Department for Environment Food & Rural Affairs

Resource efficiency and waste reduction targets

Detailed Evidence report

Date: 28 April 2022

We are the Department for Environment, Food and Rural Affairs. We're responsible for improving and protecting the environment, growing the green economy, sustaining thriving rural communities and supporting our world-class food, farming and fishing industries. We work closely with our 33 agencies and arm's length bodies on our ambition to make our air purer, our water cleaner, our land greener and our food more sustainable. Our mission is to restore and enhance the environment for the next generation, and to leave the environment in a better state than we found it.

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Contents

Statement of Interests

Conflicts of Interest

None

Statement of Transparency

This statement confirms that the authors believe the evidence base underpinning the derivation of the proposed residual waste target achieves Trustworthiness, Quality and Value.

Trustworthiness – wherever possible the evidence base draws on formally published National or Official Statistics produced either by Defra or by the Department's Arms' Length Bodies or other government departments. In addition, it promotes transparency through providing links to data used and details of methodologies throughout.

Quality – National or Official Statistics used in the evidence base have undergone a quality assessment and assurance process. Details on the methodologies used in constructing the underlying statistics are set out in the original source publications, which are referenced. Where we have developed new data series for the purpose of the evidence base, methods are detailed.

Value – The evidence base is accessible and so meets society's need for information, potentially addressing the questions that external users wish to have answered and provides a basis to meet a government commitment to produce an annual assessment of progress towards the proposed targets.

Changing status of evidence

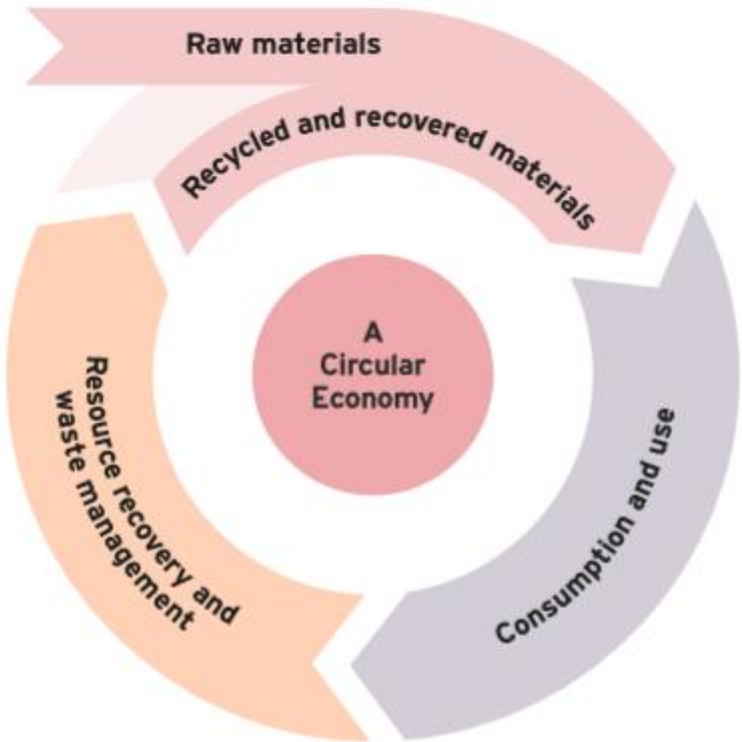
Much of the available evidence around policy impacts is necessarily centred around the collection and packaging reforms that are currently in development. Decisions and modelling around these reforms are ongoing and subject to revision, and the evidence will require update as the latest data becomes available. It is also likely that new evidence around additional policies may become available before October 2022, as further policy plans and trajectories are established. Additionally, it is likely that expected updates to published waste data will give us a better understanding of the impact of the Covid-19 pandemic on waste arisings, which may allow us to improve our modelling assumptions.

Waste reduction proposed target and evidence

Introduction

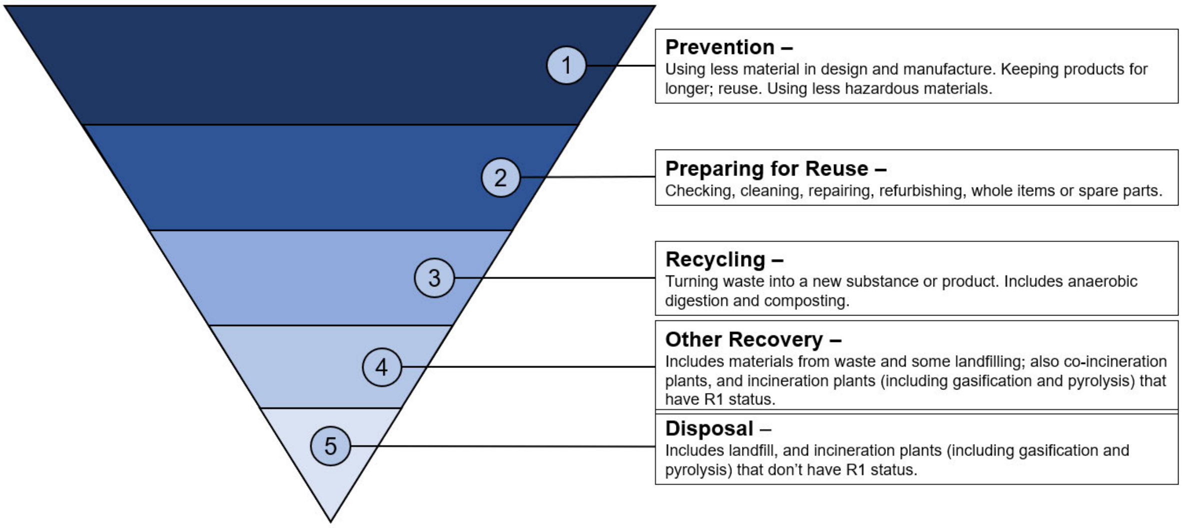
A target to reduce residual waste aligns with wider government priorities to maximise the value of resources and minimise the environmental impact of waste. In the 25 Year Environment Plan (1), the government pledged to leave the environment in a better condition for the next generation through eliminating avoidable plastic waste over the lifetime of 25 Year Environment Plan, doubling resource productivity by 2050, and eliminating avoidable waste of all kinds by 2050. We want to prolong the lives of the materials and goods that we use and move society away from the inefficient ‘linear’ economic model of ‘take, make, use, throw’. A more circular economy would keep resources in use for as long as possible and allow us to extract maximum value from them.

Figure 1: Visualisation of a circular economy (2)



The Resources and Waste Strategy for England (RWS) (2) combines actions to be taken now, with firm commitments for the coming years, to meet a clear longer-term policy direction. It includes major reforms to the way resources and waste are managed such as extended producer responsibility schemes (EPR), consistent recycling collections (consistency), and a deposit return scheme (DRS) for drinks containers. Amongst other benefits, it is hoped that these reforms will increase the proportion of waste that is recovered or sent for recycling, driving waste further up the waste hierarchy, and therefore retaining a greater amount of materials within the circular economy for a longer time.

Figure 2: The waste hierarchy – where '1) prevention' is most ideal, and '5) disposal' is least ideal in terms of environmental impacts and moving to a circular economy.



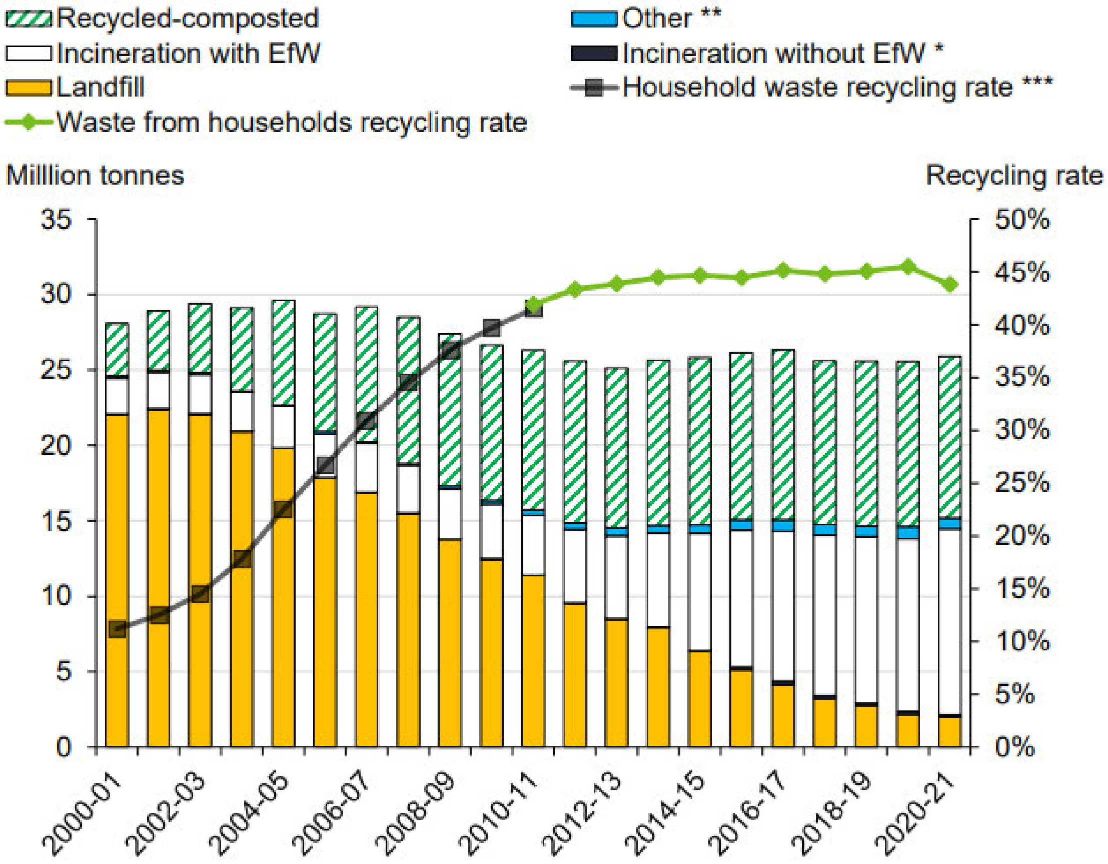
In 2018, recycling and other recovery was the most common final waste treatment option in England, accounting for 96.5 million tonnes of waste or roughly 53%, of which the majority was the recovery of mineral wastes and soils from the construction, demolition and excavation sector (3). Landfill was the second most used waste treatment option, accounting for 44 million tonnes of waste or 24% (3). This was followed by land treatment and release into water bodies (17 million tonnes, 9%), backfilling (11 million tonnes, 6%), and incineration both with and without energy recovery (both 7 million tonnes or 4% each) (3).

These figures refer to all waste treated in England, which may originate from a wide range of different waste streams, including waste from households, commercial and industrial businesses, and construction, demolition and excavation sites. The most common fate of waste is likely to be different for different waste streams.

For example, in 2020/21, total local authority collected waste in England was approximately 26 million tonnes (4). Incineration (including both with and without energy recovery) was the most common final waste treatment option for this waste, accounting for 12 million tonnes or 48% (4). Eleven million tonnes were sent for recycling or reuse (41%), and 2 million tonnes were disposed of via landfill (8%) (4). Local authority collected waste (LACW) consists of all 'waste from households,' street sweepings, municipal parks and gardens waste, beach cleansing waste, and waste resulting from the clearance of fly-tipped materials plus some commercial and/or industrial waste. It is a much narrower waste stream than ‘all waste’ and does not include waste originating from sources such as construction, demolition and excavation.

In line with the waste hierarchy, substantial progress has been made towards the better use of our resources. Since 2000/01, the amount of LACW that we send to landfill has decreased from 79% of total LACW treated to 8% of total LACW treated (4). These changes coincided with a period of increased growth in the rate of Landfill Tax. However, while the amount of LACW that is recycled or reused has risen from 12% to 41%, peaking in 2014/15 at 43%, the amount sent for incineration with energy recovery has also increased, from 9% to 48% (4). Since 2018/19, we have sent a greater proportion of LACW to incineration with energy recovery than we have recycling or reuse. The ‘waste from households’ recycling rate (excluding incinerator bottom ash metals[1]) has been stagnant between 43-45% since 2011 (4).

Figure 3 Management of all local authority collected waste and recycling rates, England, 2000/01 – 2020/21. EfW = Energy from Waste (4)



*** Incineration with energy recovery/without energy recovery** includes incinerator bottom ash (IBA) and metals from IBA. This is consistent with the existing definition for household waste recycling so is not impacted by the change in ‘waste from households’ recycling definition.

**** Other** includes waste treated/disposed of through other unspecified methods as well as process and moisture loss.

***** The Household waste recycling rate** is based on a broader measure of waste and is not directly comparable to the ‘waste from households’ recycling rate[4]. **IBA metals** are included within the ‘waste from households’ recycling rate shown on this chart from April 2015/16 onwards but are not included in household waste recycling.

Our focus remains on moving waste up the hierarchy and minimising the amount of waste we produce. Waste prevention avoids unnecessary production and processing in the first place, and therefore the costs and environmental impacts associated with those steps. For this reason, it is at the top of the waste hierarchy. To prevent waste, products need to be designed and manufactured to safely fulfil their intended function for as long as possible, to enable reuse and have their usable lives extended by repair or refurbishment.

When products do reach their end of life, we should recover constituent materials and regenerate products where optimal to do so, giving them the opportunity to fulfil useful functions and minimising the damage caused to our natural environment throughout.

Tackling hard to recycle products at the design stage can ensure that when waste does arise, it can be incorporated back into the economy through recycling. Manufacturers can use waste products of other industries as inputs to theirs.

Waste sent for recycling or reuse is typically separately collected (e.g., kerbside) and sent for sorting and reprocessing to make raw materials to re-enter production. Recycling can also include the reprocessing of organic materials (e.g., via anaerobic digestion or composting) but does not include energy recovery or the reprocessing into materials that are to be used as fuels or for backfilling operations.

Waste that is not reused or recycled, including material that is too degraded or contaminated for these purposes, is termed residual waste. Residual waste, when collected from households or businesses, is often termed “black bag” or “black wheelie bin” waste. It is typically treated by methods other than recycling or reuse - that is, sent to landfill, incineration (including with energy recovery), overseas for energy recovery as refuse derived fuel (RDF) or solid recovered fuel (SRF), or used in energy recovery for transport fuel.

Reducing residual waste would therefore mean decreasing the amount of waste that is sent to these end-of-life treatment options: landfill, incineration, overseas for energy recovery, and/or used in energy recovery for transport fuel. Other forms of energy recovery may become more commonplace in the future, and we will continue to review which treatments it is appropriate to capture in the proposed target metric as new technologies and treatment options emerge.

Reducing residual waste could be achieved in two ways:

- Preventing waste from occurring in the first place, with strong links to reduced or more efficient material consumption,
- By recycling the waste we do generate into secondary materials (a more sustainable alternative to extracting and processing raw materials), moving waste up the waste hierarchy and increasing the recycling rate.

Reducing residual waste would help address the environmental impacts of treatment, which can include air (including greenhouse gases), soil and water pollution. By reducing the amount of waste sent to landfill, we would expect:

- Reduced risk of toxic emission leaks from landfill (5),
- Reduced methane emissions from landfill (5),
- Reduced risk of toxic leaks into water systems from landfill (5),
- Reduced soil erosion from reduced landfill operations,
- Reduced disbenefit to local residents, through odour, visual disamenity or windblown material (6).

Though preferable to landfill, energy from waste treatment still has some environmental impacts. Optimising and reducing the amount of waste sent to incineration will reduce these impacts and support the circular economy principles. The visual disamenity of energy from waste plants is also recognised as an important issue to those that are located near plants (7). Although plants may also be designed to provide benefits to local residents, such as through using heat offtake to heat homes.

By preventing waste from occurring in the first place and reducing material consumption, we would expect:

- Reduced environmental risks from microplastic pollution,
- Reduced use of non-renewable resources, leading to,
- Less extraction of virgin materials and reduced soil disturbance, leading to improved soil health.

By recycling the waste we do generate into secondary materials, we would expect the resulting stimulation of the secondary materials market and increased circularity of resources to lead to decreased producer costs.

Reducing residual waste is in line with key strategic ambitions and targets across a range of policy areas, other government departments, and international bodies, as well as several key strategies such as the 25 Year Environment Plan (1), the Resources and Waste Strategy (RWS) (2), the Circular Economy Package (CEP) (8) (9), and the UN's Sustainable Development goals (10). Examples of compatible existing commitments include:

- Work towards zero food waste to landfill by 2030 (1),
- Work towards zero avoidable plastic waste by 2042 (1),
- Work towards zero avoidable waste by 2050 (1),
- Ambition to achieve a 65% municipal recycling rate by 2035 (2),
- Ambition to send less than 10% of municipal waste to landfill by 2035 (2).

Target scope

Our proposed target scope includes all residual waste excluding major mineral wastes, i.e., excluding the predominant, and largely inert, waste categories from construction and demolition, such as concrete, bricks and sand, as well as soils and other mineral wastes from excavation and mining activities.

The definition of “all waste excluding major mineral wastes” is defined by waste type at European Waste Classification (EWC) code level, rather than by source. This is the classification used by permitted waste sites to report on tonnages of waste received and removed. All waste produced has a corresponding EWC code, which can be further aggregated into mainly material-based categories by the European Waste Classification for Statistical Purposes (EWC-Stat, version 4) (11). The definition of “all waste excluding major mineral wastes” that we propose for the target scope is largely based on a Eurostat definition (12), where major mineral wastes are identified as: mineral construction and demolition waste (EWC-Stat 12.1), other mineral waste (EWC-Stat 12.2, 12.3 and 12.5), soils (EWC-Stat 12.6) and dredging spoils (EWC-Stat 12.7).

Our proposed definition of major mineral waste also captures one additional EWC waste code – 19 12 09, which is ‘minerals separated via mechanical treatment of waste’. This aligns with the definition used for reporting against landfill and incineration data as part of our Resources and Waste Strategy Progress Monitoring report (13).

We are proposing this scope to focus attention on where the environmental impact per tonne of waste is greatest, such as landfilling biodegradable materials or incinerating plastic. Furthermore, while we want to reduce overall residual waste, the data for some areas of waste is currently less robust than others, with uncertainties in construction, demolition and excavation (C,D&E) major mineral waste data of particular concern for setting a meaningful long-term target. Additionally, our evidence base on alternatives to residual treatment for major mineral wastes is less strong, and the large tonnages associated with these wastes would risk perverse outcomes. For example, including major mineral wastes is likely to mask the importance of reducing the residual treatment of other materials, which are lighter in weight, but nonetheless have significant environmental impacts, for example landfilling of biodegradable wastes or incineration of plastic wastes.

We initially identified two approaches to narrow the scope of the proposed target to exclude major mineral wastes;

> Option A) The proposed material-based scope of all residual waste, excluding major mineral wastes.
>
> Option B) A source-based scope of municipal residual waste, defined as household and household-like waste, i.e., waste from households, plus waste from other sources, such as commercial waste, which is similar in composition to household waste.

The Resources and Waste Targets Expert Group (RWTEG) (14) were consulted regarding the proposed target scope. It was agreed that, owing to the varying environmental impacts of different materials at different residual waste treatments (i.e., landfill and incineration), it is important for us to give regard to the individual materials that make up residual waste, in order to deliver the best possible environmental improvements. For example, plastic waste has relatively little environmental impact at landfill but a high impact at incineration.

We therefore propose **Option A** as the most appropriate scope. It provides a more holistic approach, which will incorporate all tonnages of a given material type, rather than limiting some materials by source. For example, a municipal waste scope would largely exclude industrial waste as well as some biodegradable materials from construction and demolition sources, such as wood waste.

In comparison to Option B, the broader scope of Option A captures approximately 7 million additional tonnes of waste (based on 2019 data) - mainly industrial waste and non-major-mineral waste from construction and demolition sources. These are waste streams where possible policy interventions are less clear and require further evidence gathering. It is not yet clear whether alternative treatment options such as reuse or recycling are available or practicable for these materials. Broadening the scope in this way therefore risks artificially reducing our ambition level, by including waste materials that it may not be feasible to reduce at residual treatments. However, despite this, we propose that this should still be the preferred scope in terms of maximising transparency around the tonnages of residual waste that we treat. It also acknowledges that within these waste streams are materials that are captured in municipal waste definitions and have the same environmental impact regardless of where they originate.

We have proposed an overarching residual waste target instead of individual, material-specific targets, such as a plastics waste reduction target, as these would risk shifting the environmental impact to other environmentally harmful material types and could even lead to increases in residual waste due to switching to heavier materials. Including a wide range of materials ensures a holistic view to waste is taken and reduces waste overall.

To address the significant public concern towards plastic waste, an overarching residual waste target will align with government commitments to eliminate avoidable plastic waste by 2042 and reach zero avoidable waste by 2050 (1). The Environment Act 2021 also provides powers to create extended producer responsibility schemes; introduce deposit return schemes; establish greater consistency in the recycling system; better control the export of plastic waste; and, building on the success of the single use carrier bag charge, gives us the power to set new charges for other single-use items made from any material. All these measures, along with public consultations on proposals to ban a number of single use plastic items, will effectively contribute to reducing plastic pollution.

Reducing residual waste from construction, demolition and excavation (C,D&E) sources is also a high priority and we are not overlooking this. Our Waste Prevention Programme (15) and policies supporting our strategic ambition to double resource productivity by 2050 will drive a reduction in waste generation from C,D&E sources. The Environment Act 2021 enables us to set additional targets in the future, which could include a residual C,D&E or mineral waste target. The introduction of an electronic waste tracking service, which will digitally capture data on movements of waste (16), is expected to deliver substantial improvements in waste generation and treatment data across all waste streams, and will enable us to review the appropriateness of setting future targets on C,D&E waste.

We think that an overarching residual waste target will provide the most helpful measure of waste reduction. We are aware that, as a weight-based target, it could be perceived that we are prioritising the reduction/improved recycling of heavier waste materials over lighter ones. We will seek to avoid that and any other unintended consequences through the monitoring of waste composition and careful consideration of policy interventions according to environmental impact.

The proposed scope will also include incinerator bottom ash metals (IBA metals) that are retrieved and ultimately recycled following incineration. Although these are ultimately recycled, we propose to still include them within the target scope (i.e., not to deduct tonnages of IBA metals from total incineration in the metric) to incentivise the separation of these materials earlier in the waste management process, before they are put through incineration.

Methodology

Expert Group

The proposed target scope and ambition were determined in consultation with the Resources and Waste Targets Expert Group (RWTEG), a group of eight independent academics appointed based on their specific skills, knowledge, and experience (14). More details of meetings can be found in published expert group minutes.

Evidence to inform the scope

To inform and support our decision to exclude major mineral wastes from the proposed target scope, we commissioned several rapid evidence assessments to investigate the life-cycle environmental impact of less reactive/inert waste materials, and potential policy options for reducing waste in the construction sector or diverting soils from landfill. This would allow us to determine whether including these materials within the proposed target scope would be not only environmentally impactful, but also result in a target that was meaningful and achievable. These reviews included:

A review into the environmental life cycle impacts of inert/less reactive waste materials, to include end-of-life treatment and upstream impacts such as at the point of manufacture and, where possible, the impact of raw material extraction and processing (17). The objectives of the review were to assess the quality of existing literature, identifying strengths, limitations, and gaps in the research; and to propose a consistent approach to use in comparing material types by their environmental life cycle impact. Inert/less reactive waste materials considered by the review included soils, stones and other minerals, concrete, bricks, tiles and ceramics, and fines.

A review of policy options to reduce resource use and waste, and divert waste from residual treatment, in England's construction sector, which aimed to provide an overview of key drivers and existing regulations that act to influence resource use, waste production and waste treatment in the construction sector in England (18). Further objectives of the review were to collate a longlist of policy levers available to government for reducing resource use and waste arisings in this sector, and to assess these against Critical Success Factors set out in the Green Book as well as potential impacts against regulatory objectives.

A review to assist in the identification and short-listing of policies to reduce soils entering landfill in England. This included an outline of current and possible drivers of topsoil and subsoil being sent to landfill in England, and the influence of the regulatory landscape (19). Here as well, further objectives were to collate a longlist of policy levers available to government for reducing soils sent to landfill, assessed against the Green Book's Critical Success Factors.

Evidence to inform the baseline

Step 1: Forecast waste arisings (using the Future Waste Arisings Project)

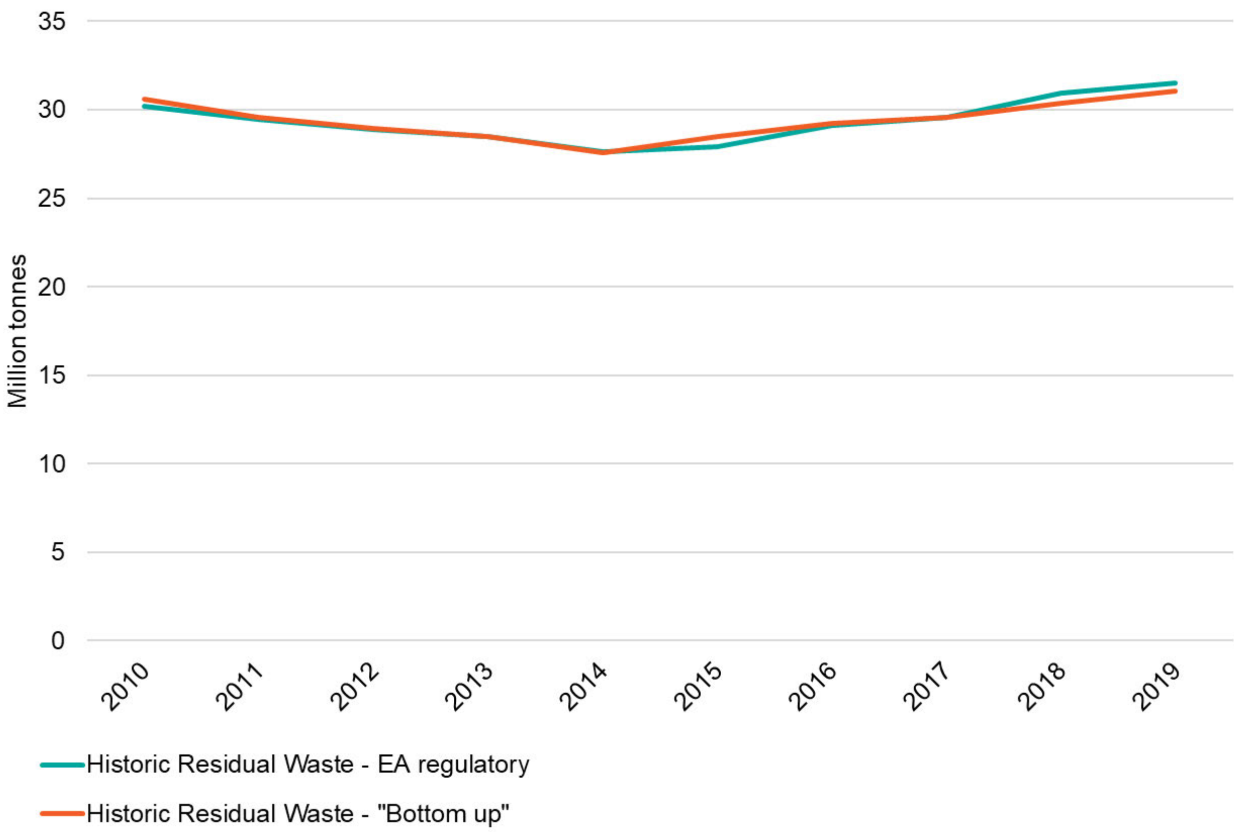
The proposed target baseline—a forecast of residual waste levels assuming no future policies—was obtained through the 'Future Waste Arisings Project', a piece of work commissioned by Defra to forecast total waste generation figures in a range of different waste streams through to 2050 (20). Waste streams that were forecast by this project include waste from households, local authority collected waste, municipal waste, commercial and industrial waste, and construction, demolition and excavation waste. The project models municipal waste as the total of waste from households plus non-household municipal waste.

Residual waste projections were derived using two forecasting methodologies:

1. A ''bottom up" approach where recycling/recovery rates were applied to total waste arisings forecasts.
2. An econometric modelling approach where waste treated as residual was forecasted directly from the Environment Agency (EA) regulatory data on waste treatment. This data is what we are proposing for our metric.

Though we are proposing to use EA regulatory data in our metric for reporting progress against the target, to arrive at a baseline forecast of residual waste excluding major mineral wastes, we chose the "bottom up" approach. This is because the "bottom up" approach provides us with the most flexibility in terms of being able to model impacts against residual waste, allowing us to manipulate both waste arisings and recycling rates by sector. To determine how closely our "bottom-up" approach matches future EA regulatory data trends, we compared the historic residual waste recorded in the EA regulatory data with the modelled residual waste predicted by the "bottom up" approach (Figure 4). In Figure 4, 'EA regulatory historic waste' is derived from tonnages of waste sent to landfill, put through incineration, sent overseas for energy recovery, and used in energy recovery as transport fuel. "Bottom up" residual waste is calculated by applying recycling/recovery rates to waste arisings data. We find that the "bottom up" approach produces modelled residual waste figures that are significantly correlated with the EA's historic regulatory data (Pearson's correlation; $r = 0.97$; $p<0.001$). This gives us confidence that the "bottom up" modelling approach used to derive our proposed target ambition level is suitable to use for the development of a target that we propose to measure progress against using the EA regulatory data.

Figure 4: Comparison between the historic residual waste excluding major mineral waste recorded in the EA regulatory data, and the modelled residual waste predicted by the "bottom up" approach.



In the “bottom up” approach, the drivers used to forecast waste from households (WfH) generation figures were:

- Historic WfH tonnages obtained through WasteDataFlow, a web-based system used by local authorities to report their waste arisings and management to government (21),
- Gross Disposable Household Income (GDHI) based on historic GDHI figures published by Office for National Statistics (ONS) (22),
- Index of Multiple Deprivation (IMD) based on figures released by Department for Levelling Up, Housing and Communities (DLUHC) (23),
- Population based on local authority population estimates and projections published by ONS (24) (25).

It is proposed that the frequency of data collection, reporting question dataset and level of detail will remain the same in the future as is it is now. When the waste tracking service comes online in 2023/24, much of the data reported currently by local authorities into WasteDataFlow should become available via automated processes linked directly to waste tracking service datasets.

Further information about WasteDataFlow, detail and guidance on reporting can be found on the guidance[1] webpages.

The drivers used to forecast non-household municipal waste (NHM) generation figures in the model were:

- Historic NHM tonnages obtained from Waste Data Interrogator (26), where the NHM tonnage is estimated based on agreed EWC codes,
- Sector-specific Gross Value Added (GVA) (27).

The drivers used to forecast commercial and industrial (C&I) generation figures in the model were:

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[1] WasteDataFlow is a web portal where local authorities in England report tonnage figures for the waste and recycling they collect and manage, to central government. In England there are three main groups of data reported via the WasteDataFlow web portal:

Waste and Recycling collection - Local authorities report quarterly tonnage data for waste they collect such as kerbside waste and recycling, materials deposited at Household Waste Recycling Centres (HWRCs) and other waste services such as bulky waste collections, street cleaning, collections of healthcare waste, etc. Where possible, recycling collection is reported by material type. Information on types of waste containment and numbers of households served is also reported.

Waste and recycling disposal - Waste management, disposal and recycling of waste in England is reported within a detailed question matrix known as question 100 (Q100). This allows for full recording of waste tonnages as it goes through often complex waste management practices. Reporting covers waste treatment by facility, facility type, waste stream, output type and material type.

Fly tipping - Under Section 71(4) of the Environmental Protection Act 1990 (28), local authorities have a statutory requirement to report information on fly-tipping incidents and actions taken through WasteDataFlow. Quarterly data is collected on number of fly tips reported, size of fly tip, legal actions and prosecutions. [redacted]

- Defra published figures on C&I waste arisings (3),
- Sector-specific Gross Value Added (GVA) (27).

Step 2: Forecast residual waste (applying recycling and non-residual treatment rates to projected waste arisings)

In order to convert the generation forecast (which includes both residual waste and waste collected for recycling or reuse) into a forecast of residual waste alone, either a predicted recycling rate or a predicted "non-residual treatment" rate was applied to the arisings forecasts. The "non-residual treatment rate" captures all waste sent to end-of-life treatment that is not landfill and incineration in England, sent overseas for energy recovery, or used as energy recovery in transport fuel. This can include, for example, recycling, reuse, other recovery (not including energy from waste incineration), or process loss. Process loss is the difference between the tonnage entering a facility and the tonnage that leaves a facility, which can occur through moisture loss or industrial processing.

Whether streams use recycling or non-residual treatment rates

For WfH, projected recycling rates were used as, based on visual inspection, these were shown to be a good predictor of residual tonnages when applied to the historic data (i.e. the vast majority of WfH was either recycled or sent to residual treatment). For the C&I data, visual inspection demonstrated that estimated recycling rates do not provide a good predictor of tonnages at residual treatment. This is due to larger tonnages of waste treated at recovery facilities and complexities in the available C&I data, which mean that process losses, waste treated in the devolved administrations and data limitations also need to be accounted for when converting from waste arisings. We therefore applied predicted rates of non-residual treatment, based upon the historic data, to the C&I projections. The C&I data was split out into NHM waste and non-municipal C&I (non-MSW C&I), to enable us to model policies that only target municipal waste. The WfH recycling rate and C&I non-residual rates feed into the "bottom up" residual waste modelling that was shown above to be significantly correlated with the EA's historic regulatory data.

The recycling or non-residual treatment rates

For WfH, we keep the recycling rate flat from the 2019 rate at 44.6% in the absence of any further policy intervention. This is consistent with historic data, where the WfH recycling rate (excluding IBA metals) has remained within one percentage point of this rate since 2012 (3). We have used WfH recycling rates that exclude IBA metals to remain consistent with our proposed target scope. For NHM, we keep the non-residual treatment rate flat from the 2019 rate at 53.1% across all years, in the absence of any further policy interventions. This is consistent with historic data, where the NHM non-residual treatment rate estimates have remained steady at around 53.0% to 53.3% since 2016. Finally, for non-MSW C&I, we keep the non-residual treatment rate flat from the 2019 estimated rate at 65.5% across all years. This method was chosen for forecasting the non-residual treatment rate as a linear projection was not found to provide a sensible prediction for non-MSW C&I (20).

Non-WfH, non-C&I, non-major mineral residual waste

The majority of the baseline was generated using the forecasts from the Future Waste Arisings Project. However, because we are proposing an "all waste excluding major mineral waste" scope, this left some additional tonnages of non-major-mineral waste from agriculture, forestry and fishing, and construction and demolition sources. To complete the baseline, we directly forecasted the residual tonnages for these using projections of GVA for the relevant sectors, along with the historic relationship between the residual waste data and GVA, which follows the approach used to model NHM waste in the Future Waste Arisings project. To do this, it was assumed that all EWC codes in Chapter 2, sub-chapter 1 of the List of Wastes (29) were derived from agricultural sources, and all Chapter 17 codes were from construction and demolition sources. A proportion of code 19 12 12 (20%) was also assumed to originate from construction and demolition activity based upon analysis of individual site inputs and outputs from Waste Data Interrogator (30).

Step 3: Deriving residual waste (excluding major mineral waste) estimates (kg per capita)

Historic residual waste excluding major mineral waste kg per capita estimates were then generated by applying published ONS data for mid-year population estimates (24) to the sum of residual waste across all of the waste streams within the proposed target scope A forecast of residual waste excluding major mineral waste kg per capita estimates to 2050 was derived using published ONS population projections to 2043 (25) and then a linear projection from 2043 to 2050.

Evidence to inform the ambition level

For the target ambition, we are proposing a 50% reduction in per capita residual waste (excluding major mineral wastes) by 2042 from 2019 levels. It is proposed that this will be measured as a reduction from 2019 levels, which are estimated to be approximately 560 kg per capita. This figure is calculated from EA Waste Data Interrogator, incinerator monitoring reports, and international waste shipments data.

We also modelled for comparison a 50% reduction by 2050, which lines up with complementary Resources and Waste Strategy goals for zero avoidable waste by 2050. Please note that our proposed target does not represent zero avoidable waste.

The proposed ambition is derived from work to model how wider government ambitions and strategies might impact residual waste and analyse how these might add to the expected impacts of the planned Collection and Packaging Reforms (CPR) that are set out in the Resources and Waste Strategy for England (2). These include ambitious plans to introduce consistency of recycling collections across households and businesses, a deposit return scheme for drinks containers, and extended producer responsibility for packaging materials.

Additional policies and measures that could be considered to further progress include price-based levers to make it more expensive to dispose of waste through waste management options typically associated with residual waste, specification of producer responsibility across a range of different products and materials, or regulatory levers to maximise municipal recycling rates beyond CPR.

The government believes it is important that local authorities continue to support comprehensive and frequent rubbish and recycling collections to households. The Government’s consistent collection proposals have included consulting on expanding food waste collections, supporting garden waste collections, and introducing a minimum collective frequency for residual waste. Such reforms would help ensure households continue to have access to a comprehensive and frequent service, whilst improving environmental outcomes.

To model the potential impacts of CPR upon our baseline, we applied the potential impacts of the reforms to both waste from household and non-household municipal waste streams (based on central modelling that assumes an 80% capture rate, where low and high scenarios assume a 70% and 90% capture rate respectively). This was done by applying the potential impact of CPR on waste from household and non-household municipal recycling rates to our model. The scenario that was used assumes the waste from households recycling rate increases from 45% in 2019 (3) to 52% by 2035, whereas the non-household municipal recycling rate increases from 40% in 2019 (based on internal, Defra calculations) to 59% by 2035. For non-household municipal waste, we add a further 13% recovery rate on top of the recycling rate to arrive at an assumed non-residual rate (53% in 2019 and then 72% in 2035).

In the CPR impacts scenario that we have used, we further assume an 80% capture rate of recyclate, determined following engagement with industry experts, which has been applied to the total non-household municipal recycled tonnage. This is as opposed to a 100% capture rate, which would assume that all businesses correctly recycle all material all of the time. The capture rate is applied to WRAP projections of non-household municipal recycling tonnages (the amount of non-household municipal waste that WRAP’s modelling suggests would be recycled in a given year), reducing the initial material recycled tonnage to 80% of its start value. This then feeds into the calculation to estimate recycling rates, where recycling rate is calculated as recycled tonnage over total waste arisings.

We also assume that 15% of all non-household municipal recycling is lost in the sorting stage, also determined following engagement with industry experts. These assumptions produce a more conservative estimate of impacts that allows for human error and ongoing behavioural change.

In addition to the potential impacts of CPR, we have also modelled illustrative potential policy pathways that include additional household measures that could contribute towards progress to meeting a target to reduce residual waste. These additional household measures are not prescriptive, and only demonstrate one possible future pathway towards achieving the proposed target.

The additional household measures modelled were primarily regulatory levers such as expanded kerbside waste collection services beyond consistent recycling requirements. This includes implementation of policies targeted at waste electricals and electronic equipment, batteries, and textiles. General policies to divert organics from residual waste were also modelled. Based on quantitative modelling carried out by WRAP (which only included the household policies described above), we estimate that these policies could divert an additional 370 thousand tonnes of waste from the household residual waste stream every year.

It is very challenging to model potential future policy pathways in the long-term as future policies are highly uncertain and will be the decisions of later governments. Following the foundations laid by the CPR reforms, with additional collection services in place, there will be several possible options to try and divert waste from residual waste treatment. We have modelled the impacts of a potential future policy pathway where we assume that suitable policies are implemented to drive improved recycling processes and behaviours between 2027 and 2042/2050. This focuses on price-based levers as these can be most appropriately modelled. The outlined policy pathway is purely illustrative but is useful when considering the achievability of the proposed target. The exact make-up of a future policy pathway will likely be a combination of interventions, including the prevention of waste being generated in the first place.

We modelled this future policy pathway based on assessing the historic impact of price-based levers on reducing waste to landfill and considering a range of assumptions around what level of reduction we might expect to be possible when applied more broadly across all residual waste tonnages.

We calculate the historic rate of decrease in waste sent to landfill between 2008 and 2014, when policies included:

- Increased year-on-year rises in Landfill Tax.
- Some requirements for separate collection of recyclates.
- Government support for infrastructure investment in the form of the Waste Infrastructure Development Programme.

We take this relationship as an indication of the rate at which residual waste can feasibly be diverted into another treatment stream when under the same level of pressure as exerted by historic waste policies.

Our modelling makes a series of assumptions, which we are seeking further views on at consultation:

- We only apply the reduction to tonnages that are deemed to be “avoidable”. This was determined by applying published definitions of “readily recyclable”, and "potentially recyclable" from the Resources and Waste Strategy Monitoring Progress Report (13) to historic landfill composition data.

- We then assume that the level of reduction in the tonnages of avoidable residual waste (calculated in step 1) over the modelled time period is between 50 and 100% of the landfill reduction seen between 2008 and 2014. This is to account for the fact that there will always be some waste for which residual treatment is the most appropriate option, and that some materials are more difficult to recycle than others, and so reducing residual waste tonnages becomes more challenging as more progress is made.
- We further reduce the level of reduction in residual waste by another 25-50% to acknowledge that removing recyclates from residual streams requires greater process and/or behavioural changes than simply shifting residual waste from landfill to incineration or energy recovery. We term this the "effectiveness".

Our modelling approach has been approved by RWTEG, who felt that the methodology stood up to scrutiny and agreed that we would expect a lower rate of change than was seen historically at landfill.

We also gave consideration to whether planned policies to tackle waste crime, including policies aimed around reducing the illegal misrepresentation of waste-by-waste carriers, brokers, or dealers to avoid paying higher rates of Landfill Tax, might drive reductions in residual waste. However, it was deemed inappropriate to consider these policies in our modelling, because:

- The tonnages of waste involved in waste crime that we are able to identify are relatively small and would be unlikely to have a significant impact.
- A large proportion of identified waste crime involves construction, demolition and excavation waste, which is largely outside of our proposed target scope.
- Generally, waste crime policies may be more likely to increase reported residual waste tonnages rather than decrease them, by increasing the tonnages captured at legitimate sites. For example, through clearing of illegal waste sites or prevention of illegal exports that are then treated domestically.
- Alternative policies to reduce residual waste may actually increase waste crime, and it would be very difficult to try and predict or model this interaction.

To provide a sense check to the modelling of potential policy pathways, we have also modelled how wider government ambitions and strategies might impact upon our baseline. The additional ambitions that have been considered in our modelling are:

- Meeting a 65% municipal recycling rate by 2035.
- Achieving zero avoidable waste by 2050.

To determine the impact of successfully meeting the ambition of a 65% municipal recycling rate by 2035 on the proposed target scope, we applied this recycling rate to our forecast of municipal waste arisings, which allowed us to project what tonnage of municipal residual waste we might expect to see if we achieved the commitment. To reach a 65% municipal recycling rate, we assumed a linear growth in the municipal recycling rate between 2019 and 2035 of approximately 1.43 percentage points per annum. We then assume a continued growth scenario, where this increase continues at a linear rate to 2042. This results in a municipal recycling rate in 2042 of approximately 75%.

If we were to assume that this linear growth in the municipal recycling rate continued at the same pace to 2050, we would expect this to result in a municipal recycling rate of approximately 86%.

The impacts of successfully meeting the ambition of zero avoidable waste by 2050 or, indeed, if we were to meet this goal by 2042, were determined using National Waste Composition data (31), to which avoidability classifications of different waste materials were applied. For more details on the avoidability classifications, see the Resources and Waste Strategy monitoring progress report (13). For the purposes of modelling the impacts of zero avoidable waste by 2050 upon the proposed target scope, avoidability was defined as waste that was:

- Readily recyclable with current technologies – items which shouldn't be in the residual waste stream whatsoever because they are recyclable or compostable at the kerbside or household waste recycling centres (HWRCs);
- Potentially recyclable with technologies in development – recycling of this material either: a) happens already but not at scale due to collection or technical challenges; or b) could be possible with technological/methodological changes that are already on the market and can be readily envisaged;
- Potentially substitutable to a material which could be recycled – it is hard to envisage a recycling route for these materials, but they could be substituted for something else which could be recycled.

From the above avoidability classifications and National Waste Composition study, our modelling estimates that 55.1% of municipal waste in the residual waste stream is readily recyclable, 75.7% is either readily or potentially recyclable, and 91.9% is either readily or potentially recyclable or potentially substitutable to a material that can be recycled. The modelling then derives the amount of municipal waste that would be left in the residual waste stream if we were to meet this commitment (baseline municipal residual rate minus the proportion assumed to be avoidable) and maps a linear trajectory towards achieving that goal.

We have applied "systems loss caps" on top of this, where we assume that a certain proportion of potentially avoidable waste is never successfully removed from the residual waste stream through, for example, inefficient waste collection, which may be a result of multiple factors such as consumer behaviour and attitudes, technological barriers, and design complexities. Our scenarios of:

- Minimal systems loss assumes that 10% of readily recyclable material, 20% of potentially recyclable material, and 20% of potentially substitutable material is never removed from the residual waste stream;

- Low systems loss assumes that 10% of readily recyclable material, 20% of potentially recyclable material, and 100% of potentially substitutable material is never removed;
- Medium systems loss assumes that 20% of readily recyclable material, 40% of potentially recyclable material, and 100% of potentially substitutable material is never removed.

Effectively, both low and medium systems loss assume scenarios in which potentially substitutable material is not included within the working definition of avoidable waste. Minimal systems loss assumes a more ambitious scenario in which this is included. For all scenarios, we assume that we remove a proportion of avoidable waste from the municipal waste stream, targeting both household and non-household municipal sources. These assumptions are illustrative only and should not be taken to represent exactly what a trajectory to reach zero avoidable waste would look like. However, they enable us to model a range of scenarios that may be possible.

Results and Discussion

Evidence to inform the scope

It was agreed that it is appropriate to set a target to reduce residual waste under the Environment Act 2021, because the treatments typically associated with residual waste are those at the lowest rungs of the waste hierarchy, which are the most environmentally harmful. A residual waste metric enables us to measure progress as a result of waste minimisation, as well as improvements in waste management processes, and so will reflect progress across all stages of the circular economy. For example, a target to increase recycling, by comparison, would not necessarily capture efforts to prevent waste from arising in the first place.

Managing waste via landfill and energy from waste comes with environmental costs. Biodegradable waste sent to landfill breaks down anaerobically to produce methane, a potent greenhouse gas. In 2019, waste management (not including emissions from incineration including with energy recovery) accounted for 5% (16 MtCO2e) of England's territorial emissions and were largely emissions from landfill (32). Landfills also generate leachate, which unless managed or treated properly can pollute soil and ground and surface water (33). The proportion of all waste sent to landfill has remained relatively constant at approximately 25% since 2010 (up to the most recent published data, which is for 2018), and 5.4 million tonnes of biodegradable waste continued to be sent to landfill in England in 2019 (19% of 1995 levels) (3).

Reducing landfilled waste, and hence landfill operations, will drive environmental improvement through reduced toxic emissions leaks, reduced methane emissions and reduced soil erosion. Though preferable to landfill, energy from waste treatment still has some environmental impacts. Optimising and reducing the amount of waste sent to incineration will reduce these impacts and support the circular economy principles.

Global resource extraction today is over 10 times greater than at the start of the 20th century. Today, extractive industries across our planet are thought to be responsible for at least half of the world's carbon emissions and more than 90% of biodiversity loss (34). Assuming that current systems of production and consumption remain unchanged, extraction of materials is projected to rise to more than double current levels by 2060 (35). In 2018, England's material footprint was an estimated 810 million tonnes (36), far higher on a per capita basis than the global average. By delivering the same (or better) products while using less resources and substituting primary for secondary materials, we can reduce the extraction of raw materials associated with our final demand, improve resource efficiency, reduce waste and reduce greenhouse gas emissions (GHGs).

We are proposing a target scope of all residual waste, excluding major mineral wastes, i.e., excluding the predominant, and largely inert, waste categories from construction and demolition, such as concrete, bricks and sand, as well as soils and other mineral wastes from excavation and mining activities.

We are proposing to exclude major mineral wastes because, while we want to reduce overall residual waste, the data for some areas of waste is currently less robust than others, with uncertainties in construction, demolition, and excavation (C, D&E) data of particular concern for setting a meaningful long-term target. Additionally, our evidence base on alternatives to residual treatment for mineral wastes is less strong, and the large tonnages associated with these wastes would risk perverse outcomes. For example, including mineral wastes is likely to mask the importance of reducing the residual treatment of other materials, which are lighter in weight, but nonetheless have significant environmental impacts, such as landfilling of biodegradable wastes or incineration of plastic wastes.

The findings from the commissioned rapid evidence assessments detailed in the Methodology section led us to conclude that the environmental benefits of including major mineral wastes within the target scope would be unclear and that more research is needed before an appropriate target could be set in this area. The rapid evidence assessments, which took the form of a combination of literature reviews and workshops with industry experts, found that:

- In recent years, there has been increased focus and effort to reduce the environmental impacts of materials such as concrete and bricks through the use of substitutes and/or alternative materials. However, environmental savings via these practices could result in knock-on effects on the technical performance of materials that could potentially lead to net negative environmental impacts over the materials' lifecycle.
- Excavation works generate excavated soil, consisting of topsoil, subsoil, and spoil, which could potentially be a material of significant environmental importance. There is a substantial lack of information regarding the fate of excavated soil (as well as a

lack of research regarding the environmental impacts of quarrying and dredging), and this blind spot could ultimately lead to important environmental impacts if left unexplored.

- There isn't a single optimum end-of-life management solution for construction and demolition waste—a multitude of parameters come into play and can considerably affect the environmental performance of a given material.
- The environmental performance of materials is only part of the picture—to be able to see the big picture, environmental analyses should be accompanied by exploration of the economic, social and technical performance of materials. A holistic, integrated approach can aid identification of the main strengths and limitations of the system, highlight where inefficiencies occur and where gaps exist. This can facilitate improved and sound decision-making processes and the development of sustainable, zero-carbon management strategies.
- Three key sets of measures could help ensure reduced residual waste in the construction sector, such as using fewer materials e.g., by extending the life of buildings in use or optimised design; preventing waste from arising, e.g., via lean production techniques during construction; and the selection of materials and building techniques that enable recycling and reuse of materials at the end of life.

We also considered the possibility of setting separate targets on individual materials, but ruled this out owing to:

- The risk of perverse outcomes, such as material substitutions, from capturing too narrow a range of materials.
- The majority of non-major-mineral waste tonnages reported at landfill and incineration sites being one of two "mixed" EWC codes, 20 03 01 (mixed municipal waste) and 19 12 12 (sorting residues from mechanical sorting of waste), for which we do not have up to date or regular estimates of composition. Any material-specific estimates would therefore be based on outdated composition data and would simply reflect the overall trend for total tonnages of these waste codes, rather than any real changes as a result of policy interventions.

Evidence to inform the metric

For the metric, we would ideally want to be able to measure residual waste at the point of collection, such as at kerbside or household waste recycling centres (HWRCs), or from commercial waste containers. This is because we want to drive change earlier in the waste management process and, at this point, the opportunity for separate collection of potential recyclates has already been missed. However, we currently only have robust data at point of collection for local authority collected waste (LACW) through WasteDataFlow, and we think that limiting the target scope in this way would be too narrow and unambitious to deliver the levels of environmental improvement we want to see. Published statistics on LACW managed waste show that, of LACW in England that was landfilled or incinerated in 2020/21, 85% was treated at Energy from Waste facilities, with just 15% landfilled or incinerated without energy recovery (4), and so an LACW specific target would do little to drive diversion of waste away from the disposal options at the very lowest rung of the waste hierarchy.

It was therefore agreed that we should propose a treatment-based point of measurement, with a metric that includes waste that is sent to landfill, put through incineration (including incineration with energy recovery), sent overseas energy recovery treatment, and/or used in energy recovery for transport fuel. This will enable us to use regularly reported EA data on permitted waste site activities (26) and international waste shipments (37) for the metric.

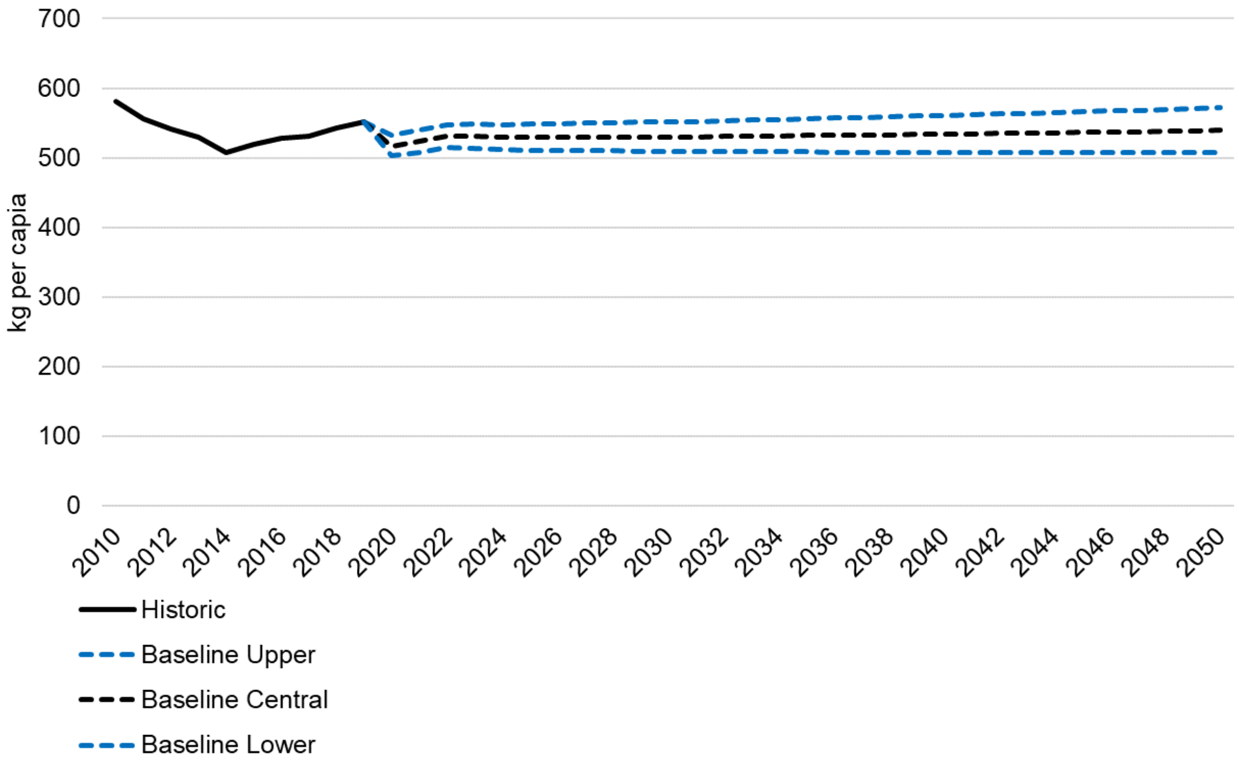
In discussions, RWTEG raised the importance of recognising that energy from waste incineration is higher in the waste hierarchy than landfill or incineration without energy recovery, is preferable to disposal of waste via landfill or incineration, and for some materials, may be the most appropriate end-of-life treatment option. While we recognise that as a recovery option, incineration with energy recovery is preferable to disposal of waste via landfill or incineration without energy recovery, we think it is important to include all these treatment options within the metric to:

- Provide the best proxy measure for waste that was collected as residual waste rather than separately collected for recycling, and
- Help to drive waste minimisation and increased recycling, to enable a more circular economy utilising the upper rungs of the waste hierarchy.

As it stands, the proposed metric will capture IBA metals within the proposed target scope.

Evidence to inform the baseline

Figure 5: Baseline: Residual waste excluding major mineral waste projections up to 2050 (kg/capita)



In the central baseline scenario (Figure 5), residual waste excluding major mineral waste is projected to decrease slightly in kg per capita over 2019-2042/2050. This is due to population being forecasted to increase at a greater rate than residual waste, leading to a projected decrease in the kg per capita metric. It falls from the 2019 figure of 552 kg per capita to 535 kg per capita in 2042, which is our proposed target end-year, and to 539 kg per capita in 2050. It is projected to rise in the upper baseline scenario, reaching approximately 563 kg per capita in 2042 (572 kg per capita in 2050), and decrease in the lower baseline scenario to 508 kg per capita in 2042 (508 kg per capita in 2050). To note, there is an initial fall in residual waste tonnages around 2020 due to the impact from Covid-19 on the economic drivers used to forecast waste arisings in our modelling, such as GDHI and sector-specific GVAs.

These figures are derived from the “bottom up” modelling approach that we have used to calculate our baseline, the potential impacts of different prospective policy pathways, and the possible trajectories of existing commitments. It is important to note that this is a different approach to that proposed for the metric, and so the kg per capita figure quoted here for 2019 (552 kg per capita) would not be expected to match the kg per capita figure quoted as a 2019 benchmark for the proposed target (560 kg per capita). Our rationale for choosing to use the “bottom up” approach for our modelling and EA regulatory data on waste treatment for our metric is given in ‘Methodology: Evidence to inform the baseline’ and ‘Results and Discussion: Evidence to inform the metric’.

Evidence to inform the ambition level

The ambition level range was determined using several different modelling approaches to sense check our outputs and align with complementary departmental strategies and commitments. This has involved modelling the collective impacts of the planned Collection and Packaging Reforms (CPR) on residual waste, as well as an illustrative potential policy pathway that includes additional household measures that could contribute towards progress to meeting a target to reduce residual waste, and the impacts of a potential future policy pathway where we assume that suitable policies are implemented to drive improved recycling processes and behaviours between 2027 and 2042/2050 (both described in ‘Methodology: Evidence to inform the ambition level’). As a sense check, we have also modelled possible trajectories of achieving a 65% municipal recycling rate by 2035 and zero avoidable waste by 2050.

As with the baseline, all figures quoted from modelling to estimate potential policy impacts and possible trajectories for existing commitments are based on the “bottom up” approach and would not be expected to match kg per capita figures calculated using EA regulatory data on waste treatment (which we estimate as 560 kg per capita in 2019). Though the figures quoted below are derived from a different approach to what is proposed for the metric (see ‘Methodology: Evidence to inform the baseline’ for a comparison), they provide an indication of what could be achieved by a potential suite of policies that we believe can reasonably be extrapolated to the metric.

Figures 6 and 7 show projected residual waste excluding major mineral waste (kg per capita) after the impacts of potential future policies have been applied. With current modelling, we estimate that CPR may reduce residual waste excluding major mineral wastes (kg per capita) by 25% by 2042 relative to 2019 figures (from 552 kg per capita in 2019 to 415 kg per capita in 2042). In absolute tonnage terms, this is a reduction from 31 million tonnes in 2019 to 26 million tonnes in 2042. Absolute tonnages see a lower percentage reduction than kg per capita as per capita accounts for population growth. By 2050, CPR may reduce residual waste excluding major mineral wastes (kg per capita) by 25% relative to 2019 figures (reduced from 552 kg per capita to 414 kg per capita in 2050). In absolute tonnage terms, this would be a reduction from 31 million tonnes to 26 million tonnes. We would not expect to see a significant difference in the impacts of CPR between 2042 and 2050 as we assume that the impacts plateau before 2042 in the absence of any further policies.

We would expect additional household measures, when added to the impacts of CPR, to reduce residual waste excluding major mineral wastes (kg per capita) by 26% by 2042 relative to 2019 figures (from 552 kg per capita in 2019 to 409 kg per capita in 2042). In absolute tonnage terms, this would be a reduction from 31 million tonnes in 2019 to 25 million tonnes in 2042. By 2050, CPR plus additional household measures may reduce residual waste excluding major mineral wastes (kg per capita) by 26% relative to 2019 figures (to 408 kg per capita). In absolute tonnage terms, this is a reduction to 26 million tonnes. The absolute tonnages have increased slightly between 2042 and 2050 while kg per capita has decreased due to a forecasted increase in population with no further impacts from the considered measures. Again, we would not expect to see a significant difference in the impacts of additional household measures between 2042 and 2050 as we assume that the impacts plateau before 2042 in the absence of any further policies.

The future policy pathway builds upon the potential impacts of CPR and additional household measures and represents a suite of potential future policies to divert waste from residual waste treatment. In the lowest impact scenario modelled, we assume that only half the level of the historic landfill reduction is possible, and that introduced policies are only 50% as effective in driving progress (i.e., a further 50% reduction in the rate of decrease). In this scenario, residual waste excluding major mineral wastes is projected to decrease to 338 kg per capita by 2042, a 39% reduction on the 2019 levels. By 2050, this decreases to 312 kg per capita, a 43% reduction on the 2019 levels.

In the highest impact scenario modelled, we assume that the same level of reduction of the historic landfill reduction is possible, and that introduced policies are 75% as effective in achieving this (i.e., we apply a 25% reduction to the rate of decrease). In this scenario, residual waste excluding major mineral wastes is projected to decrease to 254 kg per capita by 2042, a 54% reduction on the 2019 levels. By 2050, this decreases to 223 kg per capita, a 60% reduction on the 2019 levels.

The lowest and highest impact scenarios give us a potential range of impact, indicated by the yellow shading in Figures 6 and 7.

Figure 6: Residual waste excluding major mineral waste after potential future policies, up to 2042

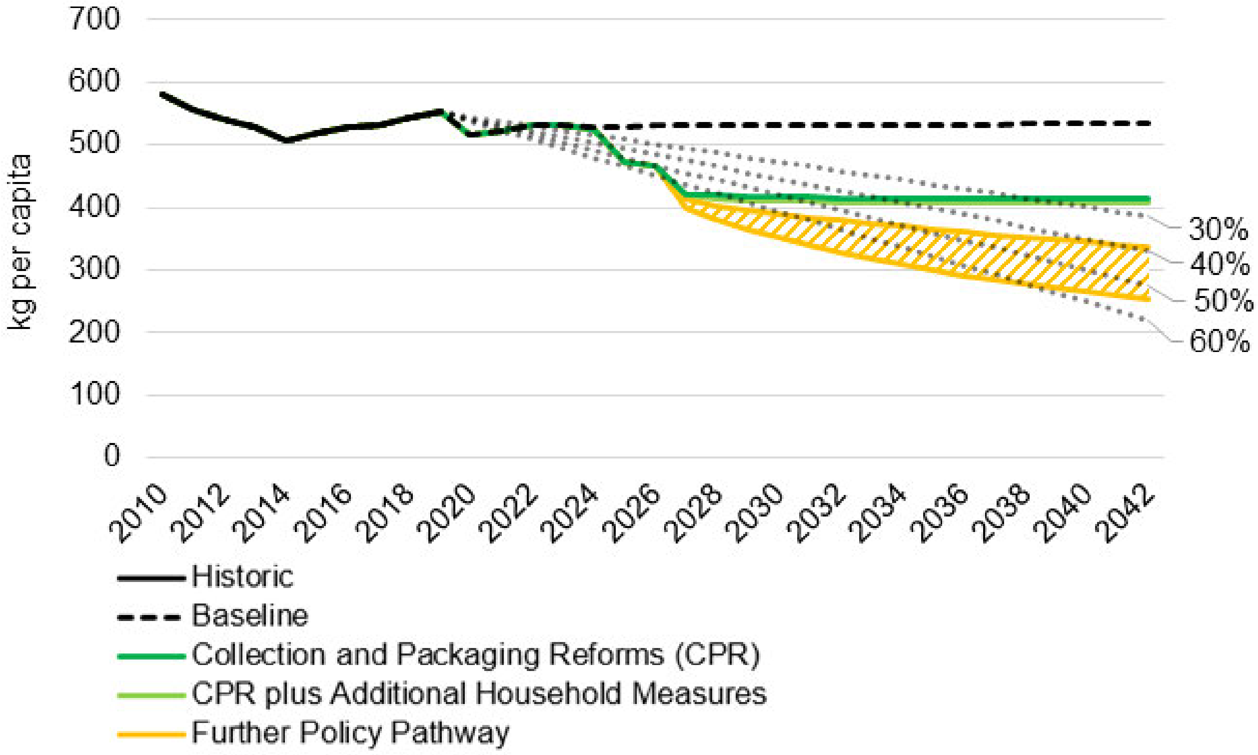
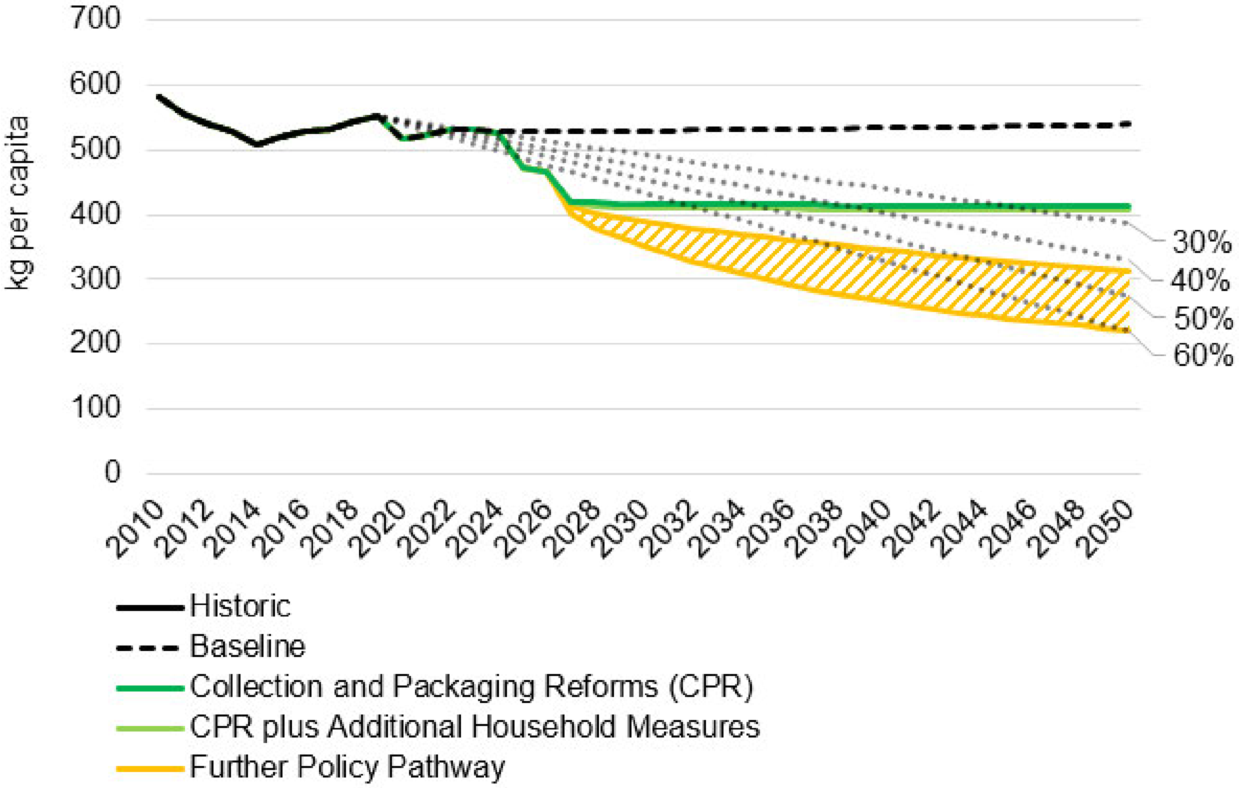


Figure 7: Residual waste excluding major mineral waste after potential future policies, up to 2050



Greater reductions in residual waste excluding major mineral wastes can be seen as a result of achieving our ambition of a 65% municipal recycling rate by 2035 and zero avoidable waste by 2042 or 2050, although the latter is dependent on our definition of "avoidable waste" and ambition level around this. Figures 8 and 9 show projected residual waste excluding major mineral wastes (kg per capita) should we achieve existing commitments (see above 'Methodology' section for descriptions of how we defined avoidability).

The minimal systems loss trajectory shows the impact of zero avoidable waste if all easily recyclable, potentially recyclable and potentially substitutable materials are removed from both household and non-household municipal residual waste streams, with systems losses assumed of 10% of readily recyclable material, 20% of potentially recyclable material, and 20% of potentially substitutable material. We assume that these systems losses are never successfully removed from the residual waste stream. The low systems loss trajectory assumes that all easily recyclable and potentially recyclable materials are removed from household and non-household municipal residual waste streams, with system loss caps of 10% and 20% of readily and potentially recyclable materials applied respectively. The medium systems loss trajectory assumes that all easily recyclable and potentially recyclable materials are removed from these waste streams, with systems loss caps of 20% and 40% applied.

Based on current modelling, we would expect reaching zero avoidable waste by 2042 to reduce residual waste excluding major mineral wastes (kg per capita) by between 47% and 65% relative to 2019 levels (from 552 kg per capita in 2019 to between 193 and 291 kg per capita in 2042). In absolute tonnage terms, this would be associated with a reduction in residual waste to between 12 and 18 million tonnes.

Due to the method used, which maps a linear trajectory to a specified proportion of waste removed from the municipal residual waste stream, the modelling produces very similar results to if we were to achieve zero avoidable waste by 2050. Accordingly, we would expect reaching zero avoidable waste by 2050 to reduce residual waste excluding major mineral wastes (kg per capita) by between 47% and 66% relative to 2019 levels (from 552 kg per capita in 2019 to between 190 and 290 kg per capita in 2050). In absolute tonnage terms, this would be associated with a reduction in residual waste to between 12 and 18 million tonnes.

In modelling the trajectory for a 65% municipal recycling rate by 2035, we take the growth rate in the municipal recycling rate required to reach this commitment and then assume a continued recycling rate growth scenario, where this increase continues at a linear rate to 2042. This results in a municipal recycling rate in 2042 of approximately 75%. Based on current modelling, we would expect this to result in a 54% reduction of residual waste excluding major mineral wastes (kg per capita) by 2042 relative to 2019 (from 552 kg per capita in 2019 to 251 kg per capita in 2042). In absolute tonnage terms, this would be associated with a reduction to 15 million tonnes in 2042 from 31 million tonnes in 2019.

If we were to assume that this linear growth in the municipal recycling rate continued at the same pace to 2050, we would expect this to result in a municipal recycling rate of approximately 86%. In the current modelling, this would be associated with a 73% reduction of residual waste excluding major mineral wastes (kg per capita) by 2050 relative to 2019 (from 552 kg per capita in 2019 to 148 kg per capita in 2050). In absolute tonnage terms, this would be associated with a reduction to 9 million tonnes in 2050.

Figure 8: Residual waste excluding major mineral waste after existing strategies and ambitions, up to 2042

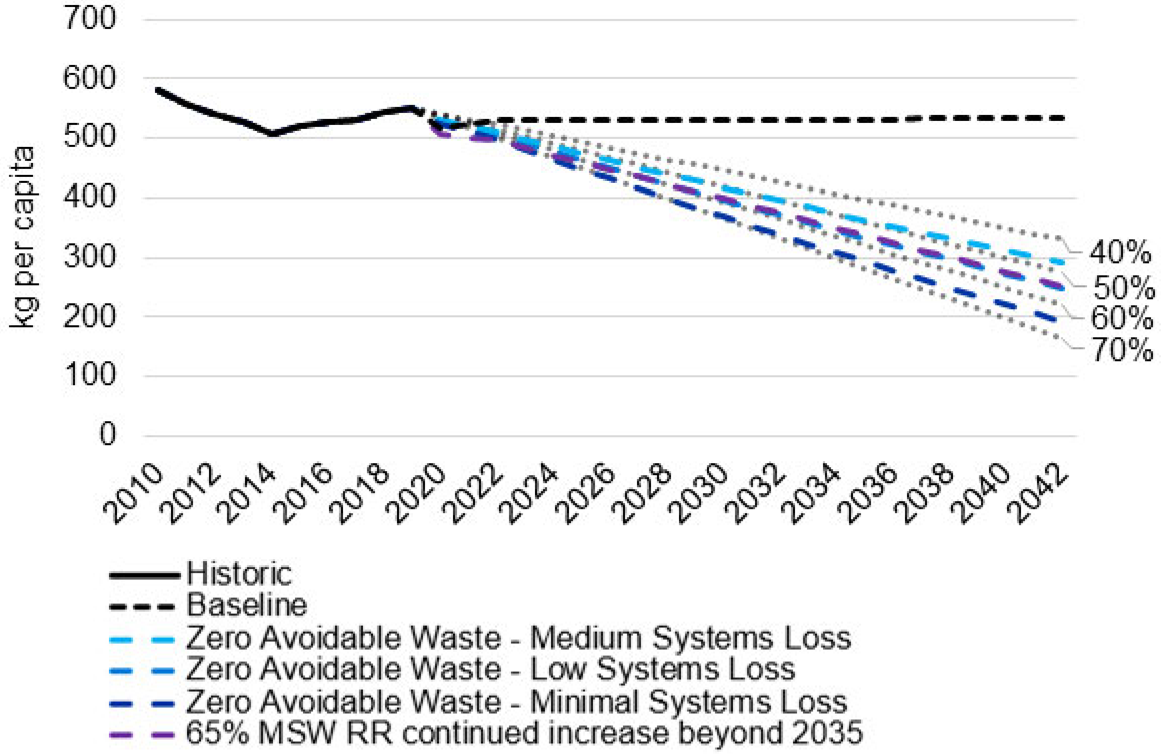
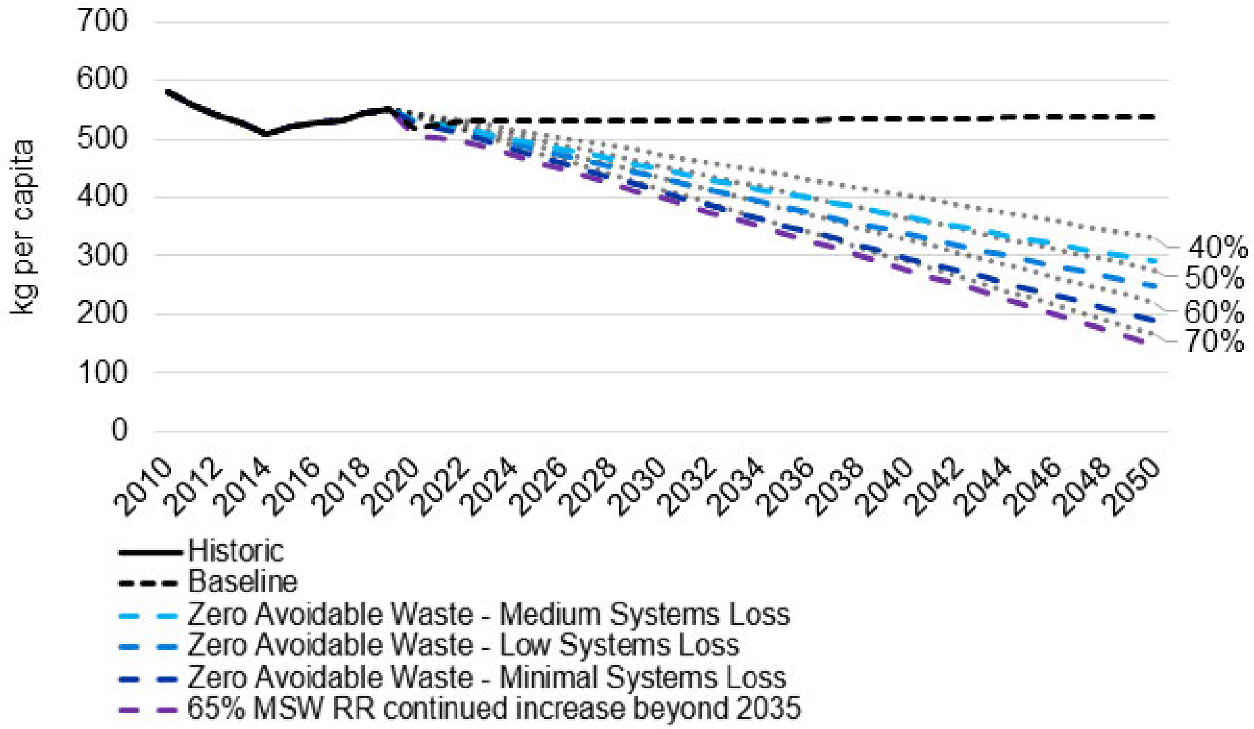


Figure 9: Residual waste excluding major mineral waste after existing strategies and ambitions, up to 2050



Our modelling indicates that a 2042 target date is highly ambitious yet achievable if a scenario close to the higher impact scenario is realised (Figure 6). The central estimate for our 2042 modelling is a reduction in residual waste excluding major mineral wastes per capita of around 46% by 2042. We can be more confident that a target date of 2050 is more easily achievable, with a central estimate for the reduction in residual waste (excluding major mineral waste) per capita being around 52% by 2050 (Figure 7).

A 50% reduction in per capita residual waste excluding major mineral wastes represents a very ambitious target, irrespective of the target date. We propose that the target should be set at the earlier date of 2042 to drive continued environmental improvement over time. However, there is a level of risk associated with this proposal, in that it allows less time for the appropriate policy interventions and long-term behavioural and waste management process changes that will be required to meet the target.

Cost Benefit Analysis

Beyond the consulted-on CPR reforms, costs and benefits will depend on the future policies implemented. Illustrative analysis and discussion on the potential costs and benefits of indicative future policies is contained within the Impact Assessment.

The modelled additional household measures are estimated to reduce service costs by around £53 million per year, with minimal up-front costs. These estimates are from WRAP modelling for Defra and only cover the policies included in our proposed target.

The indicative future policy pathway, using price-based policies as an example, includes illustrative analysis to give an idea of the scale of associated costs and benefits. A future policy pathway would likely be a combination of interventions and the impact on costs and benefits will vary depending on the policies implemented. The illustrative analysis estimates total carbon savings from the policy pathway to be £695m per year by 2042, compared to a baseline of CPR. The illustrative analysis estimates the price-based policy pathway to increase total costs to society by £498m per year by 2042.

The illustrative future pathway, including the additional household measures, is estimated to result in total present value costs of £4,563m, total present value benefits of £8,183m and a Net Present Value of £3,620m, over the appraisal period of 2022-2050.

The impact assessment also includes qualitative discussion of the costs and benefits that may arise from broad lever types that could be used to reduce residual waste. The potential benefits include increased circularity of resources leading to decreased producer costs and increased jobs in reprocessing and repair sectors. The potential costs include increased costs for resource intensive producers.

Future plans for evidence, innovation and technology

Future improvements to data on waste generation and treatment are expected via the introduction of digital waste tracking (16). This will likely result in changes to the waste arisings estimates that underpin our baseline and policy impact modelling. However, the proposed measurement at endpoint treatment will buffer the metric as far as possible against future changes. Additionally, improvements in those areas where available data is currently less robust, such as for construction, demolition and excavation waste, or for individual material streams, may offer the potential for us to review the suitability of setting additional targets in these areas in the future.

Resource Productivity evidence

Statement of Interests

Conflicts of Interest

None

Statement of Transparency

This statement confirms that the authors believe the evidence base underpinning the derivation of the potential resource productivity target achieves Trustworthiness, Quality and Value.

Trustworthiness – wherever possible the evidence base draws on formally published National or Official Statistics produced either by Defra or by the Department's Arms' Length Bodies or other government departments. In addition, it promotes transparency through providing links to data used and details of methodologies throughout.

Quality – National or Official Statistics used in the evidence base have undergone a quality assessment and assurance process. Details on the methodologies used in constructing the underlying statistics are set out in the original source publications, which are referenced. Where we have developed new data series for the purpose of the evidence base, methods are detailed.

Value – The evidence base is either already accessible or will be accessible soon, and so meets society's need for information, potentially addressing the questions that external users wish to have answered and provides a basis to meet a government commitment to produce an annual assessment of progress towards the targets.

Changing status of evidence

Much of the available evidence around policy impacts is based on proposed policies that are currently under development. Decisions and modelling around these policies are ongoing and subject to revision, and the evidence will require to be updated as the latest data becomes available. It is also likely that new evidence around additional policies may become available before October 2022, as further policy plans and trajectories are established.

Introduction

The Resources and Waste Strategy (2) for England re-affirmed commitments in the Industrial Strategy (38) and 25 Year Environment Plan (1) to double resource productivity by 2050. In line with these commitments, as discussed in the August 2020 policy paper (39), we have been exploring an Environment Act 2021 target to increase resource productivity and have been reviewing the evidence for this throughout the target development process. Given the complexity of the resource productivity target, more time is needed to develop the evidence base and assess policies. We seek views at consultation to inform future work on developing this target.

Material resources are a key input into the production of goods and services. These goods and services help meet basic human needs and produce economic and social value, however their production, and in turn, consumption of materials can place significant pressure on the environment. Between 2001 and 2018, England's material footprint (excluding fossil fuels) decreased by 15% (36). Resource productivity measures the economic value per unit of raw material use. Increasing resource productivity through stabilising or reducing our material use, can help us avoid resource depletion and reduce environmental impacts (40). In addition, resource productivity can build the economy's resilience to price volatility, increase resource security, and enhance our international competitiveness (40).

We have been exploring a potential target to increase resource productivity, measured as a ratio of national economic output e.g., Gross Domestic Product, to raw material consumption. Raw material consumption estimates the weight of materials extracted within England to produce goods and services consumed (41). It also considers the full upstream raw materials required to produce the goods and services that we import. We will need to take account of increases in absolute material use when developing a target on resource productivity to avoid achieving the target through growth in high-value areas of the economy alone. Understanding how policies can work to decouple economic growth from raw materials use will be key to developing an effective resource productivity target.

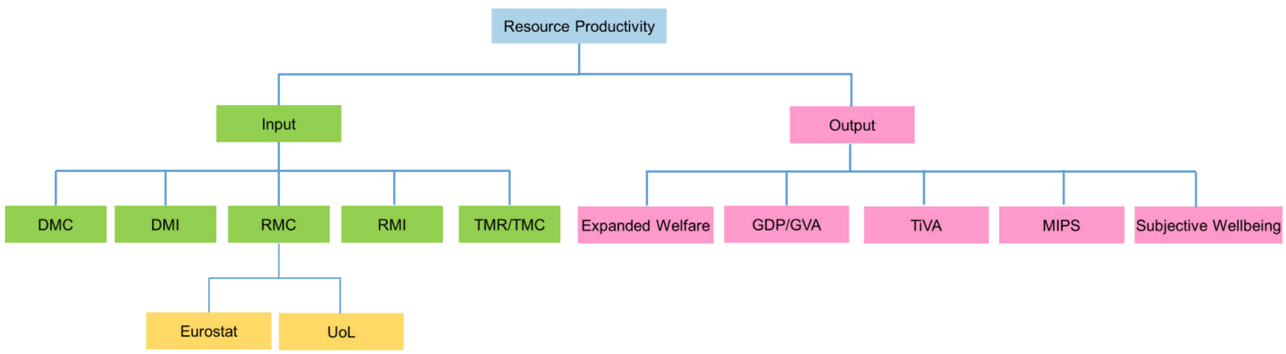
Methodology

Target scope

If a future target on resource productivity was to be set at a national (England) level, we propose to use a measure based on the ratio between aggregate economic output (defined as gross domestic product; GDP) to raw material consumption (RMC), with RMC measured using an environmentally-extended multi-regional input-output approach (EE-MRIO) (41). Incorporating these values into a single measure brings into a direct comparison the output of the domestic economy (in monetary terms) in relation to the raw material resources required to meet final demand of the population (in mass unit) (42).

Other output measures that were considered included: Consumption-based Gross Value Added (GVA), Trade in Value Added (TiVA), expanded wellbeing measures, subjective wellbeing, and material input per unit of service (MIPs). Alternative input measures considered included: Domestic Material Consumption /Domestic Material Input (DMC/DMI), Raw Material Input (RMI) and Total Material Requirement/Total Material Consumption (TMR/TMC) (summarized in Figure 10). It was agreed with RWTEG to use GDP over RMC (calculated using the University of Leeds' (UoL) EE-MRIO method (41)) as the preferred approach for measuring resource productivity because: 1) changes in GDP can be clearly linked to the rate of economic output, and 2) UoL's RMC method provides a high level of granularity whilst covering the whole economy in a systematic way, thereby avoiding truncation errors and double counting. In addition, their method draws on trade data which allows for material inputs to re-imported goods to be more accurately measured.

Figure 10: Options for defining resource productivity



Calculating Raw Material Consumption

Since 2020, the Office for National Statistics has published annual estimates of UK Raw Material Consumption (RMC), or 'material footprint', produced using UoL's environmentally-extended multi-regional input-output (EE-MRIO) method (43). This material footprint is defined as the total primary raw materials required to meet final demand for goods and services by households, government, business and charities. This includes an estimate of used materials extracted within the UK's borders to meet final demand, in addition to the full upstream material extraction associated with the production of imported goods and services. England's material footprint is produced using this method and has been published as an Official Statistic by Defra in August 2021[2] (36).

The UK MRIO that is applied to trace the full supply chain impact on raw material consumption uses a 2017 base year and comprises 106 economic sectors in each of the 15 global regions included (41). RMC outputs are comprised of 4 high-level categories, which can be subdivided into 13 sub-categories (see Table 1). It is measured in tonnes.

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[2] https://www.gov.uk/government/statistics/englands-material-footprint/englands-material-footprint

Table 1. Summary of categories within RMC metric

Material Category	Material Sub-Category
Biomass	Crops, Crop residue, Wood, Aquatic plants/animals
Non-metallic minerals	Limestone & gypsum, Clays & kaolin, Sand & gravel, Other e.g., salt
Metallic ores	Ferrous ores, Non-ferrous ores
Fossil Fuels	Coal, Oil, Natural gas

Defra proposed to exclude fossil fuels from the potential resource productivity target, the main reason being that fossil fuel use might be better managed in terms of climate impacts than their mass. This decision was supported by RWTEG group (on 13th November 2020 meeting).

Outstanding target analysis

Defra continues to explore whether including an economic numerator is the best approach for a resource-use target, as its inclusion risks the target being achieved through growth in high-value areas of the economy alone. The metric for defining the potential resource productivity target is still to be finalised. RWTEG proposed (on 13th November 2020) that Defra continues to investigate the following options for a resource productivity target metric: 1) to remove the economic numerator altogether, 2) continue to use a measure of national economic output e.g., GDP, as the numerator; 3) look for an alternative output measure for the numerator; or 4) use an environmental indicator in the denominator (CO_2 was suggested).

The following work remains to be carried out for a resource productivity target: 1) agreeing on the final indicator break-down, 2) obtaining additional evidence regarding possible impacts of potential policy levers on resource productivity, as well as 3) obtaining evidence on risks, opportunities, costs and benefits of different target ambition levels. Given the complexity of the potential resource productivity target and in order to allow time to resolve challenges around its large sectoral coverage and cross-government remit, Defra has taken the decision not to set the target in October 2022 but will still seek views on the potential target at consultation with the possibility of setting it in the future.

Reference scenario

Defra commissioned WRAP and UoL in September 2019 to develop a reference scenario for RMC in England up to 2050 to inform future policy appraisal (44). To produce the reference scenario, they first identified the historical trends in UK material use, through carrying out exploratory analysis using the UoL's UK Multi-Region Input-Output (UK MRIO) model. Next, UoL constructed a scenario projection model, linking the three 'driving forces' of material use (material intensity, structure of final demand, volume of final demand) to the UK MRIO model, to forecast RMC into the future. Two workshops were held in early 2021 with Defra's RWTEG as well as a small group of sector experts to determine the most likely future trends for each of the driving forces. These meetings resulted in a set of 5 scenarios: one reference scenario to be used for future policy appraisal, and four more exploratory scenarios. Each scenario was produced with a high, central and low variant, based on different final demand growth rates and material intensity improvements. A sub-national analysis of scenario results was also carried out to determine material footprint projections for each of the UK devolved administrations.

Policy impact analysis

Defra conducted internal policy workshops between April – May 2021 to identify five priority product groups where policy changes could drive the greatest increases to resource productivity. These included the following product groups, where the greatest material resource consumption occurs:

1. Food and drink
2. Construction
3. Vehicles
4. Furniture and furnishing
5. Electronics and electrical equipment

A long-list of sector-specific and economy-wide policies was put together, including both current commitments and exploratory policies, which were subsequently prioritised based on their environmental impact, feasibility and alignment to Defra objectives using Multi-Criteria Decision Analysis. The final, short-list of policies for further analysis included a range of regulatory, fiscal and spend-type policies.

Regulatory policy impact

Building on UoL's RMC/resource productivity reference scenario, WRAP and UoL were commissioned in September 2021 to provide a quantitative assessment of the effects of possible regulatory policy interventions on reducing resource consumption and GHG emissions associated with their production (the project is still to be published).

The project involved first translating 45 regulatory policies (short-listed by Defra) in terms of changes to their 'production recipe' (i.e., the inputs required from other industries and regions to manufacture a final product, summarised as the technical coefficients matrix in the MRIO), the 'intensity of production' and 'final demand' variables within their EE-MRIO central reference scenario model. In order to do this, WRAP/ UoL undertook a literature review for how these variables would be impacted in the construction sector, whilst WRAP collected policy evidence for how these variables would be impacted in the food and drink, furniture, vehicle and electronics sectors. The effect of these changes on environmental impact measures (RMC and GHG emissions) was then traced through the supply chain using the UK MRIO model. This project is now complete and will be published soon.

Fiscal policy impact and macro-economic analysis

Cambridge Econometrics were commissioned in September 2021 to investigate: 1) the impacts of fiscal and spend-type policies on material consumption, and 2) the macroeconomic effects of regulatory, fiscal, and spend-type policies to increase resource productivity. Macroeconomic effects can be defined as impacts on sectoral prices, output and employment as well as on national inflation, GDP and national employment. This analysis was carried out using Cambridge Econometrics' E3ME model (45), which is a computer-based model of the world's economic and energy systems and the environment. It was originally developed through the European Commission's research framework programmes and is now widely used globally for policy assessment, for forecasting and for research purposes. Cambridge Econometrics' analysis is now complete and the report will be published soon. As part of the deliverables, Cambridge Econometrics also provided an Excel tool for additional scenario analysis (for internal use).

The above projects assessing the impacts of regulatory and fiscal policies on material consumption, GHG emissions (for the regulatory policies) and at the macro-economic scale were agreed with RWTEG prior to commissioning the work.

Future analysis

Taken together, the results from the above projects assessing the impacts of regulatory and fiscal policies, along with the macro-economic analyses will inform further analysis into a potential resource productivity target and enable prioritisation of most impactful policies. Future evidence will be required on the risks, opportunities, costs, and benefits of different policy pathways to increase resource productivity.

Results and Discussion

Whilst the WRAP/ UoL and Cambridge Econometrics projects modelling resource productivity policy impacts are still to be published, we are only able to describe the results from WRAP/ UoL's earlier, UK resource productivity scenario work (44).

Reference scenario

WRAP and the UoL found in their central reference scenario, that the UK's material footprint is predicted to grow from 1.25 Gt in 2017 to 1.4Gt in 2050, which corresponds to a 12% increase (Figure 11). This increase is expected to occur despite a reduction in the material footprint of fossil fuels, due to increases in the material footprints of construction minerals and crops (Figure 12). Although it should be noted that these different material flows have vastly differently environmental impacts that cannot be represented through only material footprint.

WRAP and the UoL found that the projections of final demand for goods and services by households, governments, and charities, to have a strong influence on material footprint projections. The central reference scenario uses a final demand growth rate of 1.6%, which corresponds to the average final demand growth rate given in the OBR’s March 2020 long-term economic projections. They modelled two alternative variants of the references scenario, a low variant with a 0% final demand growth rate, corresponding to the average growth rate of the past 15 years, and a high variant with a 3% final demand growth rate. In the reference scenario, the material footprint changes from 1.25Gt in 2017 to 0.89, 1.40 or 2.09 Gt in 2050 under the low, central and high growth rate scenario variants respectively. The low, central and high variants also incorporate different short-term economic recoveries from the Covid-19 pandemic, along with varying material intensity improvements. Therefore, the changing material footprint is not solely due to differing final demand growth rates. These variants are used to capture the range of variability in potential futures.

Across the low, central, and high variants, the reference scenario sees between a 1.4-1.6 times improvement in resource productivity (GDP/RMC) by 2050 in comparison to 2017 (Table 2).

When also considering the exploratory scenarios, UoL found that the range in resource productivity improvements increased to between 1.4-3 times (summarised in Figure 13) compared to the central reference scenario. The largest improvements in resource productivity appeared when there was a strong push towards resource efficiency, along with a shift in final demand away from goods and towards services.

The material footprint results of each scenario were presented alongside recommendations regarding the suitability of the potential resource productivity target, implications for policy appraisal and suggestions for further work. Material footprint results for each of the UK’s devolved administrations were also provided.

Figure 11: Material footprint central reference scenario

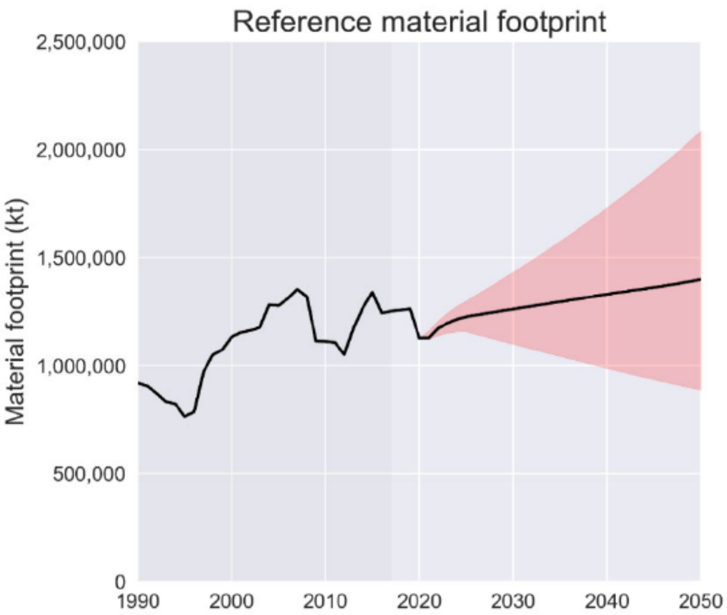


Figure 12: Sub-category break-down of material footprint central reference scenario

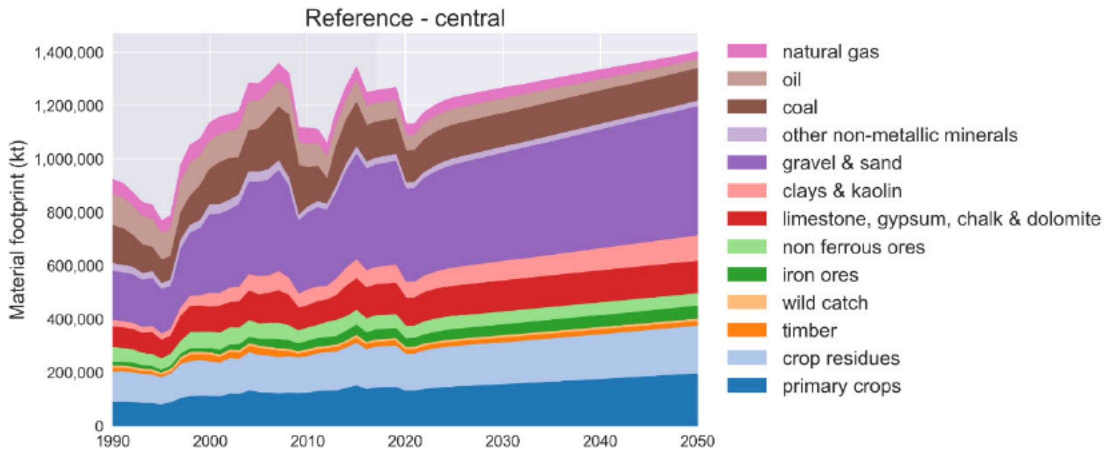
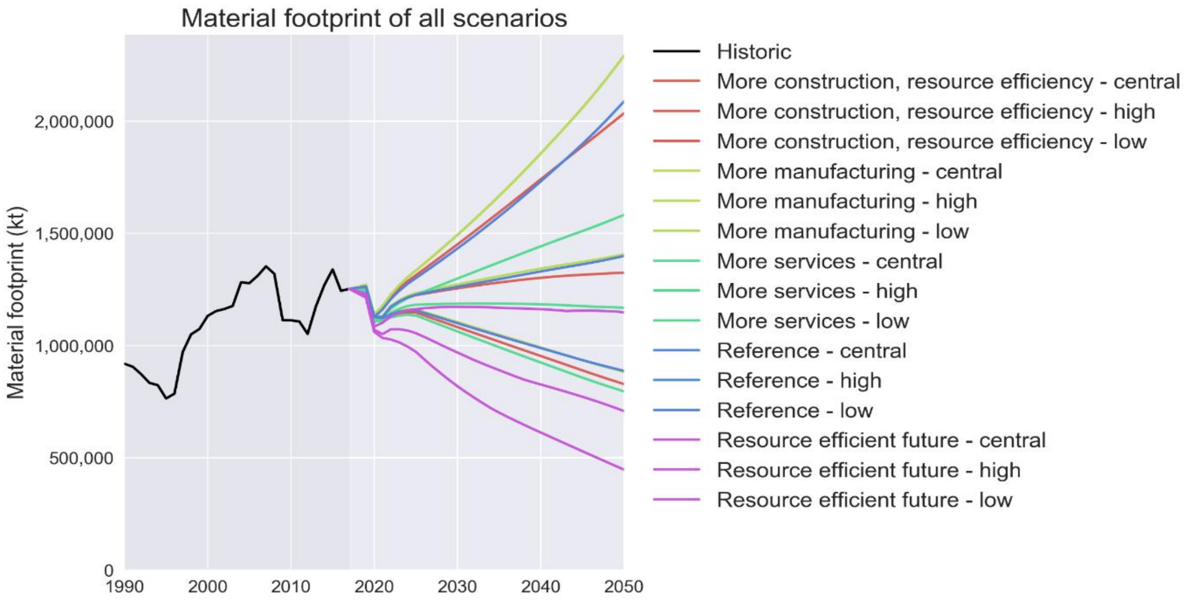


Table 2. Improvement in resource productivity (GDP/RMC) by 2050 compared with 2017

Scenario	Variation	GDP	RMC	Resource productivity (GDP/RMC)
		Values in 2050 indexed to 2017 = 100		
Reference	Central	169	112	151
	High	265	167	159
	Low	100	71	141

Figure 13: Forecast in material footprint across exploratory scenarios.



Bibliography

1. HM Government. *25 Year Environment Plan.* Available from: https://www.gov.uk/government/publications/25-year-environment-plan. [Accessed 19th January 2022].
2. HM Government. *Resources and Waste Strategy for England.* Available from: https://www.gov.uk/government/publications/resources-and-waste-strategy-for-england. [Accessed 20th January 2022].
3. Department for Environment, Food and Rural Affairs. *UK statistics on waste.* Available from: https://www.gov.uk/government/statistics/uk-waste-data. [Accessed 26th January 2022].
4. Department for Environment, Food and Rural Affairs. *Local authority collected waste management - annual results.* Available from: https://www.gov.uk/government/statistics/local-authority-collected-waste-management-annual-results. [Accessed 27th January 2022].
5. HM Government. *Resources and Waste Strategy for England - Evidence annex.* Available from: https://www.gov.uk/government/publications/resources-and-waste-strategy-for-england. [Accessed 27th January 2022].
6. Ham YJ, Maddison DJ, Elliott RJR. The valuation of landfill disamenities in Birmingham. Ecol Econ. 2013 Jan;85:116-129
7. Department for Environment, Food and Rural Affairs. *Energy from waste: a guide to the debate*. Available from: https://www.gov.uk/government/publications/energy-from-waste-a-guide-to-the-debate. [Accessed 27th January 2022].
8. Commission to the European Parliament, the Council, the European Economic and Social Committee, and the Committee of the Regions. *A new Circular Economy Action Plan - For a cleaner and more competitive Europe.* Available from: [redacted]. [Accessed 27th January 2022].
9. HM Government. *Circular Economy Package policy statement.* Available from: https://www.gov.uk/government/publications/circular-economy-package-policy-statement/circular-economy-package-policy-statement#:~:text=The%20Circular%20Economy%20Package%20(%20CEP,for%20waste%20management%20and%20recycling. [Accessed 27th January 2022].
10. United Nations Department of Economic and Social Affairs. *The 17 Goals.* Available from: [redacted] [Accessed 27th January 2022].
11. Eurostat. *European Waste Classification for Statistics, version 4. RAMON - Reference and Management of Nomenclatures.* Available from: [redacted] [Accessed 27th January 2022].
12. Eurostat. *Management of waste excluding major mineral waste, by waste management operations.* Available from: [redacted] [Accessed 27th January 2022].
13. Department for Environment, Food and Rural Affairs. *Resources and waste strategy for England: monitoring and evaluation.* Available from: https://www.gov.uk/government/publications/resources-and-waste-strategy-for-england-monitoring-and-evaluation. [Accessed 27th January 2022].
14. HM Government. *Resources and Waste Targets Expert Group*. Available from: https://www.gov.uk/government/groups/resources-and-waste-targets-expert-group. [Accessed 27th January 2022].

15. Department for Environment, Food and Rural Affairs. *Waste prevention programme for England 2021.* Available from: https://www.gov.uk/government/consultations/waste-prevention-programme-for-england-2021. [Accessed 27th January 2022].
16. Department for Environment, Food and Rural Affairs. *Implementation of mandatory digital waste tracking.* Available from: https://www.gov.uk/government/consultations/implementation-of-mandatory-digital-waste-tracking. [Accessed 27th January 2022].
17. Iacovidu E, Gerasimidou S, Martin O. *Environmental Life Cycle Impacts of Inert/Less Reactive Waste Materials.* Defra Science Search. Available from: http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=20771&FromSearch=Y&Publisher=1&SearchText=EV0152&SortString=ProjectCode&SortOrder=Asc&Paging=10#Description. [Accessed 27th January 2022].
18. Social, Environmental and Economic Solutions (SOENECS). *Identification and Short-listing of Policies to Reduce Resource Use and Waste in England's Construction Sector and Divert Waste Arisings from Residual Treatment*. Defra Science Search. Available from: http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=20775&FromSearch=Y&Publisher=1&SearchText=EV0153&SortString=ProjectCode&SortOrder=Asc&Paging=10#Description. [Accessed 27th January 2022].
19. Building Research Establishment Ltd. *A rapid evidence assessment to identify and short-list policies to reduce soils entering landfill in England.* Defra Science Search. Available from: http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=20776&FromSearch=Y&Publisher=1&SearchText=EV0154&SortString=ProjectCode&SortOrder=Asc&Paging=10#Description. [Accessed 27th January 2022].
20. Eunomia Research and Consulting Ltd. *Future Waste Arisings.* Defra Science Search. Available from: http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=20915&FromSearch=Y&Publisher=1&SearchText=EV0155&SortString=ProjectCode&SortOrder=Asc&Paging=10#Description. [Accessed 27th January 2022].
21. WasteDataFlow. Available from: [redacted]. [Accessed: 27th January 2022].
22. Office for National Statistics. *Regional gross disposal household income: local authorities by ITL1 region.* Available from: https://www.ons.gov.uk/economy/regionalaccounts/grossdisposablehouseholdincome/datasets/regionalgrossdisposablehouseholdincomelocalauthoritiesbyitl1region. [Accessed 27th January 2022].
23. Department for Levelling Up, Housing and Communities. *English indices of deprivation 2019.* Available from: https://www.gov.uk/government/statistics/english-indices-of-deprivation-2019. [Accessed 27th January 2022].
24. Office for National Statistics. *Estimates of the population for the UK, England and Wales, Scotland and Northern Ireland.* Available from: https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/datasets/populationestimatesforukenglandandwalesscotlandandnorthernireland. [Accessed 27th January 2022].
25. Office for National Statistics. *Population projections for local authorities: Table 2.* Available from:

https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationprojections/datasets/localauthoritiesinenglandtable2. [Accessed 8th March 2022].
26. Environment Agency. *2020 Waste Data Interrogator*. Available from: https://data.gov.uk/dataset/bb40d091-a346-4b75-aa54-df7d347bed93/2020-waste-data-interrogator. [Accessed 27th January 2022].
27. Office for National Statistics. *Regional gross value added (balanced) by industry: all ITL regions.* Available from: https://www.ons.gov.uk/economy/grossvalueaddedgva/datasets/nominalandrealregionalgrossvalueaddedbalancedbyindustry. [Accessed 27th January 2022].
28. *Environmental Protection Act 1990,* c.43. Available from: https://www.legislation.gov.uk/ukpga/1990/43/contents. [Accessed 9th February 2022].
29. *The List of Wastes (England) Regulation 2005*. S.I. 2005/895.
30. Department for Environment, Food and Rural Affairs. *Commercial and Industrial Waste Arisings Methodology Revisions for England.* Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1002247/Commercial_and_Industrial_Waste_Arisings_Methodology_RevisionsFeb2018_contact_details_update.pdf. [Accessed 9th March 2022].
31. WRAP. *Quantifying the composition of municipal waste*. Available from: [redacted] [Accessed 27th January 2022].
32. Department for Business, Energy and Industrial Strategy. *Greenhouse Gas Inventories for England, Scotland, Wales and Northern Ireland: 1990-2019.* Available from: https://naei.beis.gov.uk/reports/reports?report_id=1019. [Accessed 27th January 2022].
33. Environment Agency. *Improved definition of leachate source term from landfills phase 1: review of data from European landfills.* Available from: https://www.gov.uk/government/publications/improved-definition-of-leachate-source-term-from-landfills-phase-1-review-of-data-from-european-landfills. [Accessed 27th January 2022].
34. International Resource Panel. Global Resources Outlook: Natural Resources for the Future We Want. Available from: [redacted] [Accessed 28th January 2022].
35. Organisation for Economic Co-operation and Development (OECD). *Global Material Resources Outlook to 2060*. Available from: [redacted] [Accessed 28th January 2022].
36. Department for Environment, Food and Rural Affairs. *England's Material Footprint.* Available from: https://www.gov.uk/government/statistics/englands-material-footprint/englands-material-footprint. [Accessed 27th January 2022].
37. Environment Agency. *International Waste Shipments exported from England.* Available from: https://data.gov.uk/dataset/5ffdf701-05c2-43b8-ba1e-e65580bbcc08/international-waste-shipments-exported-from-england. [Accessed 27th January 2022].
38. HM Government. *Industrial Strategy: The Grand Challenges.* Available from: https://www.gov.uk/government/publications/industrial-strategy-the-grand-challenges. [Accessed 20th January 2022].
39. HM Government. *19 August 2020: Environment Bill - environmental targets.* Available from: https://www.gov.uk/government/publications/environment-bill-2020/august-2020-environment-bill-environmental-targets [Accessed 20th January 2022].
40. Organisation for Economic Co-operation and Development (OECD). *Material Resources, Productivity and the Environment.* Paris: OECD Publishing; 2015. Available from: [redacted]

41. Owen A, Giesekam J, Barrett J. *Resource efficiency metrics - initial findings*. Defra Science Search. Available from: http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=20092#Description. [Accessed 25th January 2022].
42. Pearce D. *Measuring resource productivity - A background paper for the Department of Trade and Industry and Green Alliance conference.* Available from: [redacted] [Accessed 31st January 2022].
43. Office for National Statistics. *Material footprint in the UK: 2018.* Available from: https://cy.ons.gov.uk/economy/environmentalaccounts/articles/materialfootprintintheuk/2018#:~:text=The%20UK%E2%80%99s%20material%20footprint%20was%20estimated%20as%20971,in%201999%2C%20when%20it%20was%20566%20million%20tonnes. [Accessed 27th January 2022].
44. WRAP. *UK Resource Productivity Scenarios to 2050*. Prepared by Jannik Giesekam, Rachel Carr-Whitworth, Jonathan Norman, Anne Owen and John Barrett. Banbury; 2021. Available from: [redacted]t [Accessed 31st January 2022].
45. Cambridge Econometrics. *E3ME Technical Manual v6.1.* Available from: [redacted]. [Accessed 31st January 2022].