Department for Energy Security & Net Zero

Unlocking Resource Efficiency

Phase 2 Main Report

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1.0 Introduction

The Department for Energy Security and Net Zero (DESNZ) and the Department for Environment, Food and Rural Affairs (DEFRA) commissioned Eunomia Research and Consulting to undertake a research project exploring the potential benefits from increasing resource efficiency in the UK. The results of this research are presented in this report and the accompanying sector-specific reports. A detailed description of the methodology can be found in the Technical Report accompanying this publication.

This report was written in November 2023 and so does not reflect sector developments beyond that point. Technical experts were consulted as part of research activities for this report. The following report reflects our understanding of the available evidence and is accurate to the best of our knowledge; however, if any factual errors are encountered, please contact us at Resource_efficiency@energysecurity.gov.uk.

This report has nine main sections:

- Section 1: Introduction, covering the research purpose, research objectives and key definitions;
- Sections 2 to 8: The key research findings for Phase 2 of the research for each sector (plastics, paper, chemicals, electricals, glass, food & drink), alongside the findings for one sector of Phase 1 (textiles); and
- Section 9: Key cross-sector research findings and conclusions of Phase 2.

More detail about the research findings for each sector, including information on all the resource efficiency measures identified, a discussion of the drivers and barriers for these measures, and estimates for the current, maximum and business as usual (BAU) levels of efficiency for these measures, can be found in the seven sector-specific reports which accompany this executive summary.

It is important to note that the sector-specific reports do not contain a detailed description of the methodology, and it is useful to have read this report and the Technical Summary which accompanies this publication in order to understand how the conclusions have been drawn for each sector.

1.1 Background and policy context

For the purpose of this project, resource efficiency has been defined as the optimisation of resource use so that a given level of final consumption can be met with fewer resources. This can occur at production, consumption, or end of product life.

Examples of resource efficiency measures therefore include making lighter products (e.g., making lighter electrical products), using recycled materials in production (e.g., recycled plastic, recycled paper), product sharing (e.g., chemical industry collaborative consumption) and improving product lifespan (e.g., increased product reuse, improved product repairability).

As resource efficiency can reduce demand for raw materials, reduce energy demand and carbon emissions from industrial production and reduce residual waste it has a key role to play in many of the Government's environmental and climate ambitions.

For example, resource efficiency plays a critical role in the Government's plan to decarbonise industry, as well as meet their legally binding net zero target. This is evident in the Industrial Decarbonisation Strategy[1] (which sets out how industry will decarbonise to achieve net zero) where resource efficiency is currently projected to deliver 8 MtCO2e of industrial carbon savings per year by 2035.

Resource efficiency also has a key role to play in the Government's Resources and Waste Strategy for England[2] and its ambition to maximise the value of resource use and minimise waste and its impact on the environment. This includes commitments to double resource productivity and achieve zero avoidable waste, both by 2050.

1.2 Research purpose and research objectives

There are currently substantial gaps in the evidence base which are impeding the development of evidence-based policies to deliver increased resource efficiency across the UK. The purpose of this research was to fill key gaps in the resource efficiency evidence base to inform the UK government's ambition on resource efficiency and support the development of future resource efficiency policy.

The research had four key objectives:

1. Identify a comprehensive list of resource efficiency measures across different industrial sectors;
2. Identify current and anticipated drivers and barriers which are affecting improvements in the identified resource efficiency measures, and their relative importance;
3. Build evidence-based estimates for the current "level of efficiency" and maximum "level of efficiency" in 2035 for each of the identified resource efficiency measures; and
4. Evaluate the extent to which industry is currently improving resource efficiency and build consensus estimates for the likely "levels of efficiency" in 2035 given current private sector incentives and the existing policy mix (a "business-as-usual" scenario), for each of the identified resource efficiency measures.

To achieve these research objectives, a mixed-methods methodology was developed. A literature review was conducted for each sector to synthesise evidence from the existing

[1] BEIS (2021), Industrial Decarbonisation Strategy
[2] Defra (2018), Resources and Waste Strategy for England

literature relevant to these objectives. In parallel, stakeholder interviews were conducted with industry and academic experts in each sector to test literature findings and fill any outstanding evidence gaps. A summary of findings was then presented and validated at sector-specific facilitated workshops with sector experts. Details on the methodology are available in the Phase 2 Technical Summary which accompanies this publication.

This project did not aim to identify policy recommendations but rather understand the potential for resource efficiency in the UK. It should be noted that some areas covered as part of the research fall under the responsibility of devolved nations of the UK; however, all reports cover the UK as a whole for completeness.

1.3 Research scope and definitions

1.3.1 Defining resource efficiency measures

For the purpose of this study, a resource efficiency measure has been defined as:

> *A measure that achieves a lower level of resource use for a given level of final consumption.*

Measures that meet the above definition are diverse and occur at all lifecycle stages, including production, consumption and end-of-product life.

While material substitution may not always meet the definition or resource efficiency set out above, it is considered to be in scope of this research, and has been defined as:

> *'a measure that replaces some or all of a material used in production, where this reduces the whole life carbon of the final product'*

For the purposes of the study, the term 'resource efficiency' was used to refer to both resource efficiency and material substitution measures.

Resource efficiency measures were considered to be in scope if they could be impacted by UK action. The action could be at any stage of the value chain (including design, manufacture, use, end of life).

Throughout this research, a range of actions were identified that are not themselves resource efficiency measures (they do not directly reduce resource use on their own), but support the delivery of resource efficiency measures. For the purposes of this study these actions were called 'enablers'.

1.3.2 Barriers and drivers

For each measure, barriers and drivers were identified. A barrier has been defined as anything that would prevent or reduce improvements in resource efficiency, and a driver has been defined as anything which would encourage or increase improvements in resource efficiency.

These drivers and barriers were categorised using two separate systems:

- The **PESTLE framework** which is focused on the types of changes: Political, Economic, Social, Technological, Legal and Environmental;
- The **COM-B framework** which is focused on behaviour change:
  - Capability: can this behaviour be accomplished in practice?
    - Physical Capability – e.g., measure may not be compatible for certain processes
    - Psychological Capability – e.g., lack of knowledge
  - Opportunity: is there sufficient opportunity for the behaviour to occur?
    - Physical Opportunity: e.g., bad timing, lack of capital
    - Social Opportunity: e.g., not the norm amongst the competition
  - Motivation: is there sufficient motivation for the behaviour to occur?
    - Reflective motivation: e.g., inability to understand the costs and benefits
    - Automatic motivation: e.g., lack of interest from customers, greater priorities

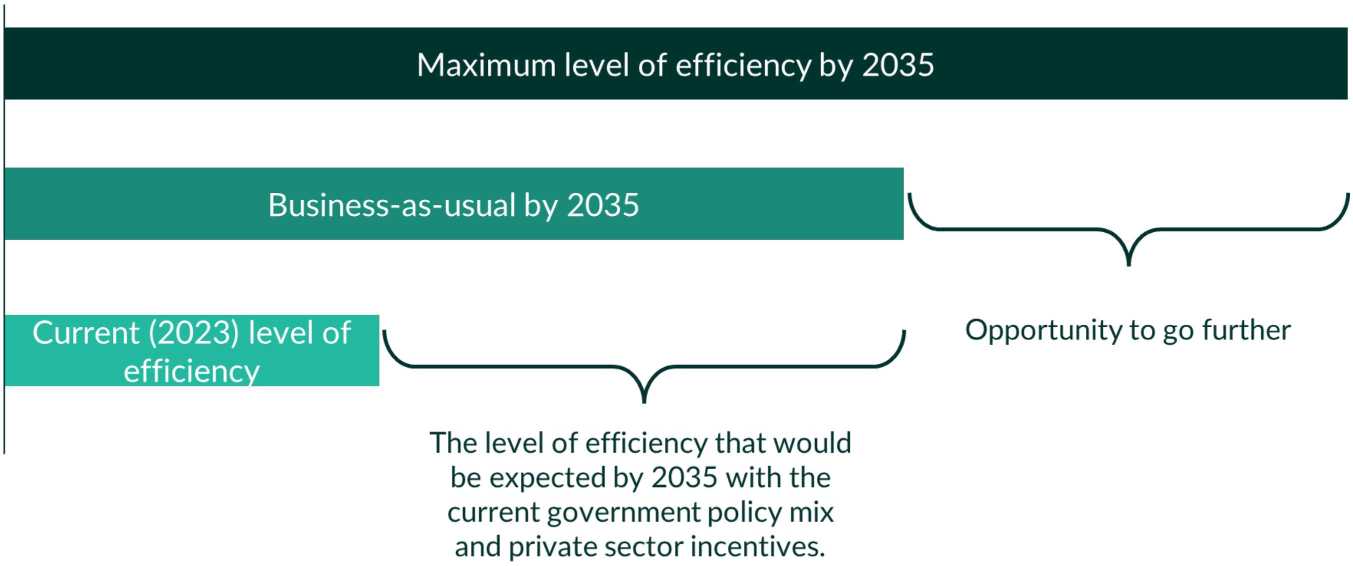
1.3.3 Defining levels of efficiency

As set out in the research objectives, one of the key objectives of this research was to build consensus estimates for three “levels of efficiency” for each of the identified resource efficiency measures. These were:

- The **current level of efficiency** which is the best estimate for the current level of the measure, meaning what is happening in UK industry/with UK consumers at the time of this research in 2023;
- The **maximum level of efficiency** which is the maximum level of efficiency that is technically possible by 2035 in the UK, without factoring in potential barriers that could be overcome by 2035, meaning irrespective of economic (or other) barriers, the maximum level that could be achieved; and
- The **BAUlevel of efficiency** which is the level of efficiency that would be expected in the UK by 2035 with the current policy mix and private sector incentives, meaning what would happen if there were no substantial changes for the policy or private sector environment.

An illustrative example of these three levels of efficiency is shown in Figure 1.

Figure 1: Illustrative example of the levels of efficiency for a resource efficiency measure



The gap between the BAU and the maximum levels of efficiency represents the opportunity for the sector to improve resource efficiency. The drivers and barriers help explain the differences between the three values.

It was expected that the BAU level of efficiency by 2035 would generally be higher than the current level of efficiency and lower than the maximum level of efficiency. However, it could also be possible that for certain measures the BAU level of efficiency in 2035 would be lower than the current level if the direction of travel of the measure is moving away from the maximum level of efficiency.

The level of efficiency estimates have been calculated for each measure independently. As there are substantial interactions between measures it should not be assumed that these levels of efficiency are additive or could all happen in parallel. More detail about the interdependencies between measures can be found in the accompanying sector-specific reports.

To estimate these levels of efficiency an indicator has been developed for each of the identified measures. These indicators have been chosen based on how well they capture the impact of the relevant measure, and how much data there is available on this basis (both in the literature review and from expert stakeholders). The purpose of the indicators in this research was so estimates on the current, maximum and BAU level of efficiency can be developed on a consistent basis. They were not intended to be used as metrics to monitor the progress of these resource efficiency measures over time, or to be used as metrics for resource efficiency policies.

Evidence RAG ratings have been provided to indicate the level of supporting evidence for each of indicator estimate. These ratings relate to the quality of evidence and not the level of efficiency.

It should be noted that for many measures with indicators that are a percentage reduction, where a robust data has not been available to produce a baseline the current level of efficiency has been set a 0% - setting the current year (2023) as the baseline in which the maximum and BAU levels of efficiency will improve upon.

1.3.4 Sector selection

As resource efficiency measures and their associated barriers and drivers differ substantially between industrial sectors, this research has been conducted at the sector level.

Eleven sectors have been selected for this research, which was divided in two phases:

- Phase 1: cement & concrete, construction, steel, vehicles and textiles; and
- Phase 2: plastic, paper, chemicals, electricals, glass, and food & drink.

These sectors have been chosen by DESNZ in collaboration with DEFRA because they have high potential for carbon reduction, virgin material reduction and waste prevention, which are departmental priorities.

This report and the accompanying sector specific reports covers the research conducted in Phase 2, with the addition of one Phase 1 sector (textiles) published alongside these. The details of Phase 1 of this research are covered in the Phase 1 Executive Summary and the accompanying sector specific-reports which were published on Gov.uk[3] in November 2023.

The 11 selected sectors for this research project are not homogenous. While some have material outputs (chemicals, steel, paper, plastics, glass, cement and concrete), others have product outputs (vehicles, textiles, electricals, construction, food and drink). This creates a situation of dependencies between the research sectors, where resource efficiency measures that apply to an upstream sector naturally apply to the downstream sector, and vice versa. Table 1 shows a high-level mapping of the sectors and their upstream and downstream dependencies.

Table 1: Mapping of sector relationships

Phase	Sector type	Upstream sector dependencies	Sector	Downstream sector impacts
Phase 1	Material		**Cement & Concrete**	Construction
Phase 1	Product	Steel, Cement & Concrete, Glass	**Construction**	
Phase 1	Material		**Steel**	Construction, Vehicles
Phase 1	Product	Steel, Plastics, Textiles, Electricals	**Vehicles**	

[3] Gov.uk (2023) Unlocking resource efficiency. Available at: link

Phase 1	Product	Plastics	**Textiles**	Vehicles
Phase 2	Product	Chemicals	**Food & Drink**	
Phase 2	Product	Steel, Plastics, (Glass)	**Electricals**	Vehicles
Phase 2	Material	Chemicals	**Glass**	Construction, (Electricals)
Phase 2	Material	Chemicals	**Paper**	
Phase 2	Material		**Chemicals**	Food & Drink, Construction, Glass, Paper, Plastics
Phase 2	Material	Chemicals	**Plastics**	Vehicles, Electricals, Textiles

1.4 Limitations

This report was commissioned by the Government to improve the evidence base on the impact of resource efficiency measures. The methodology is designed to provide robust answers to the research objectives, based on the best available evidence at the time the work was undertaken.

While every effort was made to be comprehensive in the literature review, it is inevitable that some relevant literature may not have been captured. A full list of all the literature reviewed is provided in the annexes of each sector report.

The feedback captured during the interviews and workshops represent the views of a sample of stakeholders from industry, trade associations and academia. Effort was made to ensure that interviews and workshops included a cross-section of stakeholders from each stage of the sectors' supply chain, representing a range of backgrounds and perspectives. It is, however, noted that capacity and scheduling limitations meant that some stakeholders, whose view would have been valuable to the research, were not able to participate. As such, the views expressed by research participants in this report are not representative of the sector as a whole.

A key research objective of this project is to estimate the level of efficiency of resource efficiency measures in 2035. Any future projections are inherently uncertain as they depend on a range of different factors such as technological innovation, consumer behaviour change and the macro-economic environment. The estimates from this research are the best estimates that could be produced, based on the current literature and stakeholder expertise. Evidence RAG ratings have been provided to indicate the level of supporting evidence for each of these estimates.

The report does not seek to make recommendations on the appropriate direction of Government policy or independent industry action. DESNZ and DEFRA will seek to conduct further engagement with stakeholders to inform the next steps for resource efficiency policy and strategy development within Government, ensuring that any omissions or developments in the evidence reviewed in this report are taken into account.

2.0 Plastics

This section summarises the key findings regarding the list of resource efficiency measures, the top drivers and barriers for each measure, and the levels of efficiency (and associated evidence RAG ratings) for the plastics sector. The complete findings are presented in the Unlocking Resource Efficiency: Phase 2 Plastics Report.

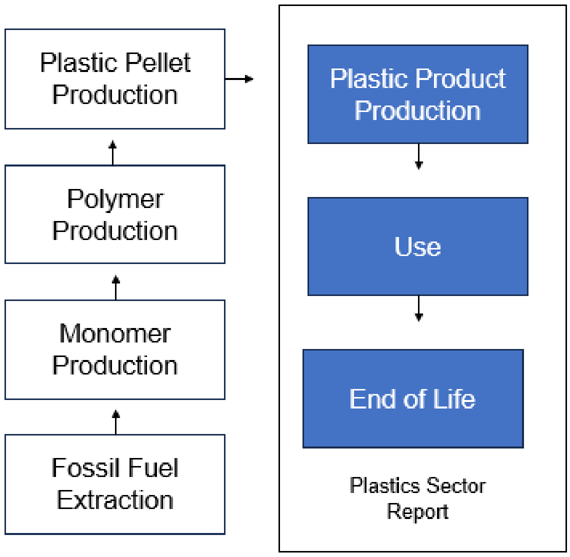
2.1 Sector introduction

Plastic is a lightweight, versatile and affordable material traditionally derived from fossil-based materials. The two main types of plastic are thermosets and thermoplastics. Thermoplastics become malleable when heat is applied and become rigid again when cooled. Thermosets, on the other hand, undergo an irreversible chemical reaction during curing that results in an infusible network structure. As a result, thermosets cannot be melted or reshaped.

The process of producing plastics involves five key steps. The first step is the extraction of raw materials, such as crude oil or natural gas, from the earth. In the second step, the fossil-based material is refined through heating, distillation and thermal cracking to produce ethylene, propylene and other chemicals, referred to as monomers. Monomers are essentially molecules which, when linked together, form the main ingredient of plastics (i.e., polymers). The third step is polymerisation, where monomers are bonded together to form polymers in a reaction chamber. The type of monomers used, and the structure of the linked monomers ultimately determines the polymer that is created. In the fourth step, any additives are added, and the molten plastic material is passed through an extruder and shredded into plastic pellets. These four steps contribute to around 60% of plastic's lifecycle carbon emissions.[4] In the fifth and final step, the plastic resin is used to produce plastic products through a moulding process such as injection moulding, extrusion or blow moulding. Step five contributes to around 30% of a plastic product's lifecycle emissions, with the remaining 10% typically associated with end of life treatment.[5] The key stages of the plastics lifecycle are outlined in Figure 2 below, with the phases within scope of this report shown in blue. Phases shown in white are covered by the chemicals sector report.

[4] Zheng, J. and Suh, S. (2019). Strategies to Reduce the Global Carbon Footprint of Plastics. Nature Climate Change. 9, p374-378.
[5] Zheng, J. and Suh, S. (2019). Strategies to Reduce the Global Carbon Footprint of Plastics. Nature Climate Change. 9, p374-378.

Figure 2: Scope of Plastics Sector Report



Due to the various mechanical and chemical properties of polymers, industries around the world use plastic as a material for a range of applications. Plastic plays a vital role in the UK economy. Around 6.3Mt of plastic is consumed in the UK each year.[6]

Much of the plastic consumed in the UK, by weight, is used for packaging (e.g., food, product and transport packaging). [7] In 2020, plastic packaging accounted for 34% of the UK's plastic consumption. Construction plastics contributed to 19% of the UK's plastic consumption in 2020. Other plastic uses in the UK include automotive parts (11% of the UK's consumption in 2020), electrical and electronic equipment (10%), household goods (5%), agricultural equipment (4%) and other plastic items (17%).[8]

Plastic packing is also a key component of the plastic waste generated in the UK, accounting for 56% of plastic waste in 2020. Other plastic wastes in the UK include construction and demolition (9% of the UK's plastic waste in 2020), waste electrical and electronic equipment (8%), automotive parts (8%), household goods (4%), agricultural equipment (4%) and other plastic items (13%).[9] Notably, the plastic waste that is generated is not necessarily the same plastic consumed that year, such as construction and automotive plastics, which can remain in use for decades. As such, some of the plastic waste generated today was designed and produced decades ago, which may not have been designed for recycling. This can cause issues with the plastic waste needing to be incinerated or landfilled, depending on its composition and presence of hazardous substances.

Resource efficiency is key in reducing the negative environmental and social impacts from plastic production and waste, as it reduces the quantity of plastic waste being generated,

[6] Plastics Europe (2023). Circular Economy for Plastics: United Kingdom – 2020.
[7] Plastics Europe (2023). Circular Economy for Plastics: United Kingdom – 2020.
[8] Plastics Europe (2023). Circular Economy for Plastics: United Kingdom – 2020.
[9] Hsu et al. (2021). How circular are plastics in the EU?: MFA of plastics in the EU and pathways to circularity. Cleaner Environmental Systems. 2, p1-9.

reduces the extraction of finite raw materials for the production of virgin plastic, and increases the amount of plastic being recycled and reused. The Waste Hierarchy Principles promote waste prevention, followed by reuse, recycling/composting, energy recovery and finally landfill.[10]

Sector scope

The scope of this report covers resource efficiency opportunities and data relating to plastic products produced, consumed and/or treated as waste in the UK.

To ensure there is no overlap with the ‘Phase 2 Chemicals Report’, this report will cover resource efficiency measures on plastic from when it becomes plastic pellets, through to the plastic product’s end of life treatment. It will not cover resource efficiency measures associated with the conversion of raw materials to polymers as these will be covered in the Chemicals report.

For material substitution measures which need to reduce whole life carbon to be considered in scope of this report, the emissions associated across the whole lifecycle of plastic products (from raw material extraction through to end of life) are taken into account.

With regard to polymers in scope, this report covers resource efficiency measures for fossil-based plastics. Bio-based plastic polymers are discussed in the context of material substitution, which replace fossil-based plastics. Bio-based plastics are plastics derived from biomass, such as plants. Note, ‘bio-based’ is not synonymous with ‘biodegradable,’ which indicates that a material can be broken down naturally by organisms in a defined ecosystem. Bio-based plastics can be classed as either biodegradable or durable, depending on the polymer type. Substitution with polymers that are biodegradable or compostable, regardless of whether they are fossil-based or bio-based, are not covered in this report. This is because biodegradable and compostable plastics do not provide an opportunity for resource efficiency savings as they are, by nature, single use. As such, the material is unable to be preserved. Additionally, there is currently a lack of infrastructure across the UK for collection and treatment of biodegradable and compostable plastics. Without this infrastructure, the presence of biodegradable and compostable plastics in ‘conventional’ plastic waste streams can reduce the quality of the recycled plastic material if it is not rejected during sorting.[11]

Due to the broad range of industries using plastic, this report focuses primarily on those that contribute most to plastic consumption and plastic waste in the UK. These are packaging, construction and demolition, automotive parts, electrical and electronic equipment and textiles, [12] [13] [14] which account for at least 75% of the UK’s plastic consumption and plastic waste, by weight, based on the reviewed literature. Additionally, resource efficiency opportunities and

[10] Defra (2011). Guidance on applying the Waste Hierarchy.
[11] Gerassimidou et al. (2021). Development of an integrated sustainability matrix to depict challenges and trade-offs of introducing bio-based plastics in the food packaging value chain. Journal of Cleaner Production. 286, pp1-16.
[12] Plastics Europe (2023). Circular Economy for Plastics: United Kingdom – 2020.
[13] Mehta et al. (2021). Using regional material flow analysis and geospatial mapping to support the transition to a circular economy for plastics. Resources, Conservation and Recycling. 179.
[14] WWF (2018). A Plastic Future: Plastics Consumption and Waste Management in the UK.

data for these industries, and in particular packaging, were identified in the literature. However, it should be noted that each measure identified is not necessarily relevant to all of the industries in scope for this report. Where particular industries are identified as not applicable to certain measures, this is described in the description of the measure.

Plastics used for agricultural and medical equipment are not a focus of this report due to their limited contribution, by weight, to plastic consumption and plastic waste in the UK. Despite this, plastic resource efficiency opportunities and data that cover plastics across all sectors in the UK are still considered in the literature review.

Finally, this report only assesses plastic material savings and/or the greenhouse gas emission savings (for material substitution measures) associated with each resource efficiency opportunity. As such, non-plastic material savings, such as water and crude oil, are not covered in this report. For example, this report will not compare the volume of water used when replacing plastic with an alternative material.

2.2 List of resource efficiency measures

Table 2 shows the resource efficiency measures identified for the plastics sector.

Table 2: List of resource efficiency measures for the plastics sector

#	Lifecycle stage	Strategy	Measure name	Measure indicator
1	Design	Lightweighting	Lean design of plastic products	% mass reduction of total UK plastic consumption due to lightweighting and avoidance compared to 2023 levels
2	Design	Material substitution	Material substitution with non-plastic materials	% CO2e reduction from substitution with alternative materials compared to 2023 levels
3	Design	Material substitution	Feedstock substitution with bio-based feedstocks	% fossil-based plastics consumption that can be replaced with bio-based, durable plastics production
4	Design	Recycled content	Recycled content in plastic products	% average recycled content

5	Manufacturing & assembly	Production efficiencies	Waste reduction in product manufacturing	% of plastic produced during the manufacturing process that is wasted
6	Sale & use	Life extension / reuse	Reuse of plastic products	% reduction in plastic demand compared to 2023 levels
7	End of life	Recycling	Recycling of post-consumer plastics	% UK post-consumer recycling rate

In the plastics sector, the focus of resource efficiency measures primarily lies in the design stage of the lifecycle, with four out of seven measures focusing on design-related measures including light-weighting (Measure 1), material substitution (Measure 2 and 3) and recycled content (Measure 4). The remaining measures focus on production efficiencies (Measure 5) through waste reduction in product manufacturing, life extension (Measure 6) through the reuse of plastic products, and recycling (Measure 7), covering recycling of post-consumer plastics. Overall, these measures reflect a holistic approach to resource efficiency throughout the plastics sector, encompassing various stages of the lifecycle to maximise resource efficiency.

2.3 Drivers & Barriers

Throughout the research, a range of drivers and barriers were identified for each of the measures. The most important ones are listed in Table 3.

Table 3: Top drivers and barriers for the plastics measures

#	Measure name	Top drivers	Top barriers
1	Lean design of plastic products	Regulatory requirements & standards. Reduced production costs. Customer demand.	Efficiency nearly maximised. Technical requirements.
2	Material substitution with non-plastic materials	Customer demand.	Technical properties.
3	Feedstock substitution with bio-based feedstocks	Carbon and raw fossil-based material savings. Customer demand.	Land use & lack of feedstock production capacity. Cost. Wider environmental and social impacts.

4	Recycled content in plastic products	Taxes and other regulatory mechanisms. Customer demand. Voluntary commitments.	Availability of recycled material. Price volatility.
5	Waste reduction in product manufacturing	Lower input material required per tonne of output. Reduction in energy consumption and other environmental impacts	Efficiency nearly maximised. Regulatory hurdles.
6	Reuse of plastic products	Voluntary commitments.	Consumer behaviour. Perceived hygiene concerns.
7	Recycling of post-consumer plastics	Regulatory requirements. Demand for recycled content. Separate collection & high-quality sorting.	Lack of domestic recycling infrastructure. Volatile markets. Lack of regulatory drivers and investment.

Customer demand is noted as being a key driver in several plastics measures (e.g., Measures 1 – 4). Reducing the use of avoidable plastic in products, and especially packaging, can be driven by demand from consumers and brands. The “Attenborough effect” is an example of consumer demand for less plastic, with more consumers demanding less plastic in their packaging.[15] In parallel, regulation (including taxes) is noted to be a driver for several resource efficiency measures (e.g., Measure 1, 4 and 7). This is complemented by voluntary commitments by companies, such as voluntary plastic recycled content targets set through the ‘UK Plastics Pact’ or the ‘Circular Plastics Alliance’ (highlighted in Measure 4 and 6).

While the demand for recycled content is a mentioned as a driver in Measure 7, the overall increased demand results in a key barrier mentioned in several measures – i.e., the availability of recycled material (e.g., Measure 4). Access to recycled material paired with a lack of domestic recycling infrastructure (e.g., Measure 7) make it difficult for industry to achieve resource efficiency gains in these areas, particularly in the context of competition for materials from other sectors (e.g., the electricals sector – see Section 6.0).

Overall, customer demand and regulatory drivers heavily influence the adoption of resource efficiency measures in the plastics sector.

[15] Hynes et al. (2020). The impact of nature documentaries on public environmental preferences and willingness to pay: entropy balancing and the blue planet II effect. Journal of Environmental Planning and Management. 64:8. pp1428-1456.

2.4 Levels of efficiency

Table 4 provides a summary of the levels of efficiency (and the evidence RAG rating in italics) for the seven identified measures of the plastics sector.

Table 4: Levels of efficiency and evidence RAG rating (*in italics*) for plastics measures

#	Measure name	Indicator	Current	Maximum in 2035	**BAU** in 2035
1	Lean design of plastic products	% mass reduction of total UK plastic consumption due to lightweighting and avoidance compared to 2023 levels	0% *Not applicable*	2 – 4% *Amber-Green*	1 – 3% *Amber-Green*
2	Material substitution with non-plastic materials	% CO2e reduction from substitution with alternative materials compared to 2023 levels	0% *Not applicable*	Not identified *Not applicable*	Not identified *Not applicable*
3	Feedstock substitution with bio-based feedstocks	% fossil-based plastics consumption that can be replaced with bio-based, durable plastics production	<1% *Amber-Green*	1 – 3% *Red-Amber*	0 – 2% *Amber*
4	Recycled content in plastic products	% average recycled content	7 – 13% *Amber-Green*	37 – 61% *Amber*	19% *Red*
5	Waste reduction in product manufacturing	% of plastic produced during the manufacturing process that is wasted	0 – 1% *Green*	0 – 1% *Amber*	0 – 1% *Amber*
6	Reuse of plastic products	% reduction in plastic demand compared to 2023 levels	0% *Not applicable*	2 – 8% *Amber*	0 – 3% *Red*
7	Recycling of post-consumer plastics	% UK post-consumer recycling rate	27 – 41% *Amber-Green*	50 – 60% *Green*	40 – 50% *Red-Amber*

General insights

Desk-based research and stakeholder engagement provided insights into the current level of efficiency, the maximum potential for efficiency improvement by 2035 and the expected BAU scenario in 2035. Across almost all of the measures identified in the plastics sector where a level of efficiency was identified, the BAU level of efficiency was higher than the current level of efficiency suggesting that the level of efficiency is expected to improve without any additional intervention, albeit to varying degrees. Three key drivers of this are the drive to decarbonise, regulations limiting plastic use, and consumer perceptions around plastic products. The exception to this trend is Measure 5 (waste reduction in product manufacturing) where the current level of efficiency is the same as the BAU level of efficiency. This is mainly due to the efficiency of product manufacturing being nearly maximised already after longstanding economic drivers to develop efficient processes. This makes it difficult to make any further improvements from a technical perspective.

Similar to the difference between the current and BAU level of efficiency, the BAU level of efficiency was lower than the maximum level of efficiency in almost all measures identified, with the exception again being Measure 5 for the same reasons stated above. This suggests full resource efficiency potential will not be achieved without a change in the market environment.

All levels of efficiency identified lack precise quantification due to limited data availability. While stakeholders generally agree that further improvements are possible across most measures, the maximum efficiency projections for 2035 vary depending on the measure. Additionally, a level of efficiency was not identified for Measure 2 (material substitution with non-plastic materials) as calculating emissions reductions for material switches involves several factors that can potentially lead to misleading conclusions. A simplistic approach to material switching overlooks crucial elements such as the specific application and its intended use. A material switch may also involve a shift towards a reusable model, complicating the issue further.

Measure-specific insights

Measures 1, 2, and 3 focus on different ways of reducing the amount of fossil-based plastic in products, either through lightweighting and avoidance or substitution with other materials (e.g., paper, glass, or bio-based plastics). These measures are predominantly driven by regulatory requirements, customer demand and voluntary plastics reduction targets set by industry. However, as a highly versatile and cost-effective material, reduction and substitution efforts face challenges around technical requirements and cost. Substitution with bio-based feedstocks in particular hinges on decisions around land use given concerns around the availability and competition for arable land, which is already under pressure to meet food demands.

Measures 4, 5 and 7 deal with the recovery and recycling of plastic throughout different parts of the value chain. Measures 4 and 7, in particular, are interconnected as the incorporation of recycled content within plastic products is contingent on having sufficient recycled content feedstock made available through post-consumer recycling. Both measures face barriers due to price volatility within both virgin and recycled plastic markets, a lack of recycling infrastructure, and technical challenges surrounding quality of recycled plastic and the presence of contaminants and additives within waste streams. Stakeholders unanimously agreed that increased investment in domestic recycling infrastructure is key to increasing resource efficiency within these measures.

Finally, Measure 6 looks at the scaling up of reuse models to drive resource efficiency by decoupling product utility from material use. The concept of reuse models is growing in popularity, particularly within the packaging industry. This is driven by upcoming regulatory requirements such as extended producer responsibility for packaging and single-use plastic bans. However, single-use plastic products are often advantageous to consumers, and uptake of reuse models may be hindered by issues such as inconvenience and perceived hygiene concerns. Scalability of these models is crucial as high reuse rates are often needed to achieve benefits. Additionally, although reusable plastic packaging can result in long-term cost savings, there are often up-front capital and operational costs required. These barriers can in part be lessened by the adoption of harmonised standards such as packaging dimensions and logistics to allow reusable packaging to be manufactured, handled, transported and cleaned more efficiently.

3.0 Paper

This section summarises the key findings regarding the list of resource efficiency measures, the top drivers and barriers for each measure, and the levels of efficiency (and associated evidence RAG ratings) for the paper sector. The complete findings are presented in the Unlocking Resource Efficiency: Phase 2 Paper Report.

3.1 Sector introduction

The pulp and paper industry (PPI) provides a significant contribution to the UK's total Gross Value Added with an addition of £3.6 bn in 2020 (of a total £1904 bn). The UK manufacture of paper and packaging products employed approximately 40,000 staff through around 1,000 businesses in 2022. Statistics also show the PPI generating a turnover of £7.7 bn in 2022 [16].

Products of the PPI discussed in this report are split into four core sub-categories:

- Packaging, which includes:
  - Cardboard;
  - Containerboard
  - Linerboard; and
  - Cartonboard.
- Print and graphical; and
- Hygiene, which includes:
  - Paper towels;
  - Toilet paper; and
  - Facial tissues.
- Specialty products

The British PPI's fibre need is met mainly through recovered feedstock with the remainder being made up of virgin feedstock.[17]

In 2022, 3.6 million tonnes of paper and paperboard were produced in UK, down from a peak of 6.6 million tonnes in 2000. Around 750,000 tonnes of products were exported, either directly or in the form of packaging of UK manufactured goods.[18] Production figures stand in stark contrast with the consumption of paper, with the UK consuming around 9 million tonnes of

[16] CPI, "Global Challenges, Local Resilience: Annual Review 2022-2023", (2022). Available at: link
[17] Back, S, "The British paper industry of today", PA Paper Advance (2021) [Online]. Available at: link
[18] CPI, "Global Challenges, Local Resilience: Annual Review 2022-2023", (2022). Available at: link

paper each year.[19] The UK is in fact the world's largest net importer of paper, the majority share being printing and writings papers, and packaging papers and boards.[20]

As of 2022, the UK used recovered fibre as a raw material for 67% of the products manufactured, with the remainder being woodpulp (26%), additives (6%) and other fibres (1%).[21] This recovered fibre is sourced from recycling collections within the UK.

To produce PPI products there are two distinct processes that are used:

- the pulp making process, where raw materials as either woodchips or recovered paper are converted into fibrous pulp; and
- the papermaking process, where the pulp is converted from fibrous pulp to a PPI product, such as packaging.

Each process has its own barriers, drivers and resource efficiency challenges and so are discussed individually hereafter.

Pulpmaking

The manufacturing of paper products begins with fibrous biomass, such as wood chips. These wood chips are then transformed into pulp. Wood pulp fibres can be recycled a number of times, but they eventually lose their papermaking qualities due to the thermal environment which they are exposed to during processing.

Pulp is a mixture of fibres that can either come from biomass or recycled sources. The three main pulping processes used are:

- Chemical: dissolving lignin that binds cellulose fibres together in chemical baths;
- Mechanical: separating wood fibres mechanically by grinding or shredding; and,
- Recycled: reusing paper fibres from secondary sources, usually by shredding and mashing them in baths and removing contaminants.

Kraft pulping, a type of chemical pulping, is the dominant process used globally due to its superior strength, aging resistance and ease of bleaching.[22] There are no chemical pulp mills in the UK.

Papermaking

The pulp is formed into a PPI product using a paper machine. Most commonly, this involves dewatering the dilute suspension of fibres from the pulping stage over several steps. First, the dilute pulp is fed onto a wire mesh and drained to form a web of fibres. Next, the web passes through pressurised rollers to remove more water. At this stage, the web is self-supporting and can go onto the final stages of pressing and drying.

[19] CPI, "Forestry", (2023). Available at: link
[20] CPI, "The economic value of the UK's paper-based industries", (2022). Available at: link
[21] CPI, "Global Challenges, Local Resilience: Annual Review 2022-2023", (2022). Available at: link
[22] Cherian, C and Siddiqua, S, "Pulp and paper mill fly ash: a review", Sustainability, (2019). Available at: link

Resource efficiency

Resource efficiency in the pulp and papermaking industry requires optimising the use of material across the lifecycle of its production.

Efficient use of resources has the potential to impact the industry's emissions and is a key potential means of addressing the sector's emissions targets.[23] The production of 'paper and paper products' emitted 1.8 MtCO2e in 2021, contributing to 0.4% of all UK greenhouse gas emissions[24]. Direct emissions originate largely from boilers and gas turbines which are used during the pulping and/or papermaking processes to drive machinery and generate heat to dry the paper produced. A second source of emissions are indirect emissions from electricity from the grid, with the paper machine – and in particular the drying process – accounting for about two-thirds of all energy use in a typical UK pulp and paper mill.[25]

Sector scope

Energy efficiency is excluded from the study scope because it does not meet the definition of resource efficiency for this research project. However, the production of pulp and paper product is an energy intensive process so resource efficiency measures may still reduce energy use. For example, a reduction in energy intensity might be achieved by optimising drying conditions or process improvement through real time energy management systems.

Another example is the use of paper material flows as fuels. For instance, the chemical pulping process leads to the generation of byproducts. These products can act as a source of fuel required for some of the paper production stages. Such instances were considered in the scope of this project, as using the byproducts as fuel offsets the need to use other fuels such as gas. There is a need to consider which fuels are being offset, especially if considering the carbon emissions savings.

Where there is an example of a material efficiency that is also an energy efficiency, it will be discussed within the relevant measure.

3.2 List of resource efficiency measures

Table 5 shows the resource efficiency measures identified for the paper sector.

Seven out of the eight resource efficiency measures identified for the paper sector fall into the design and manufacturing lifecycle stages. Two measures were identified for material substitution (Measure 2 and 3) covering the substitution of paper with alternative materials or dematerialisation, as we'll as material substitutions in the pulp and papermaking processes.

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[23] Griffin, P.W and Hammond, G.P and Norman, J.B, "Industrial Energy use and carbon emissions reduction: A UK perspective", (2014). Available at: link
[24] DESNZ, 29th June 2023 - UK greenhouse gas emissions by Standard Industrial Classification. Available at: link
[25] DECC & DBIS, "Industrial decarbonisation & energy efficiency roadmaps to 2050.", (2015). Available at: link

Three of the eight measures focus on production efficiencies, covering the improvement of the production yield ratio (Measure 6), utilisation of byproducts of the pulp and papermaking processes (Measure 7) and efficient incorporation of water in paper and pulp production (Measure 8). The only measure not part of the design or manufacturing stage is Measure 1, focused on the collection of post-consumer paper and board for recycling.

Table 5: List of resource efficiency measures for the paper sector

#	Lifecycle stage	Strategy	Measure name	Measure indicator	Product relevance		
					Packaging	Print & Graphical	Hygiene
1	End of Life	Post-consumer recycling	Collection of post-consumer paper and board for recycling	Percentage of paper and board placed on the market that is collected for recycling	X	X	X
2	Design	Material substitution / dematerialisation	Substitute paper with alternative materials or dematerialisation	Percentage whole life **CO_2**e reduction from substitution with alternative materials; and Percentage whole life **CO_2**e reduction from dematerialisation	X	X	X
3	Design / Manufacture	Material substitution	Material substitutions in the pulp and papermaking processes	Percentage reduction in **CO_2**e emissions of pulping and papermaking through material substitution, compared to a 2023 baseline	X	X	X

4	Design / Manufacture	Lightweighting	Lightweighting of paper process	Percentage reduction of PPI product mass achieved by lightweighting compared to 2023 baseline	X		
5	Design / Manufacture	Remanufacture / Recycled content (pre- & post-consumer)	Use of recovered fibre in the pulping process	Average percentage recycled input rate of all UK PPI products	X	X	
6	Manufacture	Production efficiency	Improvement of the production yield ratio	Percentage yield of pulping processes	X	X	X
7	Manufacture	By-products	Utilisation of byproducts of the pulp and papermaking processes	Percentage of byproducts reused, recycled or recovered	X	X	X
8	Manufacture	Production efficiency	Efficient incorporation of water in paper and pulp production	Percentage reduction of water usage, compared to a 2023 baseline	X	X	X

3.3 Drivers & Barriers

Throughout the research, a range of drivers and barriers were identified for each of the measures. The most important ones are listed in Table 6.

Table 6: Top drivers and barriers for the paper measures

#	Measure name	Top drivers	Top barriers
1	Collection of post-consumer paper and board for recycling	Legislation. Design for recycling. Recycling targets.	Composite materials. Changing product landscape.
2	Substitute paper with alternative materials or dematerialisation	Climate policy. Promotion of reusable packaging.	LCA standards. Safeguarding concerns.
3	Material substitutions in the pulp and papermaking processes	Potential reduction in environmental impacts. Material innovation. Reduction of need for virgin material.	LCA standards. Potential increase in environmental impacts. Changes to production lines and resulting cost implications.
4	Lightweighting of paper process	Resource efficient – less material to recycle.	Economic impacts.
5	Use of recovered fibre in the pulping process	Reduced need for felling of trees. Social perception.	Contamination of the waste stream. Digitisation of paper products. Maximum number of lifecycle for fibres.
6	Improvement of the production yield ratio	Economic incentives. Environmental incentives. Less complex manufacturing process.	Technical limitations. Other value streams for losses. Cost implications of process improvements.
7	Utilisation of byproducts of the pulp and papermaking processes	Financial benefits. Improved resource efficiency of other industrial sectors and potential reduction of environmental impact.	Restrictions on land spreading. Moisture content of sludge and rejects. Economic feasibility.

8	Efficient incorporation of water in paper and pulp production	Economic benefits. Regulation.	Cost of investment.

Several resource efficiency measures in the paper industry would require changes to manufacturing processes, including infrastructural upgrades, all of which are costly. As a result, cost implications, economic impacts and economic feasibility are mentioned as barriers in several resource efficiency measures (e.g., Measure 3, 4, 6, 7 and 8). In the case of Measure 7, the handling of by-products for example would require the setting up of new infrastructure or closure of existing facilities altogether, creating a significant barrier to the pursuit of resource efficiency interventions in this area.

Equally, economic and financial benefits are cited as being key drivers in several measures (e.g., Measure 6, 7 and 8) due to their potential for reducing losses and increasing revenue streams, such as through the sale of by-products to other industries.

A key driver mentioned in several resource efficiency measures is the reduction of environmental impacts (e.g., Measure 3, 5 and 7); conversely, the need for lifecycle assessment (LCA) standards is noted as being a key barrier for several measures (e.g., Measure 2 and 3), indicating the need to be able to understand and compare environmental outcomes of different products, materials and use cases (e.g., reusable vs. single-use paper and plastic products).

3.4 Levels of efficiency

Table 7 provides a summary of the levels of efficiency (and the evidence RAG rating in italics) for the eight identified measures of the paper sector.

Table 7: Levels of efficiency and evidence RAG rating (*in italics*) for paper measures

#	Measure name	Indicator	Current	Maximum in 2035	BAU in 2035
1	Collection of post-consumer paper and board for recycling	Percentage of paper and board placed on the market that is collected for recycling	67 – 70% *Green*	80 – 90% *Red-Amber*	70 – 80% *Red*
2	Substitute paper with alternative materials or dematerialisation	Percentage whole life CO2e reduction from substitution with alternative materials; and	0% *Not applicable*	Not identified *Not applicable*	Not identified *Not applicable*

		Percentage whole life CO_2e reduction from dematerialisation			
3	Material substitutions in the pulp and papermaking processes	Percentage reduction in CO_2e emissions of pulping and papermaking through material substitution, compared to a 2023 baseline	0% *Not applicable*	Not identified *Not applicable*	Not identified *Not applicable*
4	Lightweighting of paper process	Percentage reduction of PPI product mass achieved by lightweighting compared to 2023 baseline	0% *Not applicable*	0 – 30% *Red*	0 – 15% *Red*
5	Use of recovered fibre in the pulping process	Average percentage recycled input rate of all UK PPI products	67% *Amber-Green*	67 – 80% *Red*	67 – 80% *Red*
6	Improvement of the production yield ratio	Percentage yield of pulping processes	Mechanical – 80-95% Recycled – 85-95% *Amber*	Not identified *Not applicable*	Mechanical - NA Recycled – 85-95% *Red-Amber*
7	Utilisation of byproducts of the pulp and papermaking processes	Percentage of byproducts reused, recycled or recovered	78% *Red-Amber*	71 – 80% *Red*	71 – 80% *Red*
8	Efficient incorporation of water in paper and pulp production	Percentage reduction of water usage, compared to a 2023 baseline	0% Not applicable	Not identified *Not applicable*	Not identified *Not applicable*

General insights

Across almost all of the measures identified in the paper sector, the BAU level of efficiency was higher than the current level of efficiency suggesting that efficiency is expected to improve in the current environment. Common across all measures is the drive to achieve environmental benefits associated with improved resource efficiency, including reduced emissions impacts. These environmental benefits are often backed by efficiency targets, policy and legislation.

Measures 4 and 7 have BAU levels of efficiency that are within the same range as the current levels of efficiency. This is because many improvements have already been made in these areas, and further improvements are expected to be marginal unless significant investment is made in new technology and infrastructure.

The difference between the predicted maximum levels of efficiency and BAU levels of efficiency for measures identified in the paper sector were marginal for all but Measures 1. This suggests that based on current understanding, the sector is already on course to achieve the maximum possible efficiency in many areas, or that there are significant barriers to achieving higher levels of efficiency. There are a range of barriers which limit the uptake of measures, however some common barriers across many of the measures included uncertainty in the accuracy of measuring emissions via lifecycle assessments and the technical and economical limitations of certain initiatives.

Levels of efficiency for Measures 2, 3 and 8 (and to an extent, Measure 6) were not identified due to lack of data. For Measure 2 in particular, stakeholders agreed that any potential efficiencies achieved via this measure are out of the control of the paper industry and as such, insights into the levels of efficiency could not be provided. Similar uncertainty around the levels of efficiency associated with material substitution were found for the intersecting packaging industries of plastics and glass.

Measure-specific insights

Measures 1 and 5 each deal with minimising loss of paper and card appropriate for recycling across different stages of the value chain. The quality of material collected through the waste collection system (covered by Measure 1) directly impacts the availability of recycled pulp that can be used to make new paper products (Measure 5) and can be seen as the main barrier to achieving efficiency in Measure 5. Improvements for Measure 1 are likely to be driven by the policy and market landscape that impact the demand for recycled material, which is reflected in the levels of efficiency by steady increases in collection rates, whereas Measure 5 is driven by the societal demand for recycled products. Measure 5 is also interdependent with Measure 4, since using recycled fibres generally requires more fibres to make a product of the same strength as using virgin fibres, making the product heavier overall. This presents a barrier to lightweighting of paper products.

Measure 2 and 4 relate to reducing the use of virgin paper fibres in the production process, either by reducing the use of paper all together (Measure 2, for dematerialisation specifically) or reducing the amount of paper used per product (Measure 4). They both, therefore, have drivers associated with the potential environmental benefits that can be achieved by using less virgin material. However, the manner for measuring the potential environmental benefits can present a barrier, particularly for Measure 2 which relies on comparison via lifecycle assessments, which are not always available or consistent in their conclusions. Levels of efficiency were not estimated for this measure due to lack of data.

Measure 6 and 7 relate to the material efficiency of the papermaking process, and as such share similar drivers including the economic and environmental incentives associated with reducing process waste. However, the levels of efficiency for these measures reflect limited scope for further improvement, since stakeholders are likely to have already maximised efficiency of their production with their given technologies since they have a direct economic impact on their business operation.

4.0 Chemicals

This section summarises the key findings regarding the list of resource efficiency measures, the top drivers and barriers for each measure, and the levels of efficiency (and associated evidence RAG ratings) for the chemicals sector. The complete findings are presented in the Unlocking Resource Efficiency: Phase 2 Chemicals Report.

4.1 Sector introduction

Chemicals play a crucial role in society and are present in almost all products we purchase, consume and use. The UK chemicals industry produces fundamental components for other manufacturing processes and substances used within final consumer mixtures and products, with chemicals used in over 90% of manufactured goods.[26] The primary chemical feedstocks are utilised in subsequent manufacturing to produce a diverse array of secondary downstream products, including polymers (that are essential for plastics), paints, detergents, personal care items, agrochemicals, adhesives, fragrances, lubricants, fuel additives, construction materials and catalysts, to name but a few examples. The UK is also a global leader in pharmaceuticals.[27]

Chemical manufacturing is complex, with thousands of different substances and products, traded between hundreds of manufacturing sites across the UK and internationally. The types and application of chemical production processes are diverse but can generally be defined as being continuous or batch. Continuous chemical operations involve a continuous flow of materials through a production system, while batch operations process materials in discrete quantities, typically in separate, sequential steps.

To further aid the analysis in this report, the scoped chemical supply chain has been categorised into three broad manufacturing tiers:

- Companies engaged in **Tier 1** activities (such as SABIC, INEOS, Lanxess)[28] process basic feedstock into bulk commodity chemicals, often using energy-intensive continuous processes. These chemicals are foundational for all later stages and other production processes.
- Companies engaged in **Tier 2** activities (such as Huntsman, INEOS, Syngenta, Pfizer) take bulk commodity chemicals and undergo further chemical reactions or blending to create part/finished mixtures (refined primary chemicals) - an intermediate step in the process. There could be many intermediate steps within this tier with chemicals often

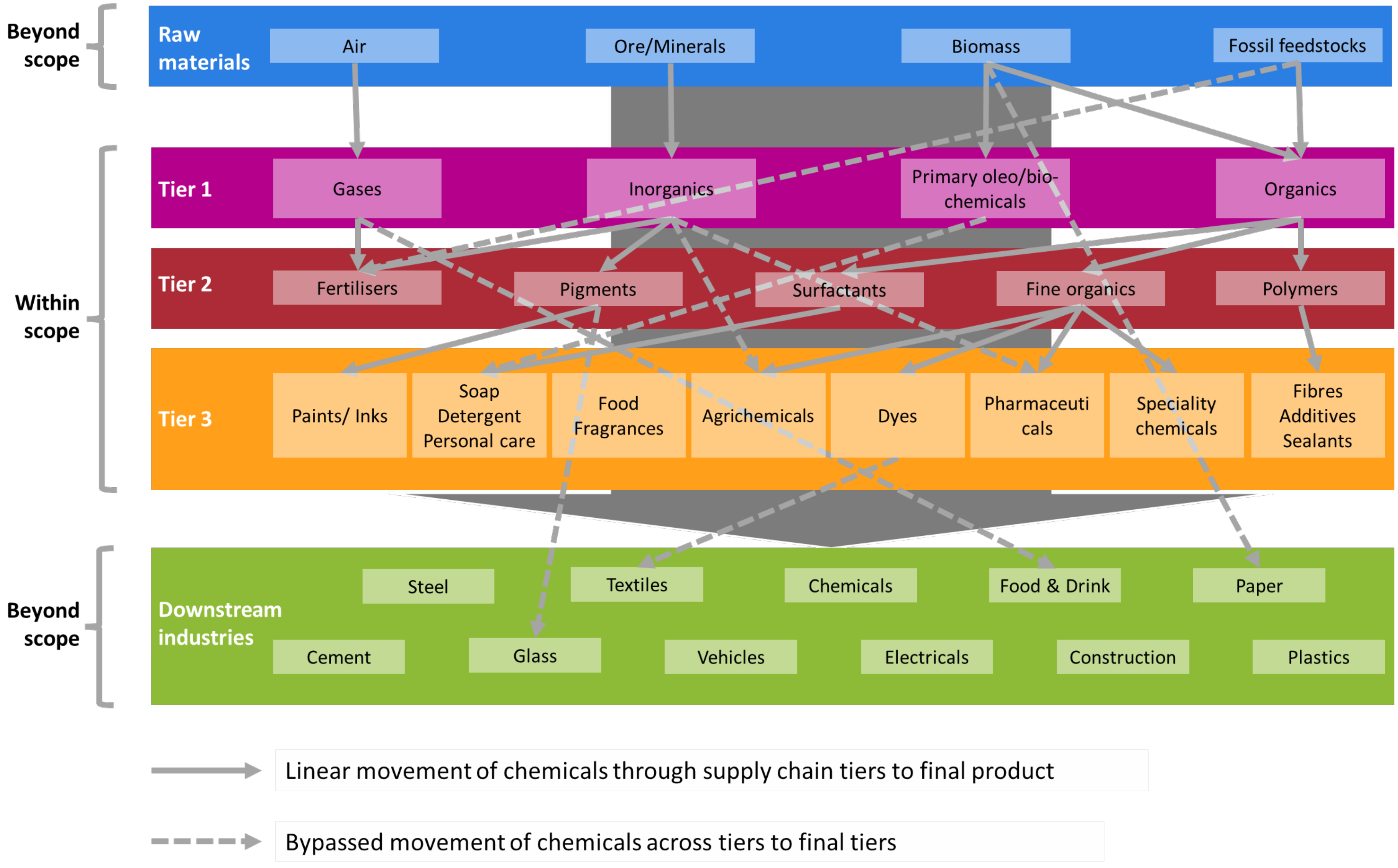
[26] Green alliance (2023) A new formula: Cutting the UK chemical industry's climate impact. Available at: link
[27] Cefic (n.d.) CHEMICAL INDUSTRY SNAPSHOT. Available at: link
[28] Note that we have defined the three tiers to provide a general steer on characterisation of production processes, types of company (size, style of manufacture, role in the market etc) and flow of substances down the supply chain. In practice it is entirely possible for a given company (e.g., INEOS, 3M, Dupont etc) to fulfil more than one tier of the chain. i.e., the manufacturing of refined feedstocks under tier 1 is used by the same company (not necessarily at the same location) to produce secondary substances or even final consumer mixtures etc.

being moved or traded between sites and/or regions. Batch processing is more prevalent in this tier than in Tier 1 which primarily comprises continuous processes, however continuous processes are still widely applied in Tier 2.

- Companies engaged in **Tier 3** activities (Such as CRODA, Dulux, Reckitt, Unilever), produce final formulations for end markets, incorporating them into articles (e.g., textiles), consumer products (e.g., shampoos, conditioners, hair dyes,) and industrial products (e.g., metal working fluids). Tier 3 stands apart from Tier 2 as it delivers the final, ready-to-use products. Batch processing is most prevalent in this tier. The sector's complexity arises from these layers, each with distinct processes, contributing to the overall chemical manufacturing landscape.

The chemicals sector is therefore heavily interlinked with other consumer industries that have been investigated separately within the wider research project, as demonstrated in the figure below. Note that the interactions presented in this diagram are not exhaustive but demonstrate some of the complexities regarding the interactions between different tiers in the chemicals sector as well as upstream and downstream sectors. The downstream industries presented in this diagram are also not exhaustive. This figure demonstrates how other sectors investigated in the wider research project are interlinked with this sector study. Solid arrows demonstrate how tiers interlink linearly with one another to create value-added products along the supply chain. However, the process is not always linear and movement of product within, and across tiers is possible. The dotted arrows show how tiers can be bypassed with minimal processing to a higher value product within the supply chain. For example, industrial gases created in Tier 1 could be used directly within the food and drink industry.

Figure 3: Demonstration of how the chemicals sector supply chain links with itself and other UK industries[29]



[29] Figure adapted from image presented during stakeholder interview.

UK chemicals sector overview

According to Cefic, the leading European trade association for the chemical industry, the UK chemical manufacturing sector is the second largest manufacturing industry in the UK behind transport and machinery. In 2021, the chemical industry turned over £75.2 billion, this contributed £30.7 billion of added GDP to UK economy. The industry also exported £54 billion worth of stock. In the UK, there are at least 4,535 companies (directly/indirectly involved in chemical production) employing over 141,000 workers.

Current major challenges faced by the UK chemicals sector include high energy prices, especially for natural gas that serves as both feedstock and fuel. A shortage of skilled chemists and engineers is also a significant concern. Competition from China and the US, particularly with China's lower energy costs poses a challenge. Moreover, uncertainties over geopolitical impacts on supply chain connections with Europe and further afield, contribute to the industry's challenges.[30]

Sector scope

The key focus of this report is on actions that improve material resource efficiency. Therefore, energy efficiency measures or fuel-switching measures (e.g., actions that reduce energy use/carbon emissions but do not impact resource use or efficiency) are outside the scope of this study. However, carbon capture for feedstock and hydrogen as a feedstock (excluding heating) will be considered as they are material inputs within the definition of resource efficiency used in this report. Measures which reduce water use are in scope whilst measures which change land use only (and not other resource use) are out of scope.

It is important to note that the chemicals industry and the energy sector are heavily interconnected as chemicals essentially function as energy storage.

Where chemicals differ to other sectors, investigated as part of the wider research project, is that energy is fundamental in converting one chemical to another. This energy is held within the chemical and passed down through the value chain (essentially as an energy storage vehicle). Stakeholders stressed that you cannot decouple the energy input from the feedstock as you could with, say the vehicles sector where energy input can be addressed completely separately to the manufacturing process.

Because of this, particularly in Tier 1 and Tier 2 companies, stakeholders noted that energy should not be decoupled from the resource efficiency measures as they have been defined for this study. The production of basic chemicals (Tier 1) are very high emitters of carbon therefore it is vital to acknowledge that energy input should not be considered in isolation to material inputs which are investigated in this report. Stakeholders stressed that the decarbonisation of energy is therefore critical to achieving a sustainable chemical industry. Nevertheless, as discussed previously, fuel switching measures are out of scope.

[30] Cefic (n.d.) CHEMICAL INDUSTRY SNAPSHOT. Available at: Link.

Furthermore, this report doesn't specifically analyse sustainability and safety concerns beyond the scope of resource efficiency. Factors like chemical safety and other environmental aspects are vital for the industry's long-term sustainability therefore resource efficiency should be considered alongside other design factors such as these when considering implementing the measures discussed in this report.

In terms of the value chain, the study focus extends from the production and use of primary building block chemicals (Tier 1) up to the formulation of chemical products, encompassing products used in various industry applications that do not require further chemical processing (Tier 3). Final products used in downstream industries and upstream raw materials extraction/refining are therefore excluded from scope as outlined in Figure 3.

The exception to the above is the use of plastics (covered separately in the Unlocking resource efficiency: Phase 2 plastic report). Whilst other end uses of chemicals are out of scope, plastics play a major role in the chemical industry. Therefore, for plastics, this report covers aspects of the value chain from basic feedstock production to the point of virgin pelletisation. Mechanical recycling of plastics is out of scope as the feedstock will come from plastics waste streams and feed directly into downstream consumer industries (this is covered in the Unlocking resource efficiency: Phase 2 plastic report). However, chemical recycling of plastics and reuse of the monomer as a secondary carbon feedstock is a key aspect for consideration within the chemicals sector as they can be reintroduced into the chemicals industry within the scoped boundaries (Tier 1 to Tier 3). Similarly, regeneration/recycling of other end of life chemicals is in scope (e.g., regeneration of used lubricants, metal working fluids, oils, solvent recovery, catalysts etc.).

While the scope covers domestic manufacturing, transportation of chemicals and transboundary movements won't be included due to difficulty in implementing and influencing these measures abroad.

4.2 List of resource efficiency measures

Table 8 shows the resource efficiency measures identified for the chemicals sector.

Table 8: List of resource efficiency measures for the chemicals sector

#	Lifecycle stage	Strategy	Measure name	Measure indicator
1	Design	Lightweighting	Reducing net resource input in formulation	% reduction in weight of chemical required to maintain functionality compared to 2023 levels
2	Design	Material substitution	Substitution of virgin fossil-	% of virgin fossil-based organic feedstock chemicals that have

			based organic feedstocks	been substituted with alternative carbon feedstocks
3	Design / End of life	Recycled content	Secondary material content	% in weight of recycled/secondary post-use material content in chemicals production
4	Design / Manufacturing and assembly	Production efficiencies	Process efficiencies (yield) (closed process)	% improvement in process yield compared to 2023 levels
5	Design / Manufacturing and assembly	Production efficiencies	Process efficiencies (water consumption)	% weight reduction in water consumption compared to 2023 levels
6	Sale and Use	Collaborative consumption	Collaborative consumption of raw material / resources / by-products	% increase in weight of production waste avoided by the chemicals sector through sharing of resources compared to 2023 levels

In the chemicals sector, the focus on resource efficiency primarily lies within the design phase of the lifecycle. This is due to the fact that most opportunities for improving resource efficiency occur during front end design with limited chances to alter or optimise the process once operational. Measures such as lightweighting focus on reducing the weight of chemicals needed to maintain functionality, while material substitution targets the replacement of virgin fossil-based organic feedstocks with alternative carbon sources, to reduce carbon emissions per tonne of material produced.

Strategies addressing secondary material span both the design and end of life phases. This involves incorporating recycled or secondary materials into chemical production. Efforts to improve production efficiencies, particularly in process yield and water consumption, are achieved in the design as well as the manufacturing and assembly stages.

Collaborative consumption sits in the sale and use phase, promoting resource sharing to minimise production waste. Overall, these measures reflect a holistic approach to resource efficiency throughout the chemicals sector, encompassing various stages of the lifecycle to maximise resource efficiency.

4.3 Drivers & Barriers

Throughout the research, a range of drivers and barriers were identified for each of the measures. The most important ones are listed in Table 9.

Table 9: Top drivers and barriers for the chemicals measures

#	Measure name	Top drivers	Top barriers
1	Reducing net resource input in formulation	Policy and regulatory drivers. Mandatory and voluntary carbon reporting may stimulate the market. Carbon Tax. Cost savings from reduced resource consumption. Consumers demand more sustainable products.	Consumer perception and acceptance (e.g., unit sizes). Regulatory barriers. High costs in improving production processes. Limited knowledge in incorporating safety and sustainability in design.
2	Substitution of virgin fossil-based organic feedstocks	Government strategy promotes development of alternative feedstocks. Net Zero Commitments,	Availability of cheap, low carbon energy. Pricing of alternative feedstocks is uncompetitive. Wider environmental issues with alternative feedstocks. Competition with other sectors. Lack of consideration of risks and trade-offs in policy support guidance.
3	Secondary material content	Producer responsibility schemes. Recycling targets stimulate markets. Design for recovery enables efficiency improvements.	Lack of recycling capacity. Technical limits to mechanical / chemical recycling. Waste regulations prevent handling of secondary material. Lack of control over downstream users.
4	Process efficiencies (yield) (closed process)	Cost savings from increased material efficiency.	Uncertainty over winning technologies.

			High costs in developing new production processes.
5	Process efficiencies (water consumption)	Increased cost of water. Abstraction regulations limit water use. Company sustainability commitments.	Low return on investment.
6	Collaborative consumption of raw material / resources / by-products	Wastes are treated as value leakage. Increased standardisation could facilitate shared resources. Increased revenue. Legislation/fines for disposal of waste.	Infrastructure and transport costs. Lack of transparency in supply of shareable resources. Regulatory barriers. Low feasibility for smaller operators.

Cost considerations heavily influence decisions within the chemicals sector, with cost savings (such as through from reduced resource consumption) emerging as primary drivers for most of the measures. This is primarily driven by price sensitivity and small margins across the sector, particularly for high throughput-low cost industries (such as Tier 1 companies). Cost also acts as a significant barrier, particularly when investment is required to implement measures. For instance, improving production processes may entail high initial costs, posing a challenge to adoption of certain measures.

Process efficiency measures, such as improving yield and reducing water consumption, are driven by cost savings and sustainability commitments but face hurdles including uncertainty over winning technologies and low return on investment.

Policy and regulatory drivers, such as mandatory carbon reporting and carbon taxes, can incentivise market stimulation and drive adoption of these measures. For example, producer responsibility schemes and recycling targets stimulate markets for secondary material content. However, regulatory barriers, also present notable challenges. This includes issues regarding waste/material handling and technical limits to using secondary feedstocks. Competition for resources with other sectors and environmental concerns surrounding alternative feedstocks also pose significant barriers.

Shareholder pressure, often driven by consumers, may influence decisions. However, whilst consumer perception and acceptance were identified as drivers for resource efficiency, much of the chemicals sector does not interact directly with consumers therefore this is mostly applicable to certain products such as fast-moving consumer goods.

Overall, cost dynamics and regulatory environments heavily influence the adoption of resource efficiency measures in the chemicals sector.

4.4 Levels of efficiency

Table 10 provides a summary of the levels of efficiency (and the evidence RAG rating in italics) for the six identified measures of the chemicals sector.

Table 10: Levels of efficiency and evidence RAG rating (in italics) for chemicals measures

#	Measure name	Indicator	Current	Maximum in 2035	BAU in 2035
1	Reducing net resource input in formulation	% reduction in weight of chemical required to maintain functionality compared to 2023 levels	0% *Not applicable*	3 – 10% *Red*	3 – 10% *Red-Amber*
2	Substitution of virgin fossil-based organic feedstocks	% of virgin fossil-based organic feedstock chemicals that have been substituted with alternative carbon feedstocks	3 – 10% *Amber-Green*	21 – 40% *Red-Amber*	6 – 15% *Amber*
3	Secondary material content	% in weight of recycled/secondary post-use material content in chemicals production	0 – 5% *Red*	10 – 20% *Red*	0 – 5% *Amber*
4	Process efficiencies (yield) (closed process)	% improvement in process yield compared to 2023 levels	0% *Not applicable*	6 – 10% *Amber*	3 – 5% *Amber*
5	Process efficiencies (water consumption)	% weight reduction in water consumption compared to 2023 levels	0% *Not applicable*	11 – 15% *Red-Amber*	0 – 10% *Red-Amber*
6	Collaborative consumption of raw material / resources / by-products	% increase in weight of production waste avoided by the chemicals sector through sharing of resources compared to 2023 levels	0% *Not applicable*	11 – 15% *Amber*	0 – 5% *Amber*

General insights

Across all measures, stakeholders provided insights into the current level of efficiency, the maximum potential for efficiency improvement by 2035, and the expected BAU scenario in 2035. In many cases, stakeholders noted that achieving significant efficiency gains beyond the current state would be challenging due to various factors such as technical limitations, market conditions, and investment requirements. However, there was general consensus that some improvements are feasible across all measures, albeit to varying degrees.

Current levels of efficiency often lack precise quantification due to limited data availability, but stakeholders generally agree that further improvements are possible. Maximum efficiency projections for 2035 vary depending on the measure, with stakeholders acknowledging ambitious targets but highlighting practical limitations and dependencies on factors including certainty in policy landscapes, regulation and technological innovation. The BAU scenario suggests modest improvements over current levels, with stakeholders recognising ongoing efforts but noting constraints such as technical barriers and market conditions.

Measure-specific insights

Measure 1: Resource efficiency in the chemical industry is constrained by several factors, including the complexity of chemical processes, market demands, and technological limitations. Current efficiency levels are difficult to quantify due to sparse data, but stakeholders suggest that companies may have already optimised operations to a significant extent and further efficiency improvement are likely to be more challenging. Furthermore, stakeholders noted that much of the design is at a product level which often falls beyond the scope of the chemicals sector therefore there are limitations to what can be achieved upstream. Stakeholders acknowledge the potential for marginal improvements, particularly in niche segments like coatings, but emphasise the limited scope for widespread gains. The intricate interplay between market forces, regulatory pressures, and technological advancements shapes the trajectory of efficiency improvements. The BAU scenario highlights the incremental nature of progress, with stakeholders anticipating modest gains driven by ongoing optimisation.

Measure 2: Substituting fossil-based feedstocks with alternatives face challenges stemming from technological readiness, market dynamics, and regulatory frameworks. While stakeholders recognise the potential of alternative feedstocks, their widespread adoption hinges on factors such as scalability, cost competitiveness, resource availability and competition with other sectors. Current substitution levels remain relatively low, but stakeholders consider that substantial adoption of this measure is possible in coming years under a maximum scenario. However, achieving these targets necessitates substantial investments in research, development, and infrastructure, alongside supportive policy measures. The BAU scenario highlights the more likely gradual pace of change, driven by evolving market dynamics and incremental technological advancements and adoption.

Measure 3: The incorporation of secondary materials into chemical production processes is constrained by technical limitations, market dynamics, and consumer preferences. While stakeholders acknowledge the potential benefits of recycling and reuse, the feasibility and scalability of such practices vary across different segments of the industry. Current efficiency levels remain modest across the sector, reflecting the limited uptake of secondary materials and the challenges associated with their integration into existing processes. Maximum efficiency projections suggest the potential for significant improvements by 2035, driven by evolving consumer preferences, regulatory pressures, and technological innovations. However, stakeholders caution that realising these gains requires concerted efforts to overcome significant technical, economic, and logistical barriers. As a result, BAU scenarios suggest gradual gains driven by market forces and ongoing industry initiatives.

Measure 4: Efforts to improve process yields face challenges arising from technical (engineering) limitations, site-specific factors, and operational constraints. While stakeholders acknowledge the potential for optimisation, particularly in batch-scale processes, the extent of achievable gains varies across different segments of the industry. Current efficiency levels remain difficult to quantify due to the lack of standardised metrics and site-specific variability. Maximum efficiency projections highlight the potential for marginal improvements by 2035, driven by incremental advancements in process optimisation and digital technology adoption. However, stakeholders caution that this requires sustained investments in research, development, and operational improvements. The BAU scenario, better reflects the more likely incremental nature of change often limited by investment.

Measure 5: Efforts to reduce water usage in the chemical industry are influenced by factors such as process design, regulatory requirements, and technological innovations. While stakeholders recognise the importance of water efficiency, achieving significant reductions poses challenges due to operational constraints and cost. Stakeholders noted that water consumption is often a lower priority compared to other sustainability considerations. Current efficiency levels for the sectors remain difficult to quantify accurately. Maximum efficiency projections highlight the potential for significant reductions by 2035, driven by advancements in, regulatory pressures, cost and industry initiatives. However, stakeholders caution that this requires collaborative efforts across the value chain and supportive policy measures. The BAU scenario reflects the more gradual pace of progress in the sector, with stakeholders anticipating modest reductions.

Measure 6: Efforts to recover waste materials in the chemical industry through sharing of resources are influenced by factors such as resource availability, market dynamics, and technological/ market readiness. While stakeholders recognise the importance of collaboration, achieving significant improvements across the sector poses challenges due to logistical constraints and commercial sensitivity. Whilst waste data is available to assess current efficiency levels of waste generation, it is difficult to determine the extent to which past improvements can be attributed solely to collaboration efforts. Maximum efficiency projections highlight the potential for significant improvements by 2035, driven by advancements in recycling technologies, collaborative initiatives, and regulatory pressures. However, stakeholders note that this requires overcoming significant technical, economic, and logistical barriers. Under the BAU scenario, stakeholders anticipate modest gains driven by ongoing optimisation efforts and industry initiatives.

5.0 Electricals

This section summarises the key findings regarding the list of resource efficiency measures, the top drivers and barriers for each measure, and the levels of efficiency (and associated evidence RAG ratings) for the electricals sector. The complete findings are presented in the Unlocking Resource Efficiency: Phase 2 Electricals Report.

5.1 Sector introduction

The electrical and electronic equipment (EEE) sector is complex, with a wide range of products consisting of various materials. Technological advances and affordability of EEE, combined with a rising global population and consumerism, have led to a sharp increase in EEE consumption in recent years.[31]

Globally, between 2014 and 2019, the amount of waste EEE (WEEE) generated increased by 21%, from 44.4 million tonnes per annum to 53.6 million tonnes per annum. By 2030, it is estimated that 74.7 million tonnes of WEEE per annum will be generated globally. Per capita, this equates to 6.4 kg in 2014, 7.3 kg in 2019 and 9.0 kg in 2030. In northern Europe, which consists of the UK, the amount of WEEE produced in 2019 was 22.4 kg per capita – the highest of any global region.[32] Consequently, WEEE has reported as being the fastest growing waste stream in the world.[33] Design for longevity, including durability, repair, refurbishment and reuse of EEE, as well as the proper collection, recovery and treatment of WEEE, are therefore imperative. Such design and operations will ensure that resources are managed as efficiently as possible as the demand for EEE continues to rise.

The EEE lifecycle is complex, with international supply chains and numerous materials sourced for the various EEE components. These factors present challenges for implementing and monitoring resource efficiency measures. The EEE lifecycle starts with the extraction and refining of raw materials, such as ores and fossil fuels which are transformed into metals and plastics, respectively. In some cases, secondary materials (recycled content) are used. These materials are used for the production and assembly of various EEE components, which are assembled to produce EEE. The EEE is then sold to and used by domestic and commercial consumers. Once the EEE has reached end-of-use, it can be reused, repaired or remanufactured for continued use by consumers. Alternatively, end-of-use or end of life EEE (WEEE) is recycled, incinerated or landfilled.

EEE contains a variety of different materials and chemical elements, including critical raw materials (CRMs, which are rare earth elements such as lithium and tantalum), base metals

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[31] Shittu et al. (2022) Prospecting reusable small electrical and electronic equipment (EEE) in distinct anthropogenic spaces. Available at: link
[32] Forti et al. (2020) The Global E-waste Monitor 2020: Quantities, flows and the circular economy potential. Available at: link
[33] Mansuy et al. (2020) Understanding preferences for EEE collection services: A choice-based conjoint analysis. Available at: link

(such as steel, aluminium and copper), precious metals (such as silver, gold and palladium) and plastics (such as polypropylene (PP) casings and polyvinyl chloride (PVC) wiring insulation). The production of EEE generally requires resource intensive manufacturing, using large amounts of energy and water, whilst often producing large quantities of waste. Overall, the combined complexity of the material extraction, manufacturing processes, use-phase requirements and end of life treatment options makes EEE a complex sector to implement and monitor resource efficiency measures into.

The design stage of EEE is a key stage at which resource efficiencies may be made. It has been estimated that 80% of a product's environmental impact is determined at the design stage.[34] This places responsibility on EEE designers to consider sustainability during the design process. However, EEE designers may not consider the likely end-of-use scenarios for their products, resulting in EEE not being possible to disassemble for repair, remanufacture or recycling.

Current practices and business models for the EEE sector are generally linear, in that they follow the 'take-make-dispose' model of production and consumption. Nevertheless, informal reuse and sharing of EEE is common in the UK, such as donating used EEE to family and friends, and selling used EEE to others through e-commerce platforms such as Gumtree and eBay. Formal reuse of EEE is observed in certain business-to-business (B2B) areas, such as asset management of used IT equipment. For instance, in the UK in 2017, 82,000 tonnes of used domestic EEE was estimated to be sent for reuse, and around 180,000 tonnes of used commercial EEE being sent for reuse.[35] However, circular economy business models such as leasing, product service system arrangements and remanufacture are infrequently utilised.

The UK has struggled to collect maximum levels of used EEE and WEEE for reuse, repair, remanufacture and recycling. Reasons for this include the delay and mismatch between EEE sales and WEEE arisings, indefinite storage of used EEE by consumers and the disposal of used EEE and WEEE into residual waste bins. Furthermore, given technological advances in recent years with increasingly lightweight EEE, such as televisions and computers, the use of weight-based targets and reporting make it challenging to accurately monitor and evaluate the effectiveness of WEEE collections and recycling rates.

Even where WEEE are recycled through formal channels in the UK, the effectiveness of recovering materials for recycling at Approved Authorised Treatment Facilities (AATFs) can be limited. For instance, some CRMs are not fully recovered, and there are generally low recycling rates of certain other materials such as precious metals and plastics. WEEE plastics are often treated as residual waste due to the likely presence of hazardous elements, such as persistent organic pollutants (POPs), which were often used as a flame retardant for EEE. This is also an issue in other countries, not just the UK. The EEE sector is therefore limited in terms of circularity, meaning there are various resource efficiency opportunities available from the design stage through to the end-of-use and end-of-list stages. However, improving the

[34] European Commission (2012) Ecodesign Your Future: How Ecodesign Can Help the Environment by Making Products Smarter. Available at: link
[35] Material Focus (2020) Electrical Waste – Challenges and Opportunities: An Independent Study on Waste Electrical & Electronic Equipment (WEEE) Flows in the UK. Available at: link

resource efficiency of EEE requires concerted action by Government, designers, manufacturers, consumers and waste management to tackle the technical, economic and social barriers facing resource efficiency improvements. In tackling these barriers, the EEE sector may be able to improve its resource efficiency.

Sector scope

The EEE in scope of this research include those covered by the UK's Waste Electrical and Electronic Equipment Regulations 2013,[36] driven by the requirements of the WEEE Directive (2012/19/EU).[37] Batteries are out of scope of this research. The scope includes fourteen categories of WEEE (and EEE):[38]

- Large household appliances.
- Small household appliances.
- IT and telecommunications equipment.
- Consumer equipment.
- Lighting equipment.
- Electrical and electronic tools (except large scale stationary industrial tools).
- Toys, leisure and sports equipment.
- Medical devices (except implanted and infected products).
- Monitoring and control equipment.
- Automatic dispensers.
- Display equipment.
- Appliances containing refrigerants.
- Gas discharge lamps and light-emitting diode (LED) light sources.
- PV panels (solar panels).

Resource efficiency measures vary greatly between these categories and the literature available often provides different assessments and findings on the effectiveness of the measures. These categories are referred to in this report where relevant.

As set out in the Defra's 'Maximising Resources, Minimising Waste', the UK Government is working with their counterparts in Scotland, Wales and Northern Ireland to consult on improvements to the current UK-wide WEEE Regulations.[39] The consultation was opened to

[36] The Waste Electrical and Electronic Equipment Regulations 2013. Available at: link
[37] European Union (2012) Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2023 of waste electrical and electronic equipment (WEEE). Available at: link
[38] UK Government (2023) Guidance: Electrical and electronic equipment (EEE) covered by the WEEE Regulations. Available at: link.
[39] Defra (2023) The waste prevention programme for England: Maximising Resources, Minimising Waste. Available at: link

the public on 28 December 2023, seeking views on reforms to the Waste Electrical and Electronic Equipment Regulations 2013.[40]

5.2 List of resource efficiency measures

Table 11 shows the resource efficiency measures identified for the electricals sector.

Table 11: List of resource efficiency measures for the EEE sector

#	Lifecycle stage	Strategy	Measure name	Measure indicator
1	Design	Lightweighting	Lightweighting of electrical and electronic equipment	Average weight decrease of new EEE products placed on the market compared to 2023 levels
2	Design	Recycled content	Use of recycled or recovered materials	% of recycled content by weight of new EEE products placed on the market
3	Design	Material substitution	Use of bio-based plastics	% of bio-based plastic in place of fossil-based plastic
4	Manufacturing and Assembly	Production efficiencies	Increasing material yield and reincorporating waste during manufacture	% of input raw materials that successfully make it in EEE products, considering material losses throughout the supply-chain
5	Sale and use	Lifetime extension	Repair and refurbishment	% of EEE products in use that are repaired or refurbished
6	Sale and use	Collaborative consumption	Rental and collaborative consumption models	% of EEE products in use via circular economy business models and collaborative consumption

[40] Defra (2023) Consultation on reforming the producer responsibility system for waste electrical and electronic equipment 2023. Available at: link

#	Lifecycle stage	Strategy	Measure name	Measure indicator
7	End of life	Remanufacture / reuse	Direct reuse	% of used EEE products that are reused
8	End of life	Remanufacture / reuse	Remanufacture	% of EEE that is remanufactured for reuse
9	End of life	Recycling	Recycling of WEEE	% recycling rate of WEEE

The nine identified resource efficiency measures in the electricals sector span across the whole value chain. At the start of the lifecycle in the design phase there are three measures, one looking into lightweighting (Measure 1), one looking at recycled content (Measure 2) and another looking at material substitution (Measure 3).

There is one measure in the manufacturing and assembly stage, looking at production efficiencies. There are a further two measures in the sale and use stage, one looking at lifetime extension (Measure 5) and another looking at collaborative consumption (Measure 6).

Finally, at the end-of-life stage there are three measures, two measures on remanufacture and reuse (Measure 7 and 8), and one looking at recycling (Measure 9).

5.3 Drivers & Barriers

Throughout the research, a range of drivers and barriers were identified for each of the measures. The most important ones are listed in Table 12.

Table 12: Top drivers and barriers for the electricals measures

#	Measure name	Top drivers	Top barriers
1	Lightweighting of electrical and electronic equipment	Cost savings through using less material. Easier and cheaper to transport as they are lighter. Legislation in the EU. Lower environmental impact through less raw materials and resources used.	Lower durability. Recyclability of some of the lighter products (i.e., if steel has been replaced with plastic which contain POPs). Design for disassembly.

2	Use of recycled or recovered materials	Cost savings. Lower energy requirements. Trends towards mandated recycled content.	Lack of supply of high-quality and in some cases food grade materials. Technical performance – e.g., strength and finishes of the final product. Costs of certain virgin materials can be cheaper than secondary materials.
3	Use of bio-based plastics	Lower carbon footprint. Consumer appeal to use more ecofriendly products. Future legislations on tightening reduction in plastic waste. Increasing range of bio-based plastic products.	Higher cost of bio-based plastics. Concerns on feedstock for bio-based plastics and its impact on the environment.
4	Increasing material yield and reincorporating waste during manufacture	Cost savings. Reduction in greenhouse gas emissions and energy consumption. Reducing demand for virgin resources and reducing waste by capturing production waste for placing back into the production process. Increase in national WEEE policy, legislation, or regulation.	Cost of construction for Lean design. Supply chain relationships. Lack of understanding among companies in the supply chain on how to develop circular economy implementation roadmaps. Inconsistent optimisation among different actors along the supply chain.
5	Repair and refurbishment	Repair and refurbishment can be cheaper for the consumer than replacing the whole product. Increased consumer awareness surrounding the environmental benefits of repair compared with replacement. Improved brand reputation, with consumers likely to	Consumer concerns surrounding warranty, data protection, quality, safety and lifetime of repaired and refurbished products. Technological obsolescence, with a lack of interoperability between old hardware and new software.

		repurchase with the same manufacturer if they experienced a positive repair experience.	Economic obsolescence, where the cost of repair is higher than replacement.
6	Rental and collaborative consumption models	Lower upfront costs for consumers compared to purchasing outright. Consumer convenience may be improved due to maintenance and repair services included in PaaS model. Consumers have access to up-to-date products at a more affordable ongoing cost.	Complex business model that requires a change in business strategy and investment. Desire from consumers to own their own products outright, particularly for products that consumers depend on for everyday use. Competition with cheaper products that do not have circular benefits hinders scale up.
7	Direct reuse	Used EEE is generally less expensive to purchase than new EEE. Some returned EEE may also be directed to charities free-of-charge or at a reduced rate. Used EEE can have the same functionality as new EEE. Consumer demand for sustainable products and acceptance of used products. EEE can be designed for reuse, whereby the durability and lifespan of the product is factored in at the design stage. This may include the use of more durable materials.	Indefinite storage of used EEE by consumers, making them unavailable for reuse. Consumer preference for new EEE and negative perceptions of used EEE (e.g., "not in fashion"). Lack of (or reduced) warranty for used EEE may be perceived by consumers as having low durability or a short lifespan. Used EEE may have shorter or unknown lifespans compared with new EEE. Consumers may be concerned about the safety of used EEE, particularly from peer-to-peer sales. For example, fire risks and hygiene. Consumers may be concerned about data privacy and security when donating, selling, or purchasing used EEE. This may also result in

			indefinite storage of used EEE by consumers or being destroyed and disposed.
8	Remanufacture	Remanufactured EEE is generally less expensive to purchase than new EEE. Cost savings for manufacturers associated with raw materials, energy and waste management compared with new EEE.	Some EEE may be designed in such a way that is challenging to disassemble and reassemble. For instance, soldering, welding and plastic melts, that can cause damage to the product when dismantled. Producers and OEMs may be reluctant to sell remanufactured EEE at a lower price than new EEE equivalents, as it may undermine sales of new EEE.
9	Recycling of WEEE	Kerbside recycling services for small WEEE are being investigated and trialled in some Local Authorities. This may increase WEEE recycling rates through improved recycling convenience. High economic value for certain materials within WEEE, which may be an income stream for treatment facilities.	Cost of recycled material can be higher than that of virgin material, resulting in reduced demand for recycled material. Limited WEEE recycling infrastructure in the UK may result in high recycling costs. Use of flame retardants and other hazardous substances restricts recycling potential, such as WEEE plastics. Limited supply chain communication that connects collectors with recyclers, and recyclers with manufacturers.

Cost savings and lower carbon footprints, either through lower energy requirements or material use, were the most common drivers. Cost does, however, also appear as a barrier, particularly when looking at fossil-based plastics compared to recycled plastic or bio-based plastics. This is because the cost of fossil-based plastics can fluctuates and can at times be cheaper or more expensive than their recycled or bio-based counterparts.

The barriers tend to be more measure specific; for example, in Measure 8, a key barrier is that producers and original equipment manufacturers may be reluctant to sell remanufactured EEE at a lower price than new EEE equivalents, as it may undermine sales of new EEE. However, consumer concerns and consumer preferences have been mentioned as barriers in Measures 5, 6 and 7. The look and feel of electronics often comes into the consumers perception of items, and safety (whether perceived or actual) plays a big role.

5.4 Levels of efficiency

Table 13 provides a summary of the levels of efficiency (and the evidence RAG rating in italics) for the nine identified measures of the electricals sector.

Table 13: Levels of efficiency and evidence RAG rating (*in italics*) for electricals measures

#	Measure name	Indicator	Current	Maximum in 2035	BAU in 2035
1	Lightweighting of electrical and electronic equipment	Average weight decrease of new EEE products placed on the market compared to 2023 levels	0% *N/A*	30 – 40% *Red*	1 – 10% *Red*
2	Use of recycled or recovered materials	% of recycled content by weight of new EEE products placed on the market	Plastic: 1% *Amber* Metal: 30% *Green*	Plastic: 70% *Amber* Metal: 90% *Amber*	Plastic: 50% *Red* Metal: 80% *Amber*
3	Use of bio-based plastics	% of bio-based plastic in place of fossil-based plastic	Less than 1% *Amber*	100% *Red*	10% *Red*
4	Increasing material yield and reincorporating waste during manufacture	% of input raw materials that successfully make it in EEE products, considering material losses throughout the supply-chain	75% *Amber*	90% *Amber*	80% *Amber*
5	Repair and refurbishment	% of EEE products in use that are repaired or refurbished	10% *Green*	70% *Green*	15% *Amber*
6	Rental and collaborative consumption models	% of EEE products in use via circular economy business models and	1 – 5% *Red*	20 – 40% *Red*	5 – 20% *Red*

		collaborative consumption			
7	Direct reuse	*% of used EEE products that are reused*	15% *Green*	30% *Amber*	20% *Red*
8	Remanufacture % of	% of EEE that is remanufactured for reuse	1 – 10% *Green*	80% *Red*	10 – 15% *Amber*
9	Recycling of WEEE	% recycling rate of WEEE	40% *Green*	60% *Red*	40% *Red*

General insights

As with other sectors, the key trend seen in the level of efficiency from electricals is that the BAU level lies between the current level of efficiency and the maximum level of efficiency, suggesting some improvement in the current environment, but that changes would be needed for the potential to be maximised.

The BAU level of efficiency was lower than the maximum level, suggesting the full resource efficiency potential will not be achieved without a change in the market environment. There are a range of barriers which limit the uptake of measures, with a key common one across multiple measures being the increased costs associated with some measures. Similarly, the BAU level of efficiency was higher than the current level, apart from in Measure 9, indicating that high levels of efficiency have already been achieved in the context of what is possible within the current market and given the current infrastructure.

In most of the measures, the BAU level of efficiency is not far off the middle point between the current level of efficiency and the maximum level of efficiency; however, in Measure 3, 5 and 8 the maximum level of efficiency is significantly higher than the BAU level of efficiency, indicating more work will need to be done in these areas.

Measure-specific insights

Measure 1 on lightweighting may improve from the current level of efficiency; however, consumer perception of lightweight products may prevent this. In addition, efficiency improvements in this area are very item dependent; for example, mobile phones have decreased in weight over the years, but fridge freezers have increased in weight. The maximum level of efficiency is up to 30-40%; however, this will likely be determined by consumer preference and demand for specific items.

Measure 2 and 3, which are both in the design phase, show a reasonably high level of potential under the maximum level of efficiency; however, Measure 2 shows a good BAU level of efficiency, where Measure 3 shows a significantly lower level of efficiency for BAU. Bio-based plastics are newer to the market than recycled plastics are, and there are concerns with bio-based plastics on the feedstock and environmental impacts.

Measure 4, which is the only measure looking at production efficiency, had the highest current level of efficiency of all measures (75%). At the same time, the maximum level of efficiency for this measure is at 90% and the BAU level of efficiency at 80%, which is the best performing measure in maximum and BAU alongside recycled metal content in Measure 2.

Measure 5 shows a potential maximum level of efficiency of 70%. The BAU shows a slight increase in levels of efficiency from 10% in the current level up to 15%. There were many concerns mentioned in the barriers on this measure such as safety and warranty, which might prevent uptake in repair and refurbishment.

Measure 6 on rental and collaborative consumption models had a current level of efficiency of 1-5%, while the maximum level of efficiency was at 20-40% and the BAU level of efficiency at 5-20% - a range exactly in the middle of the two. The ranges given are quite broad due to the dependency on consumer preference to own their own products as well as rental business models being complicated and likely requiring some system changes.

Measure 7, 8 and 9 are all in the end-of-life stage. All had RAG ratings of green for the current level of efficiency as there is a lot of reporting on recycling and reuse of EEE and is common practice already. Measure 8 (remanufacture of EEE) showed the highest level of maximum efficiency at 80%; however, the BAU level of efficiency was significantly lower at 10-15%. Measure 7, on the reuse of EEE products, has a current level of efficiency of 15%, a maximum level of efficiency at 30% and a BAU level of efficiency of 20%, which is only 5% above the current level. Measure 9 (recycling of WEEE) has a current level of efficiency of 40% and a BAU level of 40% with the maximum level of efficiency being 60%. As already mentioned above, this might indicate that we have already got to where we can in the current market or given the current infrastructure.

6.0 Glass

This section summarises the key findings regarding the list of resource efficiency measures, the top drivers and barriers for each measure, and the levels of efficiency (and associated evidence RAG ratings) for the glass sector. The complete findings are presented in the Unlocking Resource Efficiency: Phase 2 Glass Report.

6.1 Sector introduction

Glass is a non-crystalline solid that is often transparent, brittle and chemically inert. It has widespread practical, technological, and decorative use across several industries and applications, including the food and drink, construction, automotive, and electronic technology industries.

The process of producing a primary glass product can be broken down into four key stages:

- Stage 1: material sourcing
- Stage 2: raw material processing
- Stage 3: primary product
- Stage 4: secondary processing

The main raw materials comprise silica sand (silicon dioxide), soda ash (sodium carbonate) and limestone (calcium carbonate).

Glass offcuts and broken glass (known as glass cullet) are another key raw material in the production of glass. Rejects from the process in container and flat glass production are remelted in the furnace. Pre-consumer glass cullet refers to material that is recycled before the point of reaching consumers, for example offcuts or breakages that result from the fabrication process. Post-consumer glass cullet refers to glass that has been retrieved from waste collection services after it has been used by an end consumer and is fed back into the production of glass. The benefit of using glass cullet as a raw material is that melting it to produce new glass requires less energy than using primary raw materials, thereby reducing the energy intensity per unit of output whilst also reducing demand for primary material resources.[41] [42] [43]

[41] Forslund. H, Björklund. M (2018) Toward Circular Supply Chains for Flat Glass: Challenges of Transforming to More Energy-Efficient Solutions. Available at: link
[42] Hartwell, Coult, Overend (2022) Mapping the flat glass value-chain: a material flow analysis and energy balance of UK production. Available at: link
[43] Institute for Prospective Technological Studies (2013) Best Available Techniques (BAT) reference Document for the Manufacture of Glass. Available at: link

Following the manufacturing of the primary glass product, glass can then undergo secondary processing, such as toughening treatments, application of coatings and/or lamination with interlayer products.

UK Glass Sector

In 2019, the UK glass industry emitted 1.5 million tonnes of ETS CO2 emissions, with 75-85% accounted for by fossil fuel combustion in the furnace (to produce the heat to melt the raw materials), and 15-25% as CO2 emitted from the raw materials during the manufacturing process' chemical reaction, depending on the amount of recycled cullet used (recycled cullet not releasing CO2 when remelted).[44] The sector accounts for around 3% of UK industrial greenhouse gas (GHG) emissions.[45]

The glass industry contributes almost £2 billion to the UK economy each year and directly employs around 6,000 people, and indirectly supports an estimated 150,000 jobs.[46]

The majority of UK glass production is of container glass, followed by flat glass. In 2019, the UK produced 2,500 kt of container glass (which represented 60% of total UK glass production), 950 kt of flat glass (23% of production) and 288 kt of glass wool (7% of production).[47] Other applications, such as decorative and specialty glass products, account for the remaining 10% of production (395 kt).[48]

Sector scope

This report covers resource efficiency opportunities and data relating to glass products produced, consumed and/or treated as waste in the UK. Based on the estimated production volumes in the UK, the following product categories (sub-sectors) are in scope:

- container glass;
- flat glass (construction and automotive); and
- glass wool (mainly going into building insulation).

The following processes are in scope:

- design and primary manufacture;
- secondary manufacture (e.g., the manufacture of double glazing using flat glass, or the filling of container glass with product);
- installation (for flat glass);
- in use (with potential for life extension); and

[44] British Glass (2020) Glass Sector Net Zero Strategy. Available at: link
[45] Griffin, Hammond, and McKenna (2021) Industrial Energy Use and Decarbonisation in the Glass Sector. Available at: link.
[46] British Glass (2020) Glass sector net zero strategy. Available at: link.
[47] Hartwell, Coult, Overend (2022) Mapping the flat glass value-chain: a material flow analysis and energy balance of UK production. Available at: link
[48] Note the remaining 10% is from 2009 data.

- end of life (with potential for reuse and recycling).

Due to lower production volumes in the UK the following glass applications are out of scope:

- hollow glass (such as tubing and vials);
- photonic components (optical technology used in systems for navigation, satellite communication and more);
- glass beads (used in, for example, reflective paint, wet and dry blast cleaning and water filtration);
- domestic glassware (tumblers, stem glass, vases); and
- glass fibre for non-insulating products such as wind turbine blades[49], automobile bodies and more.[50]

The key focus of this report is on actions that improve material resource efficiency. Therefore, energy efficiency measures and heat energy recycling, which are actions that reduce energy use/carbon emissions but do not impact resource use or resource efficiency, are outside the scope of this study. Other processes that are outside of scope include hydrogen energy, as this relates to alternative sources of decarbonised energy rather than material resources, and carbon capture, as this aims to reduce CO2 emissions without improving resource efficiency.

6.2 List of resource efficiency measures

Table 14 shows the resource efficiency measures identified for the glass sector.

The eight resource efficiency measures identified for the glass sector are spread across all lifecycle stages, covering the design, manufacturing, sale and use and end-of-life stage. Three measures under design cover light-weighting, material substitution and recycled content (Measures 1 – 3), while one measure under manufacturing covers production efficiencies (Measure 5) and one measure under sale and use covers life extension (measure 6). Two end-of-life measures cover remanufacturing/reuse and recycling (Measure 7 and 8, respectively). As such, all parts of the lifecycle are covered comprehensively by the identified resource efficiency measures.

It should be noted that material substitution measures (Measure 2 and 3) covering both the substitution of raw materials with lower embodied carbon alternatives and the substitution of glass products with non-glass products (i.e., covering both material switches within the sector, and with other sectors), mirrors similar measures explored in the plastics and paper sectors given the interconnectedness of these sectors (see Section 9.2).

[49] Glass Fibre Europe (2023) Continuous Filament Glass Fibre. Available at: link
[50] British Glass (2023) Glass Products. Available at: link.

Table 14: List of resource efficiency measures for the glass sector

CG = Container Glass; FG = Flat Glass; GW = Glass Wool

#	Lifecycle stage	Strategy	Sub-sectors the measure applies to*	Measure name	Measure indicator
1	Design	Light - weighting	CG: Applicable FG (construction): Limited applicability GW: Applicable	Lightweighting in consumer products	Percentage reduction in weight of consumer products, relative to current (2023) levels
2	Design	Material substitution	CG: Applicable FG (construction): Applicable GW: Applicable	Substitute raw materials with lower embodied carbon alternatives	- Indicator 2a: Percentage change in dry weight substitution of the traditional raw material for the alternative raw material, relative to current (2023) levels - Indicator 2b: Percentage reduction in CO2e associated with UK glass production achieved through substitution with alternative raw materials, relative to current (2023) levels
3	Design	Material substitution	CG: Applicable GW: Applicable	Substitute glass products with non-glass products (excluding raw material substitution)	Percentage reduction in whole-life CO2e from substitution with products made from alternative materials, relative to current (2023) levels
4	Design	Recycled content	CG: Applicable FG (construction): Applicable GW: Applicable	Reincorporate glass waste back into glass manufacturing	- Indicator 4a: Percentage of internal glass cullet in primary glass manufacture - Indicator 4b: Percentage of external glass cullet in primary glass manufacture

#	Lifecycle stage	Strategy	Sub-sectors the measure applies to*	Measure name	Measure indicator
					- Indicator 4c: Percentage of glass cullet in primary glass manufacture (sum of indicators 4a and 4b)
5	Manufacture	Production efficiencies	CG: Applicable FG (construction): Applicable FG (automotive): Applicable GW: Applicable (primary production only)	Implement efficient product manufacturing and installation processes	- Indicator 5a: Percentage reduction in waste generated per tonne of glass output during primary manufacturing, relative to current (2023) levels - Indicator 5b: Percentage reduction in waste generated per tonne of glass output during secondary manufacturing, filling (container glass) and installation (flat glass), relative to current (2023) levels
6	Sale & Use	Life extension	FG (automotive): Applicable	Lifetime extension through repair of products	Percentage reduction in new consumption through repair, relative to current (2023) levels
7	End of life	Reuse	CG: Applicable FG (construction): Limited applicability FG (automotive): Limited applicability GW: Limited applicability	Reuse of glass products	- Indicator 7a: Percentage of glass products reused - Indicator 7b: Average number of times a glass product is reused - Indicator 7c: Percentage reduction in demand of new glass products through reuse, relative to current (2023) levels (calculated from indicators 7a and 7b)
8	End of life	Recycling	CG: Applicable	Recycle post-consumer glass waste	Percentage post-consumer container glass, flat glass and glass wool recycling rate

#	Lifecycle stage	Strategy	Sub-sectors the measure applies to*	Measure name	Measure indicator
			FG (construction): Applicable FG (automotive): Applicable GW: Applicable		

6.3 Drivers & Barriers

Throughout the research, a range of drivers and barriers were identified for each of the measures. The most important are listed in Table 15. A barrier with a sub-sector at the end in brackets means the barrier only applies to that specific sub-sector, whereas a barrier with no sub-sector at the end in brackets means the barrier applies to the whole of the glass sector.

Table 15: Top drivers and barriers for the glass measures

#	Measure name	Top drivers	Top barriers
1	Lightweighting in consumer products	Demand for products with a lower material and environmental footprint. Cost savings through reduced transportation weight. Competition from other packaging materials (container glass).	Consumer / brand owner perception of lighter weight being inferior (container glass). Technical strength requirements and standards. Design for reuse presents a trade-off with lightweighting.
2	Substitute raw materials with lower embodied carbon alternatives	Energy and cost savings. UK net zero policy. Demand for sustainable products.	Competition from other industries for raw material. Availability and cost of alternative materials. Lack of testing and industry experience (biomass ash).
3	Substitute glass products with non-glass products (excluding raw material substitution)	Convenience of lighter and non-fragile products (container glass).	Consumer perception of health hazards associated with chemicals in plastic packaging (container glass) Consumer perception that glass products are higher quality (container glass). Policy encouraging an increase in reusables
4	Reincorporate glass waste back into glass manufacturing	Reduced energy consumption and emission charges. Reduced emissions due to decarbonisation of raw material. Lower cost per tonne of input.	Risk of contamination/composition quality of post-consumer flat glass (construction flat glass, container glass). Inefficient logistics systems including long transport distances

			and lack of storage space for post-consumer glass products (construction flat glass).
5	Implement efficient product manufacturing and installation processes	Reduction in energy consumption and GHG emissions. Cost savings in raw materials.	Capital costs of introducing leaner manufacturing methods affect return on investment. Lack of testing / industry experience in new and innovative manufacturing technologies (e.g., Industry 4.0). Lack of standardisation of window sizes leads to higher manufacturing losses in secondary manufacturing (flat glass).
6	Lifetime extension through repair of products	Cost savings – low cost of repair compared to purchasing a new replacement (automotive flat glass).	Safety risk with attempting to repair fatal weaknesses in windscreens (automotive flat glass). Regulation limits size of chip/crack that can be repaired (automotive flat glass). Energy efficiency trade-off associated with repairing an old product instead of installing a new, more energy-efficient product (construction flat glass). Lack of suitable methods for repair (construction flat glass).
7	Reuse of glass products	Perceived environmental benefits of reuse drive consumer behaviour.	Complex collection, cleaning, redistribution and refilling infrastructure required, and additional cost associated (container glass). Quality of secondary flat glass (construction and automotive flat glass). Difference in energy efficiency between old and new building glazing (construction flat glass).

			Lack of agency within glass sector. Lack of standardisation of window dimensions (construction flat glass).
8	Recycle post-consumer glass waste	Growing consumer demand for purchasing products made from recycled content. Extended Producer Responsibility and Consistency of Collections regulations (container glass). Recycling initiatives by individual companies (flat glass). A 'remelt target' for glass packaging (container glass).	Contamination due to recycling collection methods – co-mingled systems lower cullet yield (container glass). Limitations of mixed-colour collections (container glass) Cost of collection, reprocessing and transportation higher than other materials. Specific glass product compositions (flat glass). Insufficient landfill tax (flat glass).

The environmental benefits associated with a given measure, including the potential reduction in energy use or greenhouse gas emissions, was a common top driver (Measure 1, 3, 4, 5 and 7). Another common top driver across most measures were the potential cost savings associated with reducing the use of costly materials (Measure 1, 5, 7 and 8), processing costs, including reduced energy consumption or transportation (Measures 1 and 2) or improved market conditions (Measure 7 and 8).

Another key driver across many of the measures was the policy or government legislation that enabled the measure. Measure 2, 3 and 8 in particular were driven by government policy that seeks to improve the efficiency and/or environmental impact of the industry. A final key measure was the consumer demand for more viable sustainable products or consumer drive to reduce their own environmental footprint (Measures 2, 3, 7 and 8).

Barriers were more varied across measures; however, financial implications were consistently amongst the top barriers for all measures. Such cost implications include the higher cost of alternative materials required (Measures 1 and 2) increased cost of labour or transport associated with the measure (Measures 4, 7 and 8) or the costs associated with improving technology and processes (Measures 1, 5 and 8). Other financial factors include the low landfill tax and low market value of waste that impact the market conditions (Measures 4 and 8).

Other common barriers were related to the quality aspects of the measures, be that in the precise technical specification required of the end product that limits the uptake of the measure (Measures 1, 6, 7 and 8) or the quality requirements of the feedstock (Measures 2, 4, 7 and 8) or the availability of quality materials (Measures 2 and 8). Barriers to the uptake of new technologies also featured as top barriers, for example the lack of testing or ease of implementation of new materials or technologies making uptake of the measure more challenging (Measures 2, 5 and 8). A key barrier that impacts the uptake of Measures 4, 7 and 8 are the complex logistics required for the success of the measure.

6.4 Levels of efficiency

Table 16 provides a summary of the levels of efficiency (and the evidence RAG rating in italics) for the eight identified measures of the glass sector.

Table 16: Levels of efficiency and evidence RAG rating (*in italics*) for glass measures

CG = Container Glass; FG = Flat Glass; GW = Glass Wool

#	Measure name	Indicator	Current	Maximum in 2035	BAU in 2035
1	Lightweighting in consumer products	Percentage reduction in weight of consumer products, relative to current (2023) levels	CG: 0%	CG: 15 – 25%	CG: 0 – 15%
			FG (construction): 0%	FG (construction): 0 – 2%	FG (construction): 0%
			GW: 0%	GW: 0 – 5%	GW: 0 – 2%
			Not applicable	*Red*	*Red*
2	Substitute raw materials with lower embodied carbon alternatives	Indicator 2a: Percentage change in dry weight substitution of the traditional raw material for the alternative raw material, relative to current (2023) levels Indicator 2b: Percentage reduction in CO2e associated with UK glass production achieved through substitution with alternative raw materials, relative to current (2023) levels	Total: 0% *Not applicable*	Biomass Ash: 5 – 15% dry weight replacement	Biomass Ash: 0 – 10% dry weight replacement
				Calumite: 1-5% increase in dry weight replacement in clear container glass only	Calumite: 1-5% increase in dry weight replacement in clear container glass only
				Red	*Red*
3	Substitute glass products with non-glass products (excluding raw material substitution)	Percentage reduction in whole-life CO2e from substitution with products made from alternative materials, relative to current (2023) levels	0% *Not applicable*	Not identified *Not applicable*	Not identified *Not applicable*

4	Reincorporate glass waste back into glass manufacturing	Indicator 4a: Percentage of internal glass cullet in primary glass manufacture	CG: 11 – 20%	CG: 10 – 18%	CG: 10 – 19%
			FG (construction): 10 – 20%	FG (construction): 9 – 18%	FG (construction): 9 – 19%
			GW: 0 – 10%	GW: 0 – 10%	GW: 0 – 10%
			Red-Amber	*Red*	*Red*
		Indicator 4b: Percentage of external glass cullet in primary glass manufacture	CG: 32 – 52%	CG: 65 – 70%	CG: 50 – 65%
			FG (construction): 16 – 25%	FG (construction): 40 – 50%	FG (construction): 30 – 40%
			GW: ~80%	GW: >80%	GW: >80%
			Red-Amber	*Red*	*Red*
		Indicator 4c: Percentage of glass cullet in primary glass manufacture (sum of indicators 4a and 4b)	CG: 43 – 72%	CG: 75 – 88%	CG: 60 – 84%
			FG (construction): 26 – 45%	FG (construction): 49 – 68%	FG (construction): 29 – 59%
			GW: 80 – 90%	GW: 80 – 90%	GW: 80 – 90%
			Red-Amber	*Red*	*Red*
5	Implement efficient product manufacturing and installation processes	Indicator 5a: Percentage reduction in waste generated per tonne of glass output during primary manufacturing, relative to current (2023) levels	CG: 0%	CG: 5 – 10%	CG: 0 – 5%
			FG (construction): 0%	FG (construction): 2 – 5%	FG (construction): 0 – 5%
			GW: 0%	GW: 5 – 10%	GW: 0 – 2%
			Not applicable	*Red*	*Red*

		Indicator 5b: Percentage reduction in waste generated per tonne of glass output during secondary manufacturing, filling (container glass) and installation (flat glass), relative to current (2023) levels	0%	Not identified	Not identified
			Not applicable	*Not applicable*	*Not applicable*
6	Lifetime extension through repair of products	Percentage reduction in new consumption through repair, relative to current (2023) levels	0%	Not identified	Not identified
			Not applicable	*Not applicable*	*Not applicable*
7	Reuse of glass products	Indicator 7a: Percentage of glass products reused	CG: 0 – 1%	CG: 40 – 80%	CG: 10 – 20%
			FG (construction): 0 – 1%	FG (construction): ~2%	FG (construction): 0 – 1%
			FG (automotive): 0 – 1%	FG (automotive): 1 – 2%	FG (automotive): 0 – 1%
			GW: 0 – 1%	GW: 0 – 10%	GW: 0 – 10%
			Red-Amber	*Red*	*Red*
		Indicator 7b: Average number of times a glass product is reused	CG: 20 – 25	CG: 40	CG: 25 – 40
			FG (construction): 0 – 1	FG (construction): 0 – 2	FG (construction): 0 – 2
			FG (automotive): 0 – 1	FG (automotive): 0 – 1	FG (automotive): 0 – 1
			GW: 0	GW: 1 – 2	GW: 0 – 1
			Red-Amber	*Red*	*Red*

8	Recycle post-consumer glass waste	Percentage post-consumer container glass, flat glass and glass wool recycling rate	CG: 70 – 75%	CG: ~90%	CG: 75 – 83%
			FG: 25 – 35%	FG: 60 – 80%	FG: 40 – 60%
			GW: 0 – 5%	GW: Not identified	GW: 0 – 10%
			Amber-Green	*Red*	*Red*

General insights

Across almost all of the measures identified in the glass sector, the BAU level of efficiency was the same or higher than the current level of efficiency suggesting that the level of efficiency has potential to improve in the current environment, but not guaranteed. Measures that showed the most certain levels of improvement in the BAU scenario were measures 4 and 8, associated with the gradual increase in collection and recycling of glass materials (Measure 8) and the subsequent increase in incorporation of external cullet used in producing glass products, particularly in the container and flat glass subsectors. Increases in the levels of efficiency for Measure 7 for container glass reflect the high probability of glass material being key to any reusable packaging systems that may be implemented.

Broadly speaking, the maximum levels of efficiency are the same or higher than the current levels of efficiency, suggesting that improvements can be made with adjustments to the current operation of the sector, or with changes to the market environment. There are a broad range of barriers that limit the uptake of measures, a key barrier being the financial implications of changing the current technologies or infrastructure for recycling and manufacturing glass products. Consumer/brand behaviour and policy development are also considerations, particularly when it comes to reuse of container glass (Measure 7).

Two exceptions to the general picture are in Measures 3 and 6. There was uncertainty on the impacts of Measure 3 (substitution of glass for alternative materials) due to data availability and so levels of efficiency could not be provided. Similar uncertainty around the levels of efficiency associated with material substitution were found for the intersecting packaging industries of plastics and paper. Measure 6 (repair of glass products to prolong lifetime) was found not to apply to most of the glass subsectors, with only small improvements predicted in the automotive flat glass subsector. As such, levels of efficiency could not be identified for this measure.

Measure-specific insights

Measure 1 and 3 relate to the reduction of overall use of glass material, via reduction in the weight of glass products (Measure 1) or reduction in overall use of glass material (Measure 3). Both have barriers associated with the consumer perception of the product, particularly for the container glass subsector. It is also worth noting that the levels of efficiency were not identified for Measure 3 due to the inconclusive nature of findings around both the potential changes in mass of glass placed on the market and the carbon impacts associated with this on a lifecycle basis.

Measure 4, 5, 6 and 8 are all associated with efforts to reduce glass waste across the supply chain, from reducing waste in production (Measures 4 and 5) to reducing waste of glass products via repair (Measure 6) and reducing glass going to waste by capturing it in recycling systems (Measure 8). Cost and quality concerns act as barriers to improvement for these measures, such as cost of implementing or testing new technologies or the risk of using lower quality materials meaning higher processing costs or losses due to low quality products. Nevertheless, measure 4, 5 and 8 show opportunities for improved efficiency which is reflected in the maximum levels of efficiency being the higher than the current or BAU scenarios. Measure 6, on the other hand, is unlikely to see improvements in efficiency unless safety and quality concerns can be addressed in the repair of flat glass. It is unlikely that repair of container glass would be economically viable and so it is unlikely that such a measure would impact the efficiency of the glass sector.

Measure 2 deals with the improved potential efficiency of substituting raw materials in glass making for alternatives with lower embodied carbon. There is potential for improvement with this measure, particularly via the use of biomass ash which is reflected in levels of efficiency higher than the current scenario for both BAU and maximum levels of efficiency. Availability of another alternative raw material, Calumite, is significantly hindered by the expected competition for it as a material and therefore its cost and availability for use in the glass sector. As such, the levels of efficiency in the BAU and maximum scenarios show little to no improvement on the current scenario.

Measure 7 is unique in that it calls for a novel and complex system of collection, cleaning and redistribution of glass products to facilitate their reuse. If barriers to implementing a reuse system are overcome, there is significant potential for reuse to contribute to efficiencies in the glass sector. For container glass in particular, this measure shows the greatest potential improvement between the current and maximum levels of efficiency.

7.0 Food & Drink

This section summarises the key findings regarding the list of resource efficiency measures, the top drivers and barriers for each measure, and the levels of efficiency (and associated evidence RAG ratings) for the food and drink sector. The complete findings are presented in the Unlocking Resource Efficiency: Phase 2 Food & Drink Report.

7.1 Sector introduction

The UK's food and drink sector is of high economic significance. In total, the agri-food sector (including agriculture and fishing) contributed £128.3 billion or 6.3% to the national Gross Value Added (GVA) in 2021, of which £115.2 billion was contributed by the food and drink sector beyond primary production (i.e., excluding agriculture and fishing).[51] The food and drink sector also directly employed 3.7 million people in Great Britain[52] in 2022 (excluding agriculture and fishing).[53]

Food and drink is the UK's largest manufacturing sector, with an annual turnover of £104.4 billion.[54] By GVA, the largest food and drink manufacturing sub-sectors in 2021 were: beverages, contributing £6.5 billion or 21.4% of food and drink manufacturing GVA; 'other food products', contributing £6.3 billion; bakery, contributing £4.4 billion; and meat and meat products, contributing £4 billion.[55] 97% of UK food and drink manufacturing businesses are small to medium sized enterprises (SMEs), but they account for only 22% of the industry's turnover.[56]

The UK food and drink industry is heavily reliant on international supply chains. The sector imports a significant amount of raw materials, ingredients and finished products, in particular, from the EU; 23% of UK domestic consumption originates in the EU.[57] In addition, UK food and drink exports valued at almost £25 billion per year are sent abroad.[58] The presence of international supply chains presents some challenges to identifying and implementing resource efficiency measures.

Resource efficiency in the food and drink sector focuses on reducing inputs, diverting surplus food and drink back into the value chain where possible and minimising food loss and waste throughout the various stages of the value chain. Food and drink wastage at any stage of the value chain can result in financial losses, through loss of raw materials, wasted production inputs, or costs associated with waste management. It has been estimated that household food

[51] Defra (2023). National statistics: Food statistics in your pocket.
[52] Excluding Northern Ireland, as equivalent data is not available.
[53] Defra (2023). National statistics: Food statistics in your pocket.
[54] Food and Drink Federation (2022). Our Industry at a Glance.
[55] Defra (2023). National statistics: Food statistics in your pocket.
[56] Defra (2023). National statistics: Food statistics in your pocket.
[57] Defra (2023). National statistics: Food statistics in your pocket.
[58] Food and Drink Federation (2022). Our Industry at a Glance.

waste has an annual value of £17 billion, equating to £250 per person per year or £1000 per year for a household of four.[59]

For this report, food is defined as any substance—whether processed, semi-processed, or raw—intended for human consumption.[60] The definition includes drink and any substance that has been used in the manufacture, preparation, or treatment of food. The terms ‘food’ and ‘food and drink’ are used interchangeably throughout this paper. In common with agreed guidance on interpreting Sustainable Development Goal Target 12.3 (relating to food waste and losses), both inedible and edible parts of food are considered in scope when discussing resource efficiency measures in this report. The ‘inedible’ parts are the components, in a particular food supply chain, which are not intended to be consumed by humans, e.g., bones, rinds, and pits/stones. However, it is acknowledged that what is considered inedible varies across different users and over time.[61]

Food waste is defined as the “removal from the food supply chain of food which is fit for consumption, by choice, or which has been left to spoil or expire as a result of negligence by the actor”.[62] In the UK context, the definition of food waste usually excludes any material that is sent for redistribution to people, animal feed or conversion into industrial products. Instead, food sent to these routes is collectively referred to as “food surplus”.[63] Nonetheless the “food waste hierarchy” applies to both food waste and food surplus, and prevention of both waste and surplus is the most resource efficient option in all cases.[64] This report makes this distinction between surplus and waste in the context of measure 8, where redistribution is accounted for specifically. However, in other areas of the report, when the focus is on prevention of both surplus and waste, the ways in which surplus/waste is avoided are typically grouped together for discussion.

Sector scope

The scope of this report covers resource efficiency measures applicable to stages of the food and drink supply chain after harvesting (including any immediate processing of harvested products). Specifically, the supply chain stages considered in scope are: processing and manufacturing; storage and distribution; retail; hotels, restaurants and catering (HoReCa); consumers; and end of life management. Significant resource efficiency savings (both in terms of food losses and reductions in inputs) may be achievable pre-harvest but are not a feature of this study. Additionally, the focus is on the production and consumption of food and drink as physical products, rather than wider resource efficiency measures available in the sector such as those to packaging or logistics.

The following topics are, therefore, out of scope of this study:

[59] WRAP (2023). Household Food and Drink Waste in the United Kingdom 2021-22.
[60] Hanson, C. (2017). Guidance on Interpreting Sustainable Development Goal Target 12.3.
[61] Hanson, C. (2017). Guidance on Interpreting Sustainable Development Goal Target 12.3.
[62] Food and Agriculture Organization of the United Nations (2014). Definitional Framework of Food Loss.
[63] WRAP (2020). Food surplus and waste measurement and reporting UK guidelines.
[64] Defra (2024). Food and drink waste hierarchy: deal with surplus and waste.

- Primary production: based on discussions between the project team, Defra and DESNZ, it was decided that the scope boundary for this research would be drawn at the point of harvest of food. Therefore, all stages of the value chain from the processing of harvested food, through to end of life management are considered in scope, while primary production of food, as well as any inputs to primary production, are considered out of scope. It is acknowledged that some primary production decisions and buyer requirements on primary producers may impact subsequent processing options and supply chain efficiency; these are in scope if they lead to waste that arises later in the supply chain than the farm gate.
- Dietary shift: based on discussions between the project team, Defra and DESNZ, it was decided that changes to diet composition and, in particular, dietary shift and moving from meat products to alternative proteins is out of scope for this research, considering the research is focused on resource efficiency defined as lower resource use for a given level of final consumption.
- Over-consumption: based on discussions between the project team, Defra and DESNZ, it was decided that measures related to reducing overconsumption of food and drink by consumers are not in scope for this study, considering the research is focused on resource efficiency defined as lower resource use for a given level of final consumption.
- Food packaging: food packaging was considered out of scope for the food and drink sector, as the most common food packaging materials are covered by other sectors included in the wider resource efficiency research programme (e.g., plastic, glass, paper). However, it is assumed that resource efficiency measures in the other sectors do not result in the deterioration of the product protection provided by food and drink packaging. Conversely, scope to innovate in packaging to reduce food and drink loss and waste (for example, by extending product shelf-life in store or at home) is within the scope of this study, but any wider packaging material trade-offs this may imply are not directly considered.
- Energy efficiency: not considered in scope for this study as it is considered in other studies outside of this research programme.

It is worth noting that food and drink are organic materials, representing a bioeconomy resource loop, making them different in nature to other products under examination using the common study methodology outlined for this research programme. While some of the resource efficiency measures defined in this paper are presented as relating to a particular stage in the food and drink supply chain, in reality, the sector is highly interconnected, and actions required for the implementation of the measure will sit across multiple parts of the supply chain and connect to wider economic and environmental considerations beyond the scope of both this paper and even the wider research programme.

7.2 List of resource efficiency measures

Table 17 shows the resource efficiency measures identified for the food and drink sector.

The resource efficiency measures identified are applicable across each stage of the food and drink supply chain. They reflect how resource efficiency could be improved at each stage of the supply chain, to varying extents. All the measures apply to post-harvest stages as pre-harvest production is out of scope for this study.

A series of indicators was selected for Measure 8, reflecting the share of post-farm gate food surplus and waste diverted to each option in the UK food and drink surplus and waste hierarchy.

Table 17: List of resource efficiency measures for the food and drink sector

#	Lifecycle stage	Strategy	Measure name	Measure indicator
1	Manufacturing	Production efficiencies	Use of by-products in other products	% of production waste valorised
2	Manufacturing	Production efficiencies	Optimising processing to reduce product losses	% of total production that is wasted
3	Distribution	Production efficiencies	Reduction of food waste in distribution and storage	% of food that is distributed that is wasted
4	Pre-processing & Retail	Life extension	Reduction in food waste due to revised product standards	% of harvested food that is wasted due to product standards
5	Retail	Reduced waste generation	Reduction of food waste in retail	% of food at the retail stage wasted
6	Consumer	Reduced waste generation	Reduction of food waste amongst households	% of food purchased by consumers that is wasted in the home
7	HoReCa	Reduced waste generation	Reduction of food waste in HoReCa	% of food in HoReCa that is wasted
8	End of life		End of life practices according to the UK food and drink surplus and waste hierarchy	% of post-farm gate food surplus that is redistributed (option 2 in the UK food and drink surplus and waste hierarchy) Percentage of post-farm gate food surplus and waste that is made into animal feed (option 3 in the UK food and drink surplus and waste hierarchy)

				Percentage of post-farm gate food surplus and waste that is made into biomaterials (option 4 in the UK food and drink surplus and waste hierarchy) Percentage of post-farm gate food surplus and waste that is sent to anaerobic digestion (option 5 in the UK food and drink surplus and waste hierarchy) Percentage of post-farm gate food surplus and waste that is sent to composting (option 5 in the UK food and drink surplus and waste hierarchy) Percentage of post-farm gate food surplus and waste that is used for landspreading (option 6 in the UK food and drink surplus and waste hierarchy) Percentage of food waste that is sent to energy from waste (option 7 in the UK food and drink surplus and waste hierarchy) Percentage of post-farm gate food surplus and waste that is sent to sewer and landfill (option 8 in the UK food and drink surplus and waste hierarchy)

7.3 Drivers & Barriers

Throughout the research, a range of drivers and barriers were identified for each of the measures. The most important ones are listed in Table 18.

Table 18: Top drivers and barriers for the food and drink measures

#	Measure name	Top drivers	Top barriers
1	Use of by-products in other products	Revenue generation. Cost savings. Setting a food waste reduction target.	The market price of the product obtained, relative to the cost of the manufacturing process. Lack of information on the viability and performance at the industrial scale.
2	Optimising processing to reduce product losses	Avoided costs. Continuous improvement programmes. Setting a food waste reduction target.	Poor operational practices. Poor instrumentation and controls.
3	Reduction of food waste in distribution and storage	Avoided costs. Simple education measures for workers. Setting a food waste reduction target.	Complex ownership arrangements.
4	Reduction in food waste due to revised product standards	Changing consumer preferences and awareness.	Perception that consumers will only buy products to a particular standard. Reputational risk.
5	Reduction of food waste in retail	Supply chain actors working in partnership with redistribution organisations. Dynamic markdown of products. Setting a food waste reduction target.	Trade-off between availability and waste. Poor demand forecasting.

6	Reduction of food waste amongst households	Food prices. Consumer choice and information environment.	Pricing strategies. Recursion in behaviour.
7	Reduction of food waste in HoReCa	Incentivising and training staff to take action to reduce food waste. Setting a food waste reduction target.	Contradictory incentives. Consumer perception . Lack of food waste measurement and reporting.
8	End of life practices according to the UK food and drink surplus and waste hierarchy	Improved redistribution of surplus food to humans and animal feed. Investment in separate collection and (re)processing infrastructure.	Regulation around the uses of food waste . Lack of investment in separate collections and (re)processing infrastructure. UK policy environment.

Establishing a goal for reducing food waste is the most common top driver across resource efficiency measures. Such a target not only sharpens the focus on objectives but also enhances the visibility of the food waste issue. Furthermore, it imposes a higher level of accountability on companies. Cost savings, achieved by reducing the costs related to byproduct waste disposal and product wastage, are common drivers.

Consumer perception presents a significant barrier across several measures, emphasising the influence of the consumer at various points in the supply chain. Various participants in the supply chain, such as consumers, employees and managers, are unable to contribute to food waste reporting and reduction efforts if they lack understanding of the significance and need for these initiatives. The critical role of awareness is demonstrated by its recurring presence as both a driver and a barrier in several measures.

7.4 Levels of efficiency

Table 19 provides a summary of the levels of efficiency (and the evidence RAG rating in italics) for the eight identified measures of the food and drink sector.

Table 19: Levels of efficiency and evidence RAG rating (*in italics*) for food and drink measures

#	Measure name	Indicator	Current	Maximum in 2035	BAU in 2035
1	Use of by-products in other products	% of production waste valorised	60 – 90% *Red*	80 – 100% *Red*	60 – 90% *Red*
2	Optimising processing to reduce product losses	% of total production that is wasted	2 – 5% *Green*	2 – 3% *Amber*	2 – 5% Amber
3	Reduction of food waste in distribution and storage	% of food that is distributed that is wasted	1 – 4% *Amber-Green*	0.9 – 3.8% *Amber*	1 – 4% *Amber*
4	Reduction in food waste due to revised product standards	% of harvested food that is wasted due to product standards	2-5%[65] *Red*	2-3% *Red*	2-5% *Red*
5	Reduction of food waste in retail	% of food at the retail stage wasted	>0 – 1.5% *Green*	>0 – 0.95% *Red-Amber*	>0 – 1% *Red-Amber*
6	Reduction of food waste amongst households	% of food purchased by consumers that is wasted in the home	15 – 20% *Green*	5 – 13% *Amber*	15 – 23% *Red-Amber*
7	Reduction of food waste in HoReCa	% of food in HoReCa that is wasted	18% *Amber-Green*	5 – 12.6% *Amber*	15 – 17.6% *Red*
8	End of life practices according to the UK food and drink surplus and waste hierarchy	% of post-farm gate food surplus that is redistributed (option 2 in the UK food and drink surplus and waste hierarchy).	1% *Red-Amber*	<10% *Red*	<5% *Red*

[65] It should be noted that this estimate is based on stakeholder consensus from the workshop, but some of the evidence sources reviewed suggest much higher levels of loss, especially during on farm sorting. There may also be significant variance by product.

		Percentage of post-farm gate food surplus and waste that is made into animal feed (option 3 in the UK food and drink surplus and waste hierarchy).	7% *Red-Amber*	14-20% *Red*	<10% *Red*
		Percentage of post-farm gate food surplus and waste that is made into biomaterials (option 4 in the UK food and drink surplus and waste hierarchy).	20% *Red-Amber*	<40% *Red*	<30% *Red*
		Percentage of post-farm gate food surplus and waste that is sent to anaerobic digestion (option 5 in the UK food and drink surplus and waste hierarchy). AND Percentage of post-farm gate food surplus and waste that is sent to composting (option 5 in the UK food and drink surplus and waste hierarchy)[66]	14% *Red-Amber*	<30% *Red*	<20% *Red*
		Percentage of post-farm gate food surplus and waste that is used for landspreading (option 6 in the UK food and drink surplus and waste hierarchy)	<=19% *Red-Amber*	<=19% *Red*	<=19% *Red*
		Percentage of food waste that is sent to energy from waste (option 7 in the UK food and drink surplus and waste hierarchy)	<=19% *Red-Amber*	<=19% *Red*	<=19% *Red*

[66] Unable to separate results for indicators based on the data available.

		Percentage of post-farm gate food surplus and waste that is sent to sewer and landfill (option 8 in the UK food and drink surplus and waste hierarchy)	19% *Red-Amber*	0-5% *Red*	15-19% *Red*

General insights

Across most of the measures identified in the food and drink sector, the BAU level of efficiency was very similar to the current level of efficiency, indicating that without major intervention, the level of efficiency is likely to remain the same across many measures. There are a couple of measures for which the BAU is an improvement on the current level (Measure 5 and 7), suggesting that improvements are likely to be made without intervention, yet there is still potential room for improvement to reach the maximum. A key driver in these two areas is setting of food waste targets, which has already been done by many organisations in retail and HoReCa. The BAU level for Measure 6 reflects potential for a marginal increase in food waste, although the evidence supporting this is lacking.

Many of the reported maximum levels efficiency across the various measures could be considered as theoretical maximums, which could not be reached in practice, due to the complex web of actors involved and the scale and comprehensiveness of behaviour change that is necessary to reach these levels.

Overall, the RAG ratings levels of efficiency across the various measures are poor. There are many red and amber ratings and very few green ratings. The low quality and availability of evidence is in part due to the complexity of the food system and the high variability in the level of efficiency across different food and drink subsectors and products.

Measure-specific insights

Measure 1 – There was very limited quantitative evidence from both interviews and literature review available on the current, maximum and BAU levels of efficiency. This was due to the high variability in the level of efficiency across different food and drink subsectors and products. High estimates with given in workshops by stakeholders but, as anaerobic digestion is not in scope for this measure, these estimates were adjusted down due to the potential conflation of by-products and anaerobic digestion in these estimates.

Measure 2 – The current, maximum and BAU levels of efficiency were very similar to each other for measure 2, with the maximum level of production food wasted being slightly lower, indicating marginal room for improvement. The level of efficiency for different food groups will also vary for particular food groups, with fresh food and drink posing greater challenges in general, compared to ambient foods. The current level of efficiency was given a green RAG rating, while the maximum and BAU were given amber.

Measure 3 – There was very limited to no quantitative evidence available on the current, maximum and BAU level of efficiency for Measure 3. Stakeholders agreed that there is room for marginal improvement which was reflected in the reported maximum level of efficiency. Overall, all reported levels of efficiency were very similar. As there was some literature available for the current level of efficiency and stakeholder agreement, this was given an amber-green RAG rating. Maximum and BAU reported levels of efficiency were given an amber RAG rating due to stakeholder agreement in lieu of substantial quantitative evidence.

Measure 4 – There was very limited quantitative evidence available on the current level of efficiency for Measure 4. There was limited quantitative evidence available on the maximum and BAU levels of efficiency. As there is uncertainty about the current baseline, the stakeholder estimate reflects an assumption there will be minimal change in the business-as-usual scenario. However, there was agreement among stakeholders that there may be scope for reductions, which is reflected in the slightly lower reported maximum level. This uncertainty and general lack of quantitative evidence meant that all levels were given a red RAG rating.

Measure 5 – There was reliable data available on the current level of efficiency for measure 5, which was given a green RAG rating. Stakeholders added that food waste is quite low but this is in part due to retailers pushing the occurrence of waste outwards through the supply chain to manufacturers and consumers. The RAG ratings for the maximum and BAU levels were poor in comparison. There was limited evidence from literature and stakeholders on the maximum and BAU, but workshop participants agreed there would be a slight improvement in both.

Measure 6 – Measure 6 also had reliable data on the current level of food wasted by households, which was given a green RAG rating. Stakeholders mentioned that this level could be slightly lower recently, given current inflation. Maximum levels of efficiency varied somewhat across literature and stakeholders. Participants agreed that a significantly lower level of food waste is possible, however the lower bound of this is arguably theoretical rather than actually achievable, due to the potentially unrealistic scale and comprehensiveness of behaviour change that is required to meet this. There was very limited evidence for the BAU level for this measure. If historical data is extrapolated, there may be an increase, which is reflected in the reported level of efficiency. However, a red-amber RAG rating was given here due to the lack of evidence.

Measure 7 – An amber-green evidence RAG rating was given to the current level of efficiency for this measure because although a quantitative estimate is available from a high-quality source, with support from stakeholders, this waste stream is challenging to measure, and no supporting estimates were provided by the stakeholders interviewed. Evidence from literature suggests an improvement in the maximum level of efficiency, although, this is also potentially unrealistic to be achieved in practice, even with very aggressive measures. There was very limited quantitative evidence available on the BAU level of efficiency in 2035. Only one stakeholder could provide a quantitative estimate, although, other stakeholders argued this would be lower. The reported BAU level is marginally lower than the current level, but still significantly higher than the maximum. The limited evidence for both maximum and BAU is reflected in their RAG ratings.

Measure 8 – Literature provided breakdowns of quantitate data on treatment routes and food flows in the UK, however there were inconsistencies across publications. Therefore, the more recent data is interpreted as a better reflection of current efficiency levels. Stakeholders found it difficult to provide quantitative estimates for the current level of efficiency of Measure 8 indicators. Stakeholder suggestions were inconsistent with data collected in the literature review. Stakeholders agreed with estimates for most options but disagreed with estimates for options 2 and 3. The current level was given an amber-red RAG score given there was some evidence, with inconsistencies across literature sources and stakeholder opinions.

There was very limited quantitative evidence available on the maximum level of efficiency in 2035 for Measure 8. The literature sources reviewed only provided quantitative evidence relevant to the indicator for the percentage of post-farm gate food surplus and waste that is redistributed, which indicated significant improvements are possible. However, there is likely significant variation across food product types in the potential for increased redistribution. Stakeholder workshop participants largely agreed with each other on the estimated ranges for the maximum level of efficiency for this measure.

There was also very limited quantitative evidence available on the BAU level of efficiency in 2035 for Measure 8. Stakeholder workshop participants largely agreed with each other on the estimated ranges for the business-as-usual level of efficiency for this measure. The reported estimates for maximum and BAU levels were given a red evidence RAG rating, due to the lack of supporting quantitative evidence available from the literature reviewed or stakeholder interviews.

8.0 Textiles

This section summarises the key findings regarding the list of resource efficiency measures, the top drivers and barriers for each measure, and the levels of efficiency (and associated evidence RAG ratings) for the textiles sector. The complete findings are presented in the Unlocking Resource Efficiency: Textiles Report. As noted in the Technical Report, the methodology used for the textiles sector did not include stakeholder interviews as the research was conducted in Phase 1 (see Unlocking Resource Efficiency: Technical Report).

8.1 Sector introduction

The textiles sector plays a significant role in the UK economy and is a key element to consider in the move towards more resource efficient production. In 2020, the sector employed 500,000 people and contributed almost £20 billion to the UK economy.[67] International supply chains, which are often long and complex, combined with import and export dependencies, provide significant challenges for identifying and implementing resource efficiency measures.

The textiles lifecycle comprises a long and complex value chain, from the production of polymers and fibre all the way through to disposal. There are a significant number of manufacturing stages in the supply chain, numerous means by which textiles are placed on the market and "consumed" and various options for end of life management to divert textiles from disposal.

Each aspect of the value chain provides opportunities for improvement. The stages that are most applicable to the UK include:

- Fibre, fabric and product supply chain (design and manufacture);
- Sale and use; and
- End of life.

The global textiles industry contributes more to greenhouse gas emissions than international flights and maritime shipping combined.[68] There is great potential for resource efficiency and decarbonisation within the sector. Current practices across the textile lifecycle are resource-intensive, which leads to impacts beyond emissions, such as poor resource management, biodiversity loss and water, soil and air pollution. The global nature of textile value chains means that all impacts (positive and negative) occur both within the UK and internationally.

While there are an abundance of resource efficiency measures identified within the literature, the majority are discussed qualitatively. This is largely attributed to a general lack of representative, publicly available data to quantitatively assess resource efficiency. There is

[67] UKFT (2021). UKFT's compendium of industry statistics and analysis 2020 – Executive Summary. Available at: link
[68] Ellen MacArthur Foundation (2017). A new textiles economy: Redesigning fashion's future. Available at: link

also little information generally on the involvement of novel approaches that have yet to be implemented for textiles, which makes it difficult to quantify the measures. The resource efficiency measures that have sufficient data relate to resource use, waste generation, recycled content, circular business models, product lifetimes and waste management. These resource efficiency measures can be implemented simultaneously across the various stages of the textile lifecycle, offering multiple opportunities for decarbonisation.

Sector scope

To ensure that the resource efficiency measures being identified were able to provide the most significant impact in improving resource efficiency and to facilitate the effective establishment of resource efficiency measures, it was first necessary to limit the scope of fibres, fabrics and products.

The scoping exercise considered both perspectives of production and consumption, targeting the largest quantities produced and/or placed on the market for key fibres, fabrics and products. For example, while clothing is not produced in large volumes within the UK, it is by far the largest category of textile products that are consumed. According to WRAP, 1.7 million tonnes of textiles were consumed in the UK in 2018, of which 1.04 million tonnes were clothing.[69]

Any resource efficiency measures relating to clothing consumption would hence result in significant impacts and so were included. As understanding grows and gaps are addressed, the scope can be expanded. The initial sector scoping was agreed with the Project Team and the key fibres, fabrics and products that were identified as in scope are shown in Table 20.

Table 20: Textiles sector scoping

	Fibres	Fabrics	Products	Other Materials
In scope	Cotton Polyester Wool	Knitted Woven Non-woven	Clothing (in particular tops, dresses, trousers, skirts & tights) Sheets & bedding Carpet Curtains	Dyes High-volume finishing chemicals Water
Out of scope	Cellulosics Other plant-derived fibres, e.g. hemp Other synthetic fibres, e.g. nylon		Footwear Accessories Other home textiles, e.g. towels Technical Textiles	Other chemicals

[69] WRAP (2021). Textiles market situation report 2019. Available at: link

	Other animal-derived fibres, e.g. leather			

The literature review and workshops looked to identify data aligned with the in-scope materials and products. It is important to note that in many cases, this level of granularity was not available either in the literature or from stakeholders, necessitating estimates on resource efficiency to be made for groups of in-scope materials (e.g. "fabrics" rather than individual data points for knitted, woven and non-woven materials).

8.2 List of resource efficiency measures

Table 21 shows the resource efficiency measures identified for the textiles sector.

Table 21: List of resource efficiency measures for the textiles sector

#	Lifecycle	Measure Name	Measure Indicator
1	Manufacture	Implement efficient product manufacturing processes	% of waste generated during manufacturing
2	Manufacture	Reincorporate production wastes back into manufacturing	% of yarn and fabric/textile material waste reincorporated back into manufacturing
3	Manufacture	Utilise recycled content from textiles waste	% of fibre sourced from waste recycling, for use in new textiles
4	Sale	Utilise rental and product-as-a-service consumption models	% reduction in consumption of new products through rental, hiring and subscription services
5	Sale / Use	Resell/Reuse of unsold stock and second-hand products	% reduction in consumption of new products through clothing reuse
6	Use	Repair products	% reduction in consumption of new clothing through repair
7	End of life	Recycle post-consumer (PC) textiles and unsold stock not suitable for reuse	% recycling rate of clothing, household bedding, curtains and carpet

The textiles lifecycle comprises a long and complex value chain, from the production of polymers and fibre all the way through to disposal. There are a significant number of manufacturing stages in the supply chain, numerous means by which textiles are placed on the market and “consumed”, and various options for end-of-life management to divert from disposal.

Of the identified measures for the textiles sector, two are on the manufacturing side, one is in the design phase (use of recycled content), three measures are in the sale and use stage, and one measure is in the end-of-life stage.

There are a higher number of measures within the sale and use sectors, compared to other sectors perhaps, which can be explained by the nature of the sector: it mostly operates on a business-to-consumer model; there are significant quantities of unsold stock being disposed of; the products have short lifespan as the products are highly seasonal and are influenced by fashion trends; and the products are easy to transport. These factors have resulted in a diversity of sales and use models such as rental, product-as-a-service, consumer-led and business-led reuse, and repair.

8.3 Drivers & Barriers

Throughout the research, a range of drivers and barriers were identified for each of the measures. The most important ones are listed in Table 22.

Table 22: Top drivers and barriers for the textiles measures

#	Measure name	Top drivers	Top barriers
1	Implement efficient product manufacturing processes	Production on demand well-received by distance shoppers and consumers who require non-standard sizing.	Lack legislation for compliance, e.g. introducing targets for lay plan. efficiencies, international standards. Digital design is currently used for low value, high volume products – a scenario which will never be financially viable in the UK. Making it viable requires more collaboration. Lack of training and incentivisation of factory employees. Transparency of the supply chain may hinder these indicators. Potential impact of greenwashing. Mass customisation has not yet become a reality.
2	Reincorporate production wastes back into manufacturing	Improved connections between manufacturers and recyclers to funnel waste management.	Lack of recycling technology, particularly for mixed fabrics. Yarn recycling largely unexplored in practice and not yet at industrial scale. Lack of established market for production wastes. Recycling fabric back to fibre may often be unfeasible due to accessories/additives that are difficult to dissemble or compromise usability. Lack of coordination and exchange of information across textile value chain. Lack of incentivisation of textile producers and training for employees on waste collection and reincorporation. Woven fabric recycling is more complicated, resulting in yarns of poor recycling efficiency.

			To date, costs to reincorporate are greater than recycling for use in, for example, insulation.
3	Utilise recycled content from textiles waste	Brand commitments to recycled content and decarbonisation targets.	Lack of recycled materials from textile due to a lack of systems and infrastructure. Need sufficient recycled material to replace virgin material. Lack of cost-competitiveness compared to virgin materials.
4	Utilise rental and product-as-a-service consumption models	Design for durability can facilitate rental models due to longer lasting products.	Lack of supporting policies, such as reduced or no VAT or textiles EPR. Renting is not always significantly cheaper than buying new, due to the availability and low cost of fast fashion. Requirement to restructure business models and invest in circular systems. Durable design might impact the ability to recycle/design for recycling (Measure 7 – recycle post-consumer textiles).
5	Resell/Reuse of unsold stock and second-hand products	Better national marketing on what to do with used clothes can drive behaviour change. High environmental value of reuse compared to other end of life circularity processes.	The price of fast fashion makes buying new products attractive. 'Fast fashion' and options produce poor quality items that may not be suitable for reuse or resale. Lack of textile EPR to support the reuse sector. Lack of regulation on unsold stock e.g. requirement on companies to report the quantities of unsold products and their disposal methods - could drive better practices through transparency, implementation of EPR etc.

6	Repair products	The promise of repair from retailers in case of damage, or the offering of lifetime guarantees, and the improved durability that would ultimately emerge from such schemes, could incentivise consumers to shop with them. Repair data from in-house repair services can be fed back into design decisions to enable continuous product improvement.	Repair of cheaper items is challenged by the availability and convenience of low-cost new products on the market e.g., fast fashion. Lack of awareness, general education and skills to conduct repairs individually – requires brand communication and local council initiatives. Challenges of commercial viability in the UK, including labour costs. Lack of VAT reductions on garment repair to encourage the growth of repair. Minimum standards of manufacture can extend the product lifecycle and improve the value of that product to consumers so they would rather wear a repaired item rather than dispose of it.
7	Recycle post-consumer (PC) textiles and unsold stock not suitable for reuse	Commitments from brands and manufacturers to incorporate recycled fibres into product portfolios. Avoidance of incineration/landfill costs. Mono-materials (100% cotton, 100% polyester) and simple blends (polycottons, wool-rich materials) are recyclable through existing recycling technologies. Design for recycling is a key enabler of recycling.	Lack of major recycling infrastructure in the UK. Collection, sorting and pre-processing infrastructure (for example automated sorting) is not in place at commercial scale across the UK and most of Europe. A proportion of post-consumer textiles are without a circular destination due to their fibre composition, the presence of multiple layers and/or non-removal disruptors. Textiles labelling does not support recycling, with information often inaccurate or missing.

A key driver of resource efficiency improvements in the textiles sector is demand from manufacturers or consumers, often driven by a desire to reduce the environmental impact of their actions. For example, a driver of Measure 4 is increased consumer demand for rental/hire services due to their lower environmental impact and lower costs. Another example is Measure 7 where recycling rates are increasing as brands commit to using a greater proportion of recycled content in their products.

Another key driver which cuts across several resource efficiency measures is cost savings. These can be achieved through a reduction in raw material costs (Measure 1), and landfill/waste incineration costs (Measure 7).

However, while cost is a driver for some measures it is also a key barrier to others. This is because the current low cost of new textiles, particularly clothing, means that some more resource efficient options are actually more expensive. This is the case for Measures 4, 5 and 6.

Finally, another key cross-cutting barrier is the need for collaboration between different elements of the value chain (Measure 2), and improved infrastructure for parts of the value-chain that are not yet as developed (Measure 7).

8.4 Levels of efficiency

Table 23 provides a summary of the levels of efficiency (and the evidence RAG rating in italics) for the seven identified measures of the textiles sector.

Table 23: Levels of efficiency and evidence RAG rating (*in italics*) for textiles measures

#	Measure name	Indicator	Current	Maximum in 2035	BAU in 2035
1	Implement efficient product manufacturing processes	% of waste generated during manufacturing	10 – 15% *Amber*	0 – 10% *Red*	0 – 15% *Red*
2	Reincorporate production wastes back into manufacturing	% of yarn and fabric/textile material waste reincorporated back into manufacturing	Yarn: >70% *Amber-Green*	Yarn: >80% *Red-Amber*	Yarn: >75% Red
			Fabric: 0 – 10% *Red*	Fabric: Not identified *Not applicable*	Fabric: 0 – 10% *Red*

3	Utilise recycled content from textiles waste	% of fibre sourced from waste recycling, for use in new textiles	Clothing, bedding: 1% *Green*	Clothing, bedding: Not identified *Not applicable*	Clothing, bedding: 0 – 10% *Red-Amber*
			Carpet, curtains: 1% *Red-Amber*	Carpet, curtains: Not identified *Not applicable*	Carpet, curtains: Not identified *Not applicable*
4	Utilise rental and product-as-a-service consumption models	% reduction in consumption of new products through rental, hiring and subscription services	2% *Green*	9% *Amber*	5 – 9% *Red-Amber*
5	Resell/Reuse of unsold stock and second-hand products	% reduction in consumption of new products through clothing reuse	30% *Amber*	50% *Red-Amber*	40% *Amber*
6	Repair products	% reduction in consumption of new clothing through repair	1% *Green*	5% *Red-Amber*	4% *Red-Amber*
7	Recycle post-consumer (PC) textiles and unsold stock not suitable for reuse	% recycling rate of clothing, household bedding, curtains and carpet	Clothing, home textiles, curtain: 20 – 30% *Amber*	Clothing, home textiles, curtain: 60 – 70% *Amber*	Clothing, home textiles, curtain: 20 – 30% *Red-Amber*
			Carpet: 11% *Red-Amber*	Carpet: Not identified *Not available*	Carpet: 11% *Not available*

General insights

As has been seen in other sectors, for the majority of resource efficiency measures in the textiles sector the BAU level of efficiency is higher than the current level of efficiency, but lower than the maximum level of efficiency. This suggests that some resource efficiency improvements are expected in the absence of any political interventions, but these will not maximise the resource efficiency potential. This is likely to be due to the main cross-cutting driver of the desire to decarbonise and reduce environmental impacts but also because they deliver cost savings which are desirable to manufacturers regardless, for examples Measure 1 and Measure 2. This also suggests that full resource efficiency will not be achieved without a change in the market environment which remove the identified barriers.

Another key insight in the sector, which is different from other sectors in this research, is the difficulty of quantifying the levels of efficiency for some measures. In part, this is because of the diversity of the textiles sector, which covers a wide range of different materials with different properties and potentials. This is in contrast to other sectors which are higher up the supply chain (e.g., cement and concrete and steel), though is similar to the construction sector.

Measure specific insights

Based on the levels of efficiency results, it can be inferred that the greatest potential for resource efficiency improvements is within Measures 4, 5 and 7. For Measure 4 (utilisation of rental and products-as-a-service consumption models), growth is already being seen due to market drivers such as greater consumer awareness and engagement, and the ability to provide higher margins. Key barriers are the widespread affordability of fast fashion and issues in restructuring of business models. Stakeholders noted these could be tackled through supportive policy (VAT reductions, EPR) as well as design for durability. Given the BAU scenario is only 1% lower than the maximum, it could be inferred that a large proportion of the resource efficiency will be delivered through organic market change. For Measure 5 (reuse/resale of unsold stock and second-hand products), key drivers include the growing demand for, and access to, second hand textiles. Several key barriers are limiting the measure from reaching its maximum (40% BAU, 50% maximum), in particular the availability of low-cost fast fashion. A lack of regulation is also cited, in relation to tackling unsold stock. For Measure 7 (recycling of post-consumer (PC) textiles and unsold stock not suitable for reuse), drivers include demand for recycled fibre, and increasing recycling solutions that show promise. However, there are also a significant number of barriers relevant to this measure, resulting in a large gap between the BAU and maximum efficiency scenarios (30 – 50% difference). These include a lack of commercial scale infrastructure in the UK to collect, prepare and recycle textiles; a lack of end-markets; issues in design (fibre composition, presence of disruptors); and issues in accurate labelling in support of recycling.

There is lower resource efficiency potential for Measures 1, 2 and 6. For Measures 1 and 2, while there is uncertainty reflected in the wide ranges of the levels of efficiency, current data suggests there is not a large gap between the current and the maximum (5-10%), and it is likely to be an even smaller gap between the maximum and the BAU levels of efficiency. This fits with comments made by stakeholders that waste generation and recycling has been, and continues to be, a key area of focus for the industry. Measure 6 is expected to provide a benefit to resource efficiency, reducing consumption of new clothing from 1% to between 4% (BAU) and 5% (maximum). However, the economic viability of growing repair is challenged by low-cost fast fashion, labour costs for repair, and insufficient consumer engagement. It is not possible to comment on Measure 3 due to the lack of data.

9.0 Conclusion

This chapter outlines the strategies observed within resource efficiency measures across the seven sectors included in this publication (i.e., plastics, paper, chemicals, electricals, glass, textiles, food and drink). These strategies are described in section 9.1. Section 9.2 describes key themes identified across sectors alongside interdependencies between themes. For completion, themes emerging out of the initially published reports (i.e., all eleven industrial sectors: the above, as well as cement and concrete, construction, steel, vehicles) have been included.

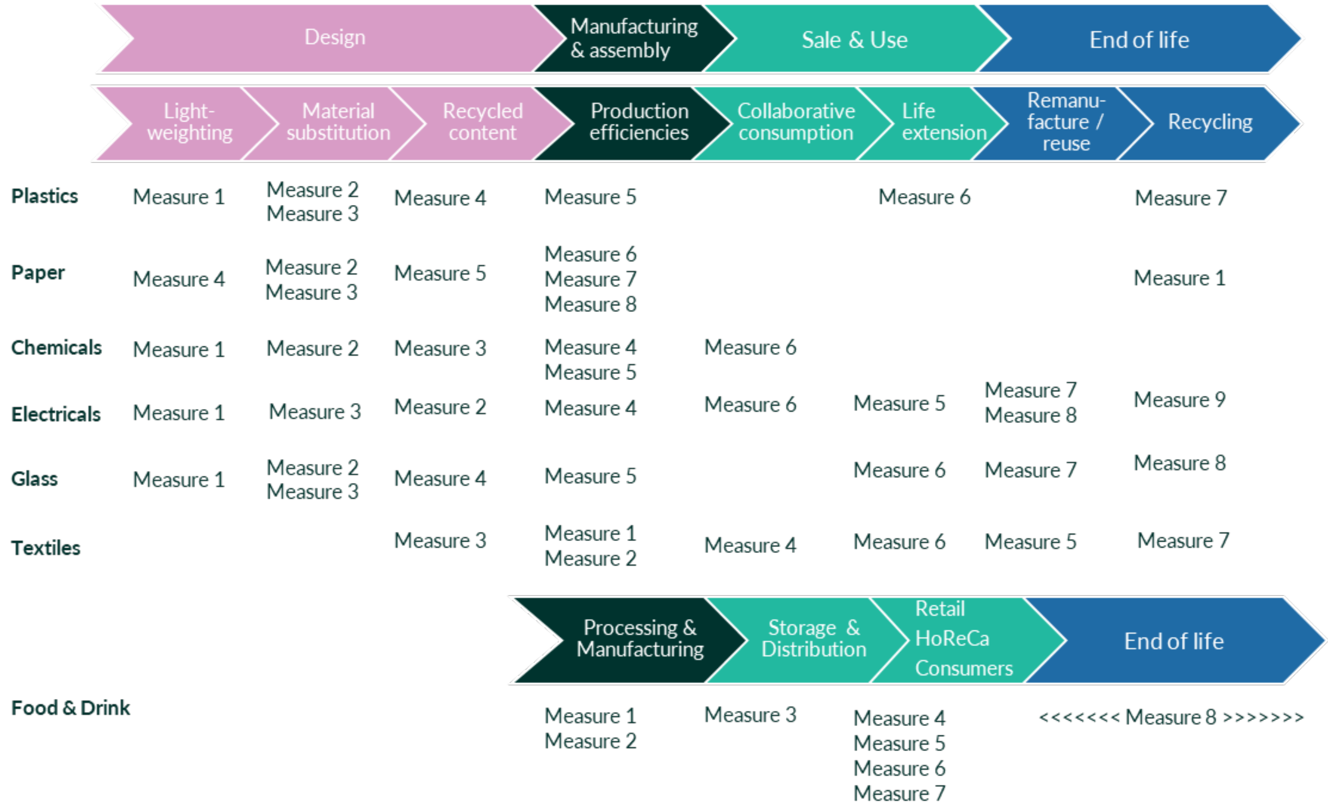
A summary of findings of the Phase 1 sectors only can be found in the 'Phase 1 Executive Summary'.[70]

9.1 Strategies across resource efficiency measures

All the identified measures across six of the seven Phase 2 sectors have been categorised into one of eight resource efficiency strategies. Measures in the food and drink sector have been classed into a different classification system (four resource efficiency strategies), due to the unique nature of the sector.

[70] Gov.uk (2023) Unlocking Resource Efficiency: Phase 1 Executive Summary. Available at: link.

Figure 4: Mapping of sector measures under the lifecycle phases and resource efficiency strategies



Further description of resource efficiency categories is included in Annex A. An overview of resource efficiency strategies of Phase 1 sectors is included in Annex B.

Comparing the different measures in each strategy across Phase 2 sectors reveals the following insights:

- **Light-weighting** can take place in almost all sectors, with the exception of the textiles and food and drink sectors. The remaining five sectors (plastics, paper, chemicals, electricals, glass) benefit from light-weighting efforts, with varying potential for resource efficiency gains. Examples of specific measures for each of these sectors are summarised as follows:
    - Plastics has one light-weighting measure (Measure 1) referring to lean design of plastic products applicable to the packaging industry. However, the lean design of plastic products was not deemed to be an applicable intervention to the construction, automotive, textiles or electronics sub-industries using plastic materials.
    - In the electricals sector (Measure 1), the potential for light-weighting interventions covering different material types (such as metals) is focused on specific product groups, while other product groups (such as larger appliances) are seeing trends of increasing product weights.

  - In the paper sector, light-weighting can cover both raw materials pre-processing and fully formed products (such as cardboard boxes), with future resource efficiency improvements for this measure likely to be slower following a several decades of more significant mass reduction interventions (Measure 4).
  - Light-weighting in the chemicals industry covers interventions focused on increasing chemical concentration formulas and improving formula quality to achieve comparable results with lower product use, though this is mainly focused on niche applications in the context of existing high levels of optimisation across sub-sectors (Measure 1).
  - In the glass sector, light-weighting potentials mainly focus on container glass and glass wool (Measure 1), with limited applicability to construction flat glass and no applicability to automotive flat glass.
- **Material Substitution**[71] was identified across five of the seven sectors, with significant interactions between the plastics, paper and glass sectors resulting in a complex opportunity landscape for resource efficiency.
  - Three sectors (plastics, paper, glass) have more than one material substitution measure, as these refer to substitutions made within the primary (focus) sector as well as substitutions made between sectors. This includes, for example, substituting fossil-based plastic feedstocks with bio-based, durable plastic, including drop-in and novel polymers (i.e., substitution within one sector). On the other hand, it also includes the substitution of plastics into glass (material moving out of the plastics sector) and glass into plastics (material moving into the plastics sector as a result of material substitutions in the glass sector).
  - The plastics sector has two material substitution measures discussing the substitution of plastic with non-plastic materials (such as paper, glass, aluminium and steel) and feedstock substitution with bio-based materials (including both drop-in and novel polymers) – Measure 2 and 3.
  - Measure 2 within the paper sector covers both material substitution of paper with alternative materials in packaging and non-packaging applications as well as the avoidance of the use of paper altogether (i.e., dematerialisation). The substitution of virgin feedstock for other materials in the pulp and papermaking process is covered by Measure 3.
  - Similarly, in the glass sector, two measures covering material substitution were identified. These cover the substitution of glass products with non-glass products (Measure 3) and the substitution of raw materials with lower embodied carbon alternatives (Measure 2).
  - Potential for resource efficiency through material substitution in the chemicals sector covers the substitution of virgin fossil-based organic feedstocks with alternative organic feedstocks (Measure 2), while in the electricals sector, the

[71] As discussed in the introduction, material substitution does not meet the definition of resource efficiency but is considered in scope of this study.

substitution of fossil fuel-based plastics with bio-based plastics has been identified as an important resource efficiency measure.

- The **use of recycled content** (or secondary raw materials) is common across six out of the seven sectors (food and drink excluded) with all sectors having one measure for this strategy.
    - In the chemicals sector, increasing the use of secondary, post-use material content in chemicals production is included as Measure 3, covering the use of secondary materials that have already served their primary purpose. This is distinct from the use of by-products from chemical reactions or unused reagents from chemicals processes which is covered under collaborative consumption (Measure 6).
    - Similarly, in the plastics sector, the resource efficiency strategy identified is the use of post-consumer recycled content from mechanical or chemical recycling processes in plastic products (Measure 4).
    - The use of recycled or secondary inputs to the manufacture of pulp and paper products is a key resource efficiency strategy (Measure 5), though trade-offs with light-weighting (Measure 4) can occur when recycled content weighs more than virgin material.
    - In the textiles sector, the incorporation of reprocessed fibres sourced from textile waste during the manufacturing stage represents a key resource efficiency strategy (Measure 3).
- **Production efficiencies** are present in all sectors (including food and drink). Three sectors (chemicals, textiles, food and drink) feature two production efficiency measures, and one sector (paper) features three. This reflects the more traditional approaches to resource efficiency, focused on improving manufacturing processes. It should be noted that these measures also tend to be those where most progress has already been made in the sector, with the potential for further improvement being lower and slower, due to the fact that new infrastructure is often required to achieve additional efficiencies.
    - In the chemicals sector, maximising the material efficiency of production processes is included as a production efficiency measure (Measure 4), aimed specifically at maximising process yields. Reducing water consumption in chemical processes through increased process efficiencies is included as a separate resource efficiency strategy (Measure 5).
    - Efficiency improvement interventions can be wide-ranging. In the food and drink sector, for example, interventions cover optimising processing to reduce product losses, such as the prevention of contamination to the processing line reducing disposal of product batches; the reduction of processing errors resulting in defect and thus discarded products; the improvement of ingredient ordering to minimise wastage and the improvement of operational practices reducing waste generated due to machinery related issues (Measure 2).

    - In the textiles sector, both the reduction of waste generated during the manufacturing process to increase material yields (Measure 1) and the use of waste created during the manufacturing process as direct feedstock (Measure 2) are highlighted as resource efficiency measures.
- **Collaborative consumption** discusses alternative business models to the traditional approach of one buyer – one user. It is notable that collaborative consumption has a wide remit and can theoretically apply across all sectors. Nonetheless, this report focuses on the strategies identified through the literature and stakeholder workshops. With this in mind, this strategy is present for three sectors (chemicals, electricals, textiles).
    - Maximising the use of by-products through collaborative consumption represents a resource efficiency strategy in the chemicals sector (Measure 6).
    - The increase in update and market penetration of rental or products-as-a-service business models by consumers and business to reduce consumption and increase product lifetimes (linked to lifetime extension measures) has been identified as a key resource efficiency strategy in the electricals sector (Measure 6). Opportunities for leasing electrical equipment particularly exist in the B2B sector where companies require larger quantities of equipment (such as vacuum cleaners leased by a commercial cleaning company).
    - In the textiles sector, an increase in the uptake of rental products-as-a-service business models by consumers to reduce consumption and increase product lifetimes (Measure 4) also forms a key resource efficiency strategy.
- **Lifetime extension** is present in five sectors (plastics, glass, electricals, textiles, food and drink).
    - In the plastics sector, lifetime extension focuses on increasing the utilisation of plastic products that are placed on the market to accomplish multiple rotations of being refilled or reused for the same purpose for which they were conceived (Measure 6).
    - In the glass sector, lifetime extension through the repair of products only applies to automotive flat glass where the use phase of the product can be increased, albeit to a limited extent. However, given that primary manufacturing of flat glass for the automotive industry takes place overseas, the impacts of repair efforts are displaced as resource reduction is achieved outside of the UK (Measure 6).
    - In the electricals sector, repair and refurbishment to enable the restoration of non or poorly functioning products back to a working and satisfactory state extends product lifetimes and delays, or potentially avoids, the purchase of new products (Measure 5).
    - Other resource efficiency strategies for some sectors may also extend product or material lifetimes; light-weighting measures (Measure 1) in the chemicals sector, for example, entail the use of higher quality formulation extending the life of the final product (e.g., longer cycles between coatings).

- In the textiles sector, the utilisation of repair services to extend product lifetimes and prevent the purchase of a replacement product (Measure 6) is highlighted as a lifetime extension strategy.
- In the food and drink sector, lifetime extension measures include the reduction in food waste due to revised product standards, a reduction of food waste in retail, a reduction of food waste amongst households and hospitality, retail and catering (Measures 4 – 7).

- Finally, the **end of life** stage of the lifecycle has different available strategies for the six out of seven sectors with relevant resource efficiency strategies:
  - Plastics is focused on the recycling of post-consumer plastics (Measure 7);
  - Paper focuses on the collection of post-consumer paper and board for recycling (Measure 1);
  - Electricals covers several end of life strategies, including direct reuse of used products (Measure 7), the remanufacture of products (Measure 8) and recycling of end of life electrical products (Measure 9);
  - Equally, glass covers the reuse of glass products (Measure 7) and recycling of post-consumer glass waste (Measure 8);
  - Textiles covers the resale and reuse of unsold stock and second-hand products (Measure 5) and recycling of post-consumer textiles (Measure 7);
  - In the food and drink sector, end of life practices mean food and drink surplus and waste is diverted to its most efficient use according to the UK food waste hierarchy (Measure 8), covering a variety of interventions such as preventing the surplus and waste in businesses, making animal feed from former food, processing surplus into biomaterials, and recovering waste by landspreading.

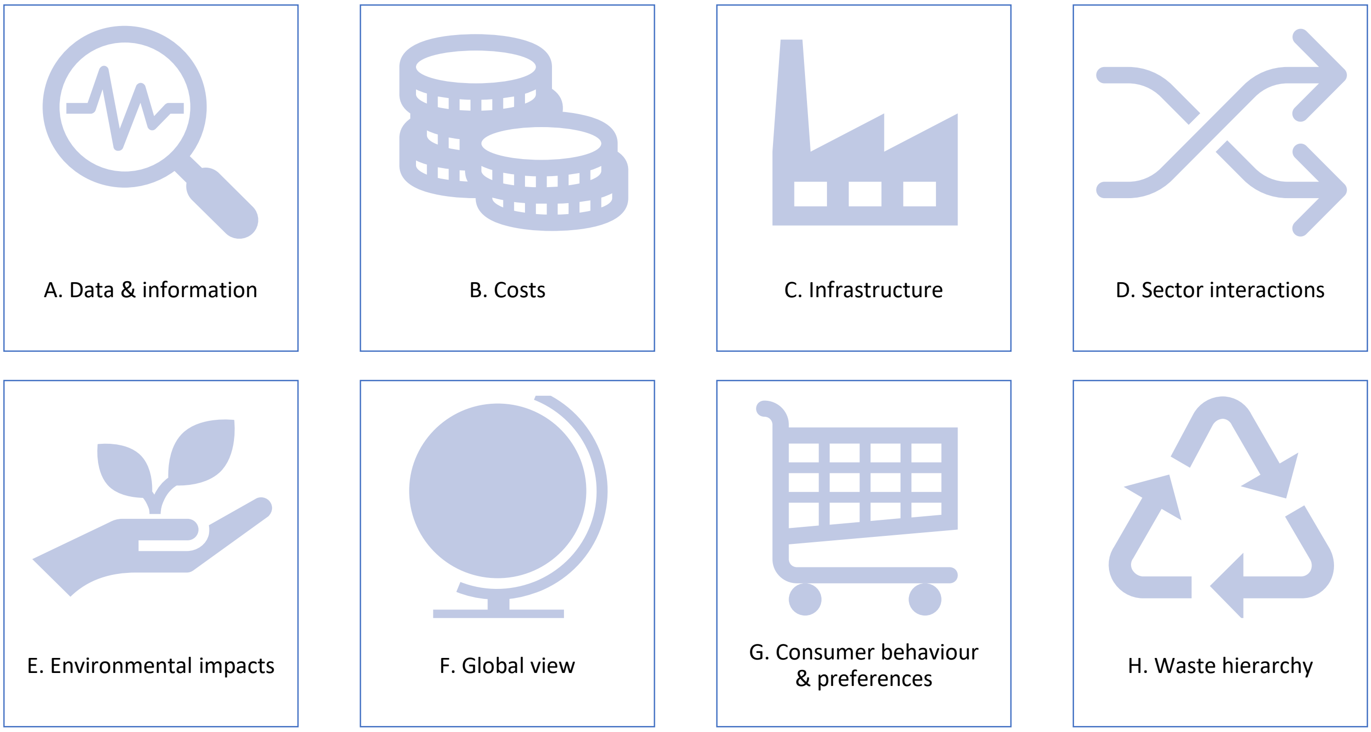
9.2 Themes across resource efficiency measures

There are several topics or themes that have consistently emerged in the literature review and stakeholder engagement for the eleven sectors covered over the course of Phase 1 and 2 of this research.[72]

Figure 5: Key themes across the resource efficiency measures[73]

[72] The 11 sectors are: cement & concrete, construction, steel, vehicles, textiles, plastic, paper, chemicals, electricals, glass, food & drink

[73] Additional themes emerging out of the Phase 1 sectors only can be found in the ‘Unlocking Resource Efficiency: Phase 1 Executive Summary.’, available at: link.



Eight themes have emerged over the course of the research across all eleven sectors. These themes are described below as well as interdependencies between them.

A. Data & information

Stakeholders across all eleven sectors mentioned the importance of having access to reliable data about materials, products and manufacturing processes to allow for evidence-based decision-making to achieve resource efficiency gains. This also includes being able to rely on accurate data to understand the impact of deploying one resource efficiency strategy over another (such as light-weighting vs. lifetime extension) and possible trade-offs between resource efficiency measures.

Across sectors, a lack of data was seen as a barrier across a multitude of interventions, including on recycled content and the use of secondary materials (e.g., plastics Measure 7, construction Measure 1, steel Measure 3, vehicles Measure 3), production efficiencies (e.g., glass Measure 5, plastics Measure 5, textiles Measure 2), processing and manufacturing (e.g., food and drink Measure 1 and 2), lifetime extension (e.g., electricals Measure 5), remanufacture and reuse (e.g., electricals Measure 7, vehicles Measure 8), and recycling (e.g., plastics Measure 7).

For example, improving the proportion of plastic materials recovered and recycled from municipal waste (plastics Measure 7) is dependent on achieving a good understanding of the quantities and types of plastic required. Such data can identify plastic types with particularly low recycling rates that require intervention – such as providing product design guidance, raising consumer awareness, improving recycling infrastructure and setting targets. However, availability of this data is currently limited. Relatedly, the vehicles sector specifically identifies a lack of clarity and robustness of waste data as a barrier to improving the capacity of recycle waste streams generated in vehicle production processes (Measure 5) due to the uncertainty it creates around the components of recycling feedstocks.

Data for waste electrical and electronic equipment is also limited as only one-third of appliances are recovered through appropriate recycling routes in Europe.[74] Waste treatment information for the remaining two-thirds is not well understood, meaning that targets and progress are difficult to monitor (electricals Measure 9). Limited plastic waste recycling data combined with varying recycling calculation methods therefore poses a barrier to effective monitoring and targeting of plastic recycling rates.

The limitations of lifecycle assessments (LCAs) in terms of data reliability and comparability in particular were highlighted as a key barrier to understanding environmental outcomes of different products and materials across sectors. For example, contention exists between LCA studies on reusable products and whether they truly reduce carbon impacts compared to single-use systems and at what level of usage (e.g., Paper Measure 2). In addition, though LCAs are governed by ISO environmental management standards, there can be significant subjectivity when conducting an LCA, particularly when specifying the system boundary of what is included in the study's scope and the parameter values chosen. For example, when comparing the impacts of single-use cardboard boxes with reusable plastic crates, results can vary widely based on how many reuses the crate is expected to achieve and how many are expected to break in the duration of service.

A lack of information on the previous life and use history of secondary material (such as scrap steel or reused construction materials) was mentioned as a barrier to increasing the use of secondary materials in the construction sector (Measure 1) and steel sector (Measure 3 and 8) for the transition from ore-based to scrap-based steel production. In the cement sector, the lack of information on proven long-term durability for novel supplementary cementitious materials (SCM) based concretes was identified as a barrier in Measure 1 (reduction of the total amount of Portland cement used in the production of concrete).

Equally, to understand the impact of material substitution measures both within and between sectors (in particular between the plastics, paper and glass sectors, within which materials are more commonly substituted ‘in’ and ‘out’), a lack of credible data on carbon savings was highlighted as a barrier to resource efficiency interventions in this area (e.g., paper Measure 2 and 3, plastics Measure 2 and 3, glass Measure 2 and 3). Material substitution measures are particularly affected by data gaps as data on the CO2e impacts of the product or material replacement taking place is required to make a robust assessment on the associated resource efficiency.

The exchange of data between different segments of the value chain as well as industry players was also highlighted as a problem in implementing effective resource efficiency strategies. In the chemicals sector, for example, stakeholders noted that the absence of transparency in information about the availability and supply of resources is a barrier to

[74] Circular Plastics Alliance (2020). Circular Plastics Alliance - State of Play on Collection and Sorting: Electronics and Electrical Equipment Working Group.

industrial symbiosis (collaborative consumption, Measure 6). The lack of visibility into resource availability, due to commercial sensitivity, makes it challenging for manufacturers to consistently utilise waste/by-products as a resource. Important by-products generated during manufacturing in one industry or sector may be classified as waste and discarded when in another sector it could represent and important input material for production. This also means key economic opportunities may be missed by the sector creating the by-product considered to be a waste in the first place. In the textile sector (production efficiencies, Measure 2), the lack of coordination and exchange of information across the textile value chain was identified as a barrier to increasing the proportion of yarn and fabric/textile material waste reincorporated back into manufacturing.

On the other hand, stakeholders in the vehicles sector (Measure 5) highlighted a desire within the industry to bridge an existing gap between manufacturers, suppliers and waste contractors, to ensure that the upstream value chain is designing and creating materials that can be captured, reused or recycled by the downstream value chain. Greater collaboration between all elements of the value chain would help improve the range of materials that can be recycled, whilst also opening dialogue to request data lacking on recycled feedstock.

Techniques to improve data such as labelling, digital product passports or even building passports were believed to be an enabler or driver when present, or a barrier when missing. These can be used to convey important information. Material passports are identified as a key driver for steel Measure 8, related to repair, reuse and remanufacturing of steel products, for example. In the electricals sector, increasing digitalisation means electrical products can be digitally tracked and their condition monitored to help optimise servicing and establish when replacement is needed (Measure 6). In the textiles sector, the ability for companies to gather direct customer information was identified as a driver to increase the provision of products-as-a-service business models (Measure 4).

B. Costs

Resource efficiency measures can have economic impacts across the different stages of the value chain, which are ultimately reflected in the final price of the product. The magnitude and direction of these costs varies, depending on the product or process, and may result in certain resource efficiency strategies being favoured over others based on respective cost implications.

In many cases, resource efficiency measures can lead to increased costs, which was identified as a top barrier across all strategies and multiple sectors. For example, cost was mentioned for light-weighting[75], material substitution[76], recycled content[77], production efficiencies[78],

[75] Paper Measure 4, chemicals Measure 1, glass Measure 1, cement and concrete Measure 1, construction Measure 4

[76] Plastics Measure 2 and 3, paper Measure 2 and 3, chemicals Measure 2, electricals Measure 3, glass Measure 2 and 4, cement and concrete Measure 1, construction Measure 2, steel Measure 2

[77] Paper Measure 5, chemicals Measure 3, electricals Measure 2, glass Measure 4, cement and concrete Measure 3 and 4, steel Measure 3

[78] Plastics Measure 5, paper Measure 6, 7 and 8, chemicals Measure 4, electricals Measure 4, glass Measure 5, steel Measure 4 and 5

collaborative consumption[79], life extension[80], remanufacture/reuse[81], recycling[82], and processing and manufacturing[83], storage and distribution[84], food waste reduction[85] and end of life[86].

For example, in Europe, the surging demand for recycled plastic in packaging has led to an escalation in recycled plastic prices, surpassing the cost of virgin plastic in certain cases.[87] This means that the costs of certain virgin materials can be cheaper than that of secondary materials, affecting resource efficiency measures aimed at increased recycled content, for example (e.g., electricals Measure 2). Equally, competition for alternative feedstocks, particularly biomass, from other sectors, including the energy and aviation sectors, mean that a consistent, low cost supply could be difficult to attain for the chemicals sector, combined with uncompetitive pricing of alternative non-fossil fuel-based feedstock (chemicals Measure 2),

Several sectors (e.g., plastics, chemicals, textiles) also highlight the impact of increased competition for recycled material on prices, which can make it difficult to justify the inclusion of recycled content over virgin materials for manufacturers. Competition with cheaper products that do not have circular benefits can also hinder the scale-up of leasing models, for instance, in a context of readily available low-cost products (e.g., electricals Measure 6).

Resource efficiency measures targeting the improvement of production efficiencies heavily cite cost as a barrier due to locked in infrastructure (also see section ‘C. Infrastructure’). The cost implications of process improvements can be significant and prolong the use of less efficient machinery and manufacturing equipment and shift in focus on alternative resource efficiency strategies as an alternative (e.g., paper Measure 6).

Measures aimed at increasing the levels of product repair and refurbishment and extending product lifetimes can be economically obsolete where product replacement is cheaper (e.g., electricals Measure 5). There can also be uncertainty about costs for manufacturers as well as for consumers, affecting uptake of new technologies or behaviours that are more in line with resource efficiency improvements (e.g., refurbishment and repair in the electricals sector, or trialling new technologies in the chemical sector). Renting may not always be cheaper than buying new products; the availability of extremely low cost ‘fast fashion’ in particular poses a significant barrier to resource efficiency strategies in the textiles sector (Measure 4).

In other cases, resource efficiency measures can reduce costs due to reduced requirements for raw materials, driving the uptake of some resource efficiency measures. The potential for cost reduction was mentioned as a driver in several sectors and across resource efficiency

[79] Chemicals Measure 6, electricals Measure 6
[80] Electricals Measure 5, plastics Measure 6, construction Measure 5
[81] Electricals Measure 8, glass Measure 7, steel Measure 8
[82] Electricals Measure 8, glass Measure 8, cement and concrete Measure 6
[83] Food and drink Measure 1 and 2
[84] Food and drink Measure 3
[85] Food and drink Measures 4 – 7
[86] Food and drink Measure 8
[87] Evans, J. (2022) Recycled plastic prices double as drinks makers battle for supplies. Available at: link

strategies, such as light-weighting[88], material substitution[89], recycled content[90], production efficiencies[91], collaborative consumption[92], life extension[93], remanufacture/reuse[94], recycling[95], and processing and manufacturing[96], food waste reduction[97] and end of life[98].

In light-weighting resource efficiency measures, for example, cost savings can be achieved during transportation. Lighter packaging requires less fuel to transport as it reduces the weight of the payload, leading to cost savings in transportation for businesses (e.g., glass Measure 1). Similarly, lower production costs due to reduced material weight were noted as a driver for businesses adopting light-weighting measures in the chemical sector (Measure 1). In the cement and concrete sector, the cost of cement (along with other construction materials) has experienced an unprecedented increase in recent years due to supply chain issues and rising energy prices amongst others. The increased cost of cement was identified as a driver for contractors placing greater value on materials and encouraging leaner design of concrete structures (Measure 4).

In other cases, resource efficiency measures can reduce costs due to the reduced requirements for raw materials, driving the uptake of some resource efficiency measures. In the cement sector, for example, it was noted that substitutes for average clinker and CEM I cement can sometimes be cheaper, with their use providing cost savings to certain manufacturers (Measure 1). While this is not applicable to all substitutes, stakeholders pointed out that additional cost savings might be realised in the future as alternative substitutes become more readily available, increasing the overall supply of SCM's and driving price reductions. This will be amplified as their effects on concrete quality (strength, durability, etc.) are more extensively researched, potentially bringing the use of CEM I in concrete down. Similarly, the future cost of scrap is also identified as a driver of steel Measure 2 (substitution of fossil-carbon reductants with hydrogen direct reduced iron in electric arc furnaces).

In the vehicles sector, the potential for lowering operational costs throughout the product use stage was identified as a key driver in Measure 1 (light-weighting through material substitution) and Measure 2 (light-weighting through reduced vehicle size) due to the impact of reduced fuel costs. Similarly, fuel savings and emissions savings per passenger/mile through increased vehicle occupancy is noted as a driver for vehicles Measure 6 (car-sharing).

In the food and drink sector, the most important driver for the use of by-products in other products is the opportunity to generate additional revenue. When a by-product is utilised in

[88] Plastics Measure 1, paper Measure 4, chemicals Measure 1, glass Measure 1, cement and concrete Measure 4, steel Measure 7, vehicles Measure 2
[89] Electricals Measure 3, cement and concrete Measure 1
[90] Plastics Measure 4, cement and concrete Measure 2 and 3
[91] Paper Measure 7 and 8, chemicals Measure 4, cement and concrete Measure 5, construction Measure 4, vehicles Measure 9
[92] Chemicals Measure 6, vehicles Measure 6
[93] Electricals Measure 5, electricals Measure 5, construction Measure 5, vehicles Measure 7
[94] Plastics Measure 6, vehicles Measure 8
[95] Electricals Measure 9, construction Measure 6, steel Measure 8
[96] Food and drink Measure 1
[97] Food and drink Measures 4 – 7
[98] Food and drink Measure 8

another product, it has economic value and so manufacturers producing a by-product can generate additional revenue directly through its sale, or indirectly through the sale of another product that incorporates the by-product. In some processes, the by-product can become a financially significant part of the overall business model and may be referred to as a coproduct (food and drink Measure 1). In addition, if material can be used in another product, manufacturers can avoid costs associated with waste management, creating an economic incentive to find ways to use material that does not get used for the primary purpose as a by-product in other products.

In the chemicals sector, a key driver for promoting industrial symbiosis (collaborative consumption, Measure 6) is the increased revenue that could be achieved through the sale of industrial by-products. In addition, reduced materials classed as waste can reduce waste disposal costs.

With the possibility of both an increase and decrease in cost for producers (and in some instances, consumers) being possible across resource efficiency measures, a balanced view needs to be taken when evaluating the potential impact of one resource efficiency measure over another within a sector, or indeed, when comparing measures between different sectors. The impact of cost on some resource efficiency strategies will be more pronounced than on others, particularly where large up-front investment is required, such as in upgraded infrastructure (see section C. Infrastructure below).

C. Infrastructure

Improving resource efficiency often necessitates upgrading specific manufacturing machinery or overhauling infrastructure more comprehensively. In addition to the cost implications of the transition to infrastructure enabling resource efficiency (outlined in ‘B. Costs’ above), in many sectors, the pace of change is determined by existing infrastructure and manufacturing sites.

Industries with significant manufacturing sites (e.g., glass, paper, plastics) rely heavily on existing infrastructure creating path dependency and a lag in the sector’s ability to transition to more resource efficient processes. In some cases, the handling of by-products for example would require the setting up of new infrastructure (e.g., paper Measure 7) or closure of existing facilities altogether.

In the chemicals sector, for example, the ability to make process improvements in operational infrastructure can be limited, given the majority of process optimisation occurs during the initial design phase, limiting the scope for major adjustments once the operation is underway (see chemicals Measure 4). Consequently, only products with higher profitability are likely to attract additional investment in required infrastructure because they offer a more favourable return in terms of scale and investment payback periods. Additionally, the infrastructure for extracting, producing and manufacturing raw materials is extremely costly, locking in less efficient processes and creating barriers to technological change.

A key barrier to increasing recycling rates of key materials includes the lack of domestic recycling infrastructure. For example, the UK exports around 19% of its plastic waste to other countries for recycling. However, the export of plastic waste in some cases is destined to low-income countries that lack sufficient recycling infrastructure, making it uncertain whether exported plastic waste is being handled appropriately and recycled. Along with the potential of lost value of unrecycled plastic, negative environmental and human health impacts from exported plastic waste can also arise. For instance, these countries may be more prone to processing plastic waste in ways that have negative impacts on the environment, or the processes used can pose health and safety risks, contribute to climate change from open-air burning and damage ecosystems from chemicals leaching into surrounding soils and waterbodies.[99] Until more plastic recycling capacity is established in the UK, the export of plastic waste for recycling poses a barrier to the confidence and efficiency of plastic recycling (plastics Measure 7).

Similarly, in the textiles sector, despite the capability in some cases of fibre-to-fibre recycling technologies, the lack of systems and infrastructure at scale (e.g., automated sorting, facilities for different fibre types) is currently acting as a barrier to accessing recycled content (Measure 3). In addition, significant industry demand for recycled materials and more costly processes producing these materials will increase the cost of recycled materials in comparison to virgin, another barrier to uptake.

In the chemicals industry, the lack of recycling capacity in the UK to allow for the recovery of key materials, particularly chemicals needed for the energy transition (e.g., 'black mass'[100] from battery reprocessing is currently exported to the Netherlands) presents a barrier to improving resource efficiency in this area (chemicals Measure 3).

The willingness and ability of certain industries to transition away from existing infrastructure can also be informed by the relatively marginal efficiency gains to be made by using new facilities, and the opportunity costs associated with constructing new infrastructure in parallel to maintaining existing infrastructure.

For example, cost implications were highlighted as a barrier to material substitution in the paper sector, which ultimately need to be borne by the manufacturers switching to new material (Measure 2). The design team which is required to make the changes to the material will require potentially extensive time to re-design any products and the logistical team will need to invest time establishing a new supply chain for the material. This may disincentivise material substitutions from being made in the first instance.

Similarly, if alternative feedstocks to production processes are selected in the paper sector, there could be cost and time implications for the company manufacturing the product. Many stakeholders stated that production sites of paper products are designed around the type of pulp that will be used, with specific processing steps required depending on the feedstock used. For instance, if recovered paper is the designated input, a de-inking step will be required,

[99] Letcher, T. (2020). Plastic Waste and Recycling: Environmental Impact, Societal Issues, Prevention, and Solutions. Elsevier Academic Press. ISBN:978-0-12-817880-5.
[100] Mixed substances obtained from lithium-ion battery recycling, which includes valuable materials like lithium, cobalt and nickel.

a process which could not be carried out if a production line was designed for use with virgin inputs. Therefore, making significant changes to the production lines are likely impractical, given the large capital investment that would be required to do so (Measure 3).

D. Sector interactions

As noted in the introduction of this report, the sectors covered by the research presented are not homogenous. While some have material outputs (chemicals, steel, paper, plastics, glass, cement and concrete), others have product outputs (vehicles, textiles, electricals, construction, food and drink). This creates a situation of dependencies between the sectors, where resource efficiency measures that apply to an upstream sector naturally apply to the downstream sector, and vice versa.

Interactions are significant both between whole sectors (e.g., between the plastics and chemicals sectors, or construction and cement and concrete sectors), and specific resource efficiency measures (e.g., between material substitution measures in the plastics, paper and glass sectors).

The plastics and chemicals sectors, for example, are deeply interconnected, with the chemicals sector serving as the primary producer for all plastics products and share a value chain. This means that many of the measures implemented in the plastics sector will have a ripple effect upstream on the chemicals sector and vice versa. For example, if products are designed to be lighter, it will result in lower consumption of chemicals and a reduction in overall material extraction within that sector. Additionally, if recycling rates within the plastics sector increase, the extraction demand for the chemicals to produce these polymers can be expected to decrease. Indeed, every measure that results in a resource efficiency improvement within the plastics sector will have the knock-on effect of decreasing demand for fossil-based plastics feedstocks from the chemical sector. Therefore, it is crucial to consider not only the plastics sector itself but the chemicals sector in tandem as the chemicals sector plays a significant role in the plastics supply chain and can significantly contribute to overall efforts aimed at achieving resource efficiency.

Similarly, the construction sector is intrinsically linked to ‘upstream’ sectors producing construction materials (such as cement and concrete, steel, plastics, paper and glass). Any resource efficiency measures in the construction sector (which reduce the demand for construction materials), will impact demand for these sectors products. Similarly, resource efficiency measures in these upstream sectors will impact the resource efficiency of the materials used by the construction sector. Construction Measure 6 (recovery of building materials for reuse/recycling) is specifically linked to cement and concrete Measure 6 (use of recycled content in concrete) – the supply chain of materials to produce recycled concrete aggregate needs to be secured for certainty in supply. Therefore, if there is a greater supply of construction site waste, then there will be a better supply of materials that can produce recycled concrete aggregate. The same also applies to Measure 3 for the steel sector (transition from ore-based to scrap-based steel production).

Measures encouraging material substitution with the aim of improving resource efficiency in one sector are inextricably linked to those of another sector. For example, a reduction in plastic use through material substitution will result in an increase in consumption of those materials being used to replace plastic products. This includes materials from other sectors within the scope of this project (such paper and glass) and those outside of this project (such as aluminium and cotton). Material substitution will also have lifecycle emissions impacts on the products produced as this intervention will impact key features such as weight, lifespan and recyclability of these products.

Additionally, a material switch within or between sectors may involve a shift toward a reusable/refillable model, such as transitioning from a single-use plastic bottle to a reusable glass bottle, adding significant complexity to understanding the effectiveness and impact of resource efficiency measures in one sector alone. Therefore, understanding material flows between sectors is inherently complex, particularly for certain applications, such as packaging (e.g., multi-material formats). Literature comprehensively assessing the net carbon impact of all material substitutions in the UK does not exist, warranting further in-depth research in this area.

The ability to achieve high levels of resource efficiency for a certain measure in one sector also often depends on gains made in another sector. Measures focusing on the collaborative consumption of resources, for example, require close connection with other industries. For instance, inert chemical waste has the potential to be repurposed in sectors such as construction as filler material or as low carbon concrete. While operators currently seek markets for by-products, enhancing the interaction between industries could further optimise this process, presenting opportunities to create high-value products (chemicals Measure 6).

In the vehicles sector, Measure 1 (light-weighting through reducing vehicle size) could have a significant impact on the steel sector. Due to the large amount of steel involved in the production of vehicles (currently around 50% of typical vehicle weight),[101] light-weighting through reducing vehicle size will have a significant impact on the outputs of the steel industry. Increased use of light-weighting, through reducing vehicle size, could reduce demand of certain materials such as steel. Stakeholders noted that the UK vehicle manufacturing is dependent on steel, particularly where original equipment manufacturers have made commitments to using recycled material.

The use of by-products in one industry or sector by another was identified as a key intervention within resource efficiency strategies. In the paper sector, for example, by-products include paper sludges, rejects, paper ash and black liquor, some of which can be used in energy recovery processes, fuelling parts of the paper or pulping mill itself, as well as other material-based uses (paper Measure 7). Another example of the sharing of resources (or industrial symbiosis) is the supply of gases to the food and drinks sector from the chemicals sector. Waste gas streams can be converted, through bioconversion methods, into zinc cell protein,

[101] Paul Wolfram, Qingshi Tu, Niko Heeren, Stefan Pauliuk, Edgar G. Hertwich (2020) Material efficiency and climate change mitigation of passenger vehicles

which can then be used as feed for salmon. Similar processes are used to produce products like Quorn through bioconversion methods.

In the steel sector, increasing the recovery and use of by-products is a resource efficiency measure in its own right (Measure 6) focused on by-products such as slag, sludge, scrap, dust, tar, process gases and benzol. Blast furnace slag can be used as a material substitute in cement and concrete manufacturing[102], for example, with 46.8% of slag in Europe being used in this way[103]. The second most common use of slag is in road construction (29.8% of slag[104]) where it is used as an aggregate in asphalt[105]. Sludges and dusts can be recovered for their metal content (either iron or alloys) and either reused within the steelmaking process or sold commercially[106]. There is also significant potential for use of steelmaking by-products as feedstocks within the chemicals industry. Benzene, toluene and xylene from coke oven gas can be used in plastic production, and naphthalene can be used to produce electrodes[107]. Lastly, there are also innovative new uses for by-products such as use of slag to protect and restore marine environments, the use of coke-making tar in medical applications, sulphur for agricultural fertilisers, and greenhouse gas removal via enhanced weathering[108, 109].

Cross-sector collaboration can maximise the efficiency of resources by increasing the potential uses available to a material beyond one sector. An example of this is where CEMEX[110], using liquid waste from INEOS[111] and a chalk reject material from OMYA[112] is able to return its cement kiln dust to OMYA's quarry.[113] Cross-sector collaboration can be critical in developing technologies and alternative uses of materials. Companies often partner with other organisations to find innovative uses of their materials. For example, companies such as BASF have strengthened relationships with a network of universities, research institutes and industry partners to benefit from their knowledge.[114]

Conversely, a lack of collaboration can also act as a barrier to improving resource efficiency. In the cement sector, for example, the lack of collaboration across the value chain is a barrier to

102 Grubeša, I. N., Barišic, I., Fucic, A., & Bansode, S. S. (2016). Application of blast furnace slag in civil engineering.
103 World Steel Association (2020). Steel industry co-products. Available online: https://worldsteel.org/publications/policy-papers/co-product-position-paper/
104 World Steel Association (2020). Steel industry co-products. Available online: https://worldsteel.org/publications/policy-papers/co-product-position-paper/
105 Dondi G, Mazzotta F, Lantieri C, Cuppi F, Vignali V, Sangiovanni C. (2021). Use of Steel Slag as an Alternative to Aggregate and Filler in Road Pavements.
106 World Steel Association (2020). Steel industry co-products. Available online: https://worldsteel.org/publications/policy-papers/co-product-position-paper/
107 World Steel Association (2021). Steel industry co-products fact sheet. Available online: https://worldsteel.org/wp-content/uploads/Fact-sheet-Steel-industry-co-products.pdf
108 World Steel Association (2020). Steel industry co-products. Available online: https://worldsteel.org/publications/policy-papers/co-product-position-paper/
109 The negative emission potential of alkaline materials | Nature Communications Available online: https://www.nature.com/articles/s41467-019-09475-5/
110 https://www.cemex.co.uk/
111 https://www.ineos.com/
112 https://www.omya.com/
113 Cefic (n.d.) Exchanging By-Products To Improve Resource Efficiency. Available at: Link
114 PwC (2019) Circular economy: A new source of competitive advantage in the chemicals industry. Available at: Link

reducing waste in concrete manufacturing, as cement manufacturers have little to no bearing over how their cement is used in concrete production, or how this concrete is ultimately used (Measure 5). Likewise, there may also be other potential uses for over-ordered concrete, but these are currently very under-utilised due to a lack of incentives to make it worthwhile; greater collaboration across the value chain and incentives to do so would help to overcome this.

At the same time, competition over key materials can also exist between sectors and act as a barrier to achieving resource efficiency. For example, the availability of recycled material (particularly in relation to plastics) critically affects the ability to achieve recycled content-related resource efficiency measures highlighted as a key strategy by ten out of eleven sectors (food and drink excluded). In plastics, for example, the availability of recycled plastic content is generally limited, with demand often exceeding supply (Measure 4). In the glass sector, competition from other industries (e.g., the cement and concrete sector) for materials such as Calumite and biomass ash raise concerns that they may limit the availability of these materials by the glass industry, impacting the sector’s ability to make resource efficiency gains through material substitution with lower embodied carbon alternatives (Measure 2).

Overall, while findings for each sector are presented separately for the purpose of this project, in practice, there is significant overlap and interaction between sectors, with the ability to achieve resource efficiency gains in one sector often being tied to those of another.

E. Environmental impacts

Stakeholders across sectors agreed that resource efficiency is not considered in isolation from environmental impacts and that there are highly complex dependencies between different environmental impacts.

In some cases, resource efficiency measures can lead to carbon savings. This is identified as a driver in several measures such as paper Measure 2 (substitute paper with alternative materials or dematerialisation), paper Measure 5 (use of recovered fibre in the pulping process), electricals Measure 1 (light-weighting), chemicals Measure 2 (substitution of virgin fossil-based organic feedstocks), food and drink Measure 2 (optimising processing to reduce product losses), vehicles Measure 3 (use of recycled content) and vehicles Measure 5 (recycling of wastes generated in production processes).

Additionally, tensions between the increase of bio-based materials and other environmental impacts were highlighted. Bio-based plastics, for example, rely heavily on large-scale production of feedstock crops such as sugarcane, maize or other cellulose-producing plants (see plastics Measure 3). This raises concerns about the availability and competition for arable land, which is already under pressure to meet food demands. Stakeholders highlighted similar impacts in relation to the use of alternative bio-based feedstocks (e.g. for vehicles Measure 4) which impact land use, fresh water and fertilisers required to grow the feedstock, competing for space with food production. To ensure sustainable land use, including biodiversity and protecting against deforestation, it is important to strike a balance between bio-based production and other land-dependent activities.

Concerns around the environmental impacts of material substitution with alternative/bio-based materials were echoed by stakeholders in several sectors, particularly in the plastics (e.g., Measure 3), chemicals (e.g., Measure 2), electricals (e.g., Measure 3), vehicles (e.g., Measure 4) and construction (e.g., Measure 2) sectors. This is compounded by a lack of robust LCA data to allow for a comprehensive understanding of the environmental impact of different materials and products (see ‘A. Data & information’). Public perception and consumer preferences can also play a key role in generating a shift away from plastic materials to alternative materials which may not necessarily be better for the environment (e.g., plastics Measure 2).

Conversely, in the food and drink sector (Measure 6), due to shifts in household consumption, indirect environmental benefits may be derived from reduced waste resulting from any shift in household consumption away from high impact food products, to either products that tend to generate less waste or products that have a lower environmental impact per tonne of waste generated. There may therefore be a disproportionately large per tonne environmental benefit from reductions in waste for some food groups relative to others, for example, meat and dairy products.

Positive environmental gains in one sector may also be offset by negative implications in another. For example, plastic plays an important role in vehicles' safety and emissions performance. The average weight of plastic as a component of a vehicle is expected to grow from 12% to 16% by 2030 in an effort to make cars increasingly lightweight[115] to save on fuel consumption. This trend is expected to continue with the shift to electric vehicles, where lighter weights will allow for a greater range, but in turn resulting in increased demand for fossil fuel-based plastic materials. In the vehicles sector, a lack of data and consensus around the impact of light-weighting on carbon emissions was noted (Measure 1). Although light-weighting can reduce in-use emissions, vehicle production impacts can remain high (or be higher) for certain materials and components compared to traditional materials such as steel.

Similarly, dematerialisation trends observed for certain applications (such as tickets or newsprint) in the paper sector, can result in a shift in impact in the electricals sector due to the digitalisation of products resulting in an overall higher environmental footprint (paper Measure 5).

Existing environmental commitments, such as brand commitments and plastic targets, were identified as key drivers for several measures (such as plastics Measure 2, 4, 6, chemicals Measure 1, vehicles Measure 3 and 10).

F. Global view

Due to globalised value chains, many sectors have extensive trade (import and export) through various stages of the lifecycle. This has an impact on the extent to which different resource efficiency measures can be impacted by UK action.

[115] Hollins, O. (2021). Driving change: A circular economy for automotive plastic.

In many cases, the UK imports manufactured products, which means resource efficiency measures on the manufacturing side take place overseas and are difficult to monitor.

The UK also exports manufactured products, and this affects the sales, use and end of life measures. If a product is sold overseas, any downstream resource efficiency measures are not likely to take place in the UK and/or be impacted by UK action. The electricals sector has a significant share of export; Measure 5 (repair and refurbishment), Measure 6 (rental and collaborative consumption models), Measure 7 (direct reuse), Measure 8 (remanufacture) can therefore happen in other countries. Similarly, the vehicles sector relies on export of its products, meaning efficiencies resulting from Measure 6 (car-sharing and increased vehicle occupancy), Measure 7 (life extension through electrification and repair), and Measure 8 (remanufacturing, reuse and reconditioning of parts) would not be captured by the UK for domestically produced vehicles that are exported.

Whilst the domestic paper industry does not have the capacity to process all material collected, the incentive to increase the rate of collection is driven by the extent to which collectors can profit by selling material for export. The global market for recyclable material, including paper and card, is increasingly driven by a trend in policy measures obligating the recycling of material in order to divert as much material away from landfills as possible. This means the UK paper industry has a growing demand for its collected recyclable material outside the UK (paper Measure 1).

The UK also exports end of life materials (such as plastics or paper for recycling) and this has been flagged as a barrier for resource efficiency as it prevents the re-introduction of end of life materials / products into the UK value chains (e.g., plastics Measure 7).

Finally, the UK can import end of life materials or products, which can be a driver of some resource efficiency measures. For example, as recyclable materials are seen more and more as a valuable resource, overseas markets for these commodities are growing. For example, the steel sector has identified that scrap is a global commodity, with the UK being both an importer and exporter of scrap (e.g., steel Measure 3).

G. Consumer behaviour & preferences

Across all sectors, consumer behaviour and preferences play a key role in driving demand for certain products and services and therefore impact in the uptake of some resource efficiency measures. Consumer-facing industries in particular cater to consumer preferences and monitor consumer trends to adapt to changing behaviours.

Increased consumer awareness of the benefits (generally the environmental benefits) of resource efficiency has been identified as a key driver in all eleven sectors. The “Attenborough effect” is an example of consumer demand for less plastic, with more consumers demanding less plastic in their packaging.[116] Additionally, YouGov found that many UK consumers feel

[116] Hynes et al. (2020). The impact of nature documentaries on public environmental preferences and willingness to pay: entropy balancing and the blue planet II effect. Journal of Environmental Planning and Management. 64:8. pp1428-1456.

guilty about their use of plastic and so are actively trying to reduce it.[117] This affects customer choices around the purchase of products with plastic packaging (plastics Measure 1), and instead increases the demand for alternative non-plastic packaging materials (such as paper, cardboard, metal or glass) even if environmental impacts can sometimes be higher for those (plastics Measure 2, 3 and 4, paper Measure 2 and 3, glass Measure 2 and 3).

In the paper sector, stakeholders noted that trends in dematerialisation of print media, such as newspapers and magazines was also driven by the perceived convenience to the consumer rather than its potential environmental benefits (Measure 2). In the glass sector, one of the drivers identified for Measure 7 (reuse of whole glass products resulting in a reduction in consumption of new products and increasing a functional product's lifetime) was an increase in the levels of grocery deliveries providing convenience to households and driving higher usage of container glass.

In the chemicals sector, customer preferences for more 'sustainable' products have a greater impact on consumer-facing industries (Measure 1). Chemicals companies involved in the manufacture of primary or intermediate chemicals that are not visible to the consumer are less influenced by this driver. However, as consumer-facing companies demand more green chemicals to generate more sustainable products, it is likely that this driver will have ripple effects on players upstream.

In the electricals sector, a key driver behind increasing electrical product reuse rates is the increased acceptance of used products (in part influenced by reuse in other sectors, such as textiles), combined with greater affordability as compared to new products (Measure 7). In the food and drink sector, changes to customer preferences and awareness mean that food and drink products that do meet strict standards (e.g., the acceptability of 'wonky' vegetables), can help drive retailers and food service outlets to relax their product requirements, thereby reducing food and drink waste (Measure 4).

In the vehicles sector, changing consumer attitudes (particularly of the younger generation) towards non-ownership models were noted as a driver behind increasing car-sharing and increased vehicle occupancy (Measure 6). The flexibility of car club models, essentially enabling multi-modal choices based on the nature and duration of travel requirements while also affording access to electric vehicles, is increasingly attractive to these consumers.

In the cement and concrete sector, increasing societal pressure for greener structures is already driving change within the sector and acting as a driver for leaner concrete structures (Measure 4). Similarly, in the construction sector, increased consumer attention on the environment was identified as a driver for increasing retrofit (Measure 5). As retrofit has been shown to reduce carbon, this could be associated with being a more sustainable choice. Therefore, the increased concern for the environment amongst the public may drive a reduction in new builds and an increase in retrofit, repair or renovation undertaken.

[117] YouGov (2019). Most Brits support ban on harmful plastic packaging.

In other cases, consumer preferences can go in the opposite direction of resource efficiency measures. For example, electricals Measure 5 (repair and refurbishment) identified consumer concerns surrounding warranty data protection, quality, safety and lifetime of repaired and refurbished products as a key barrier, as reconditioned goods can be perceived as having lower quality and reliability. Likewise, rental models for electrical products can be hindered by customer's desire to own their products outright, particularly for products of daily use (Measure 6). In addition, the lack of convenience of repair models (combined with associated costs) compared to the purchase of new products is a key barrier in the electricals sector.

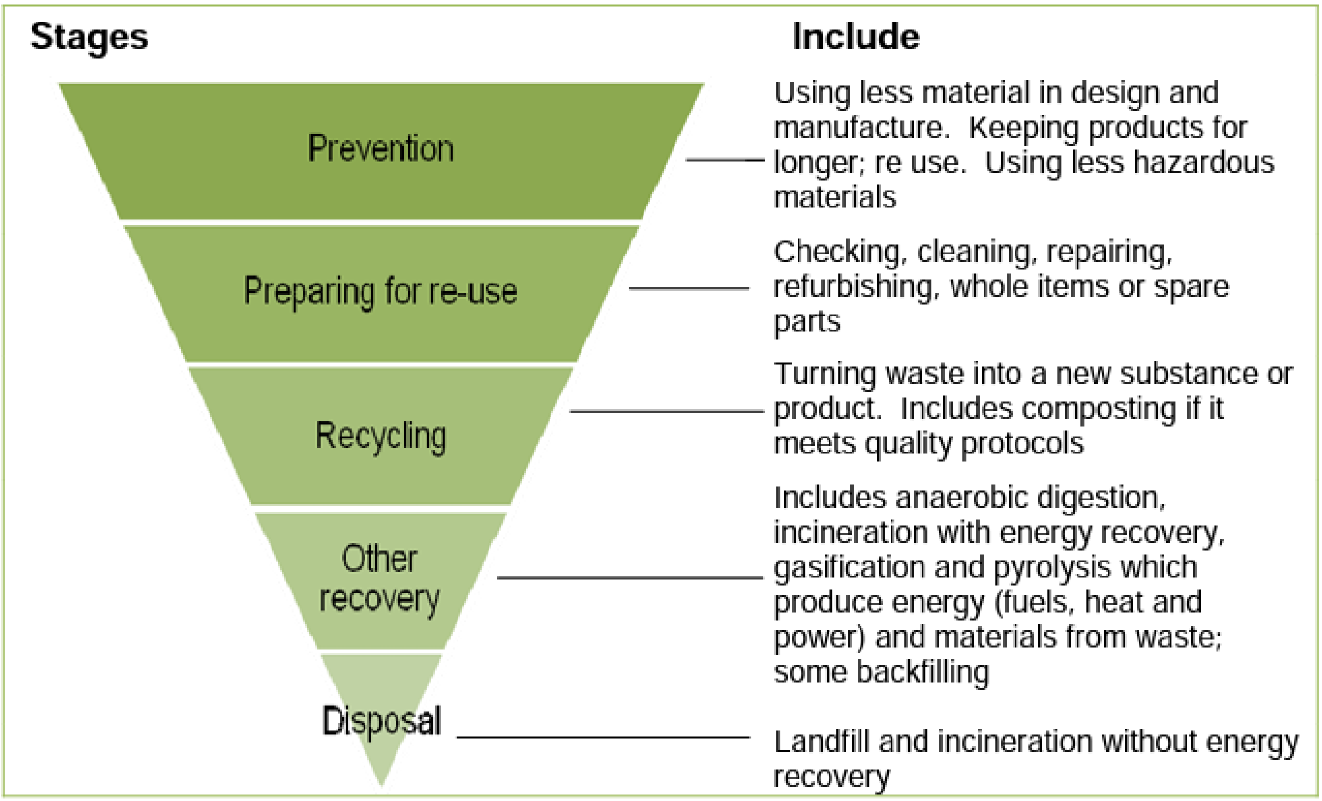
In the textiles sector, customer preferences for extremely low-cost 'fast fashion' items, are a critical barrier to a number of resource efficiency strategies (e.g., Measure 6). Similarly, consumer preference for larger vehicles (such as SUVs) was identified as a barrier in the vehicles sector for Measure 2 (light-weighting through reducing vehicle size), with a lack of consumer awareness and education of environmental benefits of smaller vehicles being an underlying contributing factor. Also, vehicles Measure 8 (remanufacturing, reuse and reconditioning of parts) identified consumer behaviour as a barrier, since reconditioned goods can be perceived as having lower quality and reliability. This is echoed in vehicles Measure 3 (use of recycled content in vehicle products) in which customer perception of recycled content being of inferior quality was identified as a barrier to increased sales of products with higher recycled content.

In the chemicals sector, stakeholders noted that while consumers express interest in greener products, they may not be willing to pay a premium for it, creating a key barrier for several resource efficiency measures (e.g., chemicals Measure 1). Equally, a key barrier to reduce net resource input in formulation of chemical products (Measure 1) is consumer perception and acceptance, meaning light-weighting measures will only work if coupled with clear consumer education, allowing them to use less material and see the benefit of reduced use. For example, cleaning detergents have become much more compact over time, resulting in much lower suggested doses. However, consumers familiar with older dosages are often sceptical about less of the same product being able to generate the same cleaning effect. Therefore, there is a tendency to use more product than required or specified. Even though the chemicals sector may be able to achieve higher levels of efficiency – e.g., via highly compacted detergents, specialised enzyme systems or bleach activators – consumption at the consumer phase is a challenge.

H. Waste hierarchy

Resource efficiency measures occur throughout the supply chain. The waste hierarchy gives a framework for how these measures should be prioritised.

Figure 6: Diagram of the waste hierarchy[118]



Stakeholders in several sectors commented on the application of the waste hierarchy and the importance of following the order of priority.

- In cement and concrete, Measure 1 received the highest level of engagement from stakeholders in the workshops and was covered the most extensively in the literature. This is consistent with the waste hierarchy framework in that Measure 1 is aligned with the highest tier of the hierarchy (i.e., preventing the unnecessary use of Portland cement (CEM I in concrete).
- In construction, several stakeholders insisted on the need to prioritise reuse over recycling under Measure 7, with the distinction that building components are reused while building materials are recycled.
- In steel, there is such a high demand for scrap, that market economics may favour recycling instead of repair or reuse (Measure 8), which goes against the waste hierarchy.
- Vehicles Measure 8 (Remanufacturing, reuse and reconditioning of parts) describes the three techniques, each with their own challenges.
- Resource efficiency measures in the plastics sector cover several parts of the waste hierarchy (waste prevention, reuse, recycling, disposal) – Measures 4, 5, 6, 7, with prevention measures being key.

[118] Defra (2011): Guidance on applying the Waste Hierarchy, available at https://www.gov.uk/government/publications/guidance-on-applying-the-waste-hierarchy

- In the electricals sector, Measure 7 (direct reuse) is favoured over recycling (Measure 9).
- In the food and drink sector, Measure 8 covers the diversion of food and drink waste to its most efficient use, according to the UK food waste hierarchy.

Stakeholders have also highlighted the trade-offs between the different parts of the waste hierarchy:

- Light-weighting would fall under “waste prevention”, which should be priority. However, light-weighting can lead to reduced lifetime (thus increased waste) and/or reduced recyclability and/or may conflict with the incorporation of recycled content. These have been identified as barriers for vehicles Measure 1 (light-weighting through material substitution).
- Stakeholders also mentioned that not all recycling is comparable, and in some cases, products are ‘downcycled’, i.e., recycled into lower value applications. This was mentioned as a barrier for vehicles Measure 1 (light-weighting through material substitution), and construction Measure 6 (recycling and reuse).

Dependencies across themes

Theme A – Data & information with Theme B – Costs

Getting the right data can be costly, but not having the right data can, in turn, result in increased costs. As an example of the latter, electricals Measure 8 (remanufacture of electrical products) mentions the need for skilled labour and technical knowledge of each product and its former use to be able to understand the technical requirements of products and allow for refurbishment. With this data not always being available, labour cost increases, in turn increasing the price of the product. At the same time, increased reporting requirements may increase administrative costs which need to be borne by manufacturers.

Theme A – Data & information with Theme D – Sector interactions

There are significant interactions and dependencies between sectors, with the availability and sharing of data being critical to allow the achievement of resource efficiency gains more broadly. For example, to understand the impact of material substitution measures both within and between sectors (in particular the plastics, paper and glass sectors between which materials are more commonly substituted ‘in’ and ‘out’), a lack of credible data on carbon savings was highlighted as a barrier to resource efficiency interventions in this area (e.g., paper Measure 2 and 3, plastics Measure 2 and 3, glass Measure 2 and 3). Industrial symbiosis/collaborative consumption requires the exchange of data between different segments of the value chain as well as industry players. The absence of transparency in information about the availability and supply of resources in the chemicals sector was highlighted as a barrier to industrial symbiosis (Measure 6). The lack of visibility into resource availability makes it challenging for manufacturers to consistently utilise waste/by-products as a resource. This also means key economic opportunities may be missed by the sector creating the by-product considered to be a waste in the first place.

Theme A – Data & information with Theme E – Environmental impacts

Having better data on the environmental impacts of certain materials or products can improve decision-making process exploring resource efficiency interventions; this holds true both for industry and end-customers. This also includes being able to rely on accurate data to understand the impact of deploying one resource efficiency strategy over another (such as light-weighting vs. lifetime extension) and possible trade-offs between resource efficiency measures. This was highlighted across all sectors as a barrier; in particular, for plastics Measure 3 (substituting fossil-based plastic feedstocks with bio-based plastics), electricals Measure 3 (use of bio-based plastics in products), glass Measure 5 (implement efficiency manufacturing and installation processes), food and drink Measure 1 and 2 (use of by-products and optimising processing to reduce losses), vehicles Measure 4 (use of biobased materials in vehicle products).

Theme A – Data & information with Theme F – Global view

Having better data and traceability of the imported/exported products would allow better monitoring of the product characteristics and impacts of the imports and exports. For example, techniques to improve data such as labelling, digital product passports or even building passports were believed to be an enabler or driver when present as they can be used to convey important information. Material passports are identified as a key driver for steel Measure 8, related to repair, reuse and remanufacturing of steel products, for example.

Theme A – Data & information with Theme G – Consumer behaviour & preferences

Consumer preferences can be influenced by the availability of decision-making data; this can take the form of information on lifetime cost savings or environmental impacts. For example, buying a lighter vehicle has reduced fuel costs as shown in vehicles Measures 1 and 2 (light-weighting through material substitution and light-weighting through reducing vehicle size), which could feed into consumer decision making.

It is worth noting, however, that the impact of data and information is not always clear cut. For example, growing customer preference for non-plastic packaging has resulted in an uptake of an increasing amount of 'alternative packaging materials' (such as paper, glass, textiles, metals, and multi-material) due to the perception of them being more 'sustainable' and better for the environment, even though data sometimes suggests these are not always the more sustainable choice.

Theme A – Data & information with Theme H – Waste hierarchy

Reliable statistics for the different end of life pathways are required to monitor progress and identify opportunities of moving further up the value chain.

Theme B – Costs with Theme C – Infrastructure

While all resource efficiency measures have cost implications, measures targeting the improvement of production efficiencies in particular, heavily cite cost as a barrier due to locked in infrastructure. The cost implications of process improvements can be significant and prolong the use of less efficient machinery and manufacturing equipment and shift in focus on alternative resource efficiency strategies as an alternative (e.g., paper Measure 6).

Theme D – Sector interactions with Theme E – Environmental impacts

Due to the complexity of some sector interactions – e.g., around particular resource efficiency measures such as material substitution – environmental impacts can sometimes be difficult to assess. At the same time, environmental impact improvements in one sector can result in a negative impact in another. For example, dematerialisation trends observed for certain applications (such as tickets or newsprint) in the paper sector, can result in a shift in impact in the electricals sector due to the digitalisation of products resulting in an overall higher environmental footprint (paper Measure 5).

Theme E – Environmental impacts with Theme G – Consumer behaviour & preferences

Raising consumer awareness about environmental topics can influence consumer trends, leading them to lean towards products with a lower environmental footprint. Brand commitments, for example, are likely to influence (and be influenced by) consumer behaviour and preferences.

Theme E - Environmental impacts with Theme H – Waste hierarchy

Stakeholders expressed the need to consider whole lifecycle impacts due to the trade-offs between carbon emissions and higher levels of the waste hierarchy. For example, reuse of products may require additional transport, which leads to increased carbon emissions, as discussed under construction Measures 1 (use of reused content in buildings) and 6 (reuse and recycle).

Glossary and abbreviations

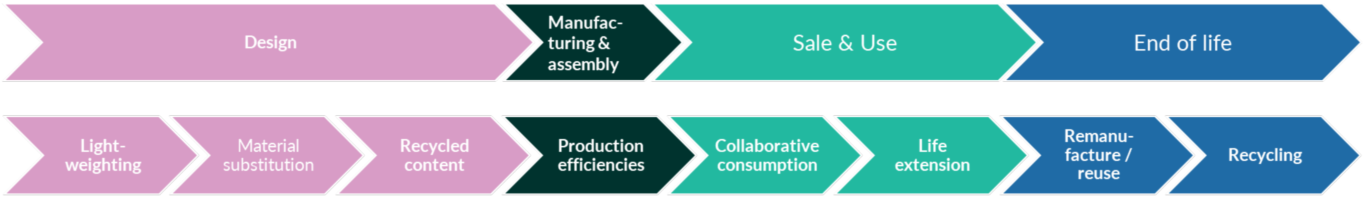
AATF	Approved Authorised Treatment Facilities
BAU	Business-as-usual
BTX	Benzene, toluene, xylene
B2B	business-to-business
CG	Container glass
CO2e	Carbon dioxide equivalent
EEE	Electrical and electronic equipment
EOL	End-of-Life
EPR	Extended Producer Responsibility
FG	Flat glass
GHG	Greenhouse gas
GVA	Gross Value Added
GW	Glass wool
HDPE	High Density Polyethylene
IAS	Indicative applicability score
ISO	International Organization for Standardization
LCA	Lifecycle Assessment
LDPE	Low Density Polyethylene
LED	Light-emitting diode
OEM	Original equipment manufacturer
ONS	Office of National Statistics (UK)
PC	Polycarbonate
PE	Polyethylene

PET	Polyethylene Terephthalate
POP	Persistent Organic Pollutants
PP	Polypropylene
PPI	Pulp and paper industry
PS	Polystyrene
PUR	Polyurethane
PV	Photovoltaic
PVC	Polyvinyl Chloride
RAG	Red-Amber-Green
RE	Resource efficiency
SCM	Supplementary cementitious materials
SUV	Sport Utility Vehicle
VAT	Value Added Tax
WEEE	Waste electrical and electronic equipment
WRAP	Waste & Resources Action Programme

Annex A – Mapping resource efficiency measures against lifecycle stages and resource efficiency strategies

Each identified resource efficiency measure has been mapped against a **framework** that shows four lifecycle stages and eight resource efficiency strategies.

Figure 7: Framework mapping lifecycle stages and resource efficiency strategies



- In the design stage of the lifecycle, many decisions are made about the product, which have impacts until the end of life. Three key resource efficiency strategies are identified:
    - Light-weighting refers to reducing the mass of the final product, which leads to resource efficiency savings in terms of material use avoided.
    - Material substitution has been discussed earlier.
    - Recycled content (also named 'use of secondary raw materials') refers to displacing virgin raw materials with material that had reached its end of life.
- After the product has been designed, it needs to be manufactured, and in some sectors, further assembled. Depending on the sector, there can be several manufacturing and assembly steps, for example raw materials converted into polymers further manufactured into plastic pellets, and plastic into components then assembled into electrical components.
    - The identified resource efficiency strategy is 'production efficiencies' which lead to reduced waste in this phase of the lifecycle and thus reduced material requirements.
- Once the product is manufactured, it is sold and then used by the consumer/user. This phase can have differing lengths. There are two identified strategies:
    - Collaborative consumption can lead to higher utilisation of the products and potentially reduced consumption, which leads to resource efficiency. This can be achieved through rental business models but also product sharing models.
    - Life extension refers to the different techniques applied by consumers or manufacturers or other actors of the value chain that can extend the usable lifetime of the product. This can take the form of repair, retrofit or refurbishment. Where lifetime extension can avoid or delay consumption of a new product, it leads to resource efficiency.

- Finally, once the product has reached the end of its (first) life, there are several strategies that can be applied to continue getting value of the product and delay the stage where it is disposed of. For simplicity, the strategies have been grouped in two:
    - Remanufacture or reuse keeps the product as a product and can provide a second (mor more) life for the product, usually in the hands of a different user. If this new life displaces or delays the consumption of a new item, it leads to resource efficiency.
    - Recycling refers to the process of turning the EOL product into a new material, which is not necessarily the same product as it was originally.

This framework is defined at a high-level to ensure that it fits the 11 industrial sectors covered over the two research phases. Therefore, it is not meant to be a comprehensive description of each sector but an instrument that will allow comparing the resource efficiency measures across the sectors.

Annex B – Phase 1 strategies across resource efficiency measures

Figure 8: Mapping of sector measures under the lifecycle phases and resource efficiency strategies

	Design			Manufactu-ring & assembly	Sale & Use		End of life	
	Light-weighting	Material substitution	Recycled content	Production efficiencies	Collaborative consumption	Life extension	Remanu-facture / reuse	Recycling
Cement & concrete	<<<<< Measure 1 >>>> Measure 4		Measure 2 Measure 3	Measure 5				Measure 6
Construction	Measure 3	Measure 2	Measure 1	Measure 4		Measure 5		Measure 6
Steel	Measure 7	Measure 1 Measure 2	Measure 3	Measure 4 Measure 5 Measure 6		<<<<<<<<<< Measure 8 >>>>>>>>>		
Vehicles	Measure 1 Measure 2	Measure 4	Measure 3	Measure 5 Measure 9	Measure 6	Measure 7	Measure 8	

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