Resource efficiency scenarios for the UK: A technical report

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Contents

Overview: resource consumption and climate change

Energy is required to transform raw materials into products. The majority of this energy is provided by fossil fuels and therefore contributes to climate change. Energy demand continues to rise globally, which means that additional renewable energy is used to meet this increase in demand. At this global level renewable energy supply increased by 81 million tonnes of oil equivalent (Mtoe) in 2017 (IEA, 2019). However, in the same period, energy demand grew by 328 Mtoe (2.3% more than the previous year) (IEA, 2019). The demand for materials and products forms an important part of this increase and, according to the International Energy Agency, global industrial energy demand is forecast to continue increasing (IEA, 2020).

At the domestic level it initially appears that the UK is moving in the opposite direction to the global trend with significant declines in industrial energy in the recent past; industrial energy demand has halved over the past 40 years (BEIS, 2020). However, as the UK has shifted to become an increasingly service based economy, the materials required to satisfy UK consumption have not declined; they are increasingly imported from elsewhere (University of Leeds and Defra, 2020). This partially explains why the energy demand of UK industry has halved in the past 40 years while industrial energy demand has not. The reality is that the industrial energy demand needed to satisfy UK consumption has remained relatively unchanged for the past 40 years (Barrett et al, 2018).

With consumption levels increasing and industrial energy demand required to meet this consumption remaining relatively unchanged, there have been improvements in the efficiency of production. This relative decoupling has ensured that industrial energy demand has not grown at the same rate as demand for materials and products. This has predominantly been met by two factors; energy efficiency improvements and changes in the structure of the economy (Hardt et al, 2018). Reducing the amount of materials to deliver our desired level of consumption has not been fully explored and implemented. In addition, there is a limited understanding of how the services provided by consumption (nutrition, shelter, mobility etc.) could be delivered with less material input. Finally, a greater appreciation is required of whether the most carbon intensive materials should be avoided.

The UK is legally required to reduce its territorial greenhouse gas (GHG) emissions to net zero by 2050. However, it is not only this target that is important but also the total GHG emissions emitted between now and 2050. It is these total GHG emissions that are linked to the climate impact rather than the level of emissions in 2050. Therefore, rapid reductions are more significant to reduce the total cumulative emissions.

Broadly speaking, the UK has three options to achieve this goal. These options are; to reduce the carbon intensity of energy; to reduce energy demand; and to remove any remaining GHG emissions. There is considerable evidence to suggest that all three are required to achieve the scale and speed of reduction required. It is simply not possible to ignore any of the three options. For industry, there are important energy efficiency improvements that can still be implemented. However, it is also important to focus on whether further reductions can be achieved by exploring the output of industry, i.e. materials and products.

Purpose of this report

This report considers the impact of changing the UK's resource consumption on GHG emissions from a territorial and consumption perspective from now until 2050.

Methodology

1. Underlying modelling approach

Instead of allocating emissions to the sector in which they are physically produced ('emissions by source'), we use the UK multiregional input-output model (MRIO) (Owen et al, 2017) to allocate UK emissions for the year 2017 to the final product they become embodied in. These final products are consumed both in the UK and abroad by households and governments, or represent large capital spend.

Goods and services are classified by 106 sectors (also referred to as product groups) according to the UK Standard Industrial Classification system (Office for National Statistics, 2009) and we aggregate the global economy into a fifteen region model of the UK and the Rest of the World (RoW) reflecting how the UK trades in goods and services. By retaining a fifteen-region structure we are able to capture emissions that were exported and then reimported to the UK across international supply chains. Embodied emissions are calculated using the standard Leontief demand-pull model. GHGs emitted directly by UK sectors are reallocated to final consumers (including exports) by following products through multiple trade and transformation steps using Equation (1):

$$q = e \cdot (I - A)^{-1} \cdot Y \qquad (1)$$

Where q is a vector of embodied emissions by sector, e the GHG intensity of production sectors (both in the UK and RoW regions), I represents an identity matrix, A is the technical coefficients matrix and Y is a diagonalised vector of the total household, government and capital final demand in the UK and RoW, including UK goods exported to RoW. The technical coefficients matrix (A) accounts for the proportion of intermediate inputs, both domestic and foreign, that a sector within a country requires to produce one unit of output, also known as a production recipe. The term (I – A)-1 is known as the Leontief inverse (L), which calculates the extent to which output rises in each sector, derived from a unit increase in final demand.

In projecting forwards a reference scenario the emissions intensity (of each sector in each region) and the level of final demand were projected, details are given in section 2 below. For the reference scenario the "production recipe" (defined by the technical coefficients matrix, A), i.e. how industries purchase outputs from each other to ultimately supply final demand, was held constant.

The effect of resource efficiency strategies were then assessed by applying such strategies onto the reference scenario. The assumptions used for the resource efficiency strategies are defined in the following section of this report. A resource efficiency strategy could impact how a product of industry was used by other industries (altering the technical coefficients matrix, A) and/ or how a product was purchased by final demand (altering the final demand vector, Y). The MRIO model was used to calculate the impact of the changes resulting from these strategies, with such impacts traced through the whole supply chain. This methodology is based on that utilised by Cooper et al. (2017) and Scott et al. (2019).

The resource efficiency strategies assessed focus on UK actions. Due to the nature of international trade, actions taken by UK industries and consumers can impact industrial production and its associated impacts in other nations – the full impacts of which are captured by consumption emissions accounting.

GHG emissions can be allocated to countries in different ways. At present, there are three main allocation methods in common use: territorial-based, production-based, and consumption-based.

- Territorial-based. The United Nations Framework Convention on Climate Change (UNFCCC) requires countries to submit annual National Emissions Inventories and follows the guidelines from the Intergovernmental Panel on Climate Change (IPCC) regarding the allocation of GHG emissions: 'emissions and removals taking place within national (including administered) territories and offshore areas over which the country has jurisdiction'. However, GHG emissions that arise in international territories, including those from international aviation and shipping, are only reported as a memo and are not allocated to individual countries. Such a system can be called a 'territorial-based emissions inventory'.
- Production-based. Some countries also report GHG emissions allocated using the same system boundary as the System of National Accounts (SNA), as is already done with gross domestic product (GDP). The GHG emissions inventories are sometimes called National Accounting Matrices including Environmental Accounts (NAMEAs). In the EU, NAMEAs are reported to Eurostat. Although most other developed countries create NAMEAs, they do not report them internationally. In the SNA, unlike the UNFCCC territorial-based system, emissions from international aviation and shipping are typically allocated to the country of the relevant vessel's operator. Similarly, emissions from international tourism are allocated based on where individual tourists are resident, rather than their destination. The NAMEAs system can be called a 'production-based emissions inventory'.

- Consumption-based. Emissions are allocated according to the country of the consumer, usually based on final consumption (as recorded in the SNA) or as trade-adjusted emissions (Peters, 2008). Conceptually, consumption-based inventories can be thought of as 'consumption equals production-based emissions minus the emissions from the production of exports, plus the emissions from the production of imports' (Consumption = Production – Exports + Imports). Such a system can be called a 'consumption-based emissions inventory'.

For further information, please see Barrett et al (2013).

2. Reference emissions scenario

A reference emissions scenario was developed for the impact of the resource efficiency strategies to be assessed against. To form such a scenario, and allow it to estimate production and consumption emissions from the UK the following information was required:

1. Final demand projections covering the UK and RoW.
2. Emissions intensity of production for UK and RoW sectors represented within the MRIO model.

The reference scenario was chosen to be aligned with current progress towards decarbonisation goals and known policies. In this manner the impact of resource efficiency strategies applied onto this reference scenario could be assessed.

2.1. Final demand projections

Growth in final demand was based on the reference scenario of the 2018 Energy and Emissions Projections produced by the Department for Business, Energy and Industrial Strategy (2020). Growth in real household disposable income was used to estimate changes in household spending. Spending of government, capital formation and other sectors was aligned with real UK GDP growth. This was also used to estimate changes in RoW spending on UK products. These projections run to 2035, they show a stable growth rate that was continued to 2050 in the current work. The relative split of spending between different products, by each consumer group, was held constant at 2017 values.

2.2. UK emissions intensity of production

The baseline for UK territorial and production emissions was the 2018 Energy and Emissions Projections produced by the Department for Business, Energy and Industrial Strategy (2020). The Reference scenario from the projections was adopted, this is based on central estimates of economic growth and fossil fuel prices and the estimated effect of current and planned policies. The projections cover the period to 2035, this was extended to 2050 by continuing the trends seen.

The BEIS projections cover carbon dioxide and other greenhouse gases at differing levels of sector disaggregation, these sectors were aligned with those in the MRIO (based on the method of Scott et al. 2019) and used to estimate the percentage change in emissions in each of the MRIO sectors from the 2017 baseline. Final demand projections (as above) were combined with the baseline structure within the MRIO model to estimate emissions intensity of each UK sector to 2050.

2.3. RoW emissions intensity of production

The Climate Change Committee (CCC) has recently commissioned Vivid Economics & UCL (2020) to undertake a project looking at unpacking aspects of leadership-driven scenarios consistent with the Paris Agreement. As part of this work, the TIAM-UCL integrated assessment model was used to develop quantitative carbon intensity projections of a world transitioning to 'well-below' 2°C broadly consistent with the principles of developed country leadership laid out in CH3 of the CCC's Net Zero report (CCC (2019), and a world with a continuation of the level of ambition in current global policies (Anandarajah et al, 2013). The reference scenario (NDC_HiRen) developed in this project, aligned with 30°C average global atmospheric warming by 2100, was used to project RoW baseline emissions intensity projections in a scenario where present levels of ambition were continued. Comparing this scenario with projections made by Climate Action Tracker (2020), who suggest current policies are aligned with 2.9°C (+1°C/–0.8°C) of warming in 2100, justify our use of the NDC_HiRen intensity projections for our RoW emissions intensity of production baseline.

Projecting international carbon intensities

To enable the use of the TIAM-UCL produced 'NDC_HiRen' as a baseline for the UKMRIO model, a number of adaptations have been made. Firstly, the 16 TIAM-UCL regions were mapped onto the 15 regions used in the UKMRIO Model. Similarly, each of the 106 UKMRIO sector categories were assigned one of the aggregated sector groups used in the TIAM-UCL projections. A detailed list of regional and sector mapping is available in the appendix to this report.

The TIAM-UCL projections were then converted into indexed form, using a 2015 baseline, and applied to the baseline intensity values (tCO_2/£million) for each of the 106 UKMRIO sector groups, across the 14 overseas regions. Given the TIAM-UCL projections had a 5 year time-step, the annual change for each MRIO sector was linearly projected between each 5 year projection.

There were several projections missing from the TIAM-UCL scenario. Where 'Industry – non-ferrous metals' projections were missing (Japan, Mexico and South Korea), the trajectories from the respective steel industries were taken. In the case of missing 'non-metallic minerals' projections (South Africa and Rest of Africa), an average of all other regions' non-metallic minerals sectors was taken, given this was judged to better reflect an estimate for the sector, than borrowing projections from another sector within the region.

Finally, where whole sector emissions were missing, across all regions (Upstream & Agriculture), emissions trajectories were taken proportionally from the UK carbon intensities projections, and applied to each of the regional baselines for those MRIO sectors, using a baseline year of 2017.

Finally, one limitation of the MRIO model is the missing baselines for all regions in a number of sectors. This is most impactful in sectors comprising the chemical industry, including: P26 – Paints, varnishes and similar coatings, printing ink and mastics; P27 – Soap and detergents, cleaning and polishing preparations, perfumes and toilet preparations; P28 – Other chemical products; P29 – Industrial gases, inorganics and fertilisers (all inorganic chemicals); P30 – Petrochemicals; P31 – Dyestuffs, agro-chemicals; P32 – Basic pharmaceutical products and pharmaceutical preparations.

3. Resource efficiency scenarios

Two resource efficiency scenarios were developed, namely:

- Ambitious scenario
- Transformative scenario

The ambitious scenario seeks to demonstrate the potential for climate change mitigation if resource efficiency measures that are already in place are implemented comprehensively across the whole economy. The "implementation time" for these strategies is, in most cases, by 2050. This means that the maximum potential for each strategy will be implemented by 2050. In some cases, where there is strong evidence to suggest that the maximum potential could be achieved early, this date has been moved forward. All the interventions require a shift in current practices to demonstrate the reduction potential compared to the baseline scenario. However, there is evidence to support each intervention with working examples within the UK or similar countries. For example, the lifetime of clothing items returns to historical patterns of use from 15 years ago. Lighter cars that already exist are promoted over heavier vehicles reversing the current trend towards the purchasing of heavier vehicles. As the name suggests, this is still an "ambitious" level of change that would require a coordinated effort with Government, industry and citizens.

The transformative scenario outlines both known strategies but also includes transformative changes in society. These changes require shifts in social practices and cultural norms where a "sharing society" becomes the norm as opposed to the exception. It involves initiatives to move away from a linear material economy to one that is circular, maximises the use of carbon intensive assets and values quality of life over increased personal economic gain. While doing this, the scenario continues to ensure that there is not a reduction in the quality of life of UK citizens but a reorientation of social practices that are more consistent with the need for rapid reductions in emissions. There is also a reduction in the time needed to achieve the changes outlined in the ambitious scenario. For example, shifts in car vehicle weight, longevity of clothing and food waste reduction all occur in a shorter timeframe.

In relation to social practices and cultural norms, these are often assumed to be fixed entities that are outside of the control of UK Government. However, there is considerable evidence that the social practices that define high levels of unsustainable use of materials and products are malleable and guided by policy decisions. The infrastructure that Government wishes to develop guides mobility decisions, taxation policy guides consumer spending on specific products and consumer standards guides the replacement rates of carbon intensive products. In addition, many of the changes look to accelerate current social trends in dietary changes, environmental awareness and changing mobility patterns.

4. Capabilities and limitations of the modelling approach

The MRIO modelling approach taken here allows multiple, diverse resource efficiency strategies to be assessed within a consistent framework. The full supply chain impacts of strategies, both within the UK and in other nations can be assessed using this approach. There are however limitations to such an approach, the main limitations in the context of this study being:

- Disaggregation level: the disaggregation of the MRIO model is limited by the data sources used in its construction. The 106 sectors of the model necessarily combine various products into the same sector. Where a resource efficiency strategy only effects part of the output of a given sector an assumption is required that the production structure and emissions intensity of the parent sector is representative of the product under consideration. Where this is not the case inaccuracies can arise.
- Disruptive changes in production systems: the current production structure is defined by the technical coefficients matrix in the baseline year. This is assumed constant in the reference case and altered to capture the impacts of the resource efficiency strategies. However, this will not capture the impacts of changes in the production systems caused by disruptive changes. For example, the impacts of vehicle production will be based on those in the baseline year. A change towards alterative drivetrains (for example electrical and hydrogen fuelled) could significantly alter the impacts of production, which would not be captured here.
- Rebound effect: the resource efficiency strategies are modelled by changes in purchasing by either industries or final consumers. A “rebound” could be expected where reductions in purchasing in one area are offset by increases in others. These effects are not accounted for, a discussion of rebound specifically related to the methodology utilised here is included in Cooper et al. (2017).


CHICKPEAS
YELLOW PEAS
GREEN PEAS
RED LENTILS

Sector modelling assumptions

A. Lean production

1. Outline

Designing lighter weighted products by reducing material input is one approach to improving resource efficiency as it enables a reduction in primary material production (Carruth et al, 2011). For energy intensive sectors like steel and aluminium, reducing the amount of these materials used to create a product can significantly reduce its embodied emissions. In this strategy, we do not explore the use of material substitution as a way to lightweight design, but rather simply whether a product can maintain its effectiveness with less material input.

This strategy, also known as "right-weighting" is probably most widely discussed in relation to packaging. Some big supermarkets have committed to targets to reduce packaging waste in the immediate future. While this is clearly necessary, packaging only represents a very small proportion of the UK's material requirements. We also consider the potential to reduce the weight of motor vehicles, and a range of options to reduce material inputs in construction through design optimisation.

2. Criteria for selection

1. Products and packaging which can be made lighter without reducing functionality or compromising product longevity.
2. Design optimisation methods which reduce material input or waste

3. Products included and assumptions

We reduce the intermediate demand for materials by manufactured sectors. These these strategies relate to supply side changes. However, this impacts some consumption patterns. For example, the light weighting of cars relates to consumers purchasing lighter vehicles and avoiding over-sized SUVs.

3.1. Intermediate demand and government

- **Sector 43** – Motor Vehicles
- **Sector 23** – Paper products
- **Sector 33** – Rubber and Plastic products
- **Sector 35** – Glass products
- **Sector 39** – Fabricated metal products
- **Sector 58** – Construction
- **Sector 40** – Computers
- **Sector 41** – Electrical equipment
- **Sector 42** – Machinery
- **Sector 46** – Other transport equipment
- **Sector 47** – Furniture
- **Sector 48** – Other manufactured products

4. Sector level assumptions

5. Motor vehicles (SIC 43)

Evidence

The average occupancy rate of cars in the UK is 1.54, and yet most cars are designed to transport 5 people (Carvalho et al. 2018). There is therefore a large amount of unused space in the average car, which could be reduced without changing the functionality of transporting one or two passengers. Reducing the size of a car can considerably reduce the consumption of energy intensive iron and steel in the production process (Gonzalez Palencia et al. 2016). Cheah (2010) estimates that if all US vehicles were downsized by one classification, then there would be a 10% reduction in average vehicle weight. In Japan, mini-sized vehicles already make up a much larger proportion of the vehicle fleet (31%), and they weigh considerably less than their larger counterparts: 48% less for internal combustion engine (ICE) vehicles and 44% less in electric vehicles (EVs) (Gonzalez Palencia et al. 2015; 2016).

However, in the UK new cars have on average been increasing in weight by 1% per year since 2000 (Cabrera Serrenho, Norman and Allwood, 2017). In recent years there has also been a rapid growth in sales of sport utility vehicles (SUVs), which now make up 21% of new car sales, compared to 6% in 2009 (UKERC, 2019). SUVs weigh between 2500-3000kgs, which is triple the weight of mini size cars like the Smart ForTwo (880kgs).

Powered light vehicles like the Renault Twizy weigh just 450kgs, and could be utilised on a large scale for short urban trips (Low Carbon Vehicle Partnership, 2019).

Scenario assumptions

Facilitated by the switch to car clubs (covered in "goods to services"), it is assumed that a large proportion of the car fleet could be mini sized vehicles, appropriate for the single or dual passenger journeys which dominate trips made in the UK. The car club model will allow the passenger requirements to be matched to the vehicle type.

Currently 10% of the UK car sales are mini vehicles, weighing ~850kgs, 65% are medium sized vehicles weighing ~1500kgs, and 25% are SUVs and vans weighing ~2500kgs (ICCT, 2019). The average car weight is therefore currently 1685kgs. In our resource efficient scenarios, it is assumed that 80% of cars will be mini-sized with an average weight of 600kgs, including both small cars like the Smart ForTwo, and powered light vehicles like the Renault Twizy. 10% of cars will be medium sized (1500kgs), and 10% of cars will be heavy SUVs/vans (2500kgs). In this scenario, the average weight of a car is 880kgs. This is a **48% reduction in average car weight**.

- In the **transformative scenario** it is assumed that this is achieved rapidly by 2035.
- In the **ambitious scenario**, it is assumed that this is achieved more slowly, by 2050.

The timeline of these assumptions is coordinated with the switch to car clubs in "goods to services".

Packaging: (SIC 23, 33, 35, 39)

Evidence

Light-weighting has historically been the most common strategy to improve resource efficiency in packaging, however there is still the potential to further lightweight packaging as well as remove unnecessary packaging altogether (van Sluisveld and Worrell, 2013). WRAP analysis has shown that using design innovations like altering the proportions of food cartons and using flexible pouches can reduce the weight of packaging in chilled/frozen ready meals by 40% (WRAP, 2007). There are also large disparities in packaging weights of similar consumer products. If all brands adopted the packaging weights of the 'best in class' products, there could be weight reductions of 34% in wine bottles, 39% in champagne bottles, 27% reduction in cereal boxes, 34% in beer cans, 50% reduction in egg boxes, and 33% in ketchup bottles (WRAP, 2007). Weight reductions of up to 40% can also go unnoticed by consumers, therefore not impacting consumer preferences.

Several large retailers like Morrison's, Waitrose and Sainsbury's have pledged to reduce plastic packaging in their stores. By shifting to refill models for items like bottled drinks and light-weighting or eliminating packaging from certain items of produce, supermarkets could reduce their plastic output by 35% (Greenpeace, 2020). For some products, for example liquids, a refill system may be preferable to further light-weighting, which may compromise the recyclability of the packaging.

Scenario assumptions

While the WRAP (2007) data is now over a decade old and some of this light weighting is likely to have already been achieved, we base our assumptions on prospect of further future innovations and therefore assume 40% reductions are possible as a future target through continuous adoption of 'best in class' packaging weights and the move to refill models for certain products.

- For the **transformative scenario** it is assumed that this is achieved by 2030.
- For the **ambitious scenario** it is assumed this is achieved by 2040.

Electronics, machinery, furniture, other transport equipment and other manufactured products (SIC 40, 41, 42, 46, 47, 48)

Evidence

There is a limited amount of evidence on the potential to lightweight electronic equipment and machinery. However, Carruth, Allwood and Moynihan (2011) propose a set of lightweight design principles which could reduce steel requirements by 25-30%.

Scenario assumptions

In our transformative scenario, we assume the lightweighting principles of Carruth, Allwood and Moynihan (2011) reduce the steel requirements of electrical equipment, machinery, furniture, and other transport equipment by 25%.

Construction (SIC 58)

Evidence

Flexible formwork technologies can be used to lightweight floors and slabs; beams and trusses; columns; wall and façade panels; foundations and certain infrastructure applications (such as marine pile jackets). See Hawkins et al. (2016) for overview and examples. Current use represents a tiny fraction of construction; however, material reductions of 25-44% in beams and 20-50% in floors have been demonstrated.

Increasing use of digital tools can also enable design optimisation and reduce life cycle impacts of materials used in construction. Iterative design with real time feedback on whole life carbon can result in reductions in carbon and energy intensity of final designs. Reductions in our scenarios are based upon estimated carbon reductions from use of BRE Impact as reported in Cooper et al. (2017). Other example software tools include OneClickLCA, eTool, EC3, Eccolab etc.

There are a range of options to achieve closer to optimal use of structural steel. Studies such as D'Amico and Pomponi (2020) and De Wolf et al. (2015) have demonstrated that a range of structural mass per unit floor area can be required depending upon key design decisions and parameters, suggesting the potential for sizable reductions to be achieved through optimisation of designs. Studies such as Moynihan and Allwood (2014) and Dunant et al. (2018) have also considered the possibility of eliminating excess material use attributable to rationalisation and repetition of structural members and overly conservative design practices of engineers, deeming 35-45% of structural steel surplus to requirements across a set of sample buildings in the UK. Drewniok, Campbell and Orr (2020) estimates that simply the routine specification of the lightest beam available from standard catalogue sizes under current standards could result in 26.5% steel savings by mass, with further reductions possible with changes to current design standards and criteria. The extent to which these results can be extrapolated across the UK industry at large has been disputed (Giesekam, 2016: 105), as, although the sample of real world structures underpinning these studies are typical of current design practice, they do not constitute a representative mix of UK structures (including a disproportionate number of low rise schools and ring structures). Implementing widespread changes in design practice amongst the industry's thousands of structural engineers is also likely to require changes in education, standards and/or client drivers. These changes could take a variety of forms, with differing suggestions outlined in Moynihan and Allwood (2014), Dunant et al. (2018), and Drewniok, Campbell and Orr (2020) and in various outputs of the MEICON project.

The greater use of computationally optimised roll-out reinforcement carpets produced through automated manufacture (e.g. BAMTEC) has been highlighted by some authors (e.g. Waugh, 2013) as a means of delivering greater material efficiency. The same manufacturing technologies can also be used for wall reinforcement under certain circumstances (e.g. BAMTEC WALL). These products can typically reduce the mass of steel rebar required by 15-30% whilst drastically reducing installation time. The first UK production line for these products launched in 1998 but had only delivered ~60 projects by 2009. Since then the number of UK manufacturers has increased, but these products have remained a relatively niche solution, reserved for large multi storey projects where programme acceleration can result in significant cost savings covering the uplift in product cost, or where the need for particularly complex steelfixing can be eliminated. Thus, although there is great technical potential for material savings through more widespread use of these products, this is unlikely to be realised without additional drivers, such as significant raw material cost increases, skilled labour shortages, or widespread adoption of challenging embodied/whole life carbon targets.

We also include assumptions on a package of measures to reduce use of cement, applied sequentially: post tensioning, precast systems, reducing cement content of concrete, use of calcined clay and limestone, reducing construction waste and reducing over-design. See full details in Shanks et al. (2019).

Scenario assumptions

We assume that flexible formwork technologies are used to lightweight cement floor slabs and beams. For our scenarios the stated ranges are taken as upper and lower bounds, with low levels of uptake under the ambitious scenario and higher levels under the transformative scenario.

We assume that use of digital tools can provide material reductions of 7%, which is achieved by 2050 in the ambitious scenario and 2030 in the transformative scenario.

We assume that a more optimal use of structural steel under the can eliminate 5% of structural steel mass under the ambitious scenario and 10% under the transformative scenario.

Under the ambitious scenario we assume a small reduction (2%) in required steel rebar for non-domestic buildings due to greater use of computationally optimised reinforcement products, and this increases to 4% under transformative scenario.

Scenario assumptions for the package of cement measures include: substitution of London clay and limestone for 45% of cement in concrete applications; 60% of mortars with low loads and 45% of remaining clinker in mortars; 60% in finishes and renders; 45% in structure screeds and 60% in non-structural screeds. Reducing binder intensity by 15% in concrete and structural screeds. Achieving 15% concrete savings from converting non-precast structural elements to precast. Achieving a 20% reduction by post-tensioning 95% of non-residential floor slabs. Reducing construction waste to world's most efficient level and reducing cement use in structural elements by 20% by eliminating over-design. These measures have a 60% adoption rate under the ambitious scenario, and a universal adoption under the transformative scenario.

Sector modelling assumptions

B. Product longevity

1. Outline

Product longevity refers to the premature obsolescence of a product by households, industry, services or government due to a range of reasons that include insufficient performance, psychological and functional obsolescence, economic factors and structural barriers. Put simply, durable products are disposed of prematurely and thus the embodied energy in the materials used in the product are not used for their maximum lifetime. New products are purchased when old products could have been repaired.

Bertling et al (2014) provide definitions for four key reasons for a product lifetime being unnecessary shortened. We have also added an additional factor, this being "structural barriers". These being:

- **Material failure** – this refers to products that do not reach their intended lifetime due to poor manufacturing practices or poor design.
- **Functional obsolescence** – this refers to products that become redundant due to their inability to cope with rapid changes in software, for example.
- **Psychological obsolescence** – this refers to the discarding of a product as a result of changing social practices such as fashion or technological trends.
- **Economic obsolescence** – this refers to when it is cheaper to replace a product than get the old product repaired. This is often due to the cheap availability of raw materials, failure of the price to indicate the full environmental impact and cheap labour used in production.
- **Structural barriers** – this refers to a lack of available infrastructure to repair products due to either a lack of expertise or the unavailability of spare parts.

Our analysis demonstrates that it is difficult to assign a generic figure to all durable products (for example, all durable products could last 30% longer). The reality is that the factors listed apply to very different degrees to different products.

For example, some products such as clothing are very susceptible to changes in fashion while this is not so important for other product groups, such as a washing machine. There is a strong culture of repairing some products (a car for example) and not for others (iron or kettle).

2. Criteria for selection

Collectively, these issues result in the premature obsolescence of many durable products. Taking these factors into account we have established a set of rules by which to explore which products are suitable for lifetime extension. These being:

1. Extending lifetimes only refers to durable products. This is defined as a product that is not perishable and lasts longer than a year.
2. Extending the lifetime for a product is only suitable for products that are not undergoing rapid change and development. For example, three years ago the smartphone was rapidly developing. Today, this development has stabilised and most of the "improvements" relate to software and not hardware.
3. Extending lifetime is not suitable for products that need to be replaced because they have high operational emissions and a new technology is emerging. A good example of this would be a car where the UK is at the beginning of a rapid transition from international combustion engines (ICEs) to electric vehicles. Therefore, extending the lifetime of ICEs is not beneficial as the operational emissions are higher than EVs. It is important to extend the lifetime of EVs as this is the "technology of the future". Products such as washing machines are not undergoing rapid development and there are limited options to make further savings in operational emissions. This would therefore be a suitable product to extend its lifetime.
4. The lifetime of the product needs to be matched with the expectation of the user, i.e. aligned to psychological obsolescence. For example, an item of clothing that lasts for 20 years is more than likely to be out of fashion and discarded. There is a danger of making a product too well, in essence over engineering the product for its intended use (Cherry at al, 2018).
5. Extremely expensive industrial machinery will already be used to its maximum potential. We exclude large industrial machinery from our analysis on the premise that the capital investment could be in the millions of pounds and therefore the company would wish to extend the life of the investment for as long as possible based on sound economic decisions. An example of this would be a blast furnace for steel production.
6. Policies should not further exacerbate inequality. There is a clear link between the value of the product and the willingness to repair it. For example, almost 100% of the population would get their car fixed if it broke down and only 1% would get a kettle fixed.

The primary reasons for this are the initial capital cost of the product and the infrastructure to repair the car (i.e. garages). One solution to promote product longevity is to increase the capital cost thus ensuring that it is cheaper to repair than replace. However, this could have negative implications on low income households and until a system of sharing, shift from goods to services and repair options are available, we exclude policies that would exasperate inequality. However, we do recognise that repairable products also offer job opportunities to reduce inequality and provide structural employment. While the majority of UK products are produced overseas, there is an opportunity for the repairing of products to be undertaken in the UK.

7. Finally, we only consider extending the lifetime of products which do not overlap with the effects of the 'goods to services' strategies, which can also act to extend the lifetime of products and therefore could otherwise lead to double counting.

3. Products included and assumptions

We reduce the expenditure on specific intermediate sectors to reflect the saving that they would make by extending the lifetime of durable products. In addition, we also reduce the expenditure by households and government to reflect the reduced expenditure due to extending the life of products (addressed below). We also address the macro-economic rebounds by increasing the size of the repair economy in the UK.

3.1. Intermediate demand and government

- **Sector 19, 20, 21 –** Textiles, wearing apparel and leather products
- **Sector 43** – Motor Vehicles
- **Sector 47** – Furniture
- **Sector 48** – Other manufactured products
- **Sector 58** – Construction

We have derived different assumptions based on the best available evidence for each of the 8 sectors and consider the increase in the three growth sectors (the repair sectors). This is our attempt to recognise the benefits of product longevity combined with an acknowledgment of rebound effects.

3.2. Products included and assumptions – final demand

For households, we can assign the SIC categories used above for industry and government to a household classification called COICOP. This allows the further disaggregation of durable products. The consumption classifications included in the analysis include:

- Clothing
- Household furniture
- Household appliances (practical)
- Electrical tools
- Cars and motorbikes

- Mobile phones
- Computers
- Electrical audio and visual equipment
- Sports equipment
- Spare parts for appliances and repairs

4. Sector level assumptions

Textiles (SIC 19, 20, 21) and Clothing (COICOP 3.1, 3.2)

Evidence

Evidence as far back as 2004 suggests that 33% of clothing is discarded while still working (Copper, 2004). Since then there has been the growth of fast fashion and a noticeable reduction in the lifetime of clothing. Laitala et al (2015) suggest that 8% of clothes that are purchased are never used. They also show that owning a large number of garments increases the chance of premature disposal as the items will be out of fashion but still functional. The average lifetime of an item of clothing was 5.4 years. However, there was evidence that some items could be used up to 50 years. Gender was an important variable. The lifetime of men's clothes is 1.5 years more than women. Women's clothes account for 62% of the market. Other evidence suggests that 22% of women's clothing items are only worn twice. The average number of times an item of clothing is worn is 7 times. There are a number of campaigns led by the Fashion industry and advocates of sustainable fashion to extend this to 30 on average.

There is also evidence that some items are no longer designed to last for 30 wears. Therefore, the issue is not just psychological but also material failure (Ellen MacArthur Foundation (2017).

The Ellen MacArthur Foundation (2017) has made calculations based on Circular Fibres Initiative materials flow analysis and Euromonitor International Apparel & Footwear 2016 Edition (volume sales trends 2005–2015) to identify a maximum potential reduction in new garment sales. In 2015, 46% (in mass) of collected garments were reused. If 100% of discarded clothing were collected, 22.2 million tonnes would be reused instead of 5.6 million tonnes as at present, meaning 16.6 million tonnes of new garment sales would be avoided, with a value of USD 460 billion.

The report also shows that there has been a 36% reduction in product longevity of clothing between 2000 and 2015 (Ellen MacArthur Foundation, 2017).

In a report by WRAP (2017), evidence shows that households in Denmark have clothing with the longest expected longevity– significantly higher than all other nations for most items. The average active life of clothing across garment types varied from 3.8 years for Germany and Italy, 4.1 years for the Netherlands, and 5.0 years for Denmark (WRAP, 2017). The UK has the lowest expected active life for clothing. A separate, but comparable survey, carried out by WRAP in 2015 found this to be 3.3 years. This equates to a 34% difference between the UK and Denmark.

Scenario assumptions

We assume a reversal in current trends, to increase clothing utilisation and thus reduce the number of purchased items. This would mean,

- Between 2020 and 2035 – a 36% reduction in clothing purchased to reserve the trend between 2000 and 2015. This is also supported by the evidence from WRAP suggesting that Danish people use clothes for 34% longer than their UK counterparts. It is clearly realistic. It was achieved in the UK in 2000 and is also achieved in the UK now. This is applied to all clothing types. Policies to deliver this include minimum pricing for individual items, campaigns and improved product warranty.

This is a realistic assumption for both the ambitious and transformative scenario. The variation in the scenarios occurs between 2035 and 2050.

- It is extremely difficult to understand what could happen past 2035. Our scenarios assume that the changes embedded between 2020 and 2035 continue at the same rate as change while the other scenario demonstrates a levelling out. This would mean the following:
- For the **transformative scenario**, we see another 36% in clothing purchased. From a technological perspective, this is clearly possible meaning that the average lifespan of an item of clothing extends from 5 years in 2035 to 6.8 years by 2050. The ambitious scenario maintains the 5 year figure between 2035 and 2050.

Electrical equipment and appliances (COICOP 5.3, 5.5, 8.2, 9.1)

A key study for the German Government (Prakash, 2016) conducted a comprehensive review of studies that explores the lifetime of electrical equipment. For large household appliances, the key conclusions were:

- The average lifetime of large appliances has reduced over the past 12 years from 14.1 to 13 years.
- A third of appliances are replaced while they are still functional. The main reason for this replacement was due to the product being broken or faulty (70%).
- The reason for replacement related to a defect in the appliance has increased by 3.5% between 2004 and 2012.
- There have been more extreme changes in some large appliances such as washing machines where the average lifetime has reduced from 16 years to 13.7 years between 2004 and 2013. 69% of replacements relate to defects. There is evidence that the standard of new appliances do not resemble the quality of older appliances.

- For smaller appliances, there has been a rapid increase in demand for many products such as mobile phones. In relation to lifetimes, laptops have reduced from 5.7 to 5.4% between 2004 and 2014, tvs from 12.2 years to 10.9 years between 2004 and 2014. For mobile phones, the average lifetime is 2.5 years with 42% of people replacing them before this date. This includes the secondary life of the mobile phone. 20% of phones last longer than 5 years (Prakash et al, 2016; Babbit et al, 2009).

Scenario assumptions

The majority of electrical appliances have now reached significantly improved levels of energy efficiency in their operational use. This has been mainly down to European standards. This now creates an opportunity to reduce the embodied emissions through lifetime extension as minimal improvements in energy efficiency can now be achieved.

We take into account the reality that decisions made on longevity by product manufacturers 12 years ago will create a lag in the system, hence improvements are not seen until 2030.

There are numerous examples when looking at the historical data for improving product lifetimes. There is no major technical breakthrough required. The main reason for replacement when it comes to large appliances is breakage or faulty appliances. Therefore, technical obsolescence is the main concern. This could be overcome by extending warranties and providing the necessary repair infrastructure which is currently lacking.

With this in mind, we assume:

- By 2030, lifetimes return to levels in 2004 for large appliances. This would mean a reduction in sales by 8% by 2030.
- From 2030 onwards we then assume that technical obsolescence is overcome by the same rate, reducing sales further by 8% between 2030 and 2040 and the same reduction between 2040 and 2050. There is also an increase in expenditure of the same proportion in repairs. We apply the same improvements for electrical appliances in households, government and industry. The transformative scenario assumes the 2050 goal could be achieved 10 years earlier and a further 8% is possible between 2040 and 2050.
- For small appliances, a return to 2004 levels for most appliances, would mean extending lifetimes by 11% compared to today. We assume an 11% improvement between 2020 and 2030 which is then replicated at the same rate between 2030 and 2040 and then 2040 to 2050. Again, this requires significant improvements in repair infrastructure and overcoming both technical and psychological obsolescence. However, products can be made today that already achieve this so no technical breakthrough is required. More and more, profit is made out of the service provided by the product as opposed to the product itself.

For the transformative scenario we assume that all phones will last for 5 years by 2050. As 20% of phones do now then we assume this is possible over a longer period.

These strategies are applied only to appliances whose lifetimes have not already been extended through the 'goods to services' strategies.

For all electrical products there will be an equivalent increase in expenditure on repair. Most of this is added to the UK economy whereas production of electrical products is mainly outside the UK (over 80%).

5. Motor vehicles (SIC 43 and COICOP 7.1)

Evidence

The UK is about to undergo a rapid transition from ICE to EVs. However, we are still very much at the beginning of this journey. EVs (plug in only) represent 4.7% of the current stock. People are more likely to currently replace their car with an ICE representing 92% of current sales. Any strategy would want to extend the lifetime of EVs but not of ICEs.

There is considerable evidence that the lifetime of an EV is longer than an ICE. It has considerably less moving parts and the main issue is the battery which is very easily replaced if needed. Consumer research suggests that the average lifetime of a modern car is 8 years compared to an EV which is 17 years. It is important to recognise that this is an estimated lifetime and specific policies would be required to ensure that technical obsolescence could be reached. These would include removing incentives to continually replace your car, design for repairability and potentially shifts form goods to service delivery models.

The CCC recommends that all vehicles are EV by 2035m therefore a growth from 4.7 to 100% by 2035. The UK Government target is the same but by 2040.

Scenario assumptions

Based on this, we assume no change in the product longevity of either ICEs or EVs. Lifetimes will simply improve due to the switch from one technology to technology. We also assume a linear growth in EVs in line with the CCC target in 2035. For the less ambitious scenario, we assume the current UK Government target of 2040. The product longevity of EVs needs to be monitored to ensure that there are no reductions in average lifetimes.

The assumptions are:

- By 2030, EVs represent 52% of the market in the ambitious scenario and 68% in the transformative scenario.
- In 2035, Evs represent 75% of the market in the ambitious scenario and 100% in the transformative scenario.
- By 2040, both scenarios are at 100% EVs.

However, our scenarios also assume a significant shift to the use of car clubs in our 'goods to services' strategy. Car clubs are an effective way of reducing the production of vehicles as the leasing model allows a single vehicle to have much higher utilisation rates, meaning fewer vehicles are required to meet mobility requirements. However the higher utilisation rates of EVs used by car clubs means it is difficult to also extend their lifetimes. Therefore lifetime extension is only assumed to occur in private vehicles.

For these vehicles, this results in the following lifetimes of:

- For the **ambitious scenario** the lifetimes would be: 8 years in 2020, 11 years in 2025, 13 years in 2030, 15 years in 2035 and 17 years in 2040.
- For the **transformative scenario** the lifetimes would be: 8 years in 2020, 11 years in 2025, 14 years in 2030 and 17 years in 2035.

Furniture (SIC 47)

Evidence

For furniture, it is very difficult to determine how much longer a product could last for. On average, office furniture lasts between 7 to 10 years while household furniture lasts for 7 to 15 years. Theoretically, it would be possible to use a furniture item for centuries. A number of studies have looked at reasons for replacement which suggest that 30% of products are discarded before having reached technical obsolescence. The most comprehensive study was undertaken for Defra by Resource Futures that calculates an average possible lifetime extension of 28%.

Scenario assumptions

We assume that a 28% lifetime extension is possible in household furniture, and this is implemented at different speeds between the two scenarios. In the ambitious scenario, the assumption is that this is achieved by 2050 and by 2040 for the transformative scenario.

Office furniture achieves longer lifetimes through a rental model described in the 'goods to services' strategy. There is a moderate increase in repair.

Other manufactured products (SIC 48)

Evidence

Within the SIC codes is an "Other manufactured products" category. It is relatively small but excluding it would give an underestimate.

Scenario assumptions

We assume the average reduction based on the analysis of all other product groups.

Construction (SIC 58)

Evidence

To extend the lifetime of various materials used in construction, we consider a range of strategies:

Vacant properties can be used for domestic housing to avoid the need to build new properties. Historically vacant properties have been 3-4% of stock for the past decade, of which around half are long term vacant. The extent to which these can be brought into use is disputed. Green Alliance (2020) estimates that between 14 and 46 per cent of new housing needs to 2030, across metropolitan counties, could be met through better use, or refurbishment, of long term vacant residential properties.

In practice it would be exceptionally challenging to deliver 100% occupancy.

Building foundations can be designed to enable future reuse. The majority of projects still use in-situ concrete ground slabs as opposed to piles and footings. These slabs are uneconomic to deconstruct and difficult to reuse. There is scope to switch foundation design practice and increase re-use of existing foundations. See the work of the RuFuS project (2006) and Chapman, Anderson and Windle (2007) for further details. For scale, rebar in UK foundations is typically in the range of 50-100kg/m3 for shallow and 40-150kg/m3 for deep foundations. A single typical steel pile is often 700-1100 kg of steel. Moynihan (2014) reports examples of purposeful overdesign of foundations to allow for greater flexibility (e.g. later addition of stories and different configurations in future uses) in London commercial property design.

Changing rail design and specification can reduce demand for iron and steel in rail construction. A range of strategies to minimise rail impacts are available and highlighted in Cooper et al. (2017), Allwood et al. (2012), and Milford and Allwood (2010). These include a range of materials (timber, steel and concrete are common but recycled plastic sleepers are being trialled in Sweden). Strategies to extend sleeper life include using stronger rail, thickening the rail head, and applying coatings to improve durability. Prototype options such as capping rail solutions, e.g. ReRail, and the use of multi-headed sections have also been identified as offering potentially deep reductions in emissions and material use. Many of the solutions with the lowest emissions per unit of service, require additional upfront material inputs yielding longer service lives.

Scenario assumptions

We assume that 14-46% of new housing needs could be met by better use of vacant properties. This results in a 1% reduction in construction materials for domestic properties in the ambitious scenario, and a 2% reduction in the transformative scenario.

By designing adaptable foundations, we assume elimination of the need to replace or supplement the foundations upon demolition and rebuild across a small proportion of non-residential building projects. For the ambitious scenario, this reduces demand for concrete aggregate by 6% in 3% of buildings, and 5% of buildings for the transformative scenario. Similarly, there are some cases where existing foundations can be reused. The potential is difficult to estimate and may be largely restricted to certain markets (e.g. London, Manchester etc.) where there is a high density of existing foundations. Here we assume eliminating the need for new foundations on a small proportion of projects (3% in Ambitious, 5% in Transformative Change).

By changing rail design and specification, we assume a 5% reduction in iron and steel in the ambitious scenario, and a 20% reduction in the transformative scenario.

Sector modelling assumptions

C. Goods to services

1. Outline

The UK is already experiencing a domestic shift from manufacturing goods to providing services. Both economic and environmental gains can be achieved through a service economy. For example, in the concept of a functional economy (the core idea being that products fulfil certain functions, such as a washing machine washing our laundry) the longer a product is used, the more often it can deliver its service and the higher its resource productivity. If products are seldom used, by sharing the product with a number of people (changing use patterns), the resource productivity of the product will be increased and the consumption of natural resources in the production stage reduced. Providing goods as a service can also increase resource productivity by shifting business interests away from planned obsolescence towards the production of longer-lasting products which can be rented out for longer periods of time.

The resource productivity brought about by renting or leasing products is not guaranteed, but is dependent on business and consumer practices extending its lifetime and utilisation. Fischer et al. (2015) detail the conditions which need to be taken into account for goods to services to improve resource efficiency:

- Optimising the lifetime of a product should take into account the intensified and more careless use of a product which occurs through renting. To counter this, products should be durable and businesses could require customers pay for insurance.
- Appropriate levels of product longevity match user expectations for leasing products which seem nearly new.
- Business models take into account the dynamics of technological advance: products which are undergoing rapid efficiency improvements may not be appropriate for leasing, as extending their life may counteract the resource productivity of newer technologies.
- A leasing or rental model should not create additional markets, which may lead to increased resource consumption.

- Direct consumer-producer business models are advantageous to third party models, as this incentivises producers to design the most efficient products.

It is also important that cultural practices around consumption are shifted towards consuming less, so that access to products through renting and leasing does not encourage consumers to consume more. Providing goods as a service is therefore connected to several other areas of resource efficiency. It should be complemented by consuming less, and extending product longevity to ensure that products are durable and can be rented out for sufficient periods of time. However, maximising product longevity is not always desirable when users require up to date technologies and where replacement would be environmentally beneficial. Therefore, combining leasing or renting business models with refurbishment and recycling schemes can help minimise waste for products that are no longer appropriate for leasing (Ellen MacArthur Foundation, 2013).

2. Criteria for selection

Considering these factors, a product is suitable for provision as a service if:

1. Products are used infrequently, or the consumer has a short-term or changing need for the quantity or type of product.
2. Products can be provided online as opposed to the purchase of a product (music, film, book).
3. Leasing facilitates the use of higher quality, longer lasting products, which may have higher upfront capital costs but are made affordable through a leasing model (for example, a higher quality washing machine).
4. The leasing model ensures that the number of times a product is used before it is disposed of is increased, and the resource efficiency benefits in production are not offset by other factors such as increased transportation to deliver products to different consumers.
5. Rebound effect does not outweigh resource efficiency benefits; consumers do not use a leasing model to consume more, for example have more clothes in their wardrobe, or travel by car instead of walk.

3. Products included and assumptions

3.1. Intermediate demand and government

- **Sector 19, 20, 21 –** Textiles, wearing apparel and leather products
- **Sector 43 –** Motor Vehicles
- **Sector 47 –** Furniture
- **Sector 26, 27, 28, 31 –** Chemicals

3.2. Products included and assumptions – final demand

For households, we can assign the SIC categories used above for industry and government to a household classification called COICOP. This allows the further disaggregation of durable products. The consumption classifications included in the analysis include:

- Clothing
- Household furniture
- Household appliances (practical)
- Electrical tools
- Cars and motorbikes
- Mobile phones
- Computers
- Electrical audio and visual equipment
- Other recreational equipment
- Books and magazines

4. Sector level assumptions

Textiles (SIC 19, 20, 21) and Clothing (COICOP 3.1, 3.2)

Evidence

The number of times an item of clothing is worn before it is discarded has declined by 36% over the last 15 years (Ellen MacArthur Foundation, 2017). The vast majority of clothing is consumed through a linear ownership model, and clothing that is worn infrequently is often discarded before it is worn out. Furthermore, in the UK, 26% of clothing is discarded because the owner didn't like it anymore, and 42% because it no longer fitted (Ellen MacArthur Foundation, 2017). Both of these reasons for disposal could have been avoided if the clothes were acquired through renting. In cases where consumers have short term, infrequent or changing needs for clothing, a rental model is a less resource intensive alternative to ownership models as the same item of clothing can be worn more frequently, reducing production requirements. This makes types of clothing like formal wear, luxury clothing, fancy dress, sports clothing, baby and child clothing, maternity clothing and school uniforms appropriate for rentals.

Several successful business models already exist providing clothing as a service. The short-term hire of formal wear has been common in the UK for decades and currently makes up almost half of the clothing rental market. Subscription services can suit customers that require frequent changes, for example Danish company VIGGA provides baby clothes through subscription. Both rental and subscription services are also increasingly emerging for more high-end fashion items that customers may not be able to afford to buy themselves, for example US company Rent the Runway.

Market surveys suggest that while a limited number of consumers currently rent clothing, there is rapid growth in this area. 15% of French consumers and 14% of US consumers have already tried renting clothing (Deloitte, 2020). In the UK, 34% are interested in using clothing rental in the future, and this increases to over 50% for younger consumers and city dwellers (Westfield, 2016; 2020). Rentals are much more commonplace in developing countries, for example in Brazil, 48% of consumers already rent items and this is expected to grow by a further 20% by 2030, indicating the potential for more far reaching rental models for clothing (Deloitte, 2020). Currently, clothing rental and subscriptions make up around 2% of the fashion market, however this could grow significantly in the future (Deloitte, 2020).

Resource efficiency gains from clothing rentals are highly dependent on business and consumer practices. The gains from reduced production can be offset by increased transportation (Zamani et al. 2017). Some models may also result in a rebound effect in which customers are encouraged to engage with fast fashion instead of reducing their consumption. To counter this, renting should be combined with a cultural shift towards buying less.

Scenario assumptions

The constraining factor on the size of the rental market is the type of clothes that are suitable for renting. There is a lack of evidence which quantifies the proportion of a wardrobe that might be suitable for renting, however if we consider that clothing must be used infrequently to have resource benefits to renting, it is assumed that 30% of the average wardrobe may fall in this category. This would include children and baby clothes, maternity clothes, work and school uniforms, formal, occasion, and 'going out' clothes. This is a reasonable assumption as currently the average piece of clothing is only worn 7 times, which would be infrequent enough to bring resource benefits from renting.

- For the **ambitious scenario**, it is assumed that by 2050, 70% of people rent out 30% of their clothes. This would grow the rental market to 21% of the clothing market by 2050.
- For the **transformative scenario**, it is assumed that 90% of people rent out 30% of their clothes by 2050. This would grow the rental market to 27% of the clothing market by 2050.

Electrical products, appliances, books and magazines (COICOP 5.3, 5.5, 8.2, 9.1, 9.5)

Evidence

A study of UK consumers shows that 53% regretted the purchase of an electrical item, and 23% regretted a purchase in the past year (Roberts, Hope and Skelton, 2017). Kitchen gadgets are the most commonly regretted item, and the most cited reasons for this were that the consumer did not use the product as much as expected (33%), or that the product was not as good as expected (28%). Accessing these goods as a service instead of purchasing them could have prevented these items from going unused.

Household electrical products which are used infrequently or only for a short period of time are suitable to be provided as a service. Typically, this includes maintenance and gardening tools, maintenance and cleaning equipment, and some audio visual (AV) and computing equipment. There is already a small market for this type of service; 18% of French consumers who accessed maintenance or gardening materials in the last 6 months, 5% of those who accessed phones and 6% of those who accessed computers did so through renting or lending (Demailly and Novel, 2014).

For large household appliances like washing machines, shifting to a rental model can achieve higher utilisation rates by incentivising the use of higher quality, longer lasting products. Under an ownership model, the average consumer who uses their washing machine infrequently is incentivised to buy a low-cost, poor quality machine. However over the long term, this costs the consumer more (27 cents per cycle compared to 12 cents for a high quality machine), as they have to replace the washing machine more frequently and it is less efficient (Ellen MacArthur Foundation, 2013). A rental model can improve resource efficiency by facilitating the use of longer lasting machines, which could be used for several 5-year leasing periods, whilst also bringing financial benefits to the consumer. Leasing business models could also facilitate much higher levels of refurbishment of old machines. Currently only 10% of collected washing machines are refurbished, despite having many reusable parts. A leasing model could pool the costs of collection, transport and refurbishing, reducing total refurbishment costs by up to 40% (Ellen MacArthur Foundation, 2013).

Scenario assumptions

COICOP 5.5. Tools and equipment for house and garden

18% of French consumers already access these products through rentals. Almost all products in this category are suitable for rentals other than small tools which are used more frequently like screwdrivers, so it is reasonable to assume that 90% can be accessed through rentals. Therefore, the difference in the two scenarios relates to how quickly there is a shift towards renting.

- For the **ambitious scenario**, it is assumed that a 90% shift is met by 2050.
- For the **transformative scenario**, it is assumed that a 90% shift is met by 2035.

COICOP 9.1.1. Audio equipment
COICOP 9.1.3. Photographic equipment
COICOP 9.5. Newspapers and books

This is the 3rd most popular type of product to rent through rental website Zilok (Demailly and Novel, 2014). It is assumed that most consumers now have cameras and recorders in their smartphones, so the use of specific audio-visual equipment will be for infrequent occasions where there are extra needs (for example, the desire for a better camera to take pictures on holiday). However some consumers who, for example have photography as a hobby, will still use audio-visual equipment frequently. Therefore it is assumed that 70% of audio-visual products are suitable for renting. Similarly, for most consumers who read books and newspapers just once, these products can be provided online or a book rental.

Again, the difference between the scenarios relates to how quickly this is achieved.

- In the **ambitious scenario**, it is assumed that 70% is rented by 2050.
- For the **transformative scenario**, it is assumed that 70% is rented by 2035.

COICOP 8.2. Telephone and telefax equipment
COICOP 9.1.2.7. Personal computers, printers and calculators

In some circumstances, for example using laptops for education, a rental model may be appropriate for accessing phones and laptops. Around 5% of French consumers access computers and phones this way. For the ambitious scenario it is assumed that this increases to 10% by 2050. For the transformative scenario this increases to 15% by 2050.

COICOP 5.3. Household appliances

For large household appliances, switching to renting is feasible when there are large upfront capital costs which inhibit consumers from purchasing high quality products.

- For the **ambitious scenario**, it is assumed that a 50% shift towards renting for large household appliances is achieved by 2050.
- For the **transformative scenario**, it is assumed that a 70% is achieved by 2050.

Motor vehicles (SIC 43)

Evidence

The average car is only in use for 3-4% of the time (Marsden et al, 2019). A third of private cars are not used every day and 8% are not used every week. At any one time, the largest proportion of the car fleet in use is just 15% (ibid.). A huge number of current car owners could therefore access a car through a rental model due to the infrequent nature of private car use. Short-term car rentals for holidays are a small but well-established rental market for motor vehicles.

However, car clubs provide much larger opportunities through access to shared vehicles in the local area through a subscription service. Research shows that membership to car clubs reduces car ownership levels and miles driven. Each car club car results in members selling or disposing of 10.5 private cars (Carplus, 2017). This means that car club members require 90% fewer cars. Long term members drive an average of 793 miles less a year (20% less than private car owners), and are also twice as likely to use active travel or public transport (CoMoUK, 2018). Car clubs are also used more efficiently than private cars as they have a higher occupancy rate: 2.2 people per car compared to 1.6 in private cars (Carplus, 2017).

Car clubs are still a small market in the UK, but they have grown eight-fold in the last decade. There are currently 250,000 car club members in the UK, and ¾ of these are in London (Marsden et al. 2018). Research by McKinsey shows that 67% of consumers expect their use of car-sharing services to increase substantially over the next two years, and that 30% of vehicle miles travelled could be delivered through a car sharing service (Grosse-Ophodd et al, 2017). CoMoUK (2020) have identified 643,000 Scottish households which could currently switch from car ownership to using a car club. This is equivalent to 37% of all car owning households in Scotland.

Furthermore, transport demand is changing and must continue to do so to meet climate change targets and improve public health. In the UK, we make 16% fewer journeys than in 1996, and travel 10% fewer miles than in 2002 (Marsden et al, 2018). The under 30s travel less than previous generations, and social circumstances mean that they are likely to continue to do so throughout their lives (ibid.). With a reduction in demand for transport, car clubs are an increasingly attractive option to consumers who use cars less frequently, allowing them to do so at a lower cost.

Scenario assumptions

With current patterns of travel and private car usage, CoMoUK (2020) estimate that 37% of households could switch to a car club. It is assumed that this quick switch is achieved by 2030 for **both scenarios**.

However, as only 15% of the car fleet is in use at any one time, it is possible that with more substantial cultural shifts away from private ownership alongside the diffusion of car clubs into smaller towns and villages, there could be a much more transformative reduction in car ownership. This could be complimented by an increased use of ride-hailing apps like Uber in urban areas.

- For the **ambitious scenario** it is assumed that 80% of the population transfer to car clubs and ride-hailing by 2050. If this leads to the 90% reduction in cars among car club members as reported by Carplus (2017), then overall the car fleet would be 28% of its current size.
- For the **transformative scenario** it is assumed that 90% of the population move away from private car ownership towards car clubs and ride-hailing by 2050. This would reduce the car fleet to 19% of its current size. This is still a reasonable assumption as we know that currently only 15% of the vehicle fleet is in use at any one time. It is possible that this could be reduced even further in the future as evidence shows that car club members use cars less than private car owners (Carplus, 2017).

Furniture (SIC 47)

Evidence

Furniture leasing makes up a small section of the furniture market, however there is a significant potential for growth in certain areas. Office furniture in particular is suitable for leasing as the needs from businesses are often changing or are shorter than the lifespan of the furniture. Research shows that 50% of office furniture that is sent to landfill is still usable (Fandrich, 2011), and therefore could have been rented out again, prolonging its life. While in the UK, leasing office furniture is relatively uncommon (~3% of the market), in the USA it accounts for 20% of the office furniture market (Cox et al, 2013).

Scenario assumptions

The largest opportunity for furniture leasing is in office furniture. It is assumed that the leasing model could also apply to other products like office carpets.

- For the **ambitious scenario**, it is assumed that a 90% switch to leasing is achieved by 2050, and in the **transformative scenario** this is achieved by 2040.

Recreational equipment (COICOP 9.3.1 – 9.220)

Evidence

Certain other recreational products like sports equipment, camping equipment and toys could also be provided through rentals.

Scenario assumptions

The same assumptions are made as for rentals of AV equipment, that:

- In the **ambitious scenario**, it is assumed that 30% is rented by 2030, 50% by 2040 and 70% by 2050.
- For the **transformative scenario**, it is assumed that 30% is rented by 2025, 50% by 2030 and 70% by 2035.

Chemicals (SIC 26, 27, 28, 31)

Evidence

There is already a small market for chemical leasing in Europe and the US, and there is potential for this to grow particularly for speciality chemicals where chemical processes are not the chemical user's core activity, for example for industrial cleaning, wastewater treatment, inks and dyes and agricultural fertilisers (OECD, 2017). 3% of German manufacturing companies used chemical leasing services in 2009, and in the US 5-15% of aerospace and 50-80% of automotive manufactures used chemical management services for chemical use in metalworking (OECD, 2017). The OECD (2017) suggests that in Europe, chemical leasing is applicable to the 'speciality chemical' sector; dyes and pigments, crop protection, paints and inks and auxiliaries for industry, which make up 27.8% of all EU chemical sales.

UNIDO (2015) analyse case studies of chemical leasing in industrial cleaning operations, and show that the model can reduce chemical usage by 10-80% across different case studies. Extrapolating evidence to the potential global impact of chemical leasing, they estimate that there could be 50% reductions in cleaning chemicals in hospitality and automotive industries, 60% reductions in cleaning of industrial equipment and 44% reduction in chemicals for wastewater treatment (UNIDO, 2015). Moser and Jakl (2015) review 33 different chemical leasing case studies, with a range in reductions of chemical use between 7-83%. The mean reduction was 32%.

Scenario assumptions

We assume that the chemical leasing could deliver a 50% reduction in chemical use in the 'speciality chemical' sectors.

- For the **ambitious scenario**, it is assumed that this is achieved by 2050.
- For the **transformative scenario**, it is assumed that this is achieved by 2035.

Sector modelling assumptions

D. Reducing waste

1. Outline

This strategy looks at how to reduce the waste of perishable products. Food waste is a frequently modelled mitigation option and subject of food policy given it is relatively uncontroversial. In the UK, households are responsible for around 70% of all food waste (p. 34, CCC, 2018), of which 60% is avoidable (p. 14, Green Alliance, 2018). By preventing waste, there is upstream impact in reducing overall demand for food production, streamlining the system. Garnett (p. 11, 2014) argues that food waste is in fact a source of 'financial inefficiency', and therefore waste reduction helps promote food security, reduce embedded emissions, and capture cost savings creating a 'triple win'. This strategy considers the potential to reduce food waste in UK households, retail, manufacturing and hospitality.

Furthermore, overconsumption has been compared to a form of food waste in supplying calories beyond nutritional requirements (p. 81, IPCC, 2018). The UK consumes an estimated 15% more calories than is nutritionally recommended (p. 5, Blake, 2014). Conversely, addressing food waste may be a result of overconsumption in the first instance, that is, buying more than is required. This strategy also considered the potential to reduce intake of food in line with government guidance.

2. Criteria for selection

1. We focus on the food and drinks sector, where there is a significant existing evidence base on reducing waste

3. Products included and assumptions

We reduce demand for products by industry sector to capture the effects of households, governments and industries implementing the strategies. The sectors affected include:

- **Sector 1** – Agriculture
- **Sector 3** – Fishing

- **Sector 8** – Meat
- **Sector 9** – Fish, fruit and vegetables
- **Sector 10** – Vegetable and animal oils and fats
- **Sector 11** – Dairy products
- **Sector 12** – Grain mill products
- **Sector 13** – Bakery products
- **Sector 14** – Other food products
- **Sector 16** – Alcoholic beverages
- **Sector 17** – Soft drinks

4. Sector level assumptions

Food waste (Sectors 8, 9, 10, 11, 12, 13, 14, 16, 17)

Evidence

Assumptions for reducing food waste are based on the UK meeting the food waste reduction targets of Courtauld 2025 and SDG 12.3. Courtauld 2025 aims for a 20% per capita reduction in food waste by 2025, and Sustainable Development Goal (SDG) 12.3 aims to halve per capita food waste by 2030, compared to 2015 levels. So far, the UK is on track to meet the Courtauld 2025 commitment; between 2015 and 2018, there was a 7% reduction in food waste in the UK, which now totals 9.5Mt per year (WRAP, 2020).

Analysis from 2014 suggested that a plausible minimum level of food waste in the UK would be around 9.1Mt per year (WRAP, 2014), however the 2030 targets exceed this. An alternative method to calculate minimum food waste is to assume that all households could reduce food waste to levels seen in the lowest quartile of households. This analysis takes a midpoint between the two estimates as a realistic theoretical minimum level of food waste, which is 55.3 kg per capita, a 58% reduction on 2007 levels of waste.

Scenario assumptions

The most perishable types of foods like fruit and vegetables are wasted at much higher rates than longer lasting products. However, this analysis does not have the scope to differentiate rates of waste reduction across different food groups. Therefore, the same rate of waste reduction is applied across all food groups. This may lead to an overestimation of the impact of this strategy due to an overestimation of possible waste reduction in emissions intensive products like meat and dairy, which are generally wasted less frequently. This is a limitation of this analysis.

- For the **transformative scenario**, we assume that food waste is reduced by 32% from 96kg per capita in 2018 to 64.9kg per capita in 2030. The theoretical minimum of 55.3kg per capita is met before 2050.
- For the **ambitious scenario**, the targets are met 10 years later.

Reducing calorific intake (Sectors 1, 3, 8, 9, 10, 11, 12, 13, 14, 16, 17)

Evidence

The Family Food Survey indicates that UK calorie consumption in 2017/18 was 2175kcal per capita (Department for Environment Food and Rural Affairs, 2018). However, it is widely noted that official estimates of calorie intake significantly underreport, particularly when data are collected via public self-reporting initiatives (e.g. food diaries). Behavioural Insights found that with currently reported levels of intake, there would be national weight loss rather than increasing obesity rates, even with minimal levels of physical activity (Harper and Hallsworth, 2016). They suggest that underreporting accounted for a 32% deficit in calorific intake (ibid). We therefore apply this underreporting rate to the FFS estimates and find an average UK calorific intake of 2871 kcal per day per capita, excluding additional calories from uneaten food (i.e. waste).

There are simultaneous crises of obesity and food poverty in the UK, parallel to unreliable reporting on national calorific intake. While a gender-weighted government recommended calorific intake is 2250kcal, we assume an upper bound calorific intake of 2500 kcal. This accommodates different metabolic needs and varying levels of physical activity, whilst accounting for the fact that the UK population does not uniformly meet a basic level of dietary need as evidenced by a rise in food poverty rates (The Trussell Trust, 2019).

Scenario assumptions

- For the **transformative scenario**, we assume that average calorific intake is reduced to 2500kcal per day by 2050.
- For the **ambitious scenario**, we assume that average calorific intake is reduced to 2686 kcal per day by 2050, which is the midpoint between the transformative scenario and a business as usual scenario which extrapolates historic trends of increase calorific intake.

E. Material substitution

1. Outline

One strategy to reduce the climate impact of products is to substitute highly carbon intensive materials for those with a lower carbon intensity that are able to perform the same role. This strategy is most widely applicable to the construction sector, given the availability of low-carbon biomaterials to replace carbon intensive materials such as steel and cement (D'Amico et al, 2021). However, many low-impact material substitutions in the construction sector are at present relatively underutilised technologies, and are thus difficult to represent in the MRIO model due to their intensity not being well represented by the aggregated sector intensities they sit within. As a result, the most significant construction material substitution option, increased use of cross laminated timber, has been excluded.

Beyond construction, this strategy also identifies the opportunity for material substitution in other industries with the aim of finding available reductions in embodied energy and associated GHG emissions. In identifying these measures, we do not reduce the basic functionality of the product, rather we consider options where materials have direct substitutes that are less materially intensive. We identify options for material substitution in furniture, motor vehicles and through dietary shifts in food.

2. Criteria for selection

1. We focus on identifying products and materials that have significant embodied GHG emissions.
2. We only consider substitutes where direct low-impact material substitutes are available, that do not alter the basic function or longevity of the product.
3. We do consider alternative materials that at present may be equally or more materially intensive than the material they are a possible substitute for, only where there is the possibility for the production of the alternative material to be less intensive in the future. For example, thanks to the decarbonisation of the electricity system.

3. Products included and assumptions

We reduce the intermediate demand for materials by manufactured sectors. The sectors considered include:

3.1. Intermediate demand and government

- **Sector 23** – Paper and paper products
- **Sector 33** – Rubber and plastic products
- **Sector 35** – Glass, refectory, clay other porcelain and ceramic, stone and abrasive products
- **Sector 36** – Basic Iron and steel
- **Sector 37** – Other basic metals and casting
- **Sector 39** – Fabricated metal products
- **Sector 43** – Motor Vehicles
- **Sector 47** – Furniture

3.2. Products included and assumptions – final demand

For households, we can assign the SIC categories used above for industry and government to a household classification called COICOP. This allows the further disaggregation of durable products. The consumption classifications included in the analysis include:

- Food and drink
- Household furniture
- Garden furniture
- Passenger Vehicles

4. Sector level assumptions

5. Motor vehicles (SIC 43)

Evidence

Aluminium is able to replace substantial amounts of high-carbon steel in passenger vehicles. Modaresi et al. (2014), calculate that in an aluminium intensive vehicle there could be a 65.75% reduction in the use of standard steel, a 85.95% reduction in the use of high strength steel and a 65.77% reduction in the use of cast iron, when compared with the average passenger vehicle at present. These high carbon parts are replaced with an increase of cast aluminium of 76.32% and an increased use of wrought aluminium of 812.12% (Modaresi et al, 2014).

In Table 1, Modaresi et al (2014) indicate the weight substitution factors of switching from steel and iron, to aluminium. Therefore, less aluminium is needed to be produced to perform the same function.

Table 1

	Steel to HSS/ AHSS	Cast iron to cast Al	Steel to cast Al	Steel to wrought Al	HSS/ AHSS to wrought Al
Body & closures	0.72	N/A	0.85	0.85	0.81
Chassis & suspension	0.72	0.53	0.64	0.64	0.89
Power train	1	0.53	N/A	0.65	N/A
Interior & miscellaneous	1	N/A	0.73	0.73	N/A

In the EU, blast furnaces are the most common production method of virgin steel, emitting between 1.8 and 3 tonnes CO_2/tonne of steel (Carbon Trust, 2011b). In contrast, the emission intensity of aluminium varies widely based on the type of aluminium produced and the method of production. For the cast aluminium components that recycled aluminium is suitable for, the emissions intensity is an average of 1tco2/tonne of aluminium. This is derived entirely from indirect electricity production so could be reduced as renewable electricity becomes more dominant. For virgin aluminium, necessary for the wrought aluminium components in a vehicle, the intensity is higher, ranging from 3 tco2/tonne for AL produced using renewable power, compared with 20tco2e/tonne for a coal powered production. Virgin aluminium can also be produced using renewable power which is further evidence that the carbon intensity of aluminium will reduce (Carbon Trust, 2011a).

Lifecycle approaches highlight the need for a recycling strategy to help leverage the potential of aluminium alloy to further improve eco-efficiency and reduce the impact of its initial high energy processing requirements (Marretta et al, 2012). This is important because recycling aluminium saves up to 4 times as much CO_2 when compared with the reprocessing of steel (Das, 2014).

There are some challenges associated with using aluminium in cars. Presently, cast aluminium has a much wider use in vehicles compared with wrought aluminium, used in engines, wheels, transmission and drivelines (Cheah and Heywood, 2010). Whilst Modaresi et al (2014) show the portion of cast aluminium increasing, the most significant substitution is the use of wrought aluminium, replacing traditional steel bodywork. This is because aluminium is a softer metal, can scratch easily and is more labour intensive to weld (Cheah and Heywood, 2010). Whilst these challenges make an aluminium body more expensive to produce than a steel one, the difference in overall manufacturing costs if much less. When taking into account the lifetime fuel savings made as a result of the lighter vehicle weight, the total lifetime usage costs ‘can approach cost parity or even a net benefit’ when compared with conventional vehicles (Tisza and Czinege, 2018).

Scenario assumptions

In this scenario, the use of steel in vehicles is replaced with aluminium. At the beginning of the scenario, aluminium is assumed to have a higher GHG intensity when compared with steel. However, as aluminium can be produced using electricity, as the scenario progresses and electricity systems decarbonise, this intensity reduces.

In both the ambitious and transformative scenarios, the amount of steel is replaced at the same rate as that of the aluminium intensive scenario developed by Modaresi et al. (2014). Thus by 2030 there is a 65.75% reduction in the use of steel in vehicles, a 85.95% reduction in the use of high strength steel, and a 65.77% reduction in the use of cast iron.

These materials are replaced by an increased use of cast-aluminium of 76.32% and an increased use of wrought aluminium of 812.12%. Beyond 2030, the material substitution is presumed to have reached its technical maximum, however the intensity of production continues to improve.

In line with Modaresi et al. (2014), these changes in materials assume:

- 100% of standard steel in body and closures replaced with aluminium (20% cast, 80% wrought)
- 100% of HSS in body and closures replaced with wrought aluminium
- 25% of standard steel in chassis and suspension replaced with aluminium (70% cast, 30% wrought)
- 100% of cast iron in chassis and suspension replaced with cast aluminium
- 50% of cast iron in power train replaced with cast aluminium
- 100% of standard steel in interior replaced with wrought aluminium

Additionally, given that aluminium is a lighter material, the amount of material used is assumed to be reduced in order with the substitution factors, given in Table 1.

The factors differentiating the ambitious and transformative scenarios pertain to the amount of recycled aluminium used as cast parts, and the extent of recycled aluminium production.

In the ambitious scenario, by 2050, it is assumed that 95% of the cast aluminium used is taken from recycled sources. In contrast, the transformative scenario, this rate is 95% by 2045.

Further, in the ambitious scenario, these measures are only applied to passenger vehicles, whereas in the transformative scenario, all road vehicles are used.

Furniture (SIC 47)

Evidence

Material substitution of high GHG intensive materials for wood can significantly reduce the GHG emissions associated with furniture production. In 2012 in China, only 35% of furniture produced was wood furniture, yet the GHG emission factors (kg CO_2eq/kg) are considerably higher for materials like steel (2.6), glass (2.8) and PVC (4.6) than for wood (0.29) (Geng et al, 2019). This is because the manufacture of wood is less energy intensive (Geng et al, 2019). Moreover, 50% of the dry weight of wood is composed of carbon, and combining wood harvesting with sustainable forest management techniques allows carbon to be stored in forests, soils and in wood products (Sathre and O'Connor, 2010). Several studies have investigated the CO_2 emission displacement factor of substituting wood for non-wood materials. Geng et al (2019) show that every ton of carbon used in wood furniture results in an average of 1.46 tons of carbon emissions reduction (tC/tC). In Sathre and O'Connor's (2010) meta-analysis of studies, the average was 2.1tC/tC.

The following assumptions are taken from Geng et al (2019), who through studying a Chinese basket of furniture goods, compare the GHG savings available by switching to more wood-dominant furniture. The relative savings found in their scenario are used to develop a less materially intensive scenario for the UK.

Scenario assumptions

This scenario replaces high GHG intensive materials used in the production of furniture for wood products that have a relatively low GHG intensity. The basket of furniture goods assessed, and the changes in materials used are taken from Geng et al.'s (2019) increased wood use scenario. Whilst this scenario focuses on the case study of China, the basket of common furniture goods, and use of materials, is unlikely to be substantially different from furniture in the UK. It is thus assumed that the same proportional reductions can be achieved in the UK by switching highly intensive materials for less intensive materials. The basket of goods, and changes in material use are summarised below.

- Kitchen cabinet
- Bed
- Wardrobe
- Coffee table
- Sofa
- Dining chair
- Public space chair
- Office chair
- Office desk
- Office cabinet
- Student chair

Across this basket of goods, Table 2 indicates the following change in the materials used in the production of furniture. These reductions are assumed to be representative of the furniture manufacturing industry.

Table 2

Material	% change in material use
Wood	37%
Steel	–56%
Plastic products	13%
Glass	–100%
Aluminium	–100%

In the high ambition scenario, these reductions in the use of GHG intensive materials are expected to change by 2040. The transformative change scenario sees the same % change in material use but is implemented by 2030.

Packaging (SIC 23, 33, 39)

Evidence

If current trends continue, "EU CO_2 emissions from plastics packaging are set to double to 2050 on current course, from 43 to 85 Mt CO_2 per year. While 43 Mt are just 1% of EU 2016 emissions, 85 Mt in 2050 would claim 30% of the remaining emissions, given a 95% reduction target from 1990's levels" (Material Economics, 2018). Whilst there are other strategies available to reduce these emissions, using different materials to fulfil the function of plastic packaging is an important one.

One material substitution option is to replace plastic packaging with packaging made from wood fibres. Presently, wood fibre lifecycle emissions are 0.7kg CO_2e per kg of packaging (assuming a present recycling rate of 54%), compared with 2.1kg for plastics, a saving of 65%. Moreover, this intensity is calculated to be expected to fall as economies decarbonise, falling to 0.4kgCO_2e/kg packaging (40% reduction) in 2030, and 0.3kg (65% reduction) in 2050 (Material Economics, 2018).

The Material Economics study suggests that 25% of packaging could be replaced without significant compromise of product functionality, such as preserving product longevity (Material Economics, 2018). It suggests that a substitute is suitable in two key forms, (i) where the current application of plastic does not actually utilise the properties that make plastic packaging unique (i.e. transparency) (ii) where the amount of plastic in a product's packaging can be reduced to a single film, whilst replacing the bulk of the package.

At a European level it is suggested that the subsequent increase in wood pulp equates to 17% of unclaimed European forest growth. Moreover, it is suggested this figure could be reduced to 0 by increasing recycling rates, improving forest yields, material efficiency measures, as well as 'rebalancing pulp away from other products and towards packaging' (Material Economics, 2018).

Scenario assumptions

25% of plastic packaging will be substituted by 2030.

For the ambitious scenario, it is assumed that in line with the product innovations projected by the Material Economics report (2018), 50% of plastic packaging is substituted by 2040. Wood-based packaging requires 1.5 times the weight of inputs compared with plastic (Material Economics, 2018). By 2030, 0.6Mt (25%) of plastic packaging is replaced by wood-fibre packaging weighing 0.9Mt. Given there is ~ 3Mt of paper-based packaging in the UK (WRAP, 2010), this represents an increase of 30% by 2030 and a 60% increase in pulp-based packaging.

For the transformative scenario, it is assumed that there are higher levels of product innovation and cultural acceptance of packaging that functions differently (for example, compromising the transparency of plastic films on certain products). This means that 75% of plastic packaging can be substituted by 2040, equating to a 90% increase in paper packaging.

Construction (SIC 58)

Evidence

Use of hempcrete to replace concrete

Hemp can be used in a range of building applications – see Ingrao et al (2015) and NHBC Foundation (2013) for typical details and examples of recently constructed UK buildings. Current UK hemp production is less than 3,000 ha, equating to sufficient hemp for ~2000 houses (NHBC Foundation, 2013). However, rapid expansion in UK hemp cultivation is expected in the near term (mirroring recent 30% year on year growth in Europe).

Straw bale construction

Straw bales are predominantly used in low level structures, generally residential properties of up to 3 storeys (though examples of school blocks, showrooms and other non-domestic applications are becoming more common – with 6 examples winning high profile design awards in recent years). See NHBC Foundation (2013) and Sutton et al (2011) for typical details and examples of recently constructed UK buildings (a database of all such buildings in the UK and Ireland was in preparation at the time of writing).

Annual production of straw is more than sufficient to meet annual construction of all commercial and residential buildings in the UK (Watson, 2012), and the straw typically constitutes less than 2% of the total cost of a modern prefabricated panel such as ModCell®. The primary constraint on additional straw bale construction is not cost or availability of raw materials but public acceptance. In a survey of 572 potential UK home purchasers, 39% of respondents said they would not purchase a house built with straw bale because of perceived concerns with fire performance, durability and high maintenance requirements (Watson, 2012).

Whilst public acceptance is the most significant barrier to increased use of straw-bales in construction, a significant shift in building practices would have to be undertaken by a significant segment of the market to achieve the rates of change assumed in this report.

Scenario assumptions

Use of hempcrete to replace concrete

For this scenario we assume cultivation expands to 10,000 ha in the ambitious scenario and 20,000 ha in the transformative scenario. This is still small relative to the current European market of 125,000 ha. It is assumed that the majority of this is then directed towards meeting demand for housing through sprayed or cast on site hempcrete. In practice, a proportion is likely to be used on low rise industrial and retail structures, similar to existing examples like M&S Cheshire Oaks and Adnams Brewery Distribution Centre. Assuming displacement of cellular concrete walls this results in an embodied energy saving of ~178 MJ per m^2 of wall (Ingrao et al, 2015). Assuming average sized UK housing of 84m2 with typical dimensions (RIBA, 2011), this translates into an approximate energy saving of 23580 MJ per home. We assume that hempcrete could replace 1% of concrete used in construction in the ambitious scenario, and 3% in the transformative scenario.

Straw bale construction

This scenario represents a highly significant increase on current levels of construction and would require the continued move towards modern methods of construction, with a greater number of suppliers. Though numerous studies have assessed potential carbon savings, embodied energy has received less attention. Assuming the displacement of brick-faced masonry construction, adoption of straw bale could reduce embodied carbon of materials on a functionally equivalent UK social housing project by ~31% excluding sequestration (Sodagar et al, 2011). A corresponding embodied energy saving of approximately ~130,000 MJ per house is estimated here using material quantities from Sodagar et al (2011) and embodied energy quotients from the Inventory of Carbon and Energy (ICE) database.

Food and drink (COICOP 1 – 2.1)

Evidence

Animal products are disproportionately emissions intensive; per unit of expenditure (GBP £) meat products consumed in the UK are 21 times more emissions intensive (CO_2e) than the average for fruit, vegetables and cereals, dairy 3 times more emissions intensive.

Green Alliance estimated that livestock agriculture is responsible for around 70% of emissions from the agricultural sector in the UK (p. 10, Green Alliance, 2019), and the CCC estimated that 58% of UK agricultural emissions were attributable to cattle and sheep farming in 2016 (p. 31, CCC, 2018). Dietary shifts reducing consumption of meat and dairy have the potential to significantly reduce the emissions intensity of our diets.

We are already observing unprecedented shifts in UK diets, with a 350% increase in the number of vegans in the UK from 2006 to 2016 being reported (Ipsos MORI, 2016). This represents a generational shift (42% of vegans are in the 15-34 age group, ibid), and we therefore considered a significant (exponential) increase in the proportion of the population following plant-based diets to 2050 highly likely.

Scenario assumptions

There is limited available data on current food consumption by diet type, particularly as older studies are unlikely to reflect the recent uptake in plant based diets. We assume a baseline diet profile of the UK population, to be 21% flexitarian, 9.5% vegetarian and 3% vegan based on data from industry surveys (Waitrose & Partners, 2019) and YouGov UK (2017). Table 3 shows the assumed dietary shifts for the two scenarios.

Table 3

	Current % in UK population	Ambitious	Transformative
Omnivore	66.5%	17%	5%
Flexitarian	21%	27%	28%
Vegetarian	9.5%	36%	42%
Vegan	3%	20%	25%

Giving scope for at least a third of the population to continue following an omnivorous diet (albeit a largely healthier one) is both realistic and sensitive to cultural factors at play in the composition of diet.

Sector modelling assumptions

F. Recycling

1. Outline

The definition of 'recycling' under Article 3(17) of the Waste Framework Directive is: 'any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations.' The common idea behind recycling is that a waste material is processed in order to alter its physical chemical properties allowing it to be used again for the same or other applications. It is the explicit goal of the WFD that the EU should become more of a 'recycling society', seeking to avoid waste generation and to use waste as a resource.

Rather than modelling the increase of recycling rates in society, this strategy models the displacement of virgin materials used in production process, caused by increasing use of recycled materials. For the large majority of materials, use of recyclates can reduce the emissions by reducing demand for energy, and in particular non-electricity energy sources. It can also reduce direct process emissions (steel being a good example). In 2018, UK manufacturing accounted for 14% of UK Greenhouse gas emissions (GHGs), a proportion which has remained largely unchanged since 2008. This excludes emissions from use of grid electricity by the manufacturing sector. Of this, 14% is associated with steel and aluminium, 4% plastics, 3% paper and card and up to 4% is glass.

In order to develop an objective to show territorial savings for the UK, it is necessary to set a baseline for current use of recycled content in manufacture. The following sections consider the baseline and a level of ambition for use of recyclates in manufacturing by 2050.

2. Criteria for selection

1. We focus on identifying products and materials that have significant embodied GHG emissions.

2. Implementing the waste hierarchy can alter the flow of virgin and secondary materials and products. This brief considers how the use of secondary materials can reduce emissions associated with UK manufacturing. The purpose of recycling is to ensure that the embodied energy within a product is used to its maximum effect. Therefore, the analysis does not consider the role of recycling rates but instead, considers the input of secondary materials into production chains to reduce the use of virgin material. High recycling rates would be needed to meet the increased demand for secondary materials.

3. Products included and assumptions

We reduce the intermediate demand for materials by manufactured sectors. Currently recycling strategies are modelled through a reduction in the quantity of virgin materials displaced by higher rates of recyclates used. We are currently developing a method for reflecting the reduced energy intensity of recycled production, however, we are unable to reflect this in the current results.

3.1. Intermediate demand and government

- **Sector 36** – Basic Iron and Steel
- **Sector 37** – Other basic metals and casting
- **Sector 35** – Glass, refractory, clay other porcelain and ceramic, stone and abrasive products
- **Sector 23** – Paper and paper products
- **Sector 33** – Rubber and Plastic products

4. Sector level assumptions

Basic iron and steel (SIC 36)

Evidence

Steel production in the UK is about 7m tonnes a year, or less than half of UK demand (15 million tonnes). Recycling steel could theoretically make the UK self-sufficient in steel.

Two-thirds of the steel currently used is made from primary production, and most of the remainder comes from off-cuts of the steel-making process, rather than recycled goods. The UK generates about 10m tonnes of scrap a year. Currently, about 80% of this is exported for processing to other countries, chiefly Turkey and China. The US, by contrast, meets about half of its demand for steel by recycling, but global stocks of recyclable steel are expected to rise sharply in the coming decades.

By reducing energy demand and process emissions, recycling steel can halve GHG emissions compared to production from virgin steel. The World Steel Association LCI data for steel products includes the energy savings which can be used to show the benefit of moving to recycled steel in the UK.

Steel goods last an average of 35 to 40 years before they are scrapped, and imperfect control of metal composition in scrap steel collection and limits to today's technologies restrict the degree to which recycled steel can be substituted for primary steel.

Work by Brunel University and others is focussed on removing these technical barriers. From a baseline of 2.3 million tonnes of process scrap, an aspirational target for 2050 would therefore be that 95% of UK steel is manufactured from post-consumer recycled sources.

Unless otherwise stated, information above draws from Allwood et al (2019).

Scenario assumptions

Currently, the UK imports 8 million tonnes of steel. However, increased recycling could make the UK steel-sufficient in meeting domestic demand with recycled steel from UK furnaces. Whilst 100% recycled steel is technically feasible, this scenario allows for a 5% margin of virgin steel for applications where at present, there are greater barriers to the use of recycled steel.

Globally, flows of recyclates back into global steel flows represent 36%, as a proportion of weight of all raw materials (Cullen et al, 2012).

- For the **ambitious scenario**, the recycled content of steel including industry offcuts increases from 22% (recycled steel including industry offcuts) to 95% recycled steel by 2050.
- For the **transformative scenario**, the recycled content of steel including industry offcuts increases from 22% recycled steel to 95% of recycled steel by 2045.

Other basic metals and casting (SIC 37)

Evidence

Aluminium production in the UK has a market value of £1 billion, with 134 active businesses in 2020. However, just one operational primary smelter remains in the United Kingdom, located in Lochaber, Scotland, operated by Liberty House, an international commodities business. (Ibis World, 2020). The plant has an operational capacity of 43,000 tonnes. (Telegraph, 2011)

The European Aluminium Association (2018) identifies the energy and process emissions reductions associated with use of recyclate in place of virgin production. It requires 5900MJ to produce a tonne of wrought aluminium ingot from scrap, 95% less than virgin aluminium (European Aluminium Association, 2018).

Technically, aluminium can be recycled without degrading the grade of the material, if a high degree of material separation is able to be achieved. For many uses such as packaging, minor imperfections in recycled aluminium are unimportant, however, in industries like vehicle bodywork production, using recycled wrought aluminium may be less appropriate. In a business as usual recycling scenario, wrought aluminium from vehicles is often cascaded in grade to cast aluminium (Modaresi et al, 2014). However, it is possible to assume that there could be improvements in the end of life separation of materials, opening up potential for greater use of recycled materials in applications where at present, virgin aluminium is used (Modaresi et al, 2014).

Scenario assumptions

In this scenario, 95% primary aluminium production would be replaced by use of scrap, with energy and process emission savings taken from the European Aluminium Association

Presently, 56% of aluminium metal supply in Europe is made from recyclates (Bertram et al, 2017). Whilst there are some easy wins for the use of recycled aluminium in lower value uses of the material such as packaging, the use of recycled aluminium in vehicles, may take time to build up the aluminium stock in vehicles before enough scrap material is available (Modaresi et al, 2014).

- For the **ambitious scenario**, assuming the UK's present recycled content of aluminium is the same as the EU, the recycled content of total aluminium metal supply increases from 56% to 95% by 2050.
- For the **transformative scenario**, assuming the UK's present recycled content of aluminium is the same as the EU, the recycled content of total aluminium metal supply increases from 56% to 95%.

Imports

Regarding imported aluminium, the UK imported £3.95bn of aluminium in 2019 (International Trade Centre, 2020). UK domestic manufacturing of aluminium is worth £1.4 bn, meaning that UK production only makes up ~26% of UK consumption of aluminium. Of imports to the UK, ~60% of imported aluminium comes from the EU, with the remaining 40% coming from the rest of the world. As with other material recycling scenarios, imported aluminium from the EU is expected to contain the same recyclates percentage as the UK scenario. The percentage of recyclates in aluminium production from the rest of the world is also expected to increase, reaching 95% with a time delay of 10 years. The baseline for the rest of the world are split into the regional average rates of aluminium scrap in production (Bertram et al, 2017). This will require the government to adopt strict purchasing requirements and regulations to accelerate the recycled content of materials arriving from overseas.

Glass (SIC 35)

Evidence

Unlike other materials, so long as impurities are removed in the recycling process recycled glass has the potential to achieve the same material properties as virgin glass (Dyer, 2014). The quality of the end product is determined by the grade of glass sand available, rather than the recycling process (Lin, 2018). There are some applications of glass which are difficult to recycle, particularly glass fluorescent tubes that are contaminated with toxic substances (Dyer, 2014). However, new methods are being explored to aid recovery. Moreover, recovery of glass in construction for recycling depends on their separation from other materials to enable recycling. Whilst this is technically feasible, particularly with industry trends towards 'designing structures for deconstruction', present demolition methods often contaminate glass with other materials, preventing their recycling (Dyer, 2014).

The National Packaging Waste Database provides the proportion of packaging waste exported from the UK and reprocessed in the UK. This suggests that at least 17% of glass packaging collected for recycling is exported. The Carbon Trust report (2005) suggests that each tonne of cullet re-melted reduces furnace energy demand by 337kWh (2.5%). Increasing recycled content from 38.5% to 100% could therefore reduce energy demand by 15%. This is assumed to also apply to non-packaging glass.

Scenario assumptions

WRAP and British Glass worked together to produce a recycled content protocol in 2008. This is used to calculate the recycled content in packaging glass. For 2016, the latest year available, this is 38.5% (British Glass, 2018).

Present EU recycling targets for glass packaging is to achieve 70% recycling by 2025, and 75% recycled by 2030 (EU Parliament, 2017). This scenario extends the ambition of the EU targets.

- The **ambitious scenario** assumes that by 2045, glass recyclates will increase from 38.5% to 95%. This recognises the existence of technical barriers to 100% recycled glass.
- The **transformative scenario** assumes that by 2035, glass recyclates will increase from 38.5% to 95%.

Imports

UK produced glass makes up 58% of all glass that is consumed in the UK. This suggests that 42% of glass is imported. Of the imported glass, 55% of it comes from within the EU, meaning the remaining 45% comes from the rest of the world. Glass imported from the EU is expected to increase in recyclates content alongside the UK scenario presented above. Regarding the rest of the world, the assumptions are met 10 years later.

Paper & paper products (SIC 23)

Evidence

The Confederation of Paper Industries (2020) identifies that the recovered fibre used as a share of total fibre raw materials (excluding additives) used in UK mills was 68% in 2019. (Schenk, Moll & Potting, 2004) suggests that this could be increased to 85%. IFEU (2006) suggests producing recycled paper over virgin fibres reduces energy demand in the mill by 6.944 MWh per tonne. Laurijssen et al (2010) suggest that energy use (embodied in feedstock & process energy) is 48GJ/t of paper for virgin mechanical pulping production methods, compared with 22 GJ/t for recovered scrap paper pulp. However, it is worth considering that the UK imports around 94% of pulp, used in UK paper mills (Griffin et al, 2018). Therefore, significant amounts of embodied energy in UK virgin paper production are only accounted for when using a consumption accounting method.

For paper and card, we would also propose that the process is fuelled by Combined Heat and Power, using unrecyclable materials.

Scenario assumptions

The Confederation of Paper Industries (2020) identifies that the recovered fibre used as a share of total fibre raw materials (excluding additives) used in UK mills was 68% in 2019. (Schenk, Moll, & Potting, 2004) suggests that this could be increased to 85%.

- For the **ambitious scenario**, we assume the level of recovered fibre increases from 68% to 85%. This equates to a 17% reduction in domestic virgin paper production by 2040.
- For the **transformative scenario**, from 68% to 85% by 2030.

Imports

The UK imports £8,329,000 worth of paper and boards in 2020. As a percentage of total paper and board consumption, imports represent 57%. Of these, 67% come from the EU, 4% from the rest of Europe, 17% from Asia, 11% from the Americas, and 1% from the rest of the world (CPI, 2020). In our scenarios we assume that the recycling rate of imported paper is different depending on its origin. For the EU, it is assumed that the recycling rates in the UK are matched by EU countries. For the rest of the world, the percentage of recyclates is expected to increase, but at a slower rate. We assume that there is a 10-year delay in the time that the assumptions are met in the rest of the world.

Rubber and plastic products (SIC 33)

Evidence

The UK produces 1.7 million tonnes of plastic per annum. However, WRAP (2019a) suggest that the UK market consumes 4.8 million tonnes of plastic annually, meaning only a third of UK demand is met domestically. Overall UK plastic packaging recycling capacity is estimated at approximately 425kt. Despite the increase in domestic recycling, the UK remains dependent on export markets for recycling its plastic packaging. WRAPs analysis suggests that recycling plastic reduces energy demand by 12.78 MWh per tonne of plastic bottles reprocessed, and 3.5MWh per tonne for mixed plastic reprocessing.

Scenario assumptions

Currently, of UK produced plastic, only ~25% is recycled back into production.

- For the **ambitious scenario**, we assume an increase from 25% recycled to 95% recyclates content by 2040. This equates to a reduction of 60% of virgin plastic production by 2040.
- For the **transformative scenario**, we assume an increase from 25% to 95% recyclates content by 2030. This equates to a reduction of 60% of virgin plastic production by 2030.

Imports

This increase of recycled plastics only applies to plastics produced domestically, which comprises only one third of plastics on the UK market. Of the plastic imported to the UK, 69% comes from the EU (British Plastic Federation, 2018). As in all scenarios, the percentage of recycled plastics coming from the EU is assumed to increase in line with the UK's target of 95%.

In the remaining 31% coming from the rest of the world, the percentage of plastic coming from recycled sources is expected to increase, but at a slower rate. Therefore, in the rest of the world the assumptions are met 10 years later. The baseline for the rest of the world is assumed to be 19.5%, the global average rate of plastic waste recycling in 2015 (Geyer et al, 2017).

Results

Results are presented here in terms of UK territorial, production and consumption emissions. Consumption emissions are presented by the industry in which emissions occurred, or by product in which emissions are embodied. Territorial emissions are omitted from some representations for conciseness, and as the sector splits are similar to those in production emissions. Generally only the results of the transformative scenario are shown where emissions are split by sector or region for conciseness.

Reference scenario

Figure 1 shows the production and consumption emissions in 2050 under the reference scenario, split by sector. Figure 2 shows how consumption emissions are split by region in 2050. The differences between allocating consumption emissions to source industry or embodied product are clear here, for example the metals industry shows substantial emissions by source industry, but by embodied product almost no emissions as the metals industry produces few products for final demand itself, but is a key intermediate input to many other products (for example vehicles).

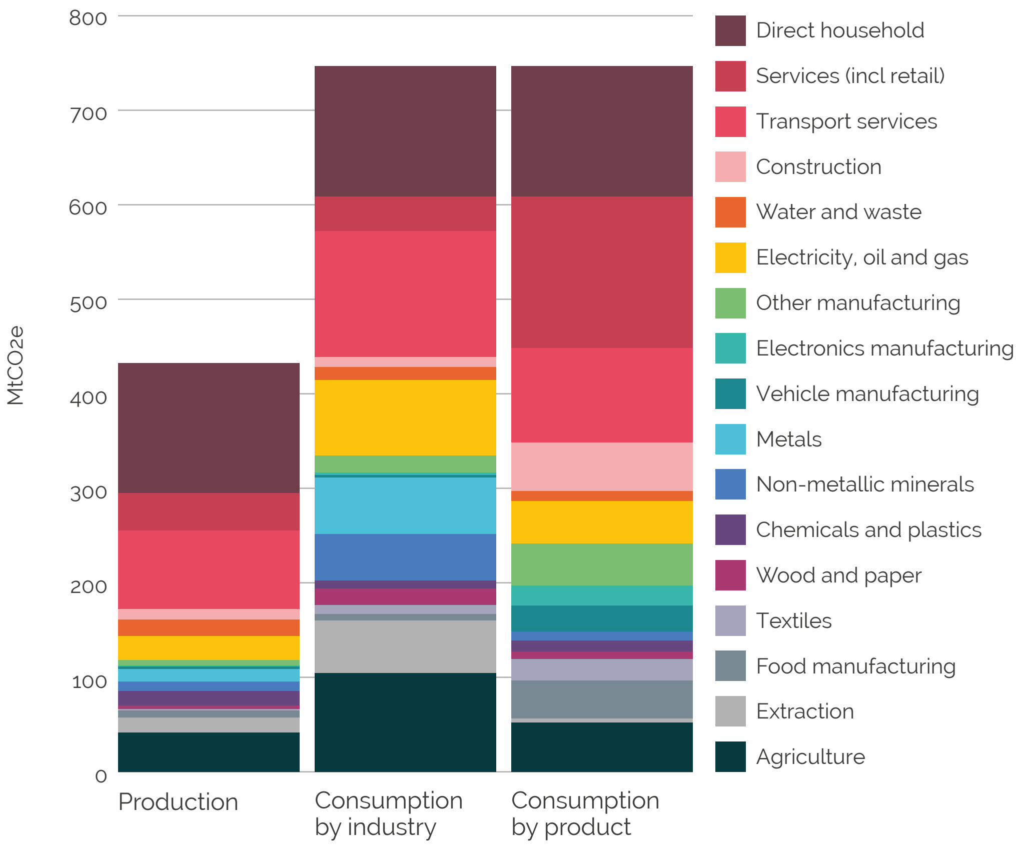

Figure 1: UK production and consumption emissions under the reference scenario in 2050. Consumption emissions are split by source industry and by the final product they are embodied in.

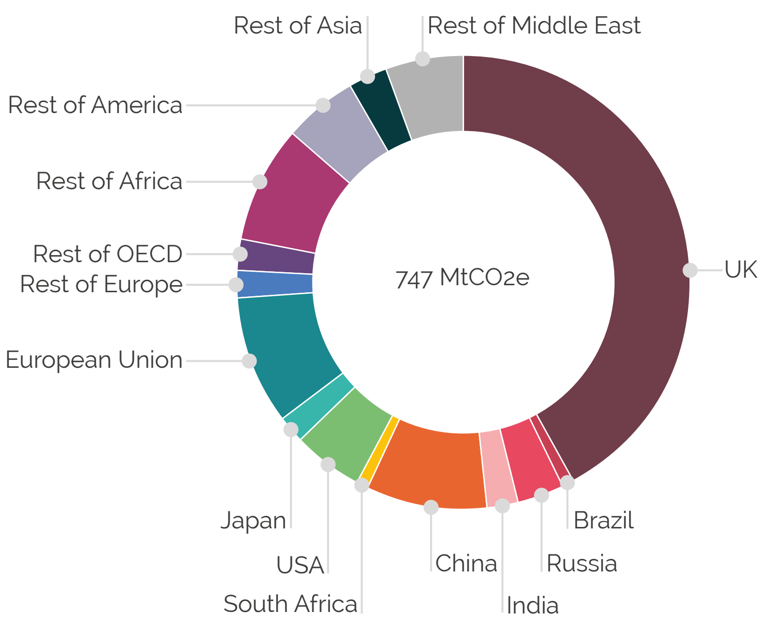

Figure 2: Regional split of UK consumption emissions under the reference scenario in 2050.

Overall reductions

Figure 3 shows the overall trend in the UK territorial, production and consumption emissions, under the reference case and with the high ambition and transformative levels of resource efficiency applied. The savings from resource efficiency strategies in comparison to the reference case are detailed in Table 4.

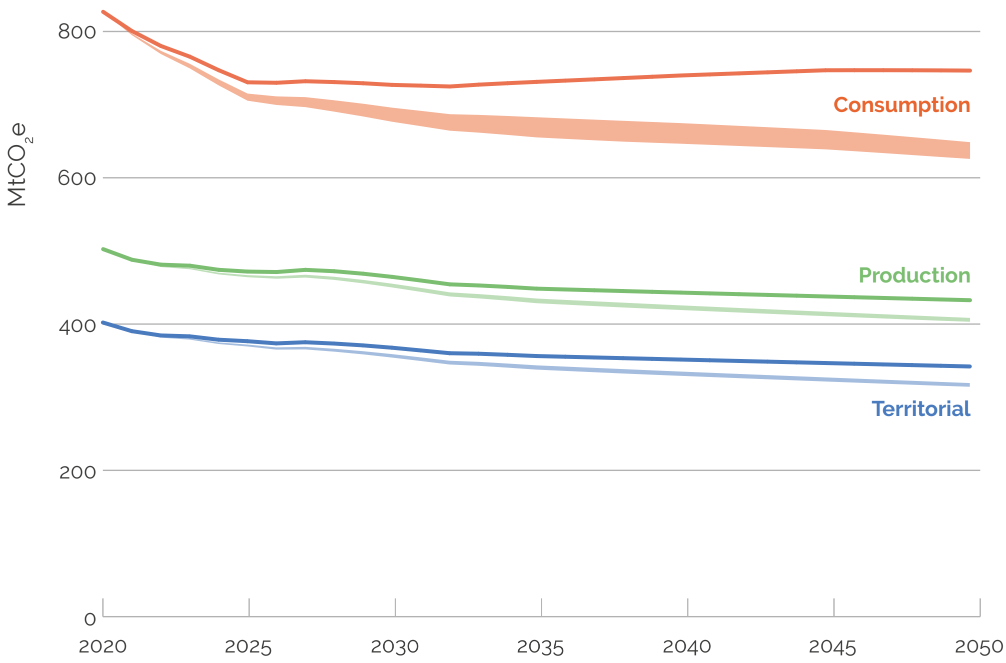

Figure 3: UK territorial, production and consumption emissions under the reference scenario (solid line) and with the high ambition and transformative levels of resource efficiency applied (shaded area).

Table 4: Emissions savings from the resource efficiency scenarios, shown as savings from the reference case and as a percentage of the reference case emissions. The range shown represents the high ambition and transformative scenario.

	2050 ($MtCO_2e$)	2050 %	2020–2050 ($MtCO_2e$)	2020–2050 %
Territorial	22.7–27.7	10.3–12.7%	379–519	5.2–7.1%
Production	24.2–29.5	8.2–10.0%	403-555	4.1–5.7%
Consumption	97.8–120.7	16.1–19.8%	1503–2133	8.0–11.4%

Figure 4, Figure 5 and Table 5 show the savings made from the reference scenario at the sector level.

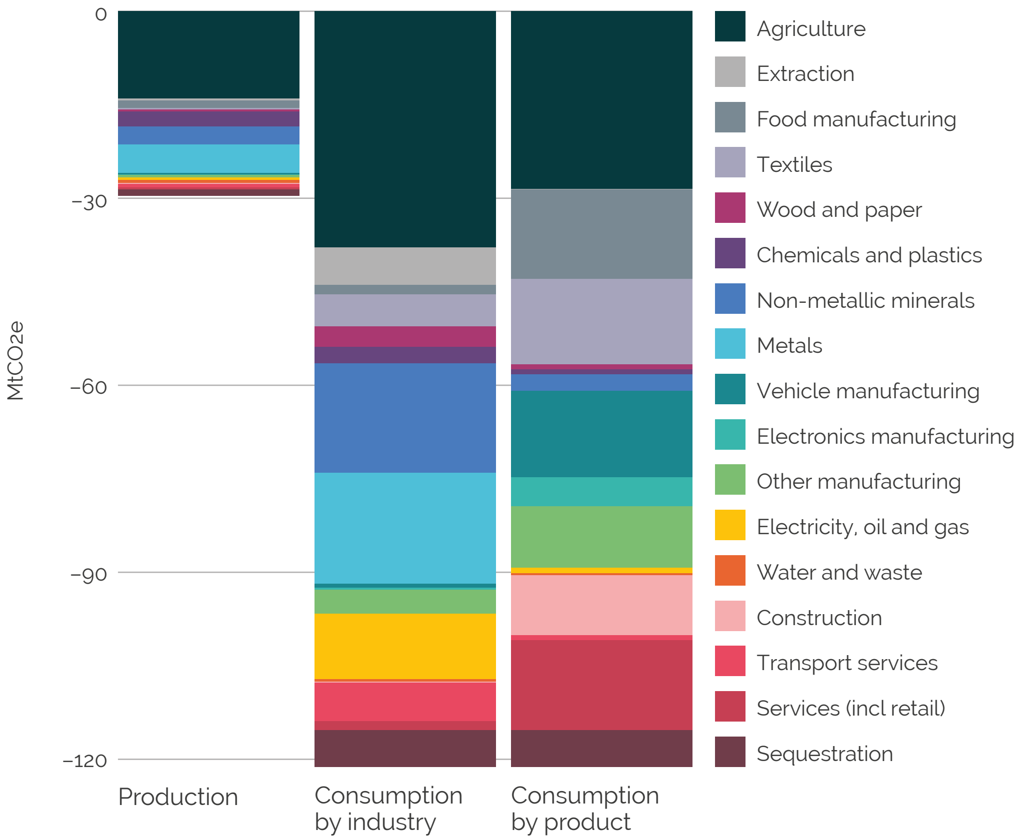

Figure 4: Emissions reduction under the transformative scenario from the reference case in 2050. UK production emissions, consumption emissions by industry and by end product are shown.

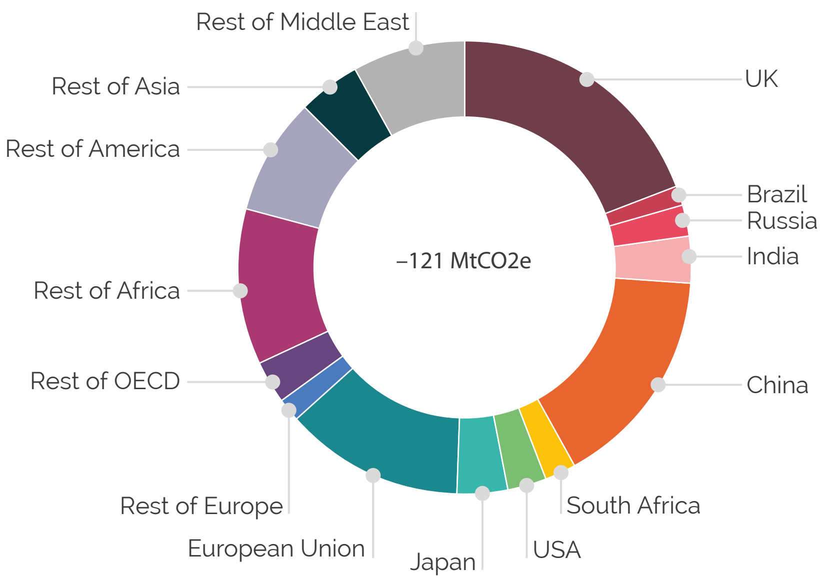

Figure 5: UK consumption emissions reduction from the reference scenario in 2050 under the transformative scenario. Emissions are split by region where the savings are made.

Table 5: Relative savings from resource efficiency strategies in comparison to the reference case at the sector level (sector disaggregation can be seen in the Appendices). Consumption emissions savings show reductions for the UK and RoW combined. * sector emissions increase in the transformative scenario in comparison to the high ambition scenario as more or these materials are used in material substitution strategies.

Sector	Production emissions savings	Consumption emissions savings, by industry	Consumption emissions savings, by product
Agriculture	27.0–33.6%	28.8–36.2%	43.9–54.8%
Extraction	1.4–1.7%	8.9–10.7%	1.0–1.1%
Food manufacturing	13.1–16.6%	17.8–22.9%	27.9–35.7%
Textiles	13.8–17.7%	42.2–55.3%	45.7–59.8%
Wood and paper	9.2–8.8%*	17.4–18.6%	9.7–9.9%
Chemicals and plastics	14.0–15.7%	28.3–32.3%	6.6–7.3%
Non-metallic minerals	23.1–28.8%	28.3–35.3%	22.6–27.1%
Metals	28.8–33.8%	25.9–29.7%	6.2–7.2%
Vehicle manufacturing	11.3–12%	22.7–24.5%	47.4–50.9%
Electronics manufacturing	1.9–2.2%	9.6–12.0%	16.5–21.4%
Other manufacturing	6.8–7.9%	17.0–21.3%	17.9–22.5%
Electricity, oil and gas	1.3–1.5%	10.7–13.1%	1.6–1.9%
Water and waste	2.1–2.5%	2.2–2.6%	2.0–2.4%
Construction	1.4–1.6%	1.7–1.9%	14.4–18.7%
Transport services	0.7–0.8%	3.9–4.6%	0.8–0.9%
Services (incl retail)	0.6–0.7%	3.2–3.8%	7.9–8.9%

Grouped savings

Figure 6, Figure 7 and Figure 8 show the savings from groups of resource efficiency strategies on production emissions and consumption emissions from an industry and product perspective. Due to the full supply chain impacts of resource efficiency strategies and the interactions between the savings from different strategies the sum of these strategy groups will be different to the case where all strategies are applied together. The strategies principally relating to food consumption, diet and waste are shown as a separate group here. The full definition of the sector grouping used is given in the Appendices.

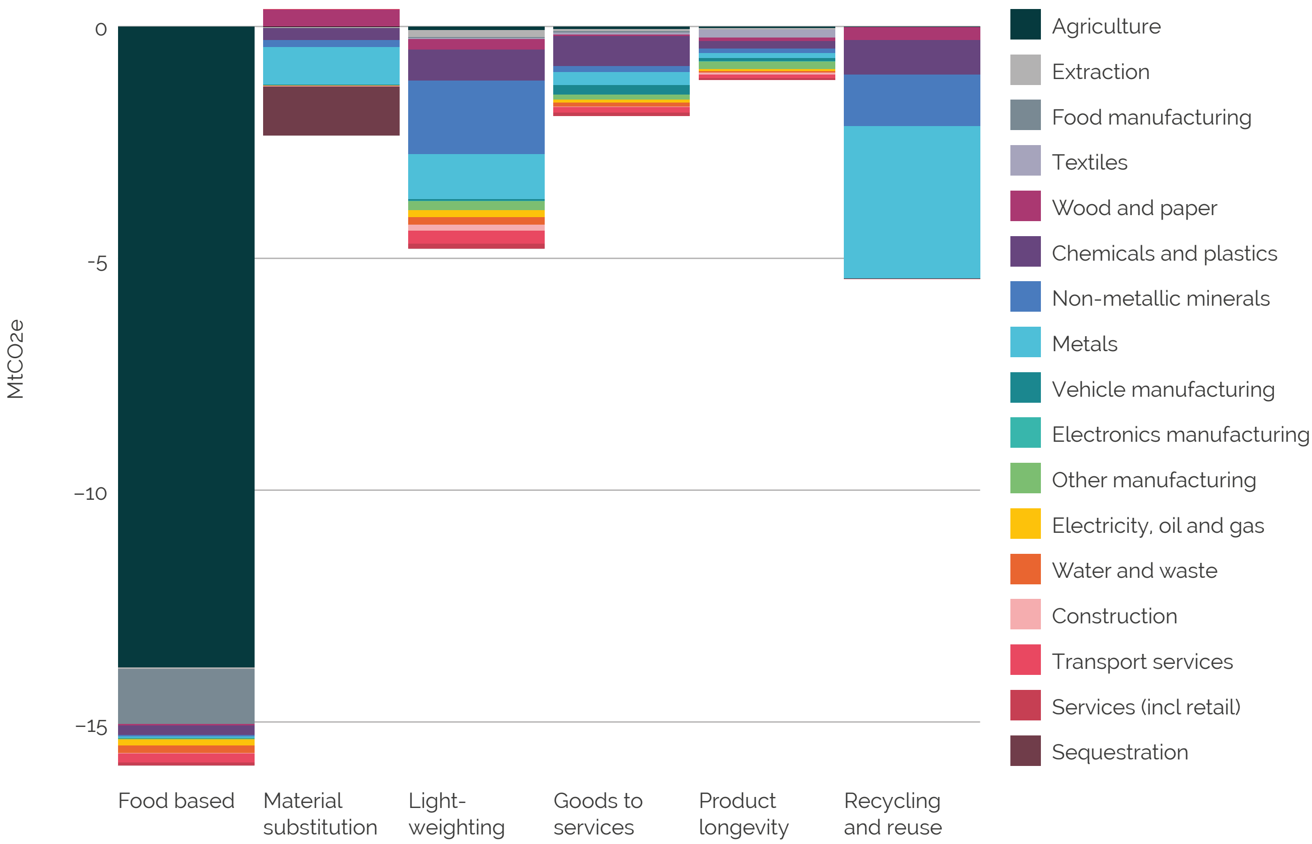

Figure 6: UK production emission savings from the reference case in 2050, under the transformative scenario. Groups of resource efficiency strategies applied independently are shown.

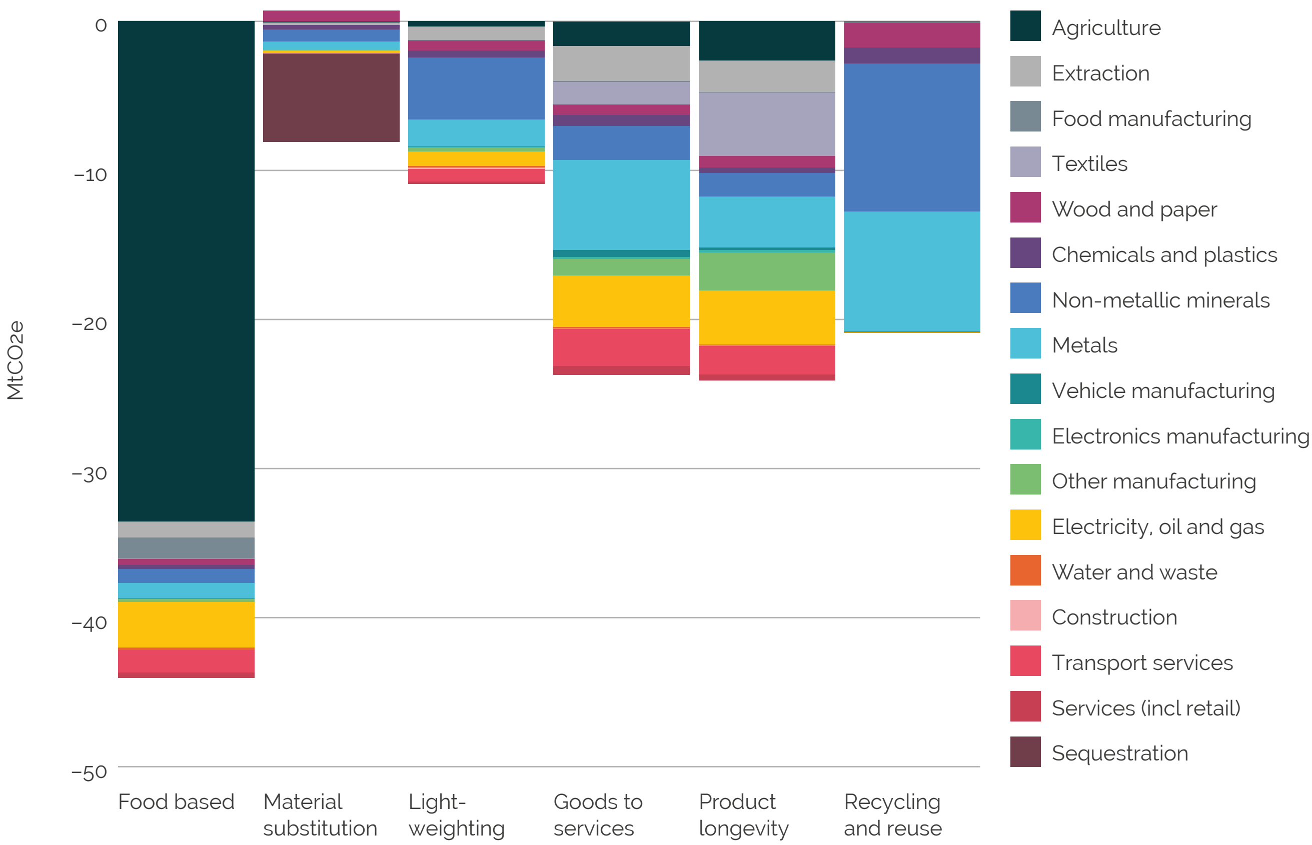

Figure 7: UK consumption emission savings from the reference case in 2050, under the transformative scenario. Savings are shown by source industry. Groups of resource efficiency strategies applied independently are shown.

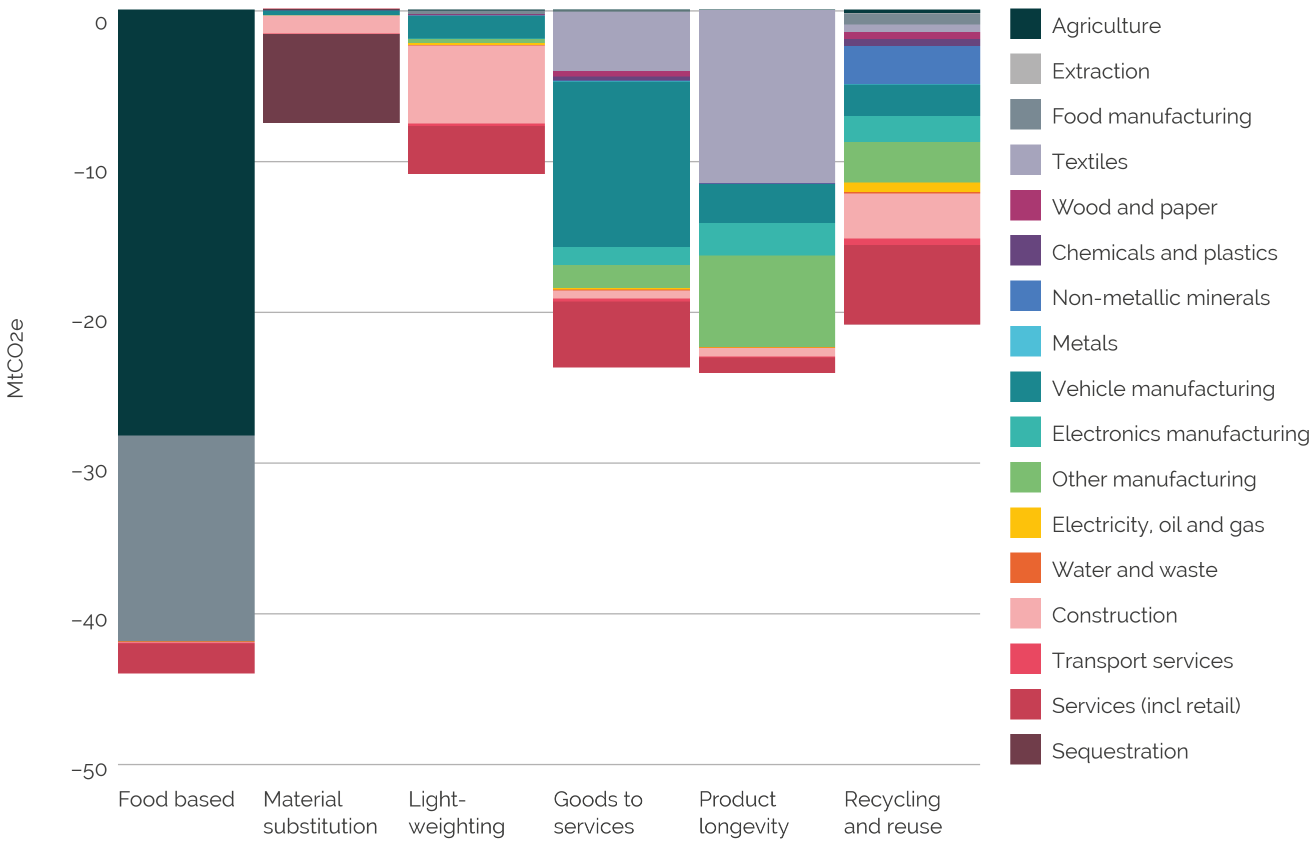

Figure 8: UK consumption emission savings from the reference case in 2050, under the transformative scenario. Savings are shown by final product. Groups of resource efficiency strategies applied independently are shown.

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Appendix

Rest of World emissions intensity projections methodology

I. Regional decomposition

The TIAM-UCL has a 16 region breakdown (Africa, Australia, Canada, Central and South America, China, Eastern Europe, Former Soviet Union, India, Japan, Mexico, Middle East, Other Developing Asia, South Korea, UK, USA, Western Europe). Mapping to the UKMIRO regions is provided below.

WWF-UKMIRO database region	EXIOBASE regions	Covering TIAM regions	Allocation for projections
UK	UK	UK	CCC domestic scenarios
Brazil	Brazil	Central and South America (CSA)	Central and South America (CSA)
Russia	Russia	Former Soviet Union (FSU)	Former Soviet Union (FSU)
India	India	India (IND)	India (IND)
China	China	China (CHI)	China (CHI)
South Africa	South Africa	Africa (AFR)	Africa (AFR)
USA	USA	USA (USA)	USA (USA)
Japan	Japan	Japan (JAP)	Japan (JAP)
Rest of the European Union	Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Germany, Denmark, Estonia, Spain, Finland, France, Greece, Hungary, Ireland, Italy, Latvia, Luxemburg, Lithuania, Malta, Netherlands, Poland, Romania, Sweden, Slovakia, Slovenia	Western Europe (WEU)	Western Europe (WEU)
Rest of Europe	Switzerland, Norway, Rest of Europe	Eastern Europe (EEU);	Eastern Europe (EEU);

WWF-UKMIRO database region	EXIOBASE regions	Covering TIAM regions	Allocation for projections
Rest of the OECD	Canada, Korea, Mexico, Australia, Turkey	Canada (CAN), Mexico (MEX), Australia (AUS), South Korea (SKO)	Average of CAN, MEX, AUS, SKO weighted by current trade patterns
Rest of Africa	Rest of Africa	Africa (AFR)	Africa (AFR)
Rest of the Americas	Rest of the Americas	Central and South America (CSA)	Central and South America (CSA)
Rest of Asia and Oceania	Taiwan, Indonesia, Rest of Asia and Oceania	Other Developing Asia (ODA)	Other Developing Asia (ODA)
Rest of the Middle East	Rest of Middle East	Middle-east (MEA)	Middle-east (MEA)

II. Sectoral decomposition

TIAM-UCL breaks regional emissions down into sectors: Electricity, Upstream, Industry, Agriculture, Residential, and Transport. A draft first cut mapping of the consumption emissions database sectors (106 sectors) to the TIAM-UCL sectors is shown below:

Consumption emissions sectors	Mapping to dominant TIAM emissions sector(s)
Products of agriculture, hunting and related services	Agriculture
Products of forestry, logging and related services	Agriculture
Fish and other fishing products; aquaculture products; support services to fishing	Agriculture
Coal and lignite	Upstream (coal mining)
Extraction Of Crude Petroleum And Natural Gas & Mining Of Metal Ores	Upstream (oil and gas extraction)
Other mining and quarrying products	Upstream
Mining support services	Upstream
Preserved meat and meat products	Industry – other
Processed and preserved fish, crustaceans, molluscs, fruit and vegetables	Industry – other
Vegetable and animal oils and fats	Industry – other
Dairy products	Industry – other
Grain mill products, starches and starch products	Industry – other
Bakery and farinaceous products	Industry – other
Other food products	Industry – other
Prepared animal feeds	Industry – other
Alcoholic beverages	Industry – other

Consumption emissions sectors	Mapping to dominant TIAM emissions sector(s)
Soft drinks	Industry – other
Tobacco products	Industry – other
Textiles	Industry – other
Wearing apparel	Industry – other
Leather and related products	Industry – other
Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials	Industry – pulp & paper
Paper and paper products	Industry – pulp & paper
Printing and recording services	Industry – pulp & paper
Coke and refined petroleum products	Upstream
Paints, varnishes and similar coatings, printing ink and mastics	Industry – chemical
Soap and detergents, cleaning and polishing preparations, perfumes and toilet preparations	Industry – chemical
Other chemical products	Industry – chemical
Industrial gases, inorganics and fertilisers (all inorganic chemicals) – 20.11/13/15	Industry – chemical
Petrochemicals – 20.14/16/17/60	Upstream – chemical
Dyestuffs, agro-chemicals – 20.12/20	Industry – chemical
Basic pharmaceutical products and pharmaceutical preparations	Industry – chemical
Rubber and plastic products	Industry – chemical
Manufacture of cement, lime, plaster and articles of concrete, cement and plaster	Industry – non-metal
Glass, refractory, clay, other porcelain and ceramic, stone and abrasive products – 23.1-4/7-9	Industry – non-metal
Basic iron and steel	Industry – Iron & steel
Other basic metals and casting	Industry – non-ferrous
Weapons and ammunition	Industry – other
Fabricated metal products, excl. machinery and equipment and weapons & ammunition – 25.1-3/25.5-9	Industry – non-ferrous
Computer, electronic and optical products	Industry – other
Electrical equipment	Industry – other
Machinery and equipment n.e.c.	Industry – other
Motor vehicles, trailers and semi-trailers	Industry – other
Ships and boats	Industry – other
Air and spacecraft and related machinery	Industry – other

Consumption emissions sectors	Mapping to dominant TIAM emissions sector(s)
Other transport equipment – 30.2/4/9	Industry – other
Furniture	Industry – other
Other manufactured goods	Industry – other
Repair and maintenance of ships and boats	Industry – other
Repair and maintenance of aircraft and spacecraft	Industry – other
Rest of repair; Installation – 33.11-14/17/19/20	Industry – other
Electricity, transmission and distribution	Electricity
Gas; distribution of gaseous fuels through mains; steam and air conditioning supply	Industry – other
Natural water; water treatment and supply services	Industry – other
Sewerage services; sewage sludge	Industry – other
Waste collection, treatment and disposal services; materials recovery services	Industry – other
Remediation services and other waste management services	Industry – other
Construction	Transport – road
Wholesale and retail trade and repair services of motor vehicles and motorcycles	Buildings non-residential
Wholesale trade services, except of motor vehicles and motorcycles	Buildings non-residential
Retail trade services, except of motor vehicles and motorcycles	Buildings non-residential
Rail transport services	Transport – rail
Land transport services and transport services via pipelines, excluding rail transport	Transport – road
Water transport services	Transport – water
Air transport services	Transport – air
Warehousing and support services for transportation	Buildings non-residential
Postal and courier services	Buildings non-residential
Accommodation services	Buildings non-residential
Food and beverage serving services	Buildings non-residential
Publishing services	Buildings non-residential
Motion Picture, Video & TV Programme Production, Sound Recording & Music Publishing Activities & Programming And Broadcasting Activities	Buildings non-residential
Telecommunications services	Buildings non-residential
Computer programming, consultancy and related services	Buildings non-residential
Information services	Buildings non-residential
Financial services, except insurance and pension funding	Buildings non-residential
Insurance and reinsurance, except compulsory social security & Pension funding	Buildings non-residential

Consumption emissions sectors	Mapping to dominant TIAM emissions sector(s)
Services auxiliary to financial services and insurance services	Buildings non-residential
Real estate services, excluding on a fee or contract basis and imputed rent	Buildings non-residential
Owner-Occupiers' Housing Services	Buildings non-residential
Real estate services on a fee or contract basis	Buildings non-residential
Legal services	Buildings non-residential
Accounting, bookkeeping and auditing services; tax consulting services	Buildings non-residential
Services of head offices; management consulting services	Buildings non-residential
Architectural and engineering services; technical testing and analysis services	Buildings non-residential
Scientific research and development services	Buildings non-residential
Advertising and market research services	Buildings non-residential
Other professional, scientific and technical services	Buildings non-residential
Veterinary services	Buildings non-residential
Rental and leasing services	Buildings non-residential
Employment services	Buildings non-residential
Travel agency, tour operator and other reservation services and related services	Buildings non-residential
Security and investigation services	Buildings non-residential
Services to buildings and landscape	Buildings non-residential
Office administrative, office support and other business support services	Buildings non-residential
Public administration and defence services; compulsory social security services	Buildings non-residential
Education services	Buildings non-residential
Human health services	Buildings non-residential
Residential Care & Social Work Activities	Buildings non-residential
Creative, arts and entertainment services	Buildings non-residential
Libraries, archives, museums and other cultural services	Buildings non-residential
Gambling and betting services	Buildings non-residential
Sports services and amusement and recreation services	Buildings non-residential
Services furnished by membership organisations	Buildings non-residential
Repair services of computers and personal and household goods	Buildings non-residential
Other personal services	Buildings non-residential
Services of households as employers of domestic personnel	Buildings non-residential

Sector aggregation in results

For clarity results are presented at an aggregate level, rather than the full level of disaggregation available in the MRIO model. The table below indicates how the aggregate sectors are composed.

Aggregate sector (results)	Disaggregate sectors (modelled)
Agriculture	Crop And Animal Production, Hunting And Related Service Activities
	Forestry And Logging
	Fishing And Aquaculture
Extraction	Mining Of Coal And Lignite
	Extraction Of Crude Petroleum And Natural Gas & Mining Of Metal Ores
	Other Mining And Quarrying
	Mining Support Service Activities
Food manufacturing	Processing and preserving of meat and production of meat products
	Processing and preserving of fish, crustaceans, molluscs, fruit and vegetables
	Manufacture of vegetable and animal oils and fats
	Manufacture of dairy products
	Manufacture of grain mill products, starches and starch products
	Manufacture of bakery and farinaceous products
	Manufacture of other food products
	Manufacture of prepared animal feeds
	Manufacture of alcoholic beverages
	Manufacture of soft drinks; production of mineral waters and other bottled waters

Aggregate sector (results)	Disaggregate sectors (modelled)
Textiles	Manufacture Of Textiles
	Manufacture Of Wearing Apparel
	Manufacture Of Leather And Related Products
Wood and paper	Manufacture Of Wood & Products Of Wood & Cork, Except Furniture; Manuf. Of Articles Of Straw
	Manufacture Of Paper And Paper Products
	Printing And Reproduction Of Recorded Media
Chemicals and plastics	Manufacture of paints, varnishes and similar coatings, printing ink and mastics
	Manufacture of soap & detergents, cleaning & polishing, perfumes & toilet preparations
	Manufacture of other chemical products
	Manufacture of industrial gases, inorganics and fertilisers (inorganic chemicals) – 20.11/13/15
	Manufacture of petrochemicals – 20.14/16/17/60
	Manufacture of dyestuffs, agro-chemicals – 20.12/20
	Manufacture Of Basic Pharmaceutical Products And Pharmaceutical Preparations
	Manufacture Of Rubber And Plastic Products
Non-metallic minerals	Manufacture of cement, lime, plaster and articles of concrete, cement and plaster
	Manufacture of glass, refractory, clay, porcelain, ceramic, stone products – 23.1-4/7-9
Metals	Manufacture of basic iron and steel
	Manufacture of other basic metals and casting
Vehicle manufacturing	Manufacture Of Motor Vehicles, Trailers And Semi-Trailers
	Building of ships and boats
	Manufacture of air and spacecraft and related machinery
	Manufacture of other transport equipment – 30.2/4/9
Electronics manufacturing	Manufacture Of Computer, Electronic And Optical Products
	Manufacture Of Electrical Equipment
Other manufacturing	Manufacture Of Tobacco Products
	Manufacture of weapons and ammunition
	Manufacture of fabricated metal products, excluding weapons & ammunition – 25.1-3/5-9
	Manufacture Of Machinery And Equipment N.E.C.
	Manufacture Of Furniture
	Other Manufacturing
	Repair and maintenance of ships and boats

Aggregate sector (results)	Disaggregate sectors (modelled)
Other manufacturing	Repair and maintenance of aircraft and spacecraft
	Rest of repair; Installation – 33.11-14/17/19/20
Electricity, oil and gas	Manufacture Of Coke And Refined Petroleum Products
	Electric power generation, transmission and distribution
	Manufacture of gas; distribution of gaseous fuels through mains; steam and aircon supply
Water and waste	Water Collection, Treatment And Supply
	Sewerage
	Waste Collection, Treatment And Disposal Activities; Materials Recovery
	Remediation Activities And Other Waste Management Services
Construction	Construction
Transport services	Rail transport
	Land transport services and transport services via pipelines, excluding rail transport
	Water Transport
	Air Transport
	Warehousing And Support Activities For Transportation
Services (including retail)	Wholesale And Retail Trade And Repair Of Motor Vehicles And Motorcycles
	Wholesale Trade, Except Of Motor Vehicles And Motorcycles
	Retail Trade, Except Of Motor Vehicles And Motorcycles
	Postal And Courier Activities
	Accommodation
	Food And Beverage Service Activities
	Publishing Activities
	Motion Picture, Video & TV Programme Production, Sound Recording & Music Publishing Activities & Programming And Broadcasting Activities
	Telecommunications
	Computer Programming, Consultancy And Related Activities
	Information Service Activities
	Financial Service Activities, Except Insurance And Pension Funding
	Insurance and reinsurance, except compulsory social security Pension funding
	Activities Auxiliary To Financial Services And Insurance Activities
	Buying and selling, renting and operating of own or leased real estate, excluding imputed rent
	Owner-Occupiers' Housing

Aggregate sector (results)	Disaggregate sectors (modelled)
Services (including retail)	Real estate services on a fee or contract basis
	Legal activities
	Accounting, bookkeeping and auditing activities; tax consultancy
	Activities Of Head Offices; Management Consultancy Activities
	Architectural And Engineering Activities; Technical Testing And Analysis
	Scientific Research And Development
	Advertising And Market Research
	Other Professional, Scientific And Technical Activities
	Veterinary Activities
	Rental And Leasing Activities
	Employment Activities
	Travel Agency, Tour Operator And Other Reservation Service And Related Activities
	Security And Investigation Activities
	Services To Buildings And Landscape Activities
	Office Administrative, Office Support And Other Business Support Activities
	Public Administration And Defence; Compulsory Social Security
	Education
	Human Health Activities
	Residential Care & Social Work Activities
	Creative, Arts And Entertainment Activities
	Libraries, Archives, Museums And Other Cultural Activities
	Gambling And Betting Activities
	Sports Activities And Amusement And Recreation Activities
	Activities Of Membership Organisations
	Repair Of Computers And Personal And Household Goods
	Other Personal Service Activities
	Activities Of Households As Employers Of Domestic Personnel
	Wholesale And Retail Trade And Repair Of Motor Vehicles And Motorcycles

C R E D S

About CREDS

The Centre for Research into Energy Demand Solutions (CREDS) was established as part of the UK Research and Innovation's Energy Programme in April 2018, with funding of £19.5M over 5 years. Its mission is to make the UK a leader in understanding the changes in energy demand needed for the transition to a secure and affordable, low carbon energy system. CREDS has a team of over 140 people based at 24 UK universities.

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