Online]. Available: http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=19019. [Accessed: 04-Apr-2018].

[64] WRAP Cymru, “National municipal waste compositional analysis in Wales,” 2016.

[65] Environment Agency, “Waste management for England 2015,” 2016. [Online]. Available: https://www.gov.uk/government/statistics/waste-management-for-england-2015. [Accessed: 04-Apr-2018].

[66] National Grid, “Future Energy Scenarios (FES 2017),” 2017.

[67] HM Treasury, “The Green Book,” 2018.

[68] WRAP, “Indicitive cost and performance online tool.” [Online]. Available: http://laportal.wrap.org.uk/ICPTool.aspx. [Accessed: 04-Apr-2018].

[69] Green Investment Bank, “The UK residual waste market,” 2014.

[70] Eunomia, “Residual Waste Infrastructure Review Issue 12,” 2017.

[71] Biffa, “The Reality Gap,” 2017.

[72] SUEZ, “Mind the Gap (2017-2030),” 2017.

[73] ESA, “UK Residual Waste: 2030 Market Review,” 2017.

[74] BEIS, “Digest of UK Energy Statistics (DUKES) 2017: Main Report,” 2017. [Online]. Available: https://www.gov.uk/government/statistics/digest-of-uk-energy-statistics-dukes-2017-main-report. [Accessed: 05-Apr-2018].

[75] Ofgem, “National Grid gas distribution,” 2015. [Online]. Available: https://www.ofgem.gov.uk/sites/default/files/docs/national_grid_gas_distribution_-_commercial_biosng_demonstration_plant.pdf. [Accessed: 05-Apr-2018].