Department for Energy Security & Net Zero

Unlocking Resource Efficiency

Phase 2 Paper Report

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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. This report outlines the findings of this research for the paper sector.

For the purposes of this report, resource efficiency is defined as any action that achieves a lower level of resource use for a given level of final consumption. This can occur at any stage of the supply chain including production, consumption, and end-of-life. While material substitution may not always meet the definition of resource efficiency set out above, it is in scope of this research where it reduces whole life carbon.

This research was conducted in the second half of 2023, and reports were written in November 2023. As such, this report 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.

Methodology

This aim of this research was to achieve four key objectives:

- Identify a comprehensive list of resource efficiency measures for each sector;
- Identify current and anticipated drivers and barriers which are affecting improvements in the identified resource efficiency measures in each sector, and their relative importance;
- Build consensus estimates for the current “level of efficiency” and maximum “level of efficiency” in 2035, for each of the identified resource efficiency measures in each sector; and
- Identify 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 in each sector.

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 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.

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.

This project has attempted to identify three level of efficiency estimates for each resource efficiency measure:

- The **current level of efficiency** which is the best estimate for the current level of efficiency of the measure i.e., what is happening in the UK now (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 barriers that could be overcome by 2035 i.e., what is the maximum level that could be achieved; and
- The **business-as-usual (BAU) scenario** which is the level of efficiency that would be expected in the UK by 2035 with the current policy mix and private sector incentives i.e., what would happen if there were no substantial changes in the policy or private sector environment.

These levels of efficiencies have been identified to understand the potential for resource efficiency and do not represent government targets.

To estimate these levels of efficiency, indicators have 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).

For some measures, the current level of efficiency is baselined to 2023. This is not an indication of historic progress, but rather has been done in order to understand the potential for further progress to be made (in the maximum and BAU scenarios) where it was not otherwise possible to quantify a current level of efficiency. The paper sector has already made historic gains in resource efficiency, and so is operating from a pre-existing base. This is discussed further on a measure-by-measure basis in the report.

Note, the purpose of the indicators in this research is so estimates on the current, maximum and BAU level of efficiency can be developed on a consistent basis. They are not intended 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.

A high-level overview of the research stages is presented below. A more detailed version of this methodology is presented in the Phase 2 Technical Summary which accompanies this publication.

Literature Review

The literature sources were identified through an online search, and through known sources from DESNZ, DEFRA, the research team, and expert stakeholders.

Once literature sources had been identified they were reviewed by the research team and given an Indicative Applicability Score (IAS) ranging from 1 to 5 which indicated the applicability of the sources to the research objectives of this study. This score was based on five key criteria: geography, date of publication, sector applicability, methodolo-gies used and level of peer review.

After the five criteria of the IAS had been evaluated, the overall IAS score was calculated, ranging from 1 to 5, according to the number of criteria scoring ‘high’ and ‘low.’

A detailed overview of the parameters used to assess high / medium / low scores for each of the five criteria feeding into the IAS calculation and methodology for calculating the score can be found in Appendix A.

The research team drafted a rapid evidence assessment and literature summaries as part of interim reports for each sector which synthesised the best available evidence from the literature for each of the four research objectives. When drafting these summaries, literature sources with a higher IAS score were weighted more than those with a lower IAS score.

Stakeholder interviews

The findings from the literature review were presented to, and tested with, expert stakeholders from each sector through a series of stakeholder interviews. The interviews aimed to capture a range of sector experts from both academia and industry (covering different aspects of the value chain) but it should be noted this is not an exhaustive or representative sample of the sector. The purpose of these interviews was to test the findings of the literature review against stakeholder expertise, and to fill any evidence gaps from the literature.

Following the completion of stakeholder interviews, one half-day facilitated workshop was conducted for each sector. Stakeholders who participated in interviews were given the chance to contribute to supplement and validate findings.

Stakeholders contributed through sticky notes in a shared virtual Mural board, by participating in the verbal discussions and by voting on pre-defined ranges on the levels of efficiency and the top drivers and barriers. They were also given the chance to contribute further information through a post-workshop survey. The stakeholders were asked to signal the level of confidence they had in their votes and were advised to vote for a ‘don’t know’ option if they felt the information fell outside their expertise. It is possible however that some votes were cast in areas where stakeholders may not have had expertise, so caution is advised when interpreting the findings.

Finally, the findings of the literature review and the stakeholder engagement were combined to reach final conclusions against each research objective. For the estimates on the level of efficiency for each measure (Objectives 3 and 4), a five-tier evidence RAG rating was assigned to indicate the level of evidence supporting the proposed figures. Only where the datapoints were supported by literature sources with high IAS and a high degree of consensus amongst experts in the interviews and workshop*,* were the datapoints considered to have a “green” evidence RAG rating. The definitions are as follows:

- **Red:** Limited evidence available from literature review or stakeholders

- **Red-Amber:** Some evidence available from literature review but it is not relevant/out of date, Limited evidence from stakeholders, stakeholders are not experts on this measure
- **Amber:** High quality evidence from either literature or stakeholders
- **Amber-Green:** High quality evidence from literature or stakeholders, evidence from stakeholders is supported by some information in the literature (or vice versa)
- **Green:** High quality evidence from literature supported by stakeholder expertise.

It should be noted that the business-as-usual (BAU) level of efficiency was only informed by the stakeholder engagement, so the maximum evidence RAG rating for the BAU is amber.

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 within Government, ensuring that any omissions or developments in the evidence reviewed in this report are taken into account.

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).[1] The UK manufacture of paper and packaging products employed approximately 40,000 staff through around 1,000 businesses in 2022 as shown in Table 1.[2] Statistics also show the PPI generating a turnover of £7.7bn in 2022.

Table 1: UK manufacture of articles of paper and paperboard 2022[3]

	Businesses	Employment	Turnover
Manufacture of corrugated paper and paperboard and of containers of paper and paperboard	*380*	*28,547*	*£6.0 bn*
Manufacture of paper stationery	*295*	*3,073*	*£0.3 bn*
Manufacture of other articles of paper and paperboard	*385*	*9,080*	*£1.4 bn*
TOTAL	***1,060***	***40,700***	***£7.7 bn***

As of 2023, the UK has 40 paper mills in total. These produce packaging, graphic paper (e.g., newsprint), speciality materials (e.g., tea bags) and tissue and hygiene products (e.g., paper towels, toilet paper). Products of the PPI discussed in this report are split into four core sub-categories:

- Packaging, which includes:
    - Cardboard;
    - Containerboard
    - Linerboard; and
    - Cartonboard.

[1] CPI, "Global Challenges, Local Resilience: Annual Review 2022-2023", (2022). Available at: link
[2] ibid.
[3] ONS," Analysis of enterprises in the printing and paper industry 2021 and 2022", (2023). Available at: link

- Print and graphical; and
- Hygiene, which includes:
    - Paper towels;
    - Toilet paper; and
    - Facial tissues.
- Speciality products.

The paper mills which produce these products within the UK are outlined in Appendix E: UK paper mills.

The UK PPI is dominated by multi-national organisations with headquarters outside the UK. The ten largest PPI sites represent more than 75% of the total UK production capacity and nine of them are run by organisations head-quartered outside the UK.[4]

The British PPI's fibre need is met mainly through recovered feedstock with the remainder being made up of virgin feedstock.[5]. This is explained by the UK's lack of forests and a high consumption of PPI products, which once consumed are subsequently made available for recycling[6]. The UK has two modern integrated pulp and paper mills operated by Holmen Paperboard in Workington and UPM Caledonian in Irvine which make virgin pulp by mechanically grinding wood.[7] Both mills use all the pulp they produce to make paper and therefore do not sell pulp to the market. Virgin pulps used in other UK mills are imported, and no chemical pulp is produced in the UK. The imports are predominantly sourced from Scandinavian and North American conifers or eucalyptus pulp from plantations in southern Europe or South America.[8]

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.[9] Production figures stand in stark contrast with the consumption of paper, with the UK consuming around 9 million tonnes of paper each year.[10] The UK is the world's largest net importer of paper, the majority share being printing and writings papers, and packaging papers and boards.[11] A breakdown of the UK consumption of PPI products is shown in Table 2.

Pulp and papermaking are separate processes that can be on the same or different sites. Pulp plants can either feed directly into the papermaking process on the same site (an integrated mill) or produce pulp for use at remote sites (market pulp mills). Market pulp mills tend to be in areas with large forest resources, selling their pulp to paper-making mills located elsewhere. The UK has no market pulp mills. Mills using recycled fibre as a raw material have their own

[4] CPI, "Global Challenges, Local Resilience: Annual Review 2022-2023", (2022). Available at: link
[5] Back, S, "The British paper industry of today", PA Paper Advance (2021) [Online]. Available at: link
[6] Ibid
[7] ibid.
[8] CPI, "Annual Review 2019-2020", (2020). Available at: link
[9] CPI, "Global Challenges, Local Resilience: Annual Review 2022-2023", (2022). Available at: link
[10] CPI, "Forestry", (2023). Available at: link
[11] CPI, "The economic value of the UK's paper-based industries", (2022). Available at: link

pulping plant that feeds directly into the papermaking process (an integrated recycling mill). These mills may also blend virgin fibre into their feedstock if they are making product with particular characteristics. There are a small number of recycled pulp mills that process paper and card into recycled fibre sold onto the market for use elsewhere. None are located in the UK, though recycled pulp can be shipped between companies in the same group.

Mills without their own pulping plant buy in processed pulp – this can be either virgin fibre or recycled fibre pulp. As of 2022, 67% of the raw materials used by UK paper mills was recovered fibre with the remainder being woodpulp (26%), additives (6%) and other fibres (1%).[12] This recovered fibre is predominantly sourced from UK recycling collections. However, not all PPI products collected for recycling are used as feedstock in production. Of the 7.5 million tonnes of paper and packaging collected for recycling in 2019, 43% was used in UK-based paper production and 57% was exported.[13] The remaining feedstock required to meet production needs (which is derived from virgin feedstocks) is either domestic mechanical pulp or imported from other territories to the UK. As will be discussed further in Measure 5 – Use of recovered fibre in the pulping process, one of the key limiting factors preventing the use of recovered fibre as a raw material for more than 67% of inputs is the limit to how many times fibres can be recycled and paper being lost to the recycling system (such as hygiene papers). Whilst this limit exists, there will always be a need for virgin feedstock in production.

Table 2: UK Paper Consumption and Production 2022[14]

	UK Consumption 2022 (tonnes)	UK Production 2022 (tonnes)	UK Production 2023 (number of mills)
Packaging	5.8m (58%)	1.9m (52%)	9 (23%)
Print and graphical 'Other'	2.9m (29%)	1.0m (29%)	15 (37%)
Hygienic	1.3m (13%)	0.7m (19%)	16 (40%)
Total	**10m (100%)**	**3.6m (100%)**	**40 (100%)**

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.

[12] CPI, "Global Challenges, Local Resilience: Annual Review 2022-2023", (2022). Available at: link
[13] Back, S, "The British paper industry of today", PA Paper Advance (2021) [Online]. Available at: link
[14] Adapted from CPI, "*Grid Connection Assessment, Electrification of UK Paper Mills*", (2022). Available at: link

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 physical environment to which they are exposed 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.

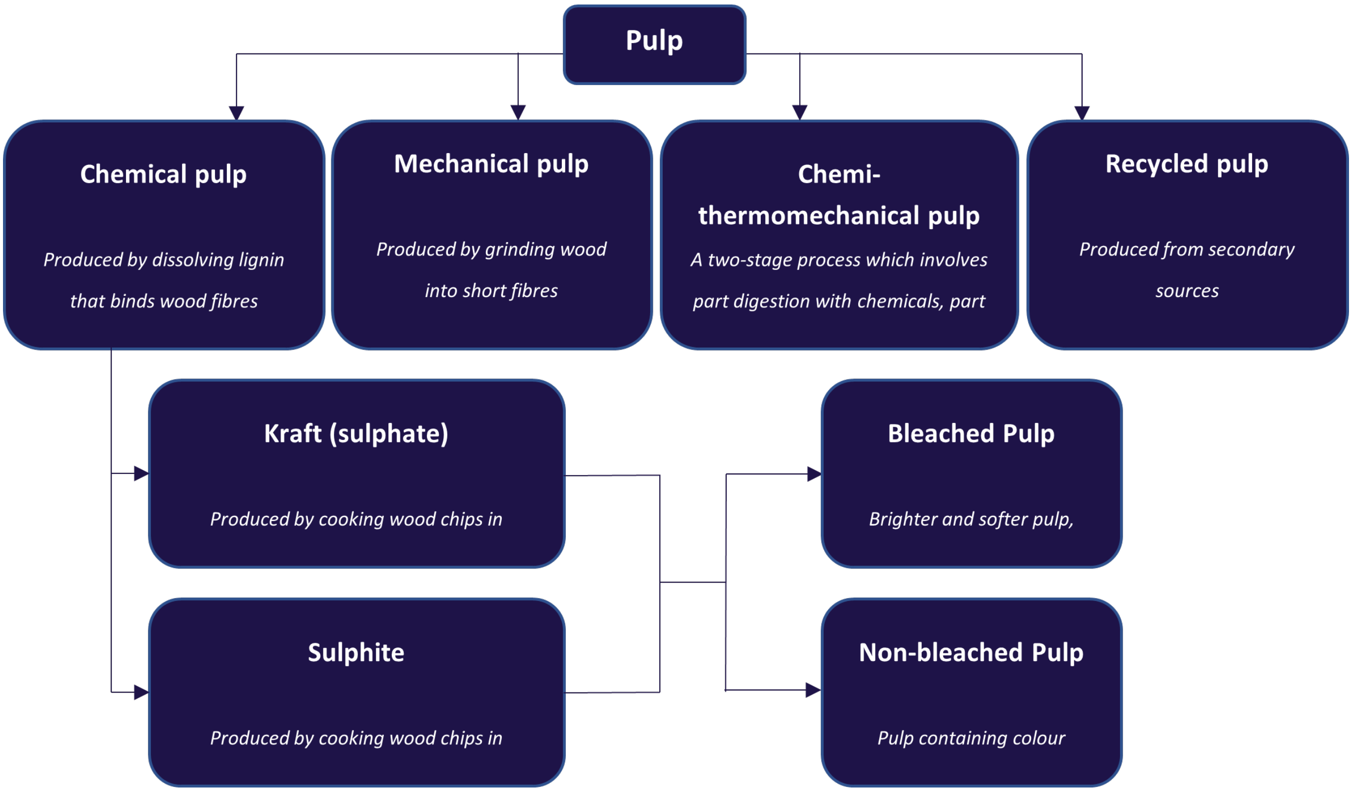
There are no chemical pulp mills in the UK. Kraft pulping, a type of chemical pulping, is the dominant process used globally due to its superior strength, aging resistance and ease of bleaching.[15]

Two sub-categories of chemical pulp are bleached and non-bleached pulps. The most significant difference between bleached and non-bleached pulp is the colour and appearance, with bleached being whiter and requiring more energy to produce. The pulping type employed may depend on factors such as the colour, quality and durability intended for the end product.

All pulping types are shown for ease of visualisation in Figure 1.

[15] Cherian, C and Siddiqua, S, "Pulp and paper mill fly ash: a review", Sustainability, (2019). Available at: link

Figure 1: Types of pulp used in the papermaking process.



It is reported that chemical pulping represents 72% of global primary (virgin) pulp production,[16] however, the global paper sector relies significantly on recycled feedstock.

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.

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 impacts the industry's emissions and is a key potential means of addressing the sector's emissions targets.[17] The production of 'paper and paper products' directly emitted 1.8 MtCO2e in 2021, contributing to 0.4% of all UK greenhouse gas emissions[18]. 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

[16] CEPI, "Key statistics report 2018", (2019). Available at: link
[17] 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
[18] DESNZ, 29th June 2023 - UK greenhouse gas emissions by Standard Industrial Classification. Available at: link

indirect emissions from electricity from the grid. The paper machine – and in particular the drying process – accounts for about two-thirds of all energy use in a typical UK pulp and paper mill.[19] These indirect emissions are attributed to the power sector in the greenhouse gas emissions statistics and therefore aren't included in the 1.8 MtCO2e figure listed above.

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 products 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.[20] [21]

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, however it is worth noting that there are no chemical pulp mills in the UK. 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.

Literature review approach

The literature review identified 176 sources that discussed resource efficiency in the paper sector. These were identified using a range of search strings relating to resource efficiency, the circular economy and the pulp and paper sectors. The search strings are listed in Appendix B. Further sources were identified from sector experts via the interviews and a Call for Evidence sent directly to stakeholders. The full list of sources used are listed in Appendix C.

These 176 sources comprised:

- 53 academic papers;
- 41 industry reports;
- 2 policy documents;
- 13 technical studies; and
- 67 website articles.

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[19] DECC & DBIS, "Industrial decarbonisation & energy efficiency roadmaps to 2050.", (2015). Available at: link
[20] Energypartnership," Energy efficiency in the pulp and paper industry", (2021). Available at: link
[21] Vieira, M.G and Estrella, L and Rocha, S.C.S, "Energy efficiency and drying kinetics of recycled paper pulp", *Drying Technology*, (2007). Available at: link

The sources were considered of generally high applicability and credibility when assessed against the data assessment framework, which recognises the relevance of the sources and the strength of their methodology. The sources had an average IAS of 4.28 (out of 5), with 135 sources exhibiting a score of 4 or above. Sixty-one sources were specific to the UK market. Stakeholder responses to the pre-workshop survey indicated that the initial literature review was reasonably comprehensive, although they also suggested some additional sources which were then incorporated. One hundred and forty-six of the sources were published in the last ten years and thus considered recent.

More detail on the purpose and approach for these literature reviews can be found in the accompanying main report.

Interview approach

A total of eight stakeholders have been interviewed for this project: three manufacturers, two trade bodies, one researcher, one designer, and one waste management provider.

Workshop approach

There were six participants in attendance at the workshop: one manufacturer, one waste processor and four representatives of trade associations, where the same trade association was represented by multiple attendees. No academic researchers were present at the workshop.

List of resource efficiency measures

The list of resource efficiency measures in the paper sector identified via the literature review and interviews can be found in Table 3.

Appendix D contains a list of resource efficiency measures that were discarded from the scope of this study with reasoning for their exclusion.

Table 3: 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_2e reduction from substitution with alternative materials; and Percentage whole life CO_2e reduction from dematerialisation	X	X	X
3	Design / Manufacture	Material substitution	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	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

1.0 Measure 1 – Collection of waste paper and board for recycling

1.1 Paper resource efficiency measure

1.1.1 Description

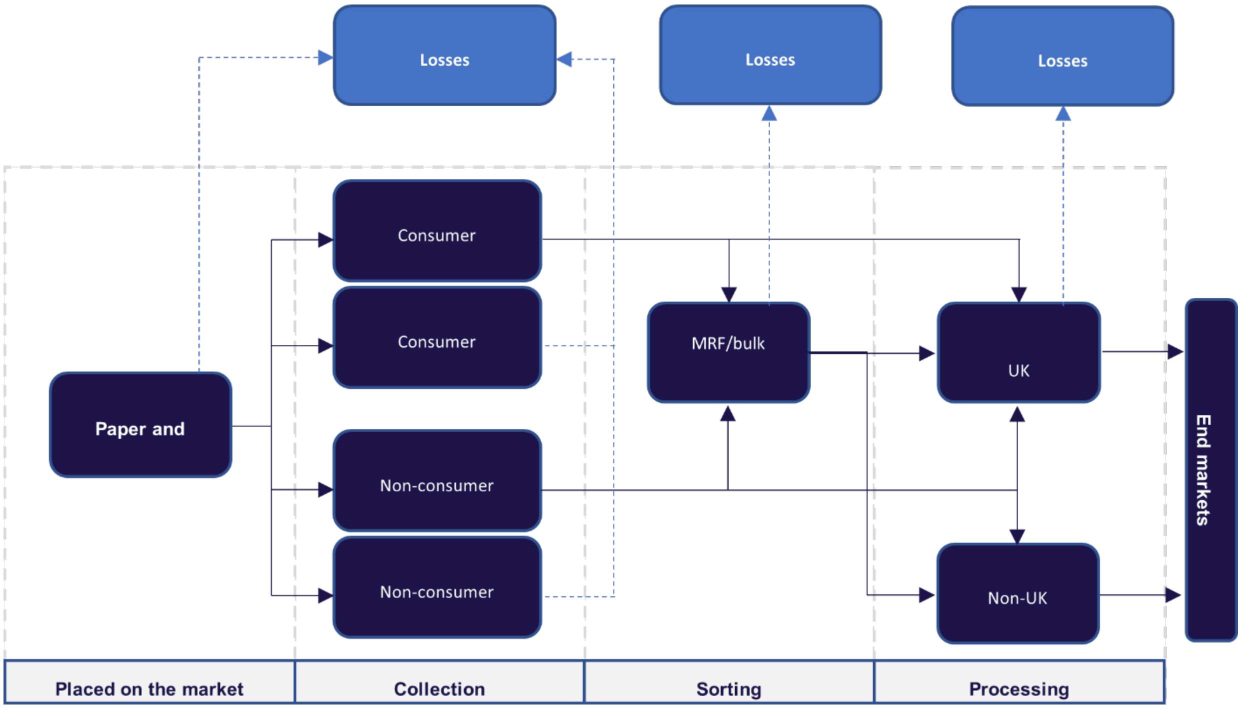
The effective collection of used paper to increase the availability of material for recycling and remanufacture.

The paper recycling market has grown steadily since the early 2000s, with around 3 million tonnes of used paper now recycled annually.[22] With its environmental and resource efficiency benefits, it has become one of the most well-established recycling streams in household waste collections.[23] Nevertheless, a significant growth in the amount of paper and board packaging placed on the market in the UK has not seen a corresponding rise in the amount treated for recycling,[24] and so it is apt to name the collection of paper and board for recycling as an important measure for resource efficiency.

This measure is distinct from Measures 5 and 6 which focus on the use of recovered fibre in the pulping process and the improvement of production yield in the pulp and paper-making processes respectively. This measure covers the collection of the material, for example from kerbside or at household waste recycling centres (HWRCs), after which it is either sorted or sent directly to paper mills. How paper is collected significantly impacts how much it can be effectively recycled, and, therefore, its level of resource efficiency. Stakeholders confirmed a need to address the collection of recycling as a distinct measure, given its unique barriers, drivers and levels of efficiency. Figure 2 provides an illustrative overview of the end-of-life routes for the paper sector, the losses that occur and the measures that cover each loss for the purpose of this report.

[22] CPI, "The economic value of the UK's paper-based industries", (2022). Available at: link
[23] Pivnenko, K et al. "Waste paper for recycling: overview and identification of potentially critical substances", (2017). Available at: link
[24] DEFRA, "Resources and Waste Strategy Monitoring Progress", (2022). Available at: link

Figure 2: Paper and card mass flow overview



Used paper can be collected from a range of pre- and post-consumer sources. Household waste paper and cardboard is collected by local authorities at the kerbside, often in a paper and card stream, or co-mingled with other recyclable materials like plastics and metals. Householders can also bring paper and card to bring sites or HWRCs where a higher level of separation, for example, between papers and cards, is more common. All household waste is considered post-consumer. Commercial waste collectors collect similar post-consumer used paper and card from businesses. However, some commercially-collected used paper and card may be considered pre-consumer, for example paper and cardboard intended for use that is discarded before consumer use. Waste collected from such commercial and industry sources is more likely to be a homogenous composition and, therefore, not in need of further sorting.[25]

The collected material may go directly to paper mills or through a further sorting stage to remove other recyclable materials or contaminants. At paper mills, it enters the pulping equipment where it is mixed with water and broken down into fibres before going through the papermaking process. The impacts of such variations in collection methods are discussed throughout this section.

It is worth noting that the collection methodology influences the volume and quality of recyclate collected. This is addressed further in Section 1.1.3 (Examples in practice) below.

[25] CEPI, “Paper-based packaging recyclability guidelines.” (2020). Available at: link

1.1.2 Measure indicator

The indicator for Measure 1 is the **‘percentage of paper and board placed on the market that is collected for recycling’**. Throughout the report we will refer to this as the collection rate. This is defined as the paper collected for recycling compared to the paper consumed.

Different organisations across the industry refer to the collection rate differently. Often in the literature the collection rate is referred to as a ‘recycling’ rate. This can be misleading, since not everything that is collected for recycling will go on to be recycled into new products. In other instances, collection rate is referred to as a ‘recovery’ rate. Figures for recovered paper include energy recovery, i.e., paper used as a fuel, either via incorporation into refuse derived fuel or simply incinerated, alongside recycling activities. Energy recovery does not present any material efficiency savings and as such is out of scope for this project.

The variation in use and meanings of the various terms highlights the need for consistent definitions in the recycling industry. For instance, the work of Ervasti et al. quotes the European paper recycling rate as 70%, yet paper products produced in the same year contained just 41% recycled fibre material.[26] The report attributes the difference between the two figures to recycling process losses, differences in moisture levels and the addition of virgin fibres alongside recycled fibres in the papermaking process, though it is possible that exports also have an impact. The process losses referred to could be paper that cannot be recycled due to poor quality (discussed in Measure 5), or paper that is not recycled due to reprocessing or manufacturing inefficiencies (discussed in Measure 6).

Measure 1 is highly interdependent on Measures 5 and 6. This interdependency is discussed in Section 9.0 Interdependencies

Important to note for Measure 1 is that the method of collection can impact the quality of paper and increase the process losses due to the collected material not being of sufficient quality and being contaminated. According to one stakeholder in interview, a commonly cited issue is that paper co-collected with other recyclable materials like plastics and glass can reduce the quality of the collected paper. For example, food and liquid remnants on some plastic packaging can make paper greasy and unrecyclable. Glass that smashes in mixed recycling collections can make its way into the paper sent to reprocessors where it is extremely hard to remove and causes high levels of wear on machinery through abrasion. Once it has been collected, the quality of paper can degrade further due to the presence of moisture as well as handling errors. All of these factors influence the amount of paper material that can actually be recycled into new products.

Nevertheless, this does not affect the collection rate and as such is not discussed in this measure. Rather, where it was deemed within scope, such issues were covered in Measure 5 which covers the use of recycled input in the manufacture of paper products.

[26] Ervasti, I and Miranda, R and Kauranen, I, “A global comprehensive review of literature related to paper recycling: a pressing need for a uniform system of terms and definitions”, Waste Management (2016). Available at: [link]

1.1.3 Examples in practice

The recycling process for paper products begins with the collection, either by local authorities or commercial waste management collectors at kerbside or at centralised facilities such as HWRCs. Sorting then places different product categories into their respective streams, with different grades having different specifications. Products must be separated so that the correct paper mill can handle and re-process them. For instance, cardboard is processed at a different mill to office papers. Material is mechanically separated into pulp fibres in the presence of water, with the pulp being screened for contaminants and deinked (if required) before the cleaned pulp passes into the papermaking process – only if the pulp is to be used at a different site is it dewatered. The amount of contamination in the input material has an impact on efficiency. Contamination can occur either due to collection methods (for example commingled recycling, which can introduce contaminants and undesired materials into the recycling stream such as plastic bottles, cans, and glass) and due to product design (for example components such as barriers, inks, varnishes, and adhesives can have an impact on recycling[27]).

There are some products within the PPI which cannot be recovered for recycling. For instance, some paper products have plastic or chemical barrier coatings to preserve the freshness of the products in the packaging.[28] There are limitations to the mass of barrier coating that can be used to protect packaging before it becomes unacceptable to recycling equipment. It is not clear from literature or interviews what the mass percentage of barrier coating to paper can be before the paper becomes unrecyclable. The recycling process of is complex, and all non-paper ingredients within a pack impact on the quality of the recycled material. A compositional assessment of a packaging item is not necessarily a determinant for its recyclability.

1.2 Available sources

1.2.1 Literature review

The literature review identified 24 sources that discussed collection of waste paper and board for recycling as a resource efficiency measure. These comprise:

- Three academic papers;[29] [30] [31]

[27] CPI, "Design for Recyclability Guidelines". (2024). Available at: link
[28] Stora Enso, "Barrier coatings", (2023) [Online]. Available at: link
[29] Ervasti, I et al, "A global comprehensive review of literature related to paper recycling: a pressing need for a uniform system of terms and definitions", (2016). Available at: link
[30] Food Packaging Forum, "Studies assess PFAS, OPEs, and plasticizers in paper & board", (2023). Available at: link
[31] 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

- Eleven industry reports;[32] [33] [34] [35] [36] [37] [38] [39] [40] [41] [42]
- One policy document;[43]
- Four technical studies;[44] [45] [46] [47] and
- Five website articles.[48] [49] [50] [51] [52]

The relevant sources were considered of high applicability and credibility when assessed against the data assessment framework, which recognises the relevance of the sources and the strength of the methodology within each. The sources exhibited an average IAS of 4.34 (out of 5) with 21 sources exhibiting a score of 4 or above. Of the literature reviewed, there was significant discussion of the UK PPI specifically which provided qualitative and quantitative data that contributed to understanding of appropriate levels of efficiency. Other sources that had a Europe-wide scope discussed UK waste and recycling targets whilst also providing qualitative comparison between our geographical neighbours. 13 of the sources were specific to the UK and all sources were published in the last 10 years. Academic literature has also provided valuable discussion on this measure, touching on the need for standardisation of definitions related to the topic of paper collected for recycling.

1.2.2 Interviews

All eight stakeholders engaged with this measure during the interviews. Some could speak to the efficiency levels for this measure, whilst others were hesitant due to the national level scope of the study. Some stakeholders held a positive view of the current state of recycling collections in the UK, albeit with room for improvement in levels of efficiency. The most frequently mentioned barrier was the collection of household recycling being co-mingled, i.e., various materials collected in the same container. This is because paper and card is more easily contaminated when it is in close contact with other materials. European legislation promotes separate paper and card collection to facilitate high-quality recycling which was supported by many of the stakeholders. However, one stakeholder suggested that the opposite

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[32] ASPAPEL, “Sustainability Report 2021: Decarbonised bi-circularity of the paper industry”, (2021). Available at: link
[33] CEPI, “Paper-based packaging recyclability guidelines.” (2020). Available at: link
[34] Confederation of Indian industry, “Resource efficiency in the steel and paper sectors”, (2019). Available at: link
[35] CPI, “2022-23 Annual Review”, (2022). Available at: link
[36] CPI, “The economic value of the UK’s paper-based industries”, (2022). Available at: link
[37] CPI, “The UK Paper Industry - Innovation and the Bioeconomy”, (2019). Available at: link
[38] Defra, “Resources and Waste Strategy Monitoring Progress”, (2022). Available at: link
[39] European Paper Recycling Council, “European declaration on paper recycling”, (2021). Available at: link
[40] Two Sides, “Paper Packaging: The Natural Choice”, (2021). Available at: link
[41] Two Sides, “Paper production and sustainable forests”, (2020). Available at: link
[42] Two Sides, “Paper recovery and recycling”, (2021). Available at: link
[43] European Parliament, “Revision of the packaging and packaging waste directive”, (2023). Available at: link
[44] CPI, “Design for recyclability guidelines”, (2022). Available at: link
[45] CPI, “Recycling of coffee cups” (2020). Available at: link
[46] ICFPA, “ICFPA Sustainability Progress Report”, (2023). Available at: link
[47] Roth, S, et al., “The pulp and paper overview paper”, (2016). Available at: link
[48] Back, S, “The British paper industry of today”, PA Paper Advance (2021) [Online]. Available at: link
[49] CPI, “Papercycle”, (2023). Available at: link
[50] Defra, “Consultation outcome – Government response”, (2023) [Online]. Available at: link
[51] McKinsey & Company, “The potential impact of reusable packaging “, (2023). Available at: link
[52] The Grocer, “Is paper really better for the Earth than plastic?”, (2023). Available at: link

was true, and that household paper and card waste collected co-mingled was of higher quality, since it will have been through a materials recovery facility (MRF) for sorting before being sent to paper mills for reprocessing. This stakeholder commented that paper and cards collected separately often contained much more contaminating material, including batteries and plastics, since the feedstock came directly from household collections without further screening and was therefore dependent on individual consumers knowing, or not knowing, the acceptable items for their paper and card bin.

1.2.3 Workshop

Measure 1 received the highest level of engagement of all measures in the workshop. All stakeholders contributed to the discussion, particularly on the recent proposed introduction of Simpler Recycling within England by 31 March 2026.[53] The Government's new proposals require councils to offer at least three waste containers per household for co-mingled dry recycling, food waste and residual waste. Defra have just consulted on providing exemptions that would allow local authorities, without the need for a written assessment, to decide the number of bins they would like to collect dry recyclables in and to co-collect food and garden waste in one bin. However stakeholders were under the impression that local authorities would be limited to only providing three containers, which would make them unable to collect different dry recycling materials separately. Under this impression, stakeholders expressed concerns on the effects that co-mingled collections will have on the rate of collection of paper and board products and the impact on its quality. Two stakeholders strongly believed that separate collection streams are the most effective route to higher recycling rates within the UK. In voting, there was a good level of engagement with current, BAU and maximum levels of efficiency. However, for the BAU scenario, many stakeholders were unable to provide an estimate as they deemed 2035 was too far into the future to predict. The barriers and drivers were also well engaged with, in both verbal discussion and workshop voting.

The level of engagement in the workshop was as follows:

- Six stakeholders across the industry were active on the mural board, voting for levels of efficiency, drivers and/or barriers.
- Four stakeholders actively contributed to verbal discussion.

1.3 Drivers & Barriers

The drivers and barriers influencing this measure were identified through a combination of the literature review, stakeholder interviews and sector workshop.

1.3.1 Drivers

Table 4 below shows the main drivers for Measure 1. The most significant drivers are shown in bold as voted for by stakeholders in the workshop.

[53] Department for Environment Food & Rural Affairs, "Consultation outcome – Government response", (2023)

Table 4: Drivers for paper measure 1

Description	PESTLE	COM-B
Legislation	**Legal/political**	**Capability – psychological**
Design for recycling	**Technological**	**Capability – physical**
Recycling targets	**Legal**	**Opportunity – physical**
Export market	Economic	Opportunity – physical
Costs associated with extended producer responsibility	Legal	Opportunity – physical

Legislation

The driver which workshop attendees felt could be significant in achieving higher rates of collection, was the proposed introduction of Simpler Recycling in England by 31 March 2026.[54] One stakeholder made the important distinction that the effect of Simpler Recycling might lead to a greater amount of paper and card being collected for recycling from households, however, the amount that could be effectively recycled might reduce from current levels due to contamination. This driver was spoken about extensively in the workshop and as such has been reflected as the most important driver for this measure.

Design for recycling

Some common composite materials, i.e., a combination of two or more materials with different physical and chemical properties, contain high levels of paper fibre. For example, single-use coffee cups are frequently made out of paper with a plastic laminate coating. To recover the fibre from the cup, mills must immerse them in water for a longer time than required for other non-laminate, fibre-based products.[55] Recycling mills will generally accept coffee cups at the 'market mix', while three UK paper mills can process coffee cups in bulk. For this reason, many local authorities do not accept coffee cups or other laminate materials in their recycling streams and good quality fibre found in such materials is not collected for recycling. Designing with this issue in mind means making composite materials that can be separated into their constituent materials in standard reprocessing facilities. As a result, local authorities would be able to accept a wider range of fibre-based laminates into the recycling stream and collect more paper and card for recycling. An example of good design enabling greater recyclability is found in Aquapak® which has, in collaboration with DS Smith Packaging, developed a plastic liner for laminated paper products that is fully compatible with the DS Smith mill.[56]

[54] Defra, "Consultation outcome – Government response", (2023) [Online]. Available at: link
[55] CPI, "Recycling of coffee cups" (2020). Available at: link
[56] The Grocer, "Is paper really better for the Earth than plastic?", (2023). Available at: link

Guidance has been produced on enabling the uptake of 'design for recyclability' principles by industry bodies, including the CPI.[57] The CPI has also released a recyclability assessment tool called Papercycle.[58] The online tool assesses the recyclability of the PPI materials, for both finished and semi-finished products. Such guidance aims to improve the knowledge of decision makers when designing fibre-based packaging products for superior recyclability. Three of the ten votes for the top drivers in the workshop were for this driver, making it one of the highest voted drivers for this measure.

Recycling targets

Recycling targets are being mandated within the UK for many sectors. For the PPI, annual recycling targets for paper and card packaging products are set at 80% by 2024 and 89% by 2030[59]. To ensure that these packaging recycling targets are met, there must be sufficient collection from domestic and commercial sources, which will lead to an increase in the recycling rate. Three of the ten votes for the top drivers in the workshop were for this driver, making it one of the highest voted drivers for this measure.

Export market

As recyclable materials are seen as a valuable resource, the consequence is a global market for these commodities. Whilst the domestic PPI does not have the capacity to process all material collected, the incentive to increase the rate of collection is therefore 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 PPI has a growing demand for its collected recyclable material outside the UK.

As of 2019, the UK PPI was the world's largest exporter of recovered paper products.[60] It has been well documented that the international trade of waste can in some instances have poor environmental consequences, where materials are leaked into the environment, or that waste is mismanaged in the destination where it is intended to be recycled. This concern prompted the UK Government to ban exports of waste to non-OECD countries in 2019, with calls to extend this to a ban of all exports of plastic waste in particular by 2027.[61] A stakeholder in the workshop agreed that the high export levels of paper and board from the UK can be a driver, but also acts as a barrier, discussed in Section 1.3.2 Barriers.

Costs associated with extended producer responsibility

Producer responsibility systems in place in the UK ensure that businesses meet, but do not exceed, their packaging waste recycling obligations. Current legislation is going through a reform to introduce extended producer responsibility (EPR) for household packaging, which

[57] CPI, "Design for recyclability guidelines", (2022). Available at: link
[58] CPI, "Papercycle", (2023). Available at: link
[59] CPI, "2022-23 Annual Review", (2022). Available at: link
[60] Back, S, "The British paper industry of today", (2021). Available at: link
[61] UK Parliament Committees, "MPs call for ban on all plastic waste exports", (2022). Available at: link

would place the responsibility and cost of managing packaging products at their end of life on the packaging producers. The new regulations should incentivise higher levels of recycling by rewarding and/or penalising producers for specified criteria, and fees paid by producers will fund recycling activities.

1.3.2 Barriers

Two barriers were identified for Measure 1.

Table 5: Barriers for paper measure 1

Description	PESTLE	COM-B
Composite materials	Technological	Capability – physical
Changing product landscape	Economic	Motivation – reflective

Composite materials

As mentioned above, products made from composite materials, such as coffee cups, are often difficult to recycle in paper mills and so not typically accepted in household recycling streams (see ‘design for recycling’ in Section 1.3.1 Drivers). As such, good quality fibre found in composite materials is not collected for recycling. To ensure that paper fibre is captured, product designers and engineers should design with recycling in mind so that products can reach their desired end-of-life destination. However, implementing new material design can be both costly and time intensive, and recycling industry collaboration is vital to its success. Another approach would be to collect these materials separately and send them to mills that can reprocess them, or adapt recycling processes to better handle such composite materials, however this too may come with high costs to develop, test and implement.

Changing product landscape

There is a huge diversity of paper products on the market which can be a challenge for waste collectors, sorters and reprocessors. According to stakeholder interviews, many of these actors in the waste industry have called for packaging producers in particular to use mono-materials, i.e., packaging consisting of only a single material, in order to facilitate high-quality recycling. Nevertheless, literature highlights that there is a trend within the packaging industry towards using more laminated products or ‘multi-materials’ to meet the growing needs of the food and drink industry, which has specific requirements around freshness to ensure product quality.[62] As highlighted in the ‘Design for Recycling’ driver in Section 1.3.1, laminated products such as those used for coffee cups are rarely accepted for generic recycling collections, nor are they able to be processed in volume by typical paper mills. The introduction of novel and diverse laminates in the paper industry could therefore negatively affect their collection rates.

[62] The Grocer, “Is paper really better for the Earth than plastic?”, (2023). Available at: link

Certain types of paper products – for instance, art works, books, photographs, and wallpaper – are unlikely to enter the recycling or recovery streams for many years.[63]

1.4 Levels of efficiency

Table 6: Levels of efficiency for paper measure 1

Indicator: Percentage of paper and board placed on the market that is collected for recycling			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value	67-70%	80-90%	70-80%
Evidence RAG	Green	Red-Amber	Red

1.4.1 Current level of efficiency

The current level of efficiency reported by the CPI for 2022 is 67%.[64] The CPI calculated this value based on the tonnage of paper and board collected compared to the tonnage placed on the market in 2022. This therefore meets the indicator definition for collection rate. During an interview, one stakeholder agreed that this level of efficiency was suitable to use for this measure. The collection rate is also shown to have decreased from 71% in 2021. Additional statistics that meet the definition of collection rate were not readily available in the literature.

At the workshop, five stakeholders voted in agreement that the current level of efficiency for this measure is in the range of 66-70%. Two voted with high confidence, three voted with medium confidence. One vote was cast in the 60-65% range with medium confidence.

Stakeholders agreed that there are likely to be significant variations in collection rates across regions of the UK. For instance, regions with more commercial recycling activities will likely have much higher collection rates, since it is generally accepted that commercial waste consists of high volumes of single materials that are accepted in recycling streams. For example, supermarket retailers may have high volumes of cardboard from deliveries, or hospitality venues may have high volumes of glass from drinks sales. One stakeholder suggested that collection rates of cardboard in business-to-business operations are likely to be close to 100%. According to the stakeholder, businesses are often driven to collect their cardboard for recycling by being offered a financial incentive, through payments or rebates from the waste collector linked to the market value of cardboard. No data was available on how widely implemented this practice is within the UK and so could not be evaluated as a level of efficiency in this work. The collection rate will correspondingly be lower in regions with a higher

[63] Griffin et al., Industrial decarbonisation of the pulp and paper sector: A UK Perspective (2018). Available at: link
[64] CPI, "2022-23 Annual Review", (2022). Available at: link

proportion of municipal waste generated, since households are not financially incentivised to recycle cardboard like businesses, they produce more contaminated paper and cardboard (e.g. food packaging) and accordingly more paper and cardboard is captured as general waste. The breakdown of commercial versus municipal consumption however was not found in the literature, and further research is required to validate the business-to-business collection rate suggested by the stakeholder.

Based on the data available, the current level of efficiency was therefore set to 67-70% with a green evidence RAG rating, given the CPI source had an IAS of 5 and the value was confirmed to be in this range by stakeholders at workshop and interview stage. However, it should be noted that this is a national level collection rate, with variations between UK regions expected.

1.4.2 Maximum level of efficiency in 2035

No literature data were identified that estimated a maximum efficiency level for this measure. During an interview, one stakeholder suggested that in theory, the collection rate could be close to 100% if hygiene PPI products are excluded. This collection rate could be achieved if there is correct implementation of collection schemes and contamination to paper via incorrect handling by stakeholders is minimised.

In the workshop, four stakeholders voted on the maximum level of efficiency. Two stakeholders voted for a maximum level of efficiency in 80-90% with medium confidence. One stakeholder voted for a maximum efficiency of 70-80% with medium confidence. A fourth stakeholder voted for a maximum level of efficiency of 40-50% with high confidence as they believed the Simpler Recycling regulation (discussed above) would reduce the recycling rate. However, since this level of efficiency represents a maximum feasible technical potential, this fourth vote has been disregarded.

In the absence of more comprehensive data, the maximum level of efficiency for this measure was estimated to be 80-90%. This was selected as it reflects the range that was voted for by the majority in the workshop. Nevertheless, the evidence RAG rating for this efficiency level is red-amber, reflecting the lack of confidence from stakeholders. Four of the six participating stakeholders voted in the workshop, however, it was clear that the voting reflected a level of disagreement amongst the stakeholders, particularly regarding the impacts of the Simpler Recycling regulation, which all felt, based on their understanding of the regulation (see Section 1.2.3 above), would have a negative impact on paper recycling in general. Because this level of efficiency reflects the maximum technical potential that is feasible for collection rates, the impact of the Simpler Recycling regulation has not been taken into account, but has been considered for the BAU case discussed below.

1.4.3 Business-as-usual in 2035

No data were identified that estimated a BAU collection rate for paper and card in the UK, however a paper and card 'recycling rate' target of 80% by 2024 and 89% by 2030 was found in a CPI report referring to packaging.[65] The report defines the recycling rate as the amount of

[65] CPI, "2022-23 Annual Review", (2022). Available at: link.

paper and card collected compared to the amount consumed, which meets the definition of collection rate for this report. The CPI report suggested that these collection rate targets are ambitious, given a 'lack of appropriate collection systems' in the UK.[66]

No other values were identified in the literature at the UK level. Other recycling rate targets were identified at an EU level, however, it is unclear whether these values reflect a target collection rate or recycling rate (i.e., whether they included paper material that is subsequently not recyclable or not). For example:

- The European paper packaging industry has set a target of 90% recycling rate by 2030;[67]
- The European beverage carton industry has a target of a 70% recycling rate by 2030;[68] and
- The Packaging and Packaging Waste Directive (PPWD), which is enforced for EU member states, mandates for a paper and cardboard recycling rate of 85% by December 2030.[69]

Because there is uncertainty over the applicability of each value to our definition of collection rate, these values have not been considered for this level of efficiency.

During an interview, one stakeholder gave an estimated level of efficiency for BAU of 80-90%.

During the workshop, five stakeholders voted, however three votes were cast in the 'other' category with commentary on the level of efficiency, and just two stakeholders voted on a BAU level of efficiency. These two stakeholders voted in the 70-80% range saying that the introduction of Simpler Recycling in England will improve the collection of paper and board but limit its recyclability due to quality issues. These votes were placed with medium confidence. One of the three comments on the BAU level of efficiency remarked that there is no evidence to suggest the collection rate will vary from the current level. Two other stakeholders suggested with high confidence that as a direct result of Simpler Recycling, the BAU collection rate would fall.

Overall, there was limited evidence provided by the literature and stakeholders on the BAU level of efficiency. Most of the literature identified referred to a recycling rate target, not a collection rate target. Moreover, where a relevant target was identified, the targets were evaluated as ambitious and therefore potentially difficult to be met. For this reason, more weight has been placed on stakeholder voting for this level of efficiency.

The BAU level of efficiency was selected to be 70-80%, reflecting workshop voting. Due to the lack of data available and the low number of votes cast in the workshop, this level of efficiency has a RAG evidence rating of red.

[66] Ibid.
[67] Two Sides, "Paper Packaging: The Natural Choice", (2021). Available at: link.
[68] ibid.
[69] European Parliament, "Revision of the Packaging and Packaging Waste Directive", (2023). Available at: link.

2.0 Measure 2 – Substitute paper with alternative materials or dematerialisation

2.1 Paper resource efficiency measure

2.1.1 Description

Substituting paper with alternative materials in packaging and non-packaging applications or avoiding the use of paper altogether.

This measure is concerned with how resource efficiency can be achieved through material substitution and dematerialisation, i.e., replacing paper with another material that has a lower overall emissions impact over its lifecycle. For instance, substituting paper for plastic or glass would imply that plastic or glass is used where paper was used before. It is assumed that the substitution must maintain or improve the product’s functionality. There is a trend in the packaging industry towards using paper in place of other single-use packaging materials such as glass, since it is much lighter and can therefore deliver emissions savings in its production and transport, and in substitution of plastics, where in some cases the poor public perception of plastics’ environmental credentials is enough to warrant substitution, whether emissions impact reductions are achieved or not. There are also efforts being to explore reusable packaging options, which can result in the substitution of single-use paper and card packaging for reusable plastic packaging options. Therefore, this section explores the extent to which paper use could be impacted by substitution through being reduced or eliminated. For this reason, this measure also concerns methods for avoiding the unnecessary use of paper or ‘dematerialisation’, for example, using digital means of viewing content that has traditionally been communicated using newsprint. During this research, evidence of dematerialisation was only found to be relevant to the print and graphical subsector.

2.1.2 Measure indicator

The indicator for this measure was split into two sub-indicators to represent the key segments of the market:

- **Percentage whole life CO_2e reduction from substitution with alternative materials compared to 2023 levels**; and
- **Percentage whole life CO_2e reduction from dematerialisation compared to 2023 levels**.

The indicators for this measure are baselined in the current year to highlight relative changes. One other indicator for this measure was identified in the literature and subsequently discarded:

- Reduction in cardboard usage by using plastic containers instead.

This indicator could not represent the savings made by substituting for all alternative materials, nor does it represent savings that could be made in formats other than boxes/tertiary packaging, and so was discarded.

Consideration was also given to splitting this measure (and associated indicator) into a measure focusing specifically on substitution with alternative materials and a measure focussing on dematerialisation. However, evidence of dematerialisation was sufficiently poor and only relevant to one aspect of the sector (print and graphical). Thus, it was not deemed suitable for splitting the measure.

A key reason for selecting CO_2e rather than a change in mass of raw materials used for this measure was the desire to reflect both a potential motivation for undertaking substitution as well as conveying the complexity of the measure. If a pure mass flow indicator was used, it would be challenging to compare where the resource efficiency (and associated carbon) gain is being made, given that a reduction of one industry's inputs will lead to an increase of another industries. By using CO_2e, a consistent unit is selected and thus can enable effective comparison of substitutions.

Where CO_2e data were not identified, available mass flow data were used. This allowed for a general understanding of the degree to which material substitutions are and could be taking place.

2.1.3 Examples in practice

As outlined in the sector introduction, the UK PPI is diverse, with a range of products across the packaging, print and graphical and hygiene subsectors. In this section, we provide some of the examples of material substitutions in practice from the various subsectors.

Two of the examples we discuss below involve reusable products. It is important to note that given the current uncertainty surrounding the environmental impact and practicalities of reuse, there are many challenges facing its further implementation within packaging products. For instance, with the release of the PPWD by the European Union, there are many efforts still underway to characterise what is defined as a reusable system. Furthermore, as will be outlined further in this report, there is contention between lifecycle assessment (LCA) studies on reusable products, and whether they truly reduce carbon impacts compared to single use systems, though it is worth noting that reuse systems might still entail non-carbon related benefits such as waste avoidance.

Reusable packaging

Most examples found were within the packaging sector, generally concerning substituting cardboard with plastics. In particular, reusable plastic packaging may offer a more sustainable alternative to single-use cardboard packaging, depending on how many reuses the reusable option can achieve. One Zero Waste Europe meta-analysis of reusable versus single-use products concluded that most studies find reusable packaging to be more environmentally sound than single-use options.[70] For example, one of the LCA's analysed suggested that the breakeven point at which the environmental benefits of a reusable plastic crate outweigh that of a single-use cardboard box was between 5 and 15 uses.[71] According to this study, 5-15 uses equates to 1 to 3 years of use. Since the standard service life of a plastic crate is estimated at 10 to 20 years, this suggests that a plastic crate would achieve many more uses than the 5-15 suggested to make it equitable with the emissions of a single-use cardboard box.

On the other hand, a recent peer-reviewed study published by FEFCO, a corrugated board manufacturers trade association, considered the impacts of reusable plastic containers against single-use corrugated cardboard trays.[72] Fifteen impact categories were considered, including the climate change impact measured in CO_2e and other categories such as ozone depletion, human toxicity and eco toxicity. The single-use corrugated box outperformed plastic in ten categories, and had a 28% lower impact in the climate change category.[73] Key parameters that affected the overall emissions outcome for this analysis were the number of reuses (in this case set to 24, however it is unclear whether there is evidence to underpin this assumption), the breakage rate of the reusable crates, and the recycling rate of the cardboard trays. The higher the number of reuses, the more favourable the reuse option becomes. In the set of boundaries made in this analysis, the breakeven point was not given, and it may be that a breakeven point is never realistically reached. Furthermore, the study conducted 14 sensitivity scenarios, including a lower breakage rate of plastic crates or a lower recycling rate of cardboard trays, and found that the cardboard tray still outperformed the plastic crate in 13 of the scenarios.

Reusable hygiene products

Many traditional disposable feminine hygiene products employ fibres such as 'fluff pulp', rayon (a highly refined cellulose fibre) as well as paper and card wrappings. The rise in reusable hygiene products such as absorbent underwear, menstrual cups and reusable pads has been associated with reduced emissions impacts. In one assessment, the given reusable products outperformed their disposable counterparts on all counts except for water use due to the water required to clean the reusable products.[74] Similarly, single-use nappies that often utilise cellulose fibres can be replaced with reusable nappies. A recent LCA by the Environment Agency asserted that reusable nappies produce 25% less CO_2e over their lifetime when compared with single-use nappies and use 97.5% less raw materials than disposables.[75] The increased use of such products could displace a small proportion of these single-use products,

[70] Zero Waste Europe, "Reusable versus single-use packaging: a review of environmental impacts", (2020). Available at: link
[71] Zero Waste Europe, "Reusable versus single-use packaging: a review of environmental impacts", (2020). Available at: link
[72] FEFCO, "Recycling vs Reuse for Packaging: Bringing the science to the packaging debate", (2022). Available at: link
[73] Impact categories – these are methods of quantifying the environmental impacts of a lifecycle assessment. One commonly used category is climate change, which measures the release of gases which lead to the warming of our planet.
[74] Fourcassier et al., "Menstrual Products: A comparable Life Cycle Assessment", (2022). Available at: link
[75] The Environment Agency, "Life Cycle Assessment of Disposable and Reusable Nappies in the UK", (2023). Available at: link

contributing to better resource efficiency for paper and other materials such as plastics and textile fibres and a reduced overall environmental impact.

Paper laminates

Paper laminates are paper products fused with a layer of additional material, such as plastic or metal foil. Lamination is a process/technique of barrier application and occurs when a sheet of a non-cellulose fibre-based material (such as a plastic or foil film) is combined with a sheet of paper or board, usually with some form of adhesive or binder to adhere the two materials together. Lamination is a technique, and not a paper component per se. Two-sided lamination occurs if a barrier has been applied on both sides of a sheet of paper or board.

These so-called ‘multi-materials’ are often used in the food and beverage industries as packaging that delivers water-resistance or extends the life of the product. Whilst these laminates are highly functional, they can be more challenging to recycle since it is hard for paper mills to separate the paper layer from the other material (see Section 1.3.1 Driversfor additional discussion of this process). One solution offered as a substitute for glass bottles could also be a suitable substitution for paper laminates, the Frugal Bottle.[76] The Frugal Bottle is a paper bottle with a plastic/foil inner pouch which the consumer can easily separate. The paper outer layer can be placed in local recycling systems, whilst the pouch can be collected for recycling in the UK at supermarkets. Whilst analysis has not compared the environmental impact of the Frugal Bottle and equivalent paper laminate bottles, the fact that it can easily be recycled rather than incinerated or landfilled like many laminates makes it a possible innovation that could reduce the emissions impact of paper and card packaging.

Dematerialisation

The impact of using digital media to replace print media, for example, newspapers, magazines and books, is not straightforward. The major direct environmental impacts associated with digital media are in the manufacturing of the electronic devices, the device usage and waste treatment. This includes the device’s energy efficiency, how long it can be used for and how much print media it replaces. For print media, the paper characteristics must be considered (newspapers are printed on thin, low-weight paper; magazines on thick, glossy paper), as well as how much content the user engages with and the end-of-life scenario of the printed item, amongst other factors. One analysis shows that a reader must substitute 30 books with an e-reader device to achieve an emissions saving, which is well within the device’s lifetime.[77] A further example is the recent digitalisation of railway network ticketing systems. For instance, ScotRail, amongst other rail companies, now actively promote the use of digital train tickets, instead of paper tickets.[78] There have been no studies which quantify the mass of paper being saved by not using paper tickets, nor the difference of GHG emissions produced by using an electronic ticket compared to a paper one.

[76] Frugalpac, "The Frugal Bottle", (2020). Available at: link
[77] Coroama, Moberg, and Hilty, “Dematerialization Through Electronic Media?”, (2014). Available at: link
[78] ScotRail, “ScotRail App”, [Online]. Available at: link

2.2 Available sources

2.2.1 Literature review

The literature review identified 33 sources that discussed the substitution of paper with alternative materials or dematerialisation as a resource efficiency measure. These comprise:

- Ten academic papers;[79] [80] [81] [82] [83] [84] [85] [86] [87] [88]
- Eight industry reports;[89] [90] [91] [92] [93] [94] [95] [96]
- One policy document;[97]
- Two technical studies;[98] [99] and

[79] Coelho, P. et al. "Sustainability of reusable packaging–Current situation and trends", (2020). Available at: link
[80] Coroama, Moberg, and Hilty, "Dematerialization Through Electronic Media?", (2014). Available at: link
[81] Fadarina et al., "Banana midribe as substitute for pulp production", (2019). Available at: link
[82] Fourcassier et al., "Menstrual Products: A comparable Life Cycle Assessment", (2022). Available at: link
[83] Herrmann, Rhein, and Sträter, "Consumers' Sustainability-Related Perception of and Willingness-to-Pay for Food Packaging Alternatives., (2022). Available at: link
[84] Norton, V. et al, "Exploring Consumers' Understanding and Perception of Sustainable Food Packaging in the UK.", 2022. Available at: link
[85] Rogers, J.G, "Paper making in a low carbon economy", (2018). Available at: link
[86] Simmonds, G. et al.,"'Show me the goods': Assessing the effectiveness of transparent packaging vs. product imagery on product evaluation", (2018). Available at: link
[87] Sumimoto, M, "Paper and paperboard containers", (1990). Available at: link
[88] Tahar, K et al. "Lifecycle greenhouse gas emissions of e-books vs. paper books: A Japanese case study", (2018). Available at: link
[89] ASAPEL, "Sustainability Report 2021: Decarbonised bicircularity of the paper industry", (2021). Available at: link
[90] Blazejewski, T. et al., "Comparison of Morrisons' Reusable Paper Bags and Plastic Bags for Life", (2019). Available at: link
[91] FEFCO, "Recycling vs Reuse for Packaging: Bringing the science to the packaging debate", (2022). Available at: link
[92] Fraunhofer, "Reusable plastic crates vs. single-use cardboard boxes - two packaging systems in competition", (2022). Available at: link
[93] The Environment Agency, "Life Cycle Assessment of Disposable and Reusable Nappies in the UK", (2023). Available at: link
[94] TwoSides, "Print and Paper, Myths and Facts", (2021). Available at: link
[95] Two Sides, "Packaging Preferences Unpacked – Consumers Prefer Paper-Based Packaging", (2023). Available at: link
[96] Zero Waste Europe, "Reusable versus single-use packaging: a review of environmental impacts", (2020). Available at: link
[97] European Commission, "Regulation of the European Parliament and of the Council on packaging and packaging waste", European Union, (2019). Available at: link
[98] DHL, "Rethinking packaging", (no date). Available at: link
[99] SITRA, University of Cambridge, "Material economics: A net-zero transition for EU industry", (2020). Available at: link

- Twelve website articles.[100] [101] [102] [103] [104] [105] [106] [107] [108] [109] [110] [111]

The relevant sources were considered of high applicability and credibility when assessed against the data assessment framework, which recognises the relevance of the sources and the strength of the methodology within each. The sources exhibited an average IAS of 4.5 (out of 5) with all but 2 sources exhibiting a score of 4 or above. Thirteen of the sources were from the UK, the other eighteen were studies with European or global level scope but were considered to be applicable to the UK market or processing landscape. Twenty seven sources were from the last ten years, two sources had no date but were assumed to be from the last ten years.

Quantitative levels of efficiency were not given in these sources. The themes of the literature covered in this measure were mostly centred around packaging, its reuse, and its environmental impacts. Only one source, which covered dematerialisation, discussed resource efficiency.[112] A common theme of the technical reports and website articles was attempting to qualify or quantify whether paper or plastic is the superior material choice from a GHG emissions and qualitative standpoint.

2.2.2 Interviews

The stakeholders interviewed did not discuss this measure at great lengths. One stakeholder commented on material substitution but suggested that the more common substitution was from plastic to paper, rather than from paper to other materials as this measure is concerned with (for more information on plastic material substitution please refer to the ‘Unlocking Resource Efficiency: Plastics Report’ Measure 2). This could be due to a perception held by stakeholders, that was not directly addressed in any interviews, that paper as a material is at the top of a material substitution hierarchy, with limited applications where there is a material more suitable than paper. Others felt they could not contribute to the discussion of material substitution because it was not in their power to drive change, rather it was down to the product specifiers to decide what material to use, not the paper industry.

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[100] Beals, R.K, “Apple to drop plastic packaging by end of next year, no leather cases for iPhone 15”, Morningstar, (2023) [Online]. Available at: link
[101] Butler, S., “Milk & More to increase reuse of bottles by 15% as glass prices soar”, (2022) [Online]. Available at: link
[102] Defra and Environment Agency, “Extended producer responsibility for packaging: who is affected and what to do”, (2022). Available at: link
[103] Frugalpac, "The Frugal Bottle", (2020). Available at: link
[104] Leadbitter glass, “How to Calculate the Weight of Glass”, (2023) [Online]. Available at: link
[105] Little Lamb, “Why Use Cloth Nappies?” [Online]. Available at: link
[106] MobileUK, “Mobile Facts”, (2023) [Online]. Available at: link
[107] ScotRail, “ScotRail App”, [Online]. Available at: link
[108] Sugam Group, “Understanding Cargo Shipping Costs And Rates In 2023”, (2023) [Online]. Available at: link
[109] Swiftpak, “Packaging advice: Plastic vs Paper Packaging: The Pros and Cons”, (2023). Available at: link
[110] The Grocer “Is Paper Packaging Really More Sustainable than Plastic?”, (2023). Available at: link
[111] Tri-pack, “Cardboard versus plastic”, Tri pack [Online]. Available at: link
[112] Coroama, Moberg, and Hilty, “Dematerialization Through Electronic Media?”, (2014). Available at: link

2.2.3 Workshop

Stakeholders were initially apprehensive around this measure recognising that they were unlikely to identify areas where their industry's outputs would be replaced by other industries. However, after some initial uncertainty there was positive discussion especially around the topic of dematerialisation and the use of e-devices instead of paper sources. Stakeholders conveyed frustration that often substitutions were made on the basis of perceived environmental benefits or consumer preference with such decisions sometimes supported by inaccurate data, or even no data. An example was given where commercial entities are placing an option on their website providing visitors with the option to 'go green and go paperless'. However, when the stakeholder requested evidence that going paperless guaranteed they would be 'green', the commercial entity can often not provide any. This further supports the need for an evidence base, especially on lifecycle assessments, for whether or not paper or other materials provide less environmental impact. Some quantitative data was gathered during the workshop for the material substitutions from paper to other materials. However, there was no quantitative data gathered for substitutions from other materials into the PPI.

The level of engagement in the workshop was as follows:

- Five stakeholders across industry were active on the mural board, voting for levels of efficiency, drivers and/or barriers.
- Four stakeholders actively contributed to verbal discussion.

2.3 Drivers & Barriers

The drivers and barriers influencing this measure were identified through a combination of the literature review, stakeholder interviews and sector workshop.

2.3.1 Drivers

The drivers for Measure 2 are shown in Table 7. Due to low levels of voting on these drivers in the workshop, the most significant drivers were taken to be those most discussed by stakeholders and are shown in bold.

Table 7: Drivers for paper measure 2

Description	PESTLE	COM-B
Climate policy	**Political**	**Opportunity – social**
Promotion of reusable packaging	**Social**	**Opportunity – physical**
Potential environmental benefits	Environmental	Opportunity – physical

Material innovation	Technological	Capability – physical
Consumer preferences	Social	Motivation – reflective
Availability of alternatives	Environmental	Opportunity – physical

Climate policy

Net-zero targets, roadmaps and waste reduction programmes from both the Government and the paper and card manufacturing industries, as well as the societal pressure from consumers for emissions reductions, will be a significant driver to reduce waste and the overall environmental footprint of card and paper products. However, stakeholders agreed at the workshop that studies declaring relative differences of GHG emissions in any two given scenarios can often have significant differences due to assumptions made within a given LCA study. Stakeholders from the UK PPI industry stated that whether or not substitutions can help their customers meet policy requirements is thus linked to the integrity of a given study.

The announcement of modulated fees for packaging under incoming EPR regulations (discussed in Section 1.3.1 Drivers) also has the potential to drive material substitution or be a barrier to it.[113] Whether modulated fees are a barrier or driver depends on announcements that will originate from the Government after consultations have been completed.

Promotion of reusable packaging and products

There is much discussion within the literature on reusable packaging products.[114] As industries across the supply chain look to reduce their environmental impacts and work towards a circular economy, switching to reusables for both packaging and non-packaging applications appears to be a neat solution to reduce single-use packaging and unnecessary use of paper and card. One literature source makes clear that the waste hierarchy is not being implemented in order of priority, i.e., reuse is not being considered before recycling or other recovery. To reduce the impact of single-use packaging, producers should be required to prove their products' benefit over a reusable system.[115] In the case of paper and card, whilst it may be highly recyclable, it has a low potential for reuse compared to materials like plastic. If the waste hierarchy is implemented more stringently, as is implied in the UK Waste Strategy, the use of paper and card may reduce in favour of reusable systems that employ other materials, though detailed assessments should underpin material substitution strategies to ensure environmental benefits are realised.

[113] Defra and Environment Agency, "Extended producer responsibility for packaging: who is affected and what to do", (2022). Available at: link
[114] FEFCO, "Recycling vs Reuse for Packaging: Bringing the science to the packaging debate", (2022). Available at: link
[115] Fraunhoffer, "Reusable plastic crates vs. single-use cardboard boxes - two packaging systems in competition", (2022). Available at: link

One stakeholder at the workshop stated that upon further uptake of the PPWD that is soon to be converted to a binding legal regulation,[116] there could be a further strengthening in the use of other materials such as plastics, in place of paper, driving this measure. Morrisons has recently introduced a paper bag which they have branded 'Reusable Paper Bag'.[117] It is unclear whether the intended use of this bag along with the associated infrastructure deems the use of 'reusable' acceptable. For instance, considering Article 10 of the PPWD, this article states that packaging shall be considered reusable if: 'it can be emptied or unloaded without damage to the packaging, which prevents its re-use'.[118] Given papers susceptibility to tearing if there is abrasion against its surface, it is unclear if a paper bag could meet this definition. Alongside other requirements contained in Article 10 of the PPWD, it is uncertain if a paper bag can be deemed reusable. This is an example of why, in the current climate of consumers seeking reusable items, there may be a material substitution drive away from paper products.

Potential environmental benefits

It was noted in the literature that minimisation of packaging has the potential to make significant carbon emissions savings.[119] This could be via lightweighting as described in 4.0 Measure 4 – Lightweighting of paper products, but also via the reduction in packaging by substituting materials or by dematerialisation as discussed in this measure. For this measure, packaging material substitution or dematerialisation could present carbon emissions savings via a reduction in consumption of raw materials and a reduction in associated transport of those products. Stakeholders were reluctant to discuss this as a driver during the workshop, as they consider this to be a driver for the product specifiers, i.e. their customers, rather than the PPI itself.

Material Innovation

Whilst the paper and card industries make efforts to reduce the impact of their products and operations, so do other materials industries. If technological or operational advances are made, this may make other materials more attractive as substitutions: for example, if plastic films become more widely recycled, they could more viably replace paper food packaging, or as electronics inevitably become more energy efficient, digital media will become more clearly favourable than print media in terms of environmental impact, though additional considerations such as fossil fuel usage for plastics production would also need to be taken into account.

Consumer preferences

Consumers may have specific reasons why they select products packaged with certain materials. For example, consumers may choose products in transparent packaging, i.e. materials such as plastic or glass, as it allows them to see the product and increases

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[116] European Commission, "Regulation of the European Parliament and of the Council on packaging and packaging waste", European Union, (2019). Available at: link
[117] Morrisons, "Morrisons to introduce paper carrier bags in all stores", (2023) [Online]. Available at: link
[118] European Commission, "Regulation of the European Parliament and of the Council on packaging and packaging waste", European Union, (2019). Available at: link
[119] Rogers, J.G, "Paper making in a low carbon economy", (2018). Available at: link

consumers expectations of freshness and quality.[120] One stakeholder also suggested that any trend in dematerialisation of print media such as newspapers and magazines was likely to be driven by the perceived convenience to the consumer rather than its potential environmental benefits. For reusable sanitary products and nappies, many brands also advertise the potential cost saving associated with their reusable option which could influence consumers' likelihood to purchase.[121] There are other benefits to reusables alongside environmental, with reusable nappies for instance being cheaper in the long run according to one online article.[122] On the other hand, consumers may choose paper products over other products which is discussed in Section 2.3.2 Barriers.

Availability of alternatives

Suggested by stakeholders, this driver refers to the dematerialisation of the UK PPI. Stakeholders suggested that due to the increased availability of e-devices such as mobile phones, UK consumers are switching to electronic devices away from newsprint and paper tickets for transportation methods such as trains, planes and coaches. It was not stated that cost was the immediate driver for this, but rather the convenience given 98% of the UK adult population own a mobile phone, a large percentage of which are likely capable of viewing tickets.[123]

2.3.2 Barriers

The barriers for Measure 2 are shown in Table 8. Due to low levels of voting on these barriers in the workshop, the most significant barriers were taken to be those most discussed by stakeholders and are shown in bold.

Table 8: Barriers for paper measure 2

Description	PESTLE	COM-B
LCA standards	**Legal**	**Opportunity – physical**
Safeguarding concerns	**Social**	**Capability – psychological**
Public perception	Social	Opportunity – social
Consumer preferences	Social	Opportunity – social
Potentially greater environmental impacts	Environmental	Opportunity – physical
Cost	Economic	Opportunity – physical

[120] Simmonds, G. et al.,"'Show me the goods': Assessing the effectiveness of transparent packaging vs. product imagery on product evaluation", (2018). Available at: link
[121] Little Lamb, "Why Use Cloth Nappies?" [Online]. Available at: link
[122] NCT, "Reusable nappies or disposable nappies?", NCT (2018). Available at: link
[123] MobileUK, "Mobile Facts", (2023) [Online]. Available at: link

LCA standards

Conducting an LCA is required to identify the GHG emissions achievable for this measure. LCAs are governed by the ISO environmental management standards.[124] Nevertheless, there is significant scope for 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 (see Section 2.1.3 Examples in practice 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 amongst other parameters. With subjectivity comes the scope for uncertainty, and in some cases, cherry-picking of data can allow industries or organisations to form narratives to promote their own interests, regardless of the actual environmental impact. Thus, when comparing the outputs of LCAs, as was attempted in this measure, there will always be a degree of uncertainty. This acts as a barrier for this measure as it is not possible to conclusively state that one material performs better than another. With this in mind, if many LCAs are available on a given topic, meta-analyses can be most helpful in ironing out differences in parameters and presenting a clearer picture of the advantages of one system over another.

Safeguarding concerns

One stakeholder raised the barrier of ensuring the transfer of information is safeguarded relating to certain paper products. The example given was patient information leaflets (PILs). The European Commission’s proposed pharmaceutical strategy leaves it to individual nations to decide whether the medicine information leaflet is in paper format electronic, or both. For the UK, The Human Medicines Regulations 2012 requires a package leaflet to be included in the packaging of a medicinal product. The stakeholder observed that dematerialisation of any such information would be impractical given that a portion of the UK population do not possess a means to read the information using electronic devices. As such, to safeguard the flow of critical information from doctor to patient, paper leaflets will remain the preferred means of communication for this application. More broadly, this means it is likely that certain applications should not be dematerialised as they would compromise on functionality, and therefore act as a barrier to reducing the consumption of paper completely.

Public perception

In research examining consumer habits and opinions on packaging materials, paper and card are consistently perceived to be of the least harm to the environment when compared with other materials.[125] [126] However, as has been made clear in this section, paper and card products do not always offer the best environmental outcomes in certain circumstances, as different applications might require different materials. Nevertheless, brands and

[124] To ensure the comparability of lifecycle assessments the International Standardisation Organisation introduced two frameworks, 14040 and 14044, which have been developed and refined since 1997.
[125] Norton et al., “Exploring Consumers’ Understanding and Perception of Sustainable Food Packaging in the UK.”, (2022). Available at: link
[126] Herrmann, Rhein, and Sträter, “Consumers’ Sustainability-Related Perception of and Willingness-to-Pay for Food Packaging Alternatives., (2022). Available at: link

manufacturers are aware of this consumer perception and many packaging products have been substituted for paper products in recent years, whether they offer an improved environmental outcome or otherwise. One stakeholder in the workshop concurred that substitutions have favoured paper and card products over other materials whether they provide environmental benefits or not.

Another facet of this barrier is the public's perception of packaging in general. The main driver for supermarket Morrisons replacing all of their reusable plastic 'bag for life' carrier bags with paper alternatives was down to evidence suggesting that customers were still only using the bags once despite being intended for reuse, and therefore not achieving a meaningful reduction in the plastic produced.[127] Arguably, if the public is unwilling to reuse products like the 'bag for life', then reuse of a paper alternative will be equally challenging. In the case of the Morrissons bag substitution, the paper bag had a lower global warming potential (GWP) based on the presumed high levels of recycling that can be achieved with paper versus plastic bags.[128] In a sensitivity analysis, if the plastic bags were recycled more frequently (which they can be if brought to supermarket collection points), their overall GWP is similar to that of the paper bag.

A stakeholder from a trade organisation stated that there is a trend of products switching from plastics to cartonboard. There could be many reasons driving these switches, but the trends identified by the stakeholder included the recyclable nature of cartonboard, as well as the perception that they have a lower GHG impact during production.

All in all, material substitutions will likely continue to occur in both directions – towards and away from paper and card products – and this could result in a net increase in paper and card products.

Consumer preferences

Consumers may have specific reasons why they select products packaged with certain materials. For instance, a Two Sides trend survey found that more and more customers choose paper packaging because it is believed to be better for the environment than other materials.[129] This could be a barrier to resource efficiency for this Measure in cases where PPI products may not actually represent the most resource efficient option.

Potentially greater environmental impacts

In some cases, the overall environmental impact of using alternative materials in place of paper and card could be higher. For example, a liquid product in glass packaging is likely to be much heavier than the same product in an equivalent paper or card based package. The areal weight, or grams per metre squared (gsm), of paper or card material can range from between

[127] Blazejewski, T. et al., "Comparison of Morrisons' Reusable Paper Bags and Plastic Bags for Life", (2019). Available at: link
[128] Ibid.
[129] Two Sides, "Packaging Preferences Unpacked – Consumers Prefer Paper-Based Packaging", (2023). Available at: link

120-700 gsm.[130] By contrast, the areal weight of standard 4-millimetre-thick glass is 10 kilograms – or 10,000 gsm: a very significant increase of mass.[131] The emissions of transportation is therefore likely to be much higher for glass packaging than for a paper or card based packaging material, since transport emissions are calculated using the weight of product transported as well as the distance. A brand may choose to switch product or packaging materials for a number of reasons, for example glass can be seen to indicate a higher quality product, or glass may be seen as more recyclable (see 'Unlocking Resource Efficiency: Glass Report'). Whilst, therefore, a switch from paper to other packaging materials may reduce material production for the PPI, the overall environmental impact of such a switch may be higher, representing an overall barrier to the resource efficiency that can be achieved through this measure across sectors.

As discussed in the Section 2.3.1 Driversabove (*Drivers: climate policy*), whether a substitution will lead to a net carbon reduction is dependent on a large number of assumptions and variables, which can vary across LCAs. As such, whilst the FEFCO study shows substituting cardboard for plastic would lead to a carbon reduction in the conditions specified in the study, there is no guarantee that other material substitutions would achieve the same carbon reduction.

Cost

Switching from paper to other materials may lead to an increase in the overall product cost. For example, recent studies have shown that manufacturers of reusable glass bottles are facing increased costs; the costs of glass bottles have been said to have doubled over recent years due to a substantially increased demand for glass bottles, coupled with a continuation of normal trade patterns post-COVID-19 pandemic.[132]

In the same way that the environmental impact of transport may increase due to the likely increase in transport mass that comes with substitutions away from PPI products, the financial cost might also increase. This is because shipping companies generally charge for transport based on the load volume and weight, with higher rates charged for larger and heavier loads.[133] The cost of any increase of product mass would therefore, impact transport costs for stakeholders across the supply chain. The low weight, and therefore cost, of paper products relative to other packaging products may disincentivise a switch to other materials. The cost implications here apply predominantly to packaging products where a like-for-like substitution is assumed. For other substitutions, such as newspapers for e-reading devices, the transport cost calculation would require further research, particularly into how many newspapers an e-reading device is likely to replace over its use. Other factors for consideration include the wastes associated with the production of electronic goods, their disposal as well as their energy use. Unsustainable extraction processes for some of the rare earths and metals as well as the difficulties of recycling are also issues associated with the electronics industry.

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[130] Sumimoto, M, "Paper and paperboard containers", (1990). Available at: link
[131] Leadbitter glass, "How to Calculate the Weight of Glass", (2023) [Online]. Available at: link
[132] Butler, S., "Milk & More to increase reuse of bottles by 15% as glass prices soar", (2022) [Online]. Available at: link
[133] Sugam Group, "Understanding Cargo Shipping Costs And Rates In 2023", (2023) [Online]. Available at: link

One stakeholder also discussed the potential cost implications, which will be borne by the producer of the material, of switching product materials. 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.

2.4 Levels of efficiency

Table 9: Levels of efficiency for paper measure 2

Indicator: Percentage whole life CO2e reduction from substitution with alternative materials and dematerialisation compared to 2023 levels			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value	0	Not available	Not available
Evidence RAG	Not applicable	Not applicable	Not applicable

2.4.1 A note on findings

The levels of efficiency for this measure were not identified. The calculation of a reduction in CO_2e requires an understanding of two factors: (1) the anticipated change in mass of PPI products placed on the market used along with the corresponding change in mass of each type of material used to replace PPI products; and (2) the carbon impacts associated with the production of each of these materials on a lifecycle basis (noting that the emissions associated with each material can vary immensely depending on features such as the origin of each material, production method, and local waste management methods). The research process did not yield sufficient information for both of these inputs to produce a meaningful level of efficiency for this measure.

3.0 Measure 3 – Material substitutions in the pulp and papermaking processes

3.1 Paper resource efficiency measure

3.1.1 Description

Substitution of virgin feedstock for other materials.

The definition of material substitution used in this measure is the same as that reported for Measure 3 and is referenced throughout the rest of the work.

Measure 3 differentiates from Measure 2 because of the level at which substitutions are being made. For Measure 2, the scope was replacing paper products with other materials such as plastic. By contrast, for Measure 3 the scope is replacing materials used to produce paper products with alternative materials. The scope applies to all of the products within the PPI sector, including print/graphic, packaging, and tissue and hygiene. Substitutions also refer to any action which will reduce the use of virgin materials to make the PPI more resource efficient. This measure will, therefore, cover the use of recovered paper in pulping.

This measure will discuss substituting virgin feedstocks for recovered sources. The use of recovered fibre, which comes from recovered paper, in the pulping and papermaking process is also discussed in Measure 5 – Use of recovered fibre in the pulping process. The indicator for this measure, as discussed in Section 3.1.2 is concerned with CO_2e emissions reduction, which could be achieved by substituting recovered paper for virgin sources. By contrast, Measure 5 is concerned with the national average, on a mass basis, of inputs to pulping that are from recovered sources. As such, while there is some degree of interaction between the measures, they are ultimately concerned with measuring different things and so are discussed separately.

3.1.2 Measure indicator

The indicator selected was **'percentage reduction in CO_2e emissions of pulping and papermaking through material substitution, compared to a 2023 baseline'.**

As with Measure 2, this measure is baselined to 2023. As a result, the current level of efficiency for this measure will be set at zero percent.

There were three other indicators for this measure identified in the literature that were discarded for this research:

- **Percentage of global paper and board production based on agricultural wastes;**
- **Percentage reduction in CO_2e emissions of pulping through material substitution; and**

- **Percentage reduction in CO_2e emissions of papermaking through material substitution.**

The first indicator was discarded as it was considered too specific for the scope of this measure. The second two indicators were discarded as it was deemed suitable to combine these two indicators into one so that stakeholders could speak to the indicator more readily at the workshops.

3.1.3 Examples in practice

Examples of material substitutions which could be made in the pulping process, as seen in a literature source[134], include:

- Use of grass pellets in place of using wood as a feedstock for pulp;
- Use of apple fibres in place of wood as a feedstock for pulp;
- Use of bamboo in place of using wood as a feedstock for pulp;
- Use of bagasse in place of using wood as a feedstock; and
- Use of recovered paper instead of wood as a feedstock.

All listed examples involve switching from using virgin wood as feedstock to one of the listed examples, for the pulping process. This implies that instead of using the cellulose from wood as a pulp another material is used in its stead. Whilst there have been publications covering what substitutions can technically be made, there is limited literature covering whether there is an emission saving. As a result, it is unclear whether these substitutions meet the definition of material substitutions as set out in this project. As will be discussed in Measure 5, it is evident from multiple sources that recovered paper is often used as a feedstock in place of wood. However, for the other substitution examples given previously, no quantitative evidence was found discussing how often these other alternative substitutions are being made. The source which discussed the substitutions outlined them as theoretically possible substitutions, rather than existing substitutions in practice.

No examples have been seen in the literature covering substitutions within other processes, such as papermaking or conversion processes (e.g. corrugating, where paper is transformed into a cardboard box). These processes can involve the combination of multiple individual materials, glues and energy, amongst other smaller items. It is re-emphasised that the previously listed examples identified are pertinent to the pulping process, which as discussed in this report’s introduction, is distinct to papermaking and conversion processes. Further research into whether different materials, such as glues, could be used during corrugated cardboard manufacture could yield valuable insights into potential resource efficiency savings.

[134] DRUPA, “Sustainability in the printing industry starts with raw materials”, (2023). Available at: link

3.2 Available sources

3.2.1 Literature review

The literature review identified three sources that discussed material substitutions in the pulp and papermaking processes a resource efficiency measure. These comprise:

- One academic paper;[135]
- One technical report;[136] and
- One website article.[137]

The relevant sources were considered of high applicability and credibility when assessed against the data assessment framework, which recognises the relevance of the sources and the strength of the methodology within each. The sources exhibited an average IAS of 4.5 (out of 5) with two sources exhibiting a score of 4 or above. Of these, all were recent (published within the last ten years), but none were directly applicable to the UK, with one being applicable to Europe and two at a global scale. The theme of the academic paper was energy efficiency, with a discussion of carbon reductions also included in the scope, making it a valuable source for this work. There was limited evidence available for this measure and there was a specific lack of academic literature covering the potential use of alternative materials in the pulping and papermaking processes from a standpoint of carbon emissions. It appears that the literature to date is concerned mostly with which material substitutions are feasible and which are not. Further work is required to assess such substitutions' carbon and other environmental implications. The other sources were centred around a general overview of the PPI and an analysis of how products can achieve greater levels of sustainability.

3.2.2 Interviews

One stakeholder discussed the process materials used in the pulping and papermaking processes. They spoke to a finely tuned product process that had been refined over the course of 20 years. However, to their knowledge, no substitutions are or could, be made in the pulp and papermaking process. Of the remaining interviews, the stakeholders interviewed could not speak to this measure due to their roles not giving them oversight of the manufacturing process in a pulping or papermaking factory. Without oversight, they could not comment on the performance of current material choices and the suitability of different substitutions.

3.2.3 Workshop

Workshop attendees did not feel that they could speak to this measure. It was felt that for the technical knowledge which attendees possessed, they could not provide relevant information. Furthermore, the general consensus from stakeholders was that the UK PPI has optimised its

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135 Kong, L, et al.," Assessment of emerging energy-efficiency technologies for the pulp and paper industry: A technical review", (2016). Available at: link
136 Roth, S, et al., "The pulp and paper overview paper", (2016). Available at: link
137 Fuchs, S, et al.," Product sustainability: Back to the drawing board", (2022). Available at: link

processes, and no further action can be taken. As such, as suggested by stakeholders, it was agreed not to discuss this measure in the workshop.

3.3 Drivers & Barriers

The drivers and barriers influencing this measure were identified through a combination of the literature review and stakeholder interviews. The drivers and barriers were not discussed during the workshop as stakeholders present felt they could not contribute relevant information as discussed in Section 3.2.3 Workshop

3.3.1 Drivers

Table 10 below shows the main drivers for Measure 3. The drivers were not discussed by stakeholders in the workshop (see Section 3.2.3 Workshop) and no evidence was provided on the most important drivers for this measure, hence, the most important drivers have not been selected.

Table 10: Drivers for paper measure 3

Description	PESTLE	COM-B
Potential reduction in environmental impacts	Environmental	Opportunity – physical
Material innovation	Technological	Capability – physical
Reduction of need for virgin material	Technological	Opportunity – physical

Potential Reduction of carbon impacts

There is a potential that with the selection of alternative feedstocks for the production of PPI products, there will be a reduction in carbon impacts. One source claimed that using bamboo and hemp as a source of pulping production reduces the carbon impact of manufacturing paper products.[138] However, there was no evidence within the source to substantiate this claim. Furthermore, the potential effect on pulping yields when using alternative feedstocks should also be considered on the overall carbon impacts. That is, not all the material that is used in a production process is transformed into the final product, due to inefficiencies (for further details see Measure 6). If the production yield of a pulping process is lower when an alternative source is used, such as those listed in Section 5.1.3, then more input material would be required. If more material is required, it would be likely that the carbon impacts would

[138] Stratus-Insights, “Top 10 pulp and paper trends in 2023”, (2023) [Online]. Available at: link

increase, but this is highly dependent on how the material is manufactured and other variables set when calculating carbon impacts.

Material Innovation

Multiple avenues are being investigated with the drive for the UK paper sector to become more resource efficient. One avenue being explored is the potential use of novel materials, which in the context of this measure is using alternative materials such as kenaf as a pulp source.[139] The products that alternative pulps could be used in will be restricted by the impact alternative materials have on final properties and the properties that are required for final use. For instance, certain products such as packaging require pulp that has high mechanical strength, usually requiring pulp from mechanical or chemical pulping methods. As such, this driver will likely only be applicable to specific product types depending on the impact of substituting alternative materials has on final properties. It is currently unknown what this impact might be, and more research is needed to understand this for potential substitutions.

Reduction of the need for primary material

By using recovered paper as a source of pulp, instead of using fibres produced by wood chips, the mass of virgin material used will be reduced. This has the benefit of improving the resource efficiency of the pulping process and also the resource efficiency of the product the pulp is subsequently used to produce. This driver is particularly pertinent to this report with such a high level of recovered fibre use within the UK. It should be noted that whilst there is a reduction of primary material required, to manufacture the same product, a greater mass of recycled fibre will be required compared to a scenario when virgin fibre is used. More recycled fibre will be required as the fibres degrade upon exposure to high thermal and mechanical loads during the recycling process. This greater material requirement may affect the company manufacturing the product, who may bear slightly higher transportation costs and produce more transportation emissions. A full LCA is recommended to consider this.

3.3.2 Barriers

The barriers for measure 3 are shown in Table 11. The barriers were not discussed by stakeholders in the workshop (see Section 3.2.3 Workshop) and no evidence was provided on the most important barriers for this measure, hence, the most important barriers have not been selected.

[139] HABER, “Alternatives to wood pulp for paper making”, (2023) [Online]. Available at: link

Table 11: Barriers for paper measure 3

Description	PESTLE	COM-B
LCA standards	Legal	Capability – psychological
Potential increase in environmental impacts	Environmental	Opportunity – physical
Changes to production lines and resulting cost implications	Economic	Opportunity – physical

LCA standards

Conducting a LCA is required to generate the carbon emissions savings for this indicator. ISO 14040 and 14044 govern the conducting of an LCA. However, there is significant scope for subjectivity when conducting an LCA, specifically when defining the system boundary of what is included in the study's scope. With subjectivity comes the scope for uncertainty. For instance, when the LCA (discussed in Section 3.2.1) was conducted to assess that bamboo and hemp have a lower impact than using virgin wood for pulp production. As both bamboo and hemp are crops grown from the ground, they have a level of organic content contained within them. Whether or not the CO_2e impact associated with this content is accounted for in any study, should be disclosed by the practitioner, but was not in the study referred to previously. As such, one study may include an impact and another not, meaning that drawing conclusions on which material produces the lowest CO_2e is not possible. If accurate comparisons cannot be made between the CO_2e impacts of two materials, this may disincentivise manufacturers from making material substitutions as a fully informed decision on which material has the lowest impact is not possible.

Potential increase in environmental impacts

This barrier is the counterpart of the driver 'potential reduction in environmental impacts'. Many of the alternatives to wood feedstocks are other naturally occurring materials, such as bagasse, kenaf and cotton.[140] The environmental impacts of producing such materials would need to be quantified. Some naturally occurring materials, such as flax, a crop cultivated mainly in France, can have high environmental impacts due to the use of pesticides and fertilisers.[141] It is often assumed that due to natural products, such as flax, being grown from the earth, they have a lower environmental impact. However, the pesticides and fertilisers

[140] HABER, "Alternatives to wood pulp for paper making", (2023) [Online]. Available at: link
[141] Summerscales, J and Dissanayake, N.P, "Allocation in the lifecycle assessment (LCA) of flax fibres for the reinforcement of composites", (2017). Available at: link

increase the impacts significantly.[142] There is no study directly comparing the relative CO_2e impacts of flax production to the growth of trees used as feedstock for paper production. However, the example of flax production illustrates the example that alternatives may not have a lower CO_2e impact simply because they are organically grown, and further research is needed on this point..

Changes to production lines and cost

If alternative feedstocks to production processes are selected, there could be cost and time implications for the company manufacturing the product. Many stakeholders stated – during an interview and the workshop – that production sites of PPI products are designed around the type of pulp that will be used. Depending on the feedstock, there may be specific processing steps required. For instance, if recovered paper is the designated input, a deinking step may be required (not for brown paper production), 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.

3.4 Levels of efficiency

With the data available from current and historical literature as well as discussions with stakeholders, it was concluded that there was insufficient data to provide final levels of efficiency for the maximum level of efficiency and business-as-usual. Qualitative discussion was still undertaken in the subsequent sections, providing a high-level overview of the potential substitutions which could be made in the pulping process.

Table 12: Levels of efficiency for paper measure 3

Indicator: Percentage reduction in CO_2e emissions by material substitution for pulping and papermaking processes			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value	0%	Not applicable	Not applicable
Evidence RAG	Not applicable	Not applicable	Not applicable

[142] Summerscales, J and Dissanayake, N.P, “Allocation in the lifecycle assessment (LCA) of flax fibres for the reinforcement of composites”, (2017). Available at: link

3.4.1 Current level of efficiency

No existing literature data was found regarding current or historical resource efficiency levels for this measure. Stakeholders were also unable to provide quantitative efficiency levels for this measure.

As the indicator for this measure is an index, relative to current levels, the estimated level of efficiency is set at 0%, serving as a baseline for subsequent scenarios. The evidence RAG rating for this efficiency level is therefore not applicable.

3.4.2 Maximum level of efficiency in 2035

There was some quantitative literature found on the levels of efficiency for this measure. The literature found mainly discussed the potential CO_2e savings from lab-scale technologies. For the purposes of this study, it is important to note that the CO_2e emissions estimated in these lab-scale studies might vary upon realisation at an industrial scale. As such, whilst the following discussion provides an illustration of the potential CO_2e savings, it should not be taken as representative of the potential larger savings. The small-scale technologies covered within the literature are discussed hereafter.

Use of recovered paper

One of the most common substitutions for virgin wood as a source of pulp is using recovered paper as a source instead. This is the main substitution, known to take place at an industrial scale, within the UK PPI. A website stated that for 100% recycled paper, a 32% reduction in carbon dioxide emissions can be achieved compared to using entirely virgin paper during production, however it was not stated what the source of this reduction was.[143] A 2010 study assessing the manufacture of tissue paper compared its production using both recycled and virgin sources.[144] The study found that the use of recovered paper as pulp led to a 30% CO_2e reduction. A further study gave a range of potential CO_2e reductions of 20-50% (35% being the midpoint) when using recycled paper instead of virgin paper, without defining the product that was used for the study.[145] The quality of the sources which provided the data previously discussed was not high. The reason for this was none of the literature sources discussed provided specific information on how the CO_2e values were calculated. Without such information, the studies are of limited use for estimating potential levels of efficiency. As such, no comment can be made on the potential for CO_2e reductions when substituting recovered for virgin material sources during pulping. Further research is required which explicitly states what material is being studied when the CO_2e saving is being considered.

[143] Arjowiggins, “Eural”, (2023) [Online]. Available at: link
[144] Savi, A, “Recycled paper vs virgin paper; reduce the carbon footprint of your business”, EcoPack (2022) [Online]. Available at: link
[145] Bajpai, P, “Recycling and Deinking of Recovered Paper: Preprint”, (2014). Available at: link

Organic ink

Another relevant source was a web article from McKinsey covering a footwear company attempting to reduce the carbon impact of its packaging.[146] One technology discussed was the use of non-fossil fuel based inks, one example of which was using algae-derived inks. A 9% reduction of CO_2e emissions against an undefined baseline could be achieved by incorporating organic algae ink. A stakeholder also recommended the use of organic ink as a potential solution. It was stated that if a packaging product is made of a high level of recycled content with the attempt of reducing environmental impact but is using fossil fuel-based inks, use of vegetable inks could reduce the environmental impact further. A data point on the level of CO_2e reduction by using vegetable inks was not available from the stakeholder, but it indicates that they could be a viable material substitution.

No baseline was disclosed on what the potential CO_2e savings could be for substituting organic inks them in place of fossil-fuel based inks. Inks are used for many PPI products, such as packaging, tissue paper (for gifts) notebooks and shipping boxes. There is no quantitative evidence suggesting how many of these applications use inks. Significant assumptions would be required to estimate this value and as a result introduce an unacceptably high level of uncertainty.

Deep Eutectic Solvents (DES)

Another lab scale technology reported to reduce the carbon impacts of pulping is the use of Deep Eutectic Solvents (DES).[147] DES are produced by plants and can break down cellulosic fibres, used in the production of paper products. Using DES reduces the need for chemicals and energy for use in the pulping process, where it would be substituted for either mechanical or chemical pulping. Substituting DES for mechanical or chemical pulping could help to achieve resource efficiency by avoiding the need to produce and use primary chemicals. Preliminary studies show that if the technology is investigated further, there is potential that DES implementation could reduce emissions by 20%, compared to 2011 levels when considering energy and material saving benefits. As there was no discussion found on the types of pulp which could be substituted for DES, it is not possible to estimate the potential impact of using DES in place of other pulps. This technology is also not yet commercially deployable.

Summary

Reporting a maximum level of efficiency for this measure was challenging. The literature reports potential CO_2e reductions for a substitution which already occurs (the use of recovered paper as a feedstock) and two lab-scale technologies which are yet to be investigated at a commercial scale. Furthermore, the literature on CO_2e reductions possible due to material substitutions is not reliable as the sources do not specify which products were studied.

[146] Fuchs, S, et al.," Product sustainability: Back to the drawing board", (2022). Available at: link
[147] Roth, S, et al., "The pulp and paper overview paper", (2016). Available at: link

As such, it was decided that there was insufficient data available to provide a maximum level of efficiency for this measure. Despite the high IAS of the studies, there was no quantitative data found which enabled translation of the lab-scale data points to the national level indicator required for this measure. Furthermore, data was not present quantifying the extent of which certain products were placed on the market. Finally, there was no indication given within the literature on the likelihood of the lab-scale technologies being scaled up to commercial scale. Where data was given on the potential CO_2e savings of using algae-based inks for instance, it was not possible to translate such findings to an industry wide value required for this study. This would require data consisting of the number of products using inks, how many could use algae inks and then how many are likely to switch. Such data would be of value to understand the potential resource efficiencies to be unlocked for this measure.

3.4.3 Business-as-usual in 2035

No existing literature data was found covering the potential BAU scenario for this measure. Stakeholders were also unable to provide quantitative levels of efficiency for material substitutions in the pulp and paper industries.

4.0 Measure 4 – Lightweighting of paper products

4.1 Paper resource efficiency measure

4.1.1 Description

Lightweighting is defined as a reduction of a product's weight whilst maintaining its functionality.

This measure explores whether the PPI industry can reduce the areal weight of products without a significant loss in functionality. The areal weight is a commonly used unit in the paper industry, meaning the weight of fibre per unit area such as grams per square metre (gsm). There is a significant variation in the areal weights of different products produced in the PPI, ranging from 40 gsm for newsprint – given by a stakeholder during interview - to 290 gsm for packaging products.[148] The areal weight can be taken as a rudimental proxy of the product's functional requirements, where packaging products that have high areal weight are used as they require greater stiffness to support their contents compared to newsprint products. Where possible, this measure will explore how lightweighting can be applied to each product within the PPI, including packaging, tissue and hygiene products, and print & graphical paper.

There are two types of lightweighting considered in this work. Firstly, the raw material is lightweighted before processing it into its final product form. For instance, the lightweighting of the kraft paper used to eventually form a cardboard box. Reducing the areal weight of a material requires less raw material during the manufacturing process. This reduction of material leads to resource efficiency and savings of water and energy (although energy efficiency is out of this report's scope).

Secondly, lightweighting of formed products was considered. For instance, when cardboard boxes are stacked, they are subjected to compressive forces. Optimisation can be undertaken on the final product, to ensure that, for instance, the compressive forces on cardboard boxes can still be withstood whilst minimising the mass required.

A key consideration for this measure is the whole lifecycle impact of a paper product. For example, if a material is produced at a lower areal weight, it will be more resource efficient from a mass perspective. However, the energy required to produce lightweighted products could be significantly greater than for a non-lightweighted product, leading to greater energy demands or associated overall emissions, according to stakeholder interviews. This is discussed in more detail in Section 4.2.3 Workshop.

[148] Heinke, I, “Considerations for cartonboard lightweighting”, (2019). Available at: link

Another key consideration is that products made with higher proportions of recycled fibres weigh more than those made of virgin fibres. This is because recycled fibres are weaker and more fibres must be used to provide the same strength to the paper product. This is a key interdependency with Measure 5 and is explored further in Section 9.0 Interdependencies.

4.1.2 Measure indicator

The indicator selected for this measure was '**percentage reduction of PPI product mass achieved by lightweighting, compared to 2023 levels'**. This indicator was informed by literature sources which discussed lightweighting of paper products.[149, 150]

No other indicators were considered for this measure.

4.1.3 Examples in practice

Material lightweighting

There has been significant progress over the decades in lightweighting the material used in PPI products, with one online source stating that carton packaging for frozen products has reduced in mass by 20% since the 1970s.[151] Lightweighting within the industry was also discussed qualitatively, with the entire PPI on a trajectory towards thinner and lighter grades of paper, according to work by WSP.[152]

Product lightweighting

Another example of lightweighting is shown by Metsä Board.[153] Using enabling tools such as finite element modelling, packaging products were shown to be readily optimised against the specific conditions anticipated during the product life. By doing so, material can be removed where it is calculated by the finite element software as being unnecessary. Whilst lightweighting of PPI products is discussed in academic literature and website articles, it is unclear how widespread the practice is within the UK PPI.

4.2 Available sources

4.2.1 Literature review

The literature review identified eleven sources that discussed lightweighting as a resource efficiency measure. These comprise:

[149] Pro Carton, "Packaging preserves our resources", (2023). Available at: link
[150] Heinke, I., "Considerations for cartonboard lightweighting", (2019). Available at: link
[151] Pro Carton, "Packaging preserves our resources", (2023). Available at: link
[152] WSP, "Industrial decarbonisation & energy efficiency roadmaps to 2050", (2015). Available at: link
[153] Metsä, "Metsä Board minimises environmental impact of packaging with simulation platform", (2021). Available at: link

- Two academic papers;[154] [155]
- One industry report;[156] and
- Eight website articles.[157] [158] [159] [160] [161] [162] [163] [164]

The relevant sources were considered of high applicability and credibility when assessed against the data assessment framework, which recognises the relevance of the sources and the strength of the methodology within each. The sources exhibited an average IAS of 4.2 (out of 5) with eight sources exhibiting a score of 4 or above. Four of the sources were authored in the UK and sources were from the last ten years bar one website article which did not specify a date of publishing. Few sources identified levels of efficiency against the selected indicator. Two of the sources discussed lightweighting from a resource efficiency perspective. Other sources discussed carbon emissions reductions associated with lightweighting.

The majority of sources found were web pages for specific paper products. These sources contained limited discussion of the broader resource efficiency landscape and how lightweighting applied to certain PPI product categories, such as hygiene and print and graphical products. In fact, the levels of efficiency identified in the literature only referenced packaging products, with no reference to hygiene or print and graphical products.

It is clear from the literature, stakeholder interviews and workshops that a significant effort has been made in the previous decades to produce lightweight paper products. Nevertheless, there was little discussion in the sources of overall trends in lightweighting over time, or when significant achievements had been made. The interviews and workshop were used to evaluate further potential to lightweight, since the literature did not make predictions about future lightweighting possibilities. Furthermore, the interaction between energy efficiency and lightweighting requires further investigation. Understanding this will enable quantification of the anticipated total energy consumption, and in turn, the net impact – accounting for the emissions and total costs – due to the lightweighting and associated energy usage can be understood. This will help to generate understanding of the holistic impacts of lightweighting.

4.2.2 Interviews

Two stakeholders engaged with this measure during interviews. They reacted positively to the measure, emphasising its importance in achieving resource efficiency. One stakeholder spoke

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[154] Fadiji, T. et al., “Mechanical design and performance testing of corrugated paperboard packaging for the postharvest handling of horticultural produce”, (2018). Available at: link
[155] Rogers, J.G, “Paper making in a low carbon economy”, (2018). Available at: link
[156] WSP, “Industrial decarbonisation & energy efficiency roadmaps to 2050”, (2015). Available at: link
[157] Dillon, M.,” Lightweighting in Packaging: The Pros and Cons”, MEYERS (2023). Available at: link
[158] Heinke, I, “Considerations for cartonboard lightweighting”, (2019). Available at: link
[159] Metsä, “Metsä Board minimises environmental impact of packaging with simulation platform”, (2023). Available at: link
[160] Packaging News, “International paper adds new basis weights to lightweight board”, (2015). Available at: link
[161] Pro Carton, “Packaging Preserves Our Resources”, (2023). Available at: link
[162] SUNTORY, “Packaging & Resource Efficiency”, (2023). Available at: link
[163] TAPPI, “Dimensional Stability Issues of Lightweight and New Paper Grades: Causes and Remedies, 18PaperCon” (2015). Available at: link
[164] Valmet Forward, “Energy efficiency and lightweighting - main challenges for containerboard makers”, (2015). Available at: link

to the level of efficiency of lightweighting newsprint products and what their customers are requesting. One stakeholder expressed concern regarding the impact on energy consumption. They mentioned that producing materials which have a lower areal weight will require a change in processing techniques leading to an increased level of energy consumption. The processing step that would require more energy was not disclosed nor the PPI products this trade-off may apply to.

4.2.3 Workshop

Stakeholders engaged well with this measure during the workshop, however, only three stakeholders voted on the levels of efficiency for this measure. One stakeholder raised that there are significant financial implications to lightweighting for the manufacturers of paper products; this is described further in Section 4.3.2 Barriers. Other stakeholders agreed that this means the drive to produce thinner paper does not come from the paper manufacturers, rather, their customers. Stakeholders at the workshop pointed out on a number of occasions that the UK PPI has made significant efforts and progress in lightweighting their products over preceding decades. There was no consensus that further gains could not be made, rather consensus that previous efforts should be acknowledged.

The level of engagement in the workshop was as follows:

- Five stakeholders across the industry were active on the mural board, voting for levels of efficiency, drivers and/or barriers.
- Four stakeholders actively contributed to verbal discussion.

4.3 Drivers & Barriers

The drivers and barriers influencing this measure were identified through a combination of the literature review, stakeholder interviews and the sector workshop.

4.3.1 Drivers

During the workshop, a stakeholder raised customer requirements as a driver. It should be noted that customer requirements underpin each of the drivers listed for this measure, as it is customers that would directly receive the benefits associated with lightweighted paper products. This has therefore not been listed as a separate driver.

Table 13 below shows the main drivers for Measure 4. Due to low levels of voting on these drivers in the workshop, the most significant driver was taken to be that most discussed by stakeholders and is shown in bold.

Table 13: Drivers for paper measure 4

Description	PESTLE	COM-B
Resource efficient – less material to recycle	**Technological**	**Capability – physical**
Environmental benefits	Environment	Opportunity – physical
Cost-benefit for logistics	Economic	Opportunity – physical

Resource efficient – less material to recycle

If a lower mass of material is used in the product, there will be a lower mass of material arising at the end of life[165] which will reduce the environmental impacts associated with the collecting and pre-processing of materials into recyclate. A lower mass of recycled material will reduce the emissions associated with recycling processing. It is also in the interest of mills to only buy the recovered fibre required to meet specifications and produce lightweight products where feasible and requested by customers.

Environmental benefits

Packaging products are often used for the transportation of goods, such as foods or liquids. If the weight per unit area mass of a product can be reduced whilst maintaining the same functionality, the mass transported will be reduced. As transport emissions are correlated to the mass of the good being transported, transport emissions may reduce. Furthermore, if a lightweighted product is being shipped, this will also benefit the companies choosing to ship the product. One source, which included quotes from a senior member of SAICA paper, confirmed that customers purchasing containerboard are requesting lightweighted products to reduce the environmental burden of transportation.[166]

There is potential that the overall impacts of producing a PPI product could be reduced as a direct result of lightweighting. From a CO_2e perspective, if the emissions from producing 1kg of material remain constant, then lightweighting will achieve a reduction of CO_2e emissions. However, as previously discussed, this result will depend on the change – if any – in energy usage because of the lightweighting undertaken. If the energy consumption increases, depending on the CO_2e emissions arising from producing said energy, then this might outweigh the impacts arising from lightweighting.

165 Metsä, "Metsä Board minimises environmental impact of packaging with simulation platform", (2023). Available at: link

166 Valmet Forward, "Energy efficiency and lightweighting - main challenges for containerboard makers", (2015) [Online]. Available at: link

Cost-benefit for logistics

Transportation costs may also be reduced if the mass transported is reduced.[167, 168] Transportation costs are determined by dimensional weight, which depending on the company undertaking the haulage. Costs are either calculated by mass or area of products being shipped. If it is assumed that the cost is calculated by mass, then by lightweighting either the packaging or product that is being shipped, the total cost of haulage will be reduced.

4.3.2 Barriers

The barriers for Measure 4 are shown in Table 14. The most significant barrier is shown in bold as voted for by stakeholders in the workshop.

Table 14: Barriers for paper measure 4

Description	PESTLE	COM-B
Economic impacts	**Economic**	**Opportunity – physical**
Technical limitations	Technological	Capability – physical
Design process investment requirements	Economic	Capability – physical

Economic impacts

One stakeholder stated that during a manufacturing process, the machinery used is already operating at its lowest limit for areal weight production. That is, paper cannot be produced at a lower grams per metre squared value, beyond what is already being produced. Any further lightweighting activities would thus require upgrades to machinery, which implies significant capital expenditure into new equipment. This is a significant barrier to the further lightweighting of paper products. Two of the four votes for the top barriers in the workshop were for this barrier, making it the highest voted barrier for this measure.

During the workshop, one stakeholder noted that some manufacturers outside the packaging sector typically sell paper products by weight, not area. If paper is lightweighted, the manufacturer would likely be spending more to produce a product that they sell for the same price. For example, a newspaper printer that buys paper in rolls from a manufacturer may prefer to buy lightweighted paper because they get more paper (i.e., a larger area) per roll of a given weight. Making the thinner paper costs the manufacturer more to produce since it requires running their machinery slower to achieve the desired thinner thickness, therefore requiring a higher overall energy consumption. It is also more prone to breakage, and so could cost the manufacturer more in wasted product. It was not stated whether the higher area of product delivered for the same cost would lead to a net change of revenue or profit for the

[167] Whether costs are calculated using mass or volume is determined by a metric called ‘Dimensional Weight’.
[168] Dillon, M.,” Lightweighting in Packaging: The Pros and Cons”, MEYERS (2023). Available at: link

manufacturer undertaking the lightweighting works. The stakeholder said it would not be as simple as increasing the cost in line with the reduction in areal weight. Further information was not disclosed due to commercial sensitivity.

Further research is recommended into the potential energy usage increases of lightweighting. At the workshop, one stakeholder stated that if a lighter-weight paper is produced, this may increase energy usage. However, there was little evidence to support this claim and without further research it is not clear what the overall environmental impact of lightweighting is when considering material savings against potential energy consumption impacts. Depending on the source of energy used at the paper mill, an increase in energy consumption as a result of lightweighting could result in cost implications for the manufacturer and consumer. One stakeholder suggested that simply increasing the prices of the material was not necessarily a viable option for them. This could lead some manufacturers to avoid implementing lightweighting as a resource efficiency measure.

Technical limitations

Packaging products are subjected to loads during their use such as compression when stacked, transportation vibrations and impacts because of dropping.[169] When selecting packaging it is important to ensure the product which they are transporting arrives safely at its destination and such issues are considered by product designers. Lightweighting of packaging products may risk the fulfilment of this objective by limiting the packaging structural capabilities. For other PPI products, such as graphical paper, tissue or hygiene products, the technical limitations will be different to packaging and stakeholders did not speak to the barriers of lightweighting with such products.

Dimensional stability was cited as another barrier facing paper manufacturing operations when attempting to achieve lightweight products. One article states that paper manufacturers do not invest in new machinery when attempting to lightweight their products. Instead, the same machinery is used but pushed towards the extremity of its specific design limits. The result of pushing the machinery beyond its limits can include defects in the final product, such as curl or shrinkage.[170] One stakeholder at the workshop also stated that thicker, heavier-weight paper is easier to make as there are fewer breaks in the material which implies less waste material and less waste costs.

Design process investment requirements

To optimise products, such as cardboard, the time and expertise of engineers and/or produce designers will be required. Their activities could be running finite element software or performing calculations to ensure the newly designed product meets functional requirements. Both these activities will incur substantial costs that may prohibit the optimisation being carried

[169] Preprint of Fadiji, T, et al. “Mechanical design and performance testing of corrugated paperboard packaging for the postharvest handling of horticultural produce”, (2018). Available at: link
[170] Parent, F, et al., “Dimensional Stability Issues of Lightweight and New Paper Grades: Causes and Remedies”, TAPPI, (2023). Available at: link

out.[171] It is also uncertain whether the benefits of optimising a product would outweigh the costs of the design process required.

4.4 Levels of efficiency

Table 15: Levels of efficiency for paper measure 4

Indicator: Percentage reduction of PPI product mass achieved by lightweighting, compared to 2023 levels			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value	0%	0-30%	0-15%
Evidence RAG	Not applicable	Red	Red

4.4.1 Current level of efficiency

As the indicator for this measure is an index, relative to current levels, the estimated level of efficiency is set at 0%, serving as a baseline for subsequent scenarios. The evidence RAG rating for this efficiency level is therefore not applicable. Two studies were found, as discussed below, with levels of efficiency reported. However, these were not appropriate to the indicator for this measure as one study did not give a reference year and the other has a reference year starting around the 1970s. The sources are still discussed hereafter to provide an overview of the progress that has been made for lightweighting.

- One website article was found which gave a historical level of efficiency for this measure. Pro Carton, a cartonboard trade association, stated that carton packaging product for frozen goods were 20% lighter than in the 1970s.[172] The source did not state whether this had been achieved by optimisation or reduction of material areal weight (grams per square metre).
- Further information on historic lightweighting was given by Packaging News, a UK-based packaging news outlet, who stated that a high-stiffness board product has been reduced by 5%, from 200 to 190 grams per square metre, whilst maintaining the same functional performance.[173] No statement was made on whether the cost of the packaging was higher.

[171] Dillon, M.," Lightweighting in Packaging: The Pros and Cons", MEYERS (2023). Available at: link
[172] Pro Carton, "Packaging preserves our resources", (2023). Available at: link
[173] Packaging News, "International paper adds new basis weights to lightweight board", (2015). Available at: link

4.4.2 Maximum level of efficiency in 2035

No maximum levels of efficiency were identified in the literature, in interviews or in the workshop for this Measure. Theoretical lightweighting figures were identified in the literature which could give some indication of future lightweighting possibilities, however, no indication was identified during the course of the research that suggested a relationship between past lightweighting achievements and future possibilities. Two examples of lightweighting were identified in the literature:

- Packaging Strategies Magazine, a packaging trends news and analysis outlet, suggested that a switch from 290 gsm to 255 gsm cartonboard could reduce the weight of a product shipment by 12%.[174] The products this calculation is based on were not specified.
- An academic paper found that a 30% weight reduction could be achieved by using functional surfaces with paper products.[175] Functional surfaces are surface coatings or pre-treatments that provide barriers against contaminants such as oil or grease, at minimal or no additional mass penalty. A stakeholder confirmed this in interview, stating that historically they had added wax to their paper products to give them a water-resistant barrier, but they now add wax only to the surfaces that require the property off water resistance (for example, the outside faces of a box) and achieve a weight reduction as a result. The overall emissions impact of using additives and functional surfaces was not discussed, and a full LCA of additional materials would be needed to understand their overall impacts.

Otherwise, the literature suggested that packaging forms could be optimised using advanced engineering software tools.[176] By analysing how loads were introduced into packaging, material could be removed in areas where it was not necessary, thereby reducing the mass required for the overall packaging.

Based on the literature, a maximum level of efficiency was presented at the workshop as a range from 0-30%. A possible maximum of 0% was suggested, since the historical improvements cannot necessarily indicate any additional lightweighting can be achieved in future, up to 30%, which was the highest possible reduction identified in the literature.

In the workshop, two of the six stakeholders voted on the maximum level of efficiency – one manufacturer and one trade body. One stakeholder voted for a maximum level of efficiency of 0-15% with medium confidence, acknowledging that significant steps have already been taken to lightweight PPI products. The other voted for a maximum level of efficiency of 16-30% with low confidence.

It was challenging to relate the levels of efficiency found to the national, industry-wide indicator that is required. The website article gave a level of efficiency applicable to packaging, whilst

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174 Heinke, I, “Considerations for cartonboard lightweighting”, (2019). Available at: link
175 Rogers, J.G, “Paper making in a low carbon economy”, (2018). Available at: link
176 Metsä, “Metsä Board minimises environmental impact of packaging with simulation platform”, (2023). Available at: link

the academic journal did not state which material the level of efficiency was related to. The UK's paper based industries most commonly consume and export packaging materials, at 58% and approximately 57% of the total respectively.[177] However, without levels of efficiency for the other product types, scaling the levels of efficiency in line with the proportion each product type takes up in the market was not possible. As such, the maximum level of efficiency was given as 0-30% as a full range. This was given a red RAG evidence rating, as the literature found discussing levels of efficiency for this measure did not give any indication of how likely these lightweighting-enabling technologies are to come into commercial and wide-scale implementation, as well as the relatively low levels of voting.

4.4.3 Business-as-usual in 2035

No quantitative data was identified in the literature. In the workshop, three of the six stakeholders voted on the BAU level of efficiency – one manufacturer and one trade body. The two stakeholders voted for a BAU level of efficiency of 0-15%, both with medium confidence, stating that both mills and packaging converters would continue to optimise packaging weight where possible.

Based on the lack of literature identified, existing implementation of the measure and the low level of voting in the workshop, the BAU level of efficiency for Measure 4 is 0-15%, with a red RAG evidence rating.

[177] CPI, "2022-23 Annual Review", (2022). Available at: link

5.0 Measure 5 – Use of recovered fibre in the pulping process

5.1 Paper resource efficiency measure

5.1.1 Description

This measure covers the use of recycled or secondary inputs to the manufacture of PPI products.

Recovered paper is a feedstock that can be used in the production of pulp and paper (PPI) products. By using feedstock that is derived from a previous lifecycle, there is a reduction in the requirement for virgin material, which leads to resource efficiency benefits such as fewer trees being required for felling. Increasing the proportion of PPI products using secondary feedstocks makes the PPI more resource efficient, by avoiding the need to use virgin material from alternative sources.[178] It is important to distinguish the boundary between Measure 1 and Measure 5.

The scope of this measure begins after paper has been collected, sorted and delivered to the factory as what will be referred to hereafter as bales. Once these bales have been delivered, the overall process of pulping can begin. This measure does not consider the effectiveness of the paper collection and sorting processes, which is captured in Measure 1.

An important point to consider when using recovered fibre for PPI products is the likelihood that the final product will be heavier than if virgin fibres were used. As discussed by stakeholders during interview, during processing, the recovered fibres are subjected to thermal stresses. These thermal stresses lead to a reduction in their mechanical properties. So to achieve the equivalent mechanical performance as if virgin fibres were used, a greater mass of fibres is required to account for their degradation.

As will be discussed further in this section, there is a technical limitation on the number of times a fibre can be recycled. While this limitation exists, virgin fibre will always be needed in paper production. Each nation that has a degree of papermaking capacity will have a unique mixture of primary/secondary production requirements. With its limited forestry supplies, the UK utilises mostly secondary input for production of UK PPI products, with virgin pulp predominantly being used for production of tissue and hygiene products. By contrast, within Europe, countries such as Sweden with its vast forestry supplies, use predominantly primary inputs for primary production. At a global level, the most predominant input type for paper product manufacture is recycled pulp, followed by chemical pulp and mechanical pulp.[179]

[178] For clarity, in the context of recycling and feedstocks, primary refers to virgin material inputs and secondary refers to recycled inputs.
[179] Van Ewijk, S. et el., "Global lifecycle paper flows, recycling metrics, and material efficiency", Jrn. Of Industrial Ecology 22, (2017). Available at: link

This measure will discuss use of recovered paper as a feedstock for pulping. The use of recovered fibre, which comes from recovered paper, in the pulping and papermaking process is also discussed in Measure 3 – material substitutions in the pulp and papermaking process. The indicator for this measure, as discussed in Section 3.1.2 is concerned with the use of recycled input as a % of all inputs to the manufacture of UK PPI products. By contrast, Measure 3 is concerned with the potential for CO_2e reductions from making substitutions, such as recovered content for virgin input. As such, while there is some degree of interaction between the measures, they are ultimately concerned with measuring different things and so are discussed separately.

5.1.2 Measure indicator

The indicator selected for this measure was the '**average percentage recycled input rate of all UK PPI products'**.

The recycled input rate (RIR) is defined here as:

'the proportion of secondary paper fibre divided by the total mass of paper (including the secondary fibre)'

Other indicators that were not selected include:

- *percentage recycled content in packaging paper as UK industry average* – this was not considered at it is limited to only one product, where this study is considering all products that fall under the PPI.
- *recovered fibres as a % of total fibres used in paper production at worldwide level* – this indicator is set a global level. The scope of this study is at a UK-specific level and as such the scopes mis-align.
- *percentage of UK paper and card being manufactured using recycled fibres collected from households* – this indicator excludes the collection of waste from commercial sources. Having discussed commercial waste collection of PPI products with stakeholders, commercial waste collection is prominent enough in the UK market that it should be considered under the scope of this measure.

As was discussed by a stakeholder at the workshop, it is important to note the importance of the national-level scale for this indicator. It is discussed in this Measure that one of the reasons why higher recycled input rates cannot be unlocked is the technical limitation on the number of recycling loops fibres can go through before they degrade and cannot be used further. Depending on the product specification, a paper mill can take in different types of fibre (including virgin and recycled) and blend to deliver the product specification.

5.1.3 Examples in practice

One website illustrates how the use of recovered fibre in the PPI yields resource efficiency benefits. Producing one tonne of Cocoon paper, previously produced by fine paper manufacturer Arjowiggins, reportedly requires 1.2 tonnes of recycled fibres.[180] The same source also states that 2.5 tonnes of wood is required to produce 1 tonne of virgin fibre paper (without specifying an exact product, e.g. a cardboard box). By using recycled fibres, the need to fell trees to produce pulp is postponed increasing the resource efficiency of the paper sector.

Other products can be made from 100% recycled sources include:

- White tissue paper;[181]
- Paper boxes;[182] and
- Cardboard boxes.[183]

It is important to illustrate that whilst individual products can be made using 100% recycled input rate, the recycled input rate is currently lower than this when considered at a national level. The national level considers the inputs of all products made within the UK PPI, whereas individual products consider only the feedstock used to manufacture a single product. Achieving a 100% recycled content level at a national scale would be a challenging prospect to implement. The barriers, to be discussed, which would need to be overcome to reach a national 100% recycled input rate include the limit of recycling loops that fibre can undergo and the fact that some PPI products, such as toilet paper, are not available for recycling.[184, 185] The removal of paper products such as toilet paper from circulation will affect recycled input rate because if the material is not available to be recycled, then virgin product must take its place.

Given the technical limit on the number of recycling loops paper may pass through, attention is also being paid to how the products which cannot be recycled further could be used. Examples of uses of the fibres that are no longer valuable to the PPI include animal bedding, use in the building industry and chemical production as well as energy production and soil improvement[186] A specific example of its use in the building industry is the incorporation of paper sludge ash and waste glass cullet to produce a lightweight filler to be used in construction applications.[187]

5.2 Available sources

5.2.1 Literature review

The literature review identified seven sources that discussed the use of recovered fibre in the pulping process as a resource efficiency measure. These comprise:

[180] Arjowiggins, “Why use recycled papers?”, (2023). Available at: link
[181] Eco-Craft, “100% recycled white tissue paper”, (2023). Available at: link
[182] Ecopackables, “100% Recycled cardboard boxes”, (2023). Available at: link
[183] Jakodan, “Mailing Box 50”, (2023). Available at: linkC
[184] CPI, “2022-23 Annual Review”, (2022). Available at: link
[185] Packaging Corporation of America, “The myth of 100% recycled content”, (2021). Available at: link
[186] Spyros Bousios, “Novel biobased products from side streams of paper and board production”, (2016). Available at: link.
[187] CPI, “The UK paper industry – Innovation and the bioeconomy”, (2019). Available at: link

- Two academic papers;[188] [189]
- Three industry reports;[190] [191] [192]
- One technical study;[193] and
- One website article.[194]

All of the sources had an IAS of 4 and above, with an average IAS of 4.7 Four of the sources were applicable specifically to the UK PPI and were also published in the year 2019 or later, giving them high IAS scores of 5. There was good discussion on the different indicators that can be used to define this measure and the complexity of the challenge when quantifying the use of recovered fibres. A journal article that investigated the global flows of the paper industry was particularly valuable due to its characterisation of the different levels of virgin and recycled content that is used in production.[195] The journal article specifically provided quantitative data on the flows of both recovered and virgin materials. It would be of value to update the flows as while the research paper was published in 2017, the material flows were used date from 2012. While it is acknowledged that this study was focused on the resource efficiency of the UK, with research mostly related to the UK, it is recommended that further research be done into the global flows of recycled and virgin material flows.

5.2.2 Interviews

Two stakeholders discussed this measure. Given the high levels of recovered paper used to manufacture primary products in the UK PPI sector, the reactions to incorporating this measure were positive. The distinction between Measure 5 and Measure 1 was also reinforced, given the unique barriers and drivers facing each.

Stakeholders specifically discussed the limitations of using recycled content for certain applications. They agreed with literature published stating that where high functional performance is required, recycled fibres are not a suitable selection. Both stakeholders also agreed with the literature on which products were not suitable for high levels of recycled content, namely tissue and hygiene products and packaging containing high value products, such as televisions or laptops. This data was used to inform some drivers and barriers, but the stakeholders did not feel confident in estimating a level of efficiency for this measure.

5.2.3 Workshop

This measure received good engagement during the workshop discussion. A strong theme of the discussion was the challenge of creating a national-level average of recovered fibre use in

[188] Ewijk, S. et el., “Global lifecycle paper flows, recycling metrics, and material efficiency”, Jrn. Of Industrial Ecology 22, (2017). Available at: link
[189] Griffin, P, et al. “Industrial decarbonisation of the pulp and paper sector: A UK Perspective”, (2018). Available at: link
[190] CPI, “2022-23 Annual Review”, (2022). Available at: link
[191] [191] CPI, “Recycled content in corrugated packaging”, (2020). Available at: link
[192] CPI, “2021-22 Annual Review”, (2022). Available at: link
[193] Roth, S. et al., “The pulp and paper overview paper’, Climate Strategies (2016). Available at: link
[194] Packaging Corporation of America, “The myth of 100% recycled content”, (2021). Available at: link
[195] Van Ewijk, S. et el., “Global lifecycle paper flows, recycling metrics, and material efficiency”, Jrn. Of Industrial Ecology 22, (2017). Available at: link

the pulping process. Stakeholders stated that the use of recycled content varied so significantly between different products that they did not feel a national average was possible. However, there were verbal comments made on the recycled content levels for some products which were included. The barriers and drivers and voting sessions also received good discussion. However, there was no voting on any of the levels of efficiency. One stakeholder commented that the levels of efficiency that were presented at the workshop were correct for national averages.

The level of engagement in the workshop was as follows:

- Five stakeholders across industry were active on the mural board, voting for drivers and/or barriers.
- Four stakeholders actively contributed to verbal discussion.

5.3 Drivers & Barriers

The drivers and barriers influencing this measure were identified through a combination of the literature review, stakeholder interviews and sector workshop.

5.3.1 Drivers

Table 16 below shows the main drivers for Measure 5. The most significant drivers are shown in bold as voted for by stakeholders in the workshop.

Table 16: Drivers for paper measure 5

Description	PESTLE	COM-B
Reduced need for felling of trees	**Environmental / Technological**	**Opportunity – physical**
Social perception	**Social**	**Opportunity – social**
Supply of recovered paper	Technological	Opportunity – physical
Reduction of fuel requirements for pulping	Economic	Opportunity – physical

Reduced need for the felling of trees

Wherever primary fibre is required for the manufacture of PPI products, trees will be felled. [196] Whilst there are many sources of sustainably-managed forests (52% of forest area in Europe is

[196] Kimberly-Clark, “Why paper products made with recycled fibres are the most sustainable option”, (2022). Available at: link

certified as being responsibly managed according to Forest Europe)[197], reducing the need to fell trees is the ideal scenario from a resource efficiency perspective. It would also help to protect forest ecosystems where the felling would otherwise be taking place. This is a positive outcome for the environment in general, as well as for manufacturers using products with recycled input, who can state they are using feedstock which does not directly lead to significant deforestation. It should be noted that in an ideal resource efficiency scenario, any felling would be avoided altogether as this also prevents material uses in terms of fuel for equipment as well as reducing the potential for negative impacts on ecosystem.

Social perception

Consumers are becoming gradually more conscious of their impact on the environment and are looking to become more associated with environmentally positive products, with a packaging report stating that 64% of consumers want their packaging to contain some level of recycled content.[198] This could lead to more consumers selecting products that are manufactured using recycled content. The driver could therefore be of benefit to manufacturers of paper products, who may see increased revenues through a greater level of sales of products. At the workshop a participant did caveat this driver with the need for rigorous assessment to ensure the evidence being provided to the public is accurate. There was a concern repeatedly raised that consumers can be misinformed that using recycled content will always be environmentally superior in terms of total material use in manufacture and GHG emissions. As was shown in Measure 3, there is evidence to suggest that there is a CO_2e emission reduction when using recycled feedstock instead of virgin feedstock.[199] [200] [201] However, the credibility of these sources was questioned as they did not disclose which paper product was being assessed, limiting the ability to draw valid conclusions. Furthermore, as was discussed in the barriers to Measure 1, there are many potential variations that can be made by an individual or organisation when conducting an LCA, which is used to calculate the CO_2e value. This means that consumers should not view any number of generic studies stating that using recycled paper leads to lower CO_2e emissions, but rather seen an assessment for the exact product they are considering purchasing and under what scenario it produces lower CO_2e emissions (recycled or virgin).

Supply of recovered paper

Recently, Government consultations on Extended Producer Responsibility (EPR) and plans for improved collection through Deposit Return Schemes (DRS) in the context of the paper sector have been discussed.[202] EPR is a policy that places the burden of responsibility for EOL product disposal on the entity which produces it, rather than the consumer, which has traditionally been the case. A DRS is a recycling system which facilitates the recycling of containers such as glass bottles and aluminium cans. The CPI has cited the Government's

[197] Forest Europe, "State of Europe's Forests: 2020", Forest Europe (2021). Available at: link
[198] FESS Group, "How important is sustainable packaging to consumers?" (2021). Available at: link
[199] Arjowiggins, "Eural", (2023) [Online]. Available at: link
[200] Savi, A, "Recycled paper vs virgin paper; reduce the carbon footprint of your business", EcoPack (2022) [Online]. Available at: link
[201] Bajpai, P, "Recycling and Deinking of Recovered Paper: Preprint", (2014). Available at: link
[202] CPI, "2021-22 Annual Review", (2022). Available at: link

Resources and Waste Strategy as having significant potential for improving the quality and volume of recovered paper available to mills, provided that improved collection strategies such as separate paper and board collection and processing are implemented.[203]

Furthermore, recent European Union legislation has mandated that 75% of paper must be recycled in European countries by 2025.[204] The resulting increase in the supply of recovered paper would likely reduce the cost of recovered paper and thus increase its use in primary production.

Reduction of fuel requirements for pulping

The manufacture of PPI products can be an energy intensive process. The production of products from recycled sources has been shown to require 31% less energy, compared to virgin fibre paper, though the energy source is biogenic in nature and rated as carbon neutral.[205] The benefit of using recycled inputs to produce products is a lower demand for fuels to run production sites. A reduction in fuel requirement will reduce both the environmental impacts associated with PPI product manufacture as well as the economic cost, benefitting the carbon impact of the production site itself and those who use the product.

5.3.2 Barriers

The barriers for Measure 5 are shown in Table 17. The most significant barriers are shown in bold as voted for by stakeholders in the workshop.

Table 17: Barriers for paper sector measure 5

Description	PESTLE	COM-B
Contamination of the waste stream	**Technological / Environment**	**Opportunity – physical**
Digitisation of paper products	**Technological**	**Opportunity – social**
Maximum number of lifecycle for fibres	**Technological**	**Capability – physical**
Economic volatility	Economic	Opportunity – physical
Higher cost of using recycled content	Economic	Opportunity – physical

[203] CPI, “Consistency of collections – improving the quality of paper for recycling”, CPI (2023). Available at: link
[204] European Commission, “Proposal for a regulation of the European Parliament and of the Council on packaging and packaging waste”, (2022). Available at: link
[205] Arjowiggins, “Why use recycled papers?”, (2023). Available at: link

Unsuitability of recycled fibres for specific applications	Technological	Opportunity – physical
Lack of demand for available material	Social	Opportunity – social
Hazards of chemicals used in paper	Technological	Capability – physical

Contamination of the waste stream

Two stakeholders both discussed that there is substantial contamination present in the waste stream they receive, one during an interview and the other at workshop. One stakeholder stated that consumers rarely provide paper waste that is sufficiently clean to be used as recycled content. Contamination can be in the form of grease or liquids on packaging or metals and plastics used as staples or barrier coatings on materials. Stakeholders discussed the contamination issue during this measure and other measures as a significant barrier to more effective use of recovered paper as feedstock for the pulping process. Simpler Recycling (see Section 1.2.3) was cited as one of the most prominent potential barriers to better use of recovered paper. Whilst a stakeholder stated that Simpler Recycling, according to their understanding of the regulation, may increase the rate of paper collection, it may reduce the quality of the collected material due to the higher presence of contaminants, which affects how much of the recovered paper can be used in production.

Contamination occurs in the form of materials such as plastics and glass in the paper stream as well as non-recyclable materials such as products with laminated coatings. For context, the CPI declared that around 2% by mass of paper products being sent for recycling are classified as ‘challenging’ and are unlikely to be recycled.[206] The technical report stated that hot and cold beverage cups, liquid food packaging and laminated food packaging products were all examples of the products that could not be recycled beyond the ‘market mix’ in standard paper mills. No quantitative data could be found on the presence of contamination in the waste stream.

Contamination can also mean foreign materials being present in the paper waste stream (this also includes board products). In terms of quantified limits, the current limit of plastic content the paper recycling technology can receive is 1.5%.[207] The fact that most local authority paper collections are comingled leads to an increased risk of contamination.[208] Single stream collections may reduce the contamination of the paper stream with foreign materials.[209] [210] However, to counter this statement, one stakeholder did raise that single stream collections imply there will be no professional sorting of materials which may lead to contamination. There

[206] The Grocer, “Is paper really better for the Earth than plastic?”, (2023). Available at: link.
[207] CPI, “Design for recyclability guidelines”, (2022). Available at: link.
[208] CPI, “The economic value of the UK’s paper-based industries”, (2022). Available at: link
[209] CPI, “The UK paper industry – innovation and the bioeconomy”, (2022). Available at: link
[210] CPI, “The economic value of the UK’s paper-based industries”, (2022). Available at: link.

was no literature found to confirm whether this was the case. Thus, there was not 100% consensus in the workshop that separate collection is the optimal sorting method to reduce contamination.

During the workshop, one stakeholder reinforced the barrier of contamination to the collection of high-quality paper and board materials. There were multiple potential sources of contamination raised. First, there is contamination raised in terms of plastics and metals in the paper streams. Second, there is contamination which takes place due to consumers leaving cardboard products in the rain, which degrades the fibre. Thirdly, there is often residual liquid left in liquid packaging board (LPB) products, which can reduce the quality of the collected material as the LPB cannot be recycled with liquid in.

During an interview, one stakeholder also disclosed that a factor in contamination rates may also be lack of information for householders. If there is insufficient information for stakeholders on what to recycle, it may lead to materials being placed into the incorrect streams. This will affect the quality of the recyclate, which will in turn adversely affect the company receiving the recovered paper bales.

Digitisation of paper products

There is a growing trend for sources such as books and news to be viewed using computerised devices. As a result, there has been a reduction in the availability of easily recovered paper grades, such as newsprint, that are subsequently available for recovery.[211] If digitisation continues, this will lessen the availability of secondary sources, which may in turn reduce the RIR for primary production.

Maximum number of lifecycles for fibres

Fibres' performance in their intended application in the PPI is governed by many factors, including their strength. With each recycling loop, the fibres are degraded slightly: the fibres can break and splinter into 'fines', which end up as part of the sludge and are filtered out with wastewater.[212] As such, there is a technical limit to the number of recycling loops paper may pass through. Literature puts the theoretical maximum at seven, but states the likely average number of loops achieved to be 3.4.[213] One stakeholder during interviews stated that the fibres are used in pulp and paper industry (PPI) products maintain integrity for up to 7 lifecycles only.[214] One stakeholder suggested that the difference between the maximum achievable number of loops and what is currently being achieved is the strength reduction of fibres during the shredding and repulping steps. Another stakeholder suggested that 3.4 loops seemed to be a low estimate of the number of loops a fibre can sustain. They stated a value of 7-8 loops was more accurate, and that as many as 25 loops had been achieved in non-published lab trials. The reason for the greater number of recycling loops which can be achieved at the lab

[211] Roth, S. et al., "The pulp and paper overview paper', Climate Strategies (2016). Available at: link
[212] Hubbe, Venditti, and Rojas, 'What Happens to Cellulosic Fibers during Papermaking and Recycling?' (2007). Available at: link
[213] Griffin et al., Industrial decarbonisation of the pulp and paper sector: A UK Perspective (2018). Available at: link
[214] CPI, "2022-23 Annual Review", (2022). Available at: link

scale compared to the commercial scale is due to the control over conditions the fibres are exposed to during their use and end of life handling stages.

Economic volatility

The cost of recovered paper, which is used to produce recycled pulp, is subject to price volatility, potentially driven by global patterns of demand. Factors driving this increased volatility have been recent falls in Heavy Goods Vehicles (HGVs) drivers and a lack of new HGV drivers to replace them, although it is likely this will impact the manufacturing of products from recycled sources also. The UK's departure from the European Union was also cited as a reason.[215] This price volatility could disincentivise paper mills from producing products from secondary sources such as recovered paper. However, on further investigation, it appears that there is price volatility of virgin paper as well.[216] It was not possible to quantify whether virgin or recycled content prices were more volatile. As a result, it cannot be concluded whether this is a significant barrier or not.

Higher cost of using recycled content

Whether using recycled pulp is more cost effective than virgin pulp is not immediately clear. One online source states that, as of 2020, using recycled pulp has a higher cost relative to virgin pulp, but it is worth noting that the relative price of virgin vs recycled fibres can fluctuate over time due to demand.[217] The higher cost of recycled pulp relative to virgin pulp was cited as the additional processing steps required for recycled pulp production, including the de-inking process where inks are removed from the recovered paper products. A further source stated that, as of 2022, manufacturing products with recycled pulp is 25% more costly than using virgin products, due to the more lengthy and complex process, reinforcing statements in the previously discussed source.[218]

Unsuitability of recycled fibres for specific applications

As evidenced by a stakeholder, as fibres pass through successive recycling loops, their functional performance is reduced. Some products requiring high-performing fibres to lend the product characteristics such as moisture resistance, will require virgin fibres. It is not immediately clear from the literature whether this technical barrier can be overcome through fibre treatment.

One stakeholder, when discussing how materials are selected for packaging products, noted that for products with high-value recycled content is rarely selected. Due to the degraded functional performance of the fibres during the recycling process, there is a higher likelihood of failure of the product, though thicker grades can be used to counteract this risk.

[215] CPI, "2021-22 Annual Review", (2022). Available at: link
[216] PaperplusUK, "Why are my paper prices so volatile?", (2019). Available at: link
[217] Anderberg print, "Why does recycled paper cost more than brand new paper?", (2020). Available at: link
[218] Wigston paper, "The complete guide to recycled paper", (2022). Available at: link

Furthermore, where applications of PPI products require high hygiene standards products such as for face coverings used by medical professionals, they will likely not use recycled fibres.[219] This was shown to be due to the increased presence of undesirable bacteria in recycled paper, being 100-1,000 times greater than levels observed with virgin paper[220] Though variation in fibre properties is likely to also be relevant.

Besides from functionality in a technical sense, one stakeholder also discussed that when using recycled papers, there is a restriction on the colours that can be selected. This may lead to the use of virgin content because a client's specification is not always flexible on the choice of colour, though it's worth noting that there are potential strategies to address this, for example layering of fibre within the product.

During the workshop, the stakeholders pointed out that recycled fibres may be unsuitable for papermaking used for certain applications as the final product will have a greater mass. The greater product mass would be driven by the need to include a larger volume of recycled fibres, to meet the same functional/technical strength requirements. One stakeholder gave an example that for corrugated cardboard boxes, the product would be 25-30% heavier if made from entirely recycled fibres as opposed to entirely virgin fibres. The effects of this would be a small increase in transportation costs and emissions, which would be borne in this instance by the company that is organising the shipment of the box.

Lack of demand for available material

As has been discussed previously, there is a well-developed market for the recovery of PPI products within the UK, but it appears that it requires further development. In 2019, 7.5 million tonnes were collected for recycling within the UK.[221] Of this, 3.2 million tonnes were used domestically, with 4.3 million tonnes being exported. The fact that there is such a high export of waste paper points to a lack of demand for recovered paper within the UK. This barrier was confirmed by the source that discussed the level of exports of recovered paper from the UK, stating that there is still the opportunity to use a greater mass of recovered paper. [222]This barrier will affect the national level of secondary fibre use and thus the levels of efficiency achieved for this measure. To deliver increases in domestic use additional investment in processing capacity will be required.

Hazards of chemicals used in paper

Literature has cited an increased call for caution around leakage of chemicals used to manufacture paper products, into the environment. Chemicals such as PFAS that are used in inks, dyes and glues of many non-food contact paper products have been linked to adverse health effects in humans.[223] When such paper products enter the recycling process, these

[219] Two Sides, "Virgin fibres from sustainably managed forests are needed to maintain the paper cycle", (2023). Available at: link
[220] Papernet, "Virgin vs recycled paper", (2023). Available at: link
[221] Back, S, "The British paper industry of today", PA Paper advance, [Online] (2021). Available at: link
[222] Back, S, "The British paper industry of today", PA Paper advance, [Online] (2021). Available at: link
[223] Food Packaging Forum, "Studies assess PFAS, OPEs, and plasticizers in paper & board", (2023). Available at: link

chemicals can migrate into the paper and board fibres which are naturally porous and cannot be removed. If these fibres are used for food-contact applications, there is a risk that chemicals may then migrate into food consumed by the public.[224] To address this, the UK Government has included the discussion of food-contact paper and board products in its ongoing chemical strategy, whilst other nations like Denmark have banned the use of PFAS in paper and board products altogether.[225] If reprocessors accept PFAS containing paper into their processes, they may risk losing the custom of manufacturers requiring food-contact only recycled paper sources. If legislation calls for the ban of such products, this could impact the feedstock for reprocessing mills. It's worth noting however that recent research by the Environment Agency indicates that the main source of PFAS in recycling mill water outflows arises from the input water and is not added through paper recycling[226]. It's also notable that PFAS is used in small quantities to give paper products specific properties (such as industrial waterproofing or fireproofing), with these types of paper not represented in recycling streams.

5.4 Levels of efficiency

Table 18: Levels of efficiency for paper measure 5

Indicator: % Average percentage recycled input rate of all UK PPI products			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value	67%	67-80%	67-80%
Evidence RAG	Amber-Green	Red	Red

5.4.1 Current level of efficiency

A variety of sources were found discussing current levels of efficiency.

Within the UK, the CPI 22-23 annual report states that currently 67% of papermaking raw materials are from recovered fibres.[227] Mills tend to use either recycled or virgin fibre as their input material, though mills can blend different types of fibre as required. The overall recycled input rate however captures the average percentage of recycled materials on the market. For example, the CPI report states that many corrugated boxes already contain 100% recycled content, with the average recycled content value for corrugated boxes manufactured within the UK given as 75%.[228]

[224] Fidra, "Forever chemicals in the food isle: PFAS content of UK supermarket and takeaway food packaging", (2021). Available at: link
[225] ENDS Report, "Is recycling creating a toxic chemical problem?", (2021). Available at: link
[226] Environment Agency, "An Investigation of PFAS Emissions from UK Paper Mills", (2023). Available at: link
[227] CPI, "2022-23 Annual Review", (2022). Available at: link
[228] CPI, "Recycled content in corrugated packaging", (2020). Available at: link

Other values were also found applying to geographical regions outside of the UK. One journal article reported a recycled input rate of 38% when considering global mass flows, for the year 2012.[229] The International Energy Agency (IEA) stated that >50% of all fibres used in paper production at a global level are from recovered sources.[230] A technical report by Two Sides gave the % of fibre from paper for recycling (recovered paper) to be 56%, with 44% from virgin sources, at a European wide level[231]. One technical report gave a further level of efficiency at a European level, with the recycled input rate given as 66% for packaging products and 6% for hygiene products. [232]

At the workshop, stakeholders did not vote on this level of efficiency despite this having been discussed. The reason there was no voting is unclear. However, one stakeholder – an expert in this field – stated they agreed with the levels of efficiency reported from the literature review.

Only one source, the CPI 22-23 annual report was found to be immediately relevant to the UK PPI. Based on this, the current level of efficiency is set as 67%. The source was from a highly-reputable entity published very recently and is applicable to the UK specifically. This lends it the highest possible IAS of 5. As there was one stakeholder who agreed with this value at the workshop, and the data source is of high-reliability, an amber-green evidence RAG rating was given.

5.4.2 Maximum level of efficiency in 2035

The work of Van Ewijk, et al. calculated the potential recycled input rate (RIR), at a global level.[233] The study was modelling global lifecycle paper flows including the recycling rate and use of recycled pulp for paper products. The authors modelled three scenarios, which saw an increase in the collection rate from 38% in the baseline to 90%, 93% and 96% in scenarios 1-3 respectively. The authors did not provide a date for when these scenarios would be realised or what would influence whether they are achieved or not. The results saw the potential RIR increase to 67%, 70% and 73%. It is important to note that the lower bound of this maximum level of efficiency of 67-73%, is the same as the current level of efficiency of 67%. The differences in methodologies between the journal article by Van Ewijk and the CPI paper are not immediately clear. Both cover different geographies, with the CPI report discussing the UK only whereas the journal article by Ewijk discusses a global perspective. The time periods are also different, with the CPI report using 2019 data and the journal article 2012 data.

During an interview, one stakeholder provided qualitative confirmation of the literature that at sector level, a 100% recycled input rate could never be achieved. The barriers include the number of recycling loops fibres may pass through before degrading and the stock of PPI products that won't be available for recycling.

[229] Van Ewijk, S. et el., "Global lifecycle paper flows, recycling metrics, and material efficiency", Jrn. Of Industrial Ecology 22, (2017). Available at: link
[230] IEA, "Paper industry overview", (Unknown). Available at: link
[231] Two Sides, "Paper production and sustainable forests", (2020). Available at: link
[232] Roth, S, et al. "The pulp and paper overview paper", (2016). Available at: link
[233] Van Ewijk, S. et el., "Global lifecycle paper flows, recycling metrics, and material efficiency", Jrn. Of Industrial Ecology 22, (2017). Available at: link

Another stakeholder added that some products will always require use of primary fibres. Primary fibres would be required in certain applications requiring superior moisture resistance, for instance, a property not possessed by secondary fibres without additional coating.

As with the current level of efficiency, stakeholders did not vote on this level of efficiency. However, one stakeholder stated they agreed with the levels of efficiency reported from the literature review. Furthermore, there was a verbal statement from another stakeholder who said the UK RIR should not be expected to rise significantly as they believed the UK was currently at the correct level of RIR. No further explanation was given.

During the workshop, one stakeholder verbally gave a Business-as-usual level of efficiency as 80% for the UK national RIR during discussion of the levels of efficiency that were proposed to stakeholders for voting. There was uncertainty in this statement, with the stakeholder stating the level of efficiency 'might' get us to 80%. The nature of the BAU and maximum technical levels of efficiency is such that unless there are technical reasons, the maximum technical level of efficiency is greater than the BAU level of efficiency. There were no reasons found during the literature review as to why the maximum technical level of efficiency for this measure would be lower than the BAU. As such, it was approximated that the 80% level of efficiency given by the stakeholder for a BAU scenario, would also apply as the upper bound of the maximum level of efficiency.

Drawing the sources together, it is clear that the maximum level of efficiency was not 100% and is unlikely to ever reach this value, at a national level. It is still important to acknowledge that the level of efficiency for individual products can be 100%, but as some products cannot use recovered paper as input due to technical limitations, this will only apply to some products but not others. The upper bound was set as 80% based on a stakeholder's comment. The lowest level of efficiency found was the lower bound of 67%, given in the academic journal article written by Van Ewijk *et al.* [234] It should be noted that this article was published at a global level which reduces the applicability score of the reference.

Overall, the level of efficiency was reported as a range between 67-80%. Only one literature source gave a level of efficiency which had limited applicability as it was published at a global level. Furthermore, whilst the upper bound was provided by an expert stakeholder, it was not corroborated by other stakeholders or a literature source. As such, there is little confidence in the reported level of efficiency range, giving a red evidence RAG rating overall.

5.4.3 Business-as-usual in 2035

During the workshop, one stakeholder verbally gave a level of efficiency, stating that the BAU level of efficiency may rise to 80%. A verbal statement by the same stakeholder was also given, alluding to the fact that the UK is currently in the 'correct place' with its RIR, around the 67% level of efficiency. During the workshop, no quantitative data was gathered from the voting on the measure. The interviews also yielded no quantitative data from stakeholders.

[234] Van Ewijk, S. et el., "Global lifecycle paper flows, recycling metrics, and material efficiency", Jrn. Of Industrial Ecology 22, (2017). Available at: link

No existing literature data was found regarding current or historical resource efficiency levels for this measure.

The BAU will thus be reported as 67-80% to reflect the range of levels of efficiency that were given by stakeholders during the workshop. As there were no literature sources found to corroborate these values and one stakeholder gave somewhat contradictory values, a red evidence RAG rating was given.

6.0 Measure 6 – Improvement of the production yield ratio

6.1 Paper resource efficiency measure

6.1.1 Description

Improving the ratio of material inputs to valuable outputs, for production processes in the pulp and paper (PPI) industry.

During any manufacturing process, there are inputs and outputs. Usually, a process will not be fully efficient. That is, some of the material input to the system will not be used to produce the intended output. It is instead either lost as an inefficiency or converted to a material that is not of value to the papermaking process. This measure investigates how the PPI can improve the production yield of this process and thus make it more resource efficient. The yield is defined as the ratio of valuable wood input to the output.[235]

The main three processes used by the PPI are the pulping, papermaking and converting processes. The pulping process is set up deliver pulp with the properties required in the paper product. The process begins with the reduction of wood into fibres through pulping. The three major types of pulping are mechanical, chemical and recycled. Each of these will have their own level of efficiency reported where levels of efficiency are discussed in Section 6.4. All of these pulping types have distinct production yields. Mechanical pulping, which uses mechanical energy to generate fibres from the wood, are typically associated with higher production yields. However, the strength and resulting pulp quality is lower than chemical pulp because of the fibres being damaged during processing. Chemical pulping, which does not damage the fibres as much as mechanical pulping, has a lower yield when compared to mechanical pulping. However chemical pulping produces a range of products alongside the pulp and so the yield of pulp can be balanced against a portfolio of other bio-based products from the same site.

Chemical pulping is also split into four further categories, some of which are discussed specifically in the subsequent text: Carbonate, Kraft, Soda and Sulphite. However, the functional performance of products manufactured using recycled pulp are often lower than that of their virgin counterparts.

Natural variations that impact the pulping yield ratio and cannot be designed out currently include the regional variation within species of trees. The type of wood also has an impact. Hardwoods have constituents which retain a greater degree of stability compared to softwoods

[235] Hamaguchi, M et al.,” Alternative Technologies for Biofuels Production in Kraft Pulp Mills—Potential and Prospects”, Energies (2012). Available at: link

and thus will garner a higher pulp yield, though these will be managed through the operation and design of the installation.

Papermaking yield values are less commonly discussed in the literature, potentially because the actual output is a portfolio of products and not just pulp.

There is a clear distinction to be made between this measure and Measure 4 – lightweighting of paper products, with both these measures being related to a mass at a stage of a paper products lifecycle. This measure discusses trying to improve the mass of valuable output of a process, for a given level of input. Measure 4, by contrast, is attempting to reduce the given level of output that needs to be achieved by design.

6.1.2 Measure indicator

The indicator selected for this measure is **‘percentage production yield of pulping processes’**. This indicates the ratio of the pulp output over the total material input.

The following two indicators were discarded:

- Percentage yield of mechanical pulping process, percentage yield of chemical pulping process and percentage yield of chemithermomechanical pulping process – each of these indicators was deemed too specific for this project which is looking to cover the measure as a whole.
- Percentage production yield of product manufacturing process – this was initially included in the study. However, after completion of the literature review, workshop, and interviews there was no data found on this indicator. Therefore, it was discarded.

6.1.3 Examples in practice

Several research areas have focussed on attempting to improve the resource efficiency of paper production. Many of the efforts centre around the pulping process with limited discussion within the literature on papermaking, where papermaking covers the conversion of pulp into a final paper products. It is not clear why there is no discussion of how the yield of the papermaking process can be improved, but it is possible this is due to already high efficiency levels, particularly for virgin fibre.

6.2 Available sources

6.2.1 Literature review

The literature review identified seven sources that discussed the improvement of the production yield ratio as a resource efficiency measure. These comprise:

- Six academic papers;[236] [237] [238] [239] [240] [241] and
- One website article.[242]

The relevant sources were considered of high applicability and credibility when assessed against the data assessment framework, which recognises the relevance of the sources and the strength of the methodology within each. The sources exhibited an average IAS of 4.7 (out of 5) with 6 sources exhibiting a score of 4 or above. Of the literature reviewed, four of the sources were nine years old or older. Just two sources source was considered recent having been published in the last 10 years. Only one of the sources was relevant to the UK specifically, with most being published as territory agnostic. This suggests a need to incentivise further research in this topic area, to provide updates on what yields are currently being achieved. The literature also appears to be reporting on isolated pockets of industrial trials, rather than industry wide best practices. Furthermore, as most of the literature found is academic, it is often written from a geographic agnostic standpoint, further providing uncertainty on the level of implementation of production yield improvement being realised within the UK PPI It is recommended that research is conducted into the state-of-the-art for UK paper and pulp mill production yield standards. Given the majority of pulping undertaken is recycled pulping – using recovered paper as a feedstock for pulping – the main focus would be on this pulping type.

6.2.2 Interviews

One stakeholder spoke to this measure, stating that because the UK has no kraft (chemical) pulping activities, with mostly recycled pulp used or imported virgin fibre, there is little scope for the improvement of production yields within the UK PPI (see Figure 1 in the sector introduction). As will become evident in the levels of efficiency section for this measure, based on the literature found there is limited scope for improvements to production yields where recycled pulp is used. Besides this comment, stakeholders did not engage with this measure.

6.2.3 Workshop

When presented with this measure, stakeholders raised concerns regarding their limited knowledge. The measure was stated as being too technically specific for the stakeholders and no attendees felt they could add to either the voting on levels of efficiency or barriers and drivers. As such, no data was gathered from stakeholders.

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[236] Van Ewijk, S. et el., “Global lifecycle paper flows, recycling metrics, and material efficiency”, Jrn. Of Industrial Ecology 22, (2017). Available at: link
[237] MacLeod, M, “The top ten factors in kraft pulp yield”, (2007). Available at: link
[238] Hart, P.W, “Production of high yield bleached hardwood kraft pulp: Breaking the kraft pulp yield barrier”, *Pulping* (2011). Available at: link
[239] Ogunwusi, A.A. and Ibrahim A.D., “Advances in pulp and paper technology and the implication for the paper industry in Nigeria”, (2012). Available at: link
[240] Rogers, J.G., “Paper making in a low carbon economy”, (2018). Available at: link
[241] Hamaguchi, M et al.,” Alternative Technologies for Biofuels Production in Kraft Pulp Mills—Potential and Prospects”, Energies (2012). Available at: link
[242] NEDMAG, “Higher yield and less waste from pulp production”, (2015). Available at: link

6.3 Drivers & Barriers

The drivers and barriers influencing this measure were identified through a combination of the literature review and one stakeholder interview.

6.3.1 Drivers

Table 19 below shows the main drivers for Measure 6. As voting was not conducted for this measure, there were no drivers found to be the most significant.

Table 19: Drivers for paper measure 6

Description	PESTLE	COM-B
Economic incentives	Economic	Motivation – automatic
Environmental incentives	Environmental	Motivation – automatic
Less complex manufacturing process	Technological	Capability – physical

Economic incentives

If paper and pulp mills are more efficient in their production steps, less material input could be required to produce the same unit output level. During the workshop, one stakeholder reported that such efficiencies would present a financial benefit to the mills and that they were likely already achieving the maximum efficiency they could with current technology. Nevertheless, there could be a direct incentive for mills to ascertain how to produce their products with a higher yield.

Environmental incentives

As well as economic incentives, if a lower mass of wood chips is required to produce the same unit level of output, there will could be a lower environmental burden. The reduced environmental burden is associated with the felling and processing of trees required to produce the wood chips. This outcome could benefit commercial entities that use paper products, whether they are attempting to reduce their Scope 3 emissions to meet Science Based Target Initiatives (SBTi) or regulatory targets. The manufacturers could also benefit as their Scope 1 emissions will be reduced, which will be a beneficial outcome if they are also attempting to reach internal/externally set emissions targets.

Less complex manufacturing process

Where the production yield of a process is not 100%, or 1, the lost materials will be converted into non-valuable materials, such as by-products. This effect is covered at greater length in Measure 7. Manufacturing process lines will be set up to handle the waste that is generated during this process. If the production yield can be increased, a lower volume of waste will be generated and manufacturing lines can be streamlined, reducing the number of steps in the manufacturing process. This could benefit pulp manufacturers through reduced capital expenditure, less labour costs and also the ability to be more agile and flexible in their manufacturing processes.

6.3.2 Barriers

The barriers for Measure 6 are shown in Table 20. As voting was not conducted for this measure, there were no barriers found to be the most significant.

Table 20: Barriers for paper measure 6

Description	PESTLE	COM-B
Technical limitations	Technological	Capability – physical
Other value streams for losses	Economic	Opportunity – physical
Cost implications of process improvements	Economic	Opportunity – physical

Technical limitations

Quality of the processing machinery has been cited as a key driver to higher production yields in kraft pulp production.[243] For instance, advanced batch and continuous digesters ensure wood chips have sufficient time in contact with steam. However, the source stated that standard systems do not have such advanced technology, resulting in a lower production yield level. As a result, these technical advantages can only be achieved once the necessary machinery has been installed. It was unclear from the literature whether, and under what scenario, the investment would lead to an overall net improvement of a pulping or paper mills financial success. While it's worth noting that the UK has no kraft (chemical) pulping, it is possible that the barrier of technical limitations also applies to other forms of production.

Other value streams for losses

This barrier applies especially to the kraft (chemical) pulp production process. As will be discussed in Measure 7, by-products such as black liquor are produced during kraft (chemical) pulp production. These by-products have a number of uses, including use as a fuel in the pulping process as a standard practice.[244]

[243] MacLeod, M, "The top ten factors in kraft pulp yield", (2007). Available at: link
[244] CPI, "Process wastes from the paper industry", (2021). Available at: link

Cost implications of process improvements

Implementing process changes, such as using new chemicals or purchasing new machinery will require investment. For instance, changing suppliers for new chemicals may entail a slight increase of costs. Purchasing of new machinery will almost certainly require significant capital expenditure and the costs could be orders of magnitude larger. Such large investments may disincentivise commercial entities from implementing strategies which will improve production yields.

6.4 Levels of efficiency

Table 21: Levels of efficiency for paper measure 6

Indicator: percentage yield of pulp processes			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value	Mechanical – 80-95% Recycled – 85-95%	Not available	Mechanical – Not available Recycled – 85-95%
Evidence RAG	Amber	Not applicable	Red-Amber

6.4.1 Current level of efficiency

Several sources were found giving levels of efficiency for this measure. However, all sources found in the literature review discussed only the pulping process efficiency, with nothing found on the efficiency of converting pulp into the final product. The levels of efficiency for the pulping processes are reported in the literature, according to the pulping type. The prevalence of each pulping type within the UK is not known exactly. What is known is that the majority of PPI feedstock is from recovered paper, with the most recent estimate at 67% according to the CPI.[245] By contrast, the same CPI report states that only 26% of inputs originated from wood pulp, which can be any of the below pulp types, with the exception of recycled pulp.[246] Of the pulping types classified as wood pulp, there is no data available on the UK's blend of them.

Each of the pulping types is discussed individually hereafter. As the UK does not have any chemical pulp mills, this has not been included in the below analysis.

[245] CPI, "2022-23 Annual Review", (2022). Available at: link
[246] Ibid

Mechanical Pulp

- 80% yield was reported when oven dry wood is used.[247] The journal article also states that whilst the yield is high, the energy requirements are also high, and the strength properties are relatively low. It is assumed the relative assertion is in comparison with chemical pulp given chemical pulp is known to produce paper which has superior strength properties to paper produced with mechanical pulp.[248] The source IAS is 5.[249]
- 90-95% yield of mechanical pulping was reported in the Journal of Industrial Ecology. The source IAS is 5.[250] No further detail was provided on this yield figure.

Summarising mechanical pulp, different ranges of current levels of efficiency are reported. The IAS of both sources is 5 and they are highly credible. The current level of efficiency for mechanical pulp will be reported as 80-95%.

Recycled Pulp

Given that in the UK, 67% of papermaking raw materials are from recovered fibres, recycled pulp was considered.[251] Two sources were found indicating current levels of efficiency at:

- 95%.[252] This value was from a journal article with an IAS of 5. The value is representative of global material flows and is not directly relevant to the UK, but the source is otherwise of high quality as it is peer-reviewed and published in a relatively recent timeframe.
- 90-95% was provided by a stakeholder during interview, with another stakeholder providing a figure of 85% yield from recovered papers to fibre.

Recycled pulping is thus given a level of efficiency of 85-95%, given the literature value reported was corroborated in the range given by the stakeholder and the IAS of the source is high, although it is noted that the source is not specifically related to the UK.

The UK PPI context

The two pulping types (mechanical and recycling) present different levels of efficiency as explored above. An overall amber rating was given as there was limited stakeholder corroboration but the literature sources were considered to be reliable as they all had an IAS of 4 and above.

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[247] Hart, P.W, "Production of high yield bleached hardwood kraft pulp: Breaking the kraft pulp yield barrier", *Pulping* (2011). Available at: link
[248] ibid
[249] ibid
[250] Van Ewijk, S. et el., "Global lifecycle paper flows, recycling metrics, and material efficiency", Jrn. Of Industrial Ecology 22, (2017). Available at: link.
[251] CPI, "2022-23 Annual Review", (2022). Available at: link
[252] Van Ewijk, S. et el., "Global lifecycle paper flows, recycling metrics, and material efficiency", Jrn. Of Industrial Ecology 22, (2017). Available at: link

6.4.2 Maximum level of efficiency in 2035

It appears that whilst there is a lot of activity within the literature on current levels of efficiency, the maximum level of efficiency is not well documented. This is perhaps due to the sentiment, shared by a stakeholder, that production yields are unlikely to increase further by significant increments as the UK PPI has already spent significant time and funds on improving the yields. Any changes that will happen are likely to be incremental.

6.4.3 Business-as-usual in 2035

At a UK level, gains in production yield improvement in a BAU scenario will be marginal, something corroborated by a stakeholder in interviews. This is because the majority, specifically 67%, of fibre inputs at UK paper mills are recovered fibres. The production yield of recovered paper yield is already very high (>85%) with little room for further improvement and stakeholders agree that yields are maximised already. As such, it is likely according to a stakeholder, that by 2035, the business-as-usual scenario for recycled pulp will not differ significantly from current levels of efficiency so the BAU level of efficiency for recycled pulp was reported as being the same as the current level of efficiency. A red-amber evidence RAG rating was set given the stakeholders comment but lack of other existing literature to support such a statement.

No existing literature or stakeholder comments were made on likely changes to the mechanical pulping production yield. As such, no BAU level of efficiency was reported.

7.0 Measure 7 – Utilisation of byproducts of the pulp and papermaking processes

7.1 Paper resource efficiency measure

7.1.1 Description

Use of unavoidable by-products in the production of pulp and paper industry (PPI) products by other industries where they deliver value.

During the paper and pulping processes, materials are generated that are not useful outputs. These are referred to as by-products. Examples of by-products of manufacturing processes, such as pulping, include paper sludges (de-inking, papermaking and effluent), rejects, paper ash and black liquor. More detail on each of these is provided below:

- **Rejects** are generally produced exclusively by mills using recovered paper as their feedstock. This byproduct was stated as the most significant for UK pulp and paper mills by a stakeholder during the workshop, presumably due to the UK's use of predominantly recovered feedstock. Stakeholders confirmed that when recovered paper arrives in bales at the paper mills, there is often contamination present in them. Contamination is often present in the form of plastics, metals, and glass, which are materials that are of no value to the paper or pulping process. One stakeholder during an interview commented that rejects can be plastic bottles, tins cans and glass. Paper mills separate the rejects as far as practicable, and where possible outputs are sent for recycling; if not feasible then they are sent to landfill or for energy recovery. The stakeholder stated that better sorting of recovered paper is required to remove the presence of contamination within the bales they received. A separate stakeholder, during the workshop, also stated that if improved sorting processes are implemented for household waste collections, the mass of rejects will reduce.
- **Paper sludge** is a mix of wet cellulosic fibres and clay type mineral fillers that accumulate during papermaking using recycled fibres. Sludge are produced at low volumes during all papermaking processes.
- **Paper and Pulp Mill Fly Ash (PPFA)** is generated by burning biomass and process wastes to run the pulping or paper mill boilers and CHP plant. During the combustion process, substances form and exit the boiler into a flue, where they are subsequently captured. A recent report by the CPI stated that very few paper mills produce paper ash currently due to a reduction of paper mills using incineration of waste products of the paper process.[253]
- **Black liquor** is by-product that is produced during the kraft (sub-class of chemical pulping) pulping process. As the wood chips are converted into the cellulose fibres, black liquor is produced in the ratio of seven units black liquor for one unit pulp.[254]

[253] CPI, "Process wastes from the paper industry", (2021). Available at: link
[254] Speight, J.G, in extract of "Heavy Oil Recovery and Upgrading", (2019). Available at: link

These by-products or waste products can be used within the papermaking process itself, and in other industries. Some uses of these by-products include energy recovery processes, fuelling parts of the paper or pulping mill itself, as well as material-based uses.[255]

There was data found on how PPFA and black liquor were both handled. However, PPFA was shown to be generated at negligible quantities by paper mills in the UK.[256] Furthermore, black liquor is only generated during the kraft (chemical) pulping process, which is not carried out within the UK. As such, only rejects and paper sludge were discussed in this measure, with PPFA and black liquor not considered.

This measure is concerned with the material-based uses of by-products that are produced during the paper and pulping processes. Where there was discussion found on how to generate energy as efficiently as possible from byproducts, it was not included in this report as it is out of scope.

7.1.2 Measure indicator

The indicator selected for this measure was '**percentage of byproducts reused, recycled or recovered'.** This definition excludes the use of by-products as fuels.

In this context, a by-product is defined as a material or product produced as secondary to the intended primary output of a manufacturing process. To illustrate this measure by means of an example, say that 1 tonne of pulp is produced, producing 10 tonnes of wood residues and black liquor called the by-products. If 30% of the 10 tonnes of by-products are used to make another valuable substance, the efficiency level is 30%. This indicator does not differentiate the value of the application in which the by-product is used in its second lifecycle. For instance, the by-product of a process may offset 1 tonne's production of a high environmental impact material and 0.5 tonnes of low environmental impact material, the different properties of these will not be captured.

It became clear at the workshop, that byproducts are already used for varied purposes, for example paper sludges are used as an agricultural soil improver or for animal bedding. Byproducts are also used for energy recovery, with a plant either located on the production site or shipped for energy recovery elsewhere. Such energy recovery offsets the need to use other fuel sources such as diesel or gas. Whilst energy recovery is lower than recycling and reuse in the waste hierarchy, as it removes material from circulation, it is counted as a resource efficiency, so was included within this indicator's scope.

Discarded indicators included:

- percentage of process waste reused – this was discarded as the term by-product was consistent with terminology in the literature.

[255] Hamaguchi, M et al.," Alternative Technologies for Biofuels Production in Kraft Pulp Mills—Potential and Prospects", Energies (2012). Available at: link
[256] CPI, "Process wastes from the paper industry", (2021). Available at: link

7.1.3 Examples in practice

Carbon fibre manufacture

One stakeholder at the workshop gave an example of paper byproducts being used in the manufacture of carbon fibre production. It appears from the literature that this use is being explored at a lab-scale and requires further research before it can be commercialised.[257] Carbon fibre production is well-known to be both energy and resource intensive, often using a petrochemical feedstock during production. Therefore, the environmental benefits in terms of GHG emissions of avoiding primary carbon fibre production could have significant positive potential benefits.

Brick manufacturing

Identified as an example by a stakeholder during interview, there has been some investigation into the use of paper sludge as a feedstock for manufacturing fired clay bricks.[258] These bricks could then go on to be used in the construction sector. This example drives innovation and could improve the resource efficiency of the UK PPI and construction sectors.

7.2 Available sources

7.2.1 Literature review

The literature review identified eight sources that discussed the utilisation of byproducts of the pulp and papermaking process as a resource efficiency measure. These comprise:

- Five academic papers;[259] [260] [261] [262] [263] and
- Three industry reports.[264] [265] [266]

The sources exhibited an average IAS of 4.3 (out of 5) with 6 sources exhibiting a score of 4 or above. Of the literature reviewed, three of the sources were nine years old or older, with five

[257] Jacobson, M, "Paper waste byproduct creates carbon fibres", (2020) [Online]. Available at: link
[258] Goel, S, "Feasibility study on valorisation of paper mill sludge (PMS) to manufacture Eco-bricks: Towards decarbonisation and sustainability in construction", Tfinetwork, (2021) [Online]. Available at: link
[259] Simão, L. et al, "Waste containing clinkers: valorisation of alternative mineral sources from pulp and paper mill", Process Saf. Environ. (2017). Available at: link
[260] Hamaguchi, M et al.," Alternative Technologies for Biofuels Production in Kraft Pulp Mills—Potential and Prospects", Energies (2012). Available at: link
[261] Cherian, C and Siddiqua, S, "Pulp and paper mill fly ash: a review", Sustainability, (2019). Available at: link
[262] Maček, A. "Research on combustion of black-liquor drops", Progress in Energy and Combustion Science 25, (1999). Available at: link
[263] Forssen, M et al.," NOX reduction in black liquor combustion – reaction mechanisms reveal novel operational strategy options", (1998). Available at: link
[264] ASPAPEL, "Sustainability Report 2021: Decarbonised bicircularity of the paper industry", (2021). Available at: link
[265] CPI, "Process wastes from the paper industry", (2021). Available at: link
[266] Material Economics, "A net-zero transition for EU Industry – what does it mean for the pulp and paper industry?", (2019). Available at: link

sources considered recent having been published in the last ten years. Only one of the sources was relevant to the UK specifically, with most being published as territory agnostic.

As was the case for Measure 6, many sources were academic reports but positively, there were also several industrial reports. Of the industrial reports, one was highly relevant as it was published by the UK CPI, discussing the byproducts of the UK PPI specifically. The academic sources which provide levels of efficiency for all pulping processes are global in nature, with no specific geographical area their subject. There was no evidence found suggesting that the pulping and other paper manufacturing processes vary between different territories. As such, it was assumed that any findings from literature studies could be applicable to the UK PPI, but were caveated in the knowledge that there may be deviations between industrial practices, when considering different territories.

7.2.2 Interviews

One stakeholder spoke to the measure during interviews, specifically on the contamination of recovered paper bales that are used to manufacture pulp in the UK. Despite this there was limited further engagement from stakeholders. This low engagement was perhaps explained by the technical nature of this measure, something which was raised by stakeholders at the workshop.

7.2.3 Workshop

This measure was engaged with by stakeholders through voting on drivers and barriers as well as some voting on the levels of efficiency. Stakeholders had a good level of knowledge of the byproducts of the pulp and papermaking processes undertaken within the UK, leading to a relatively lengthy discussion on the measure. The main points covered within the discussion were what byproducts were produced by UK pulp and papermaking mills and how these were handled. Besides the well-known byproducts of the pulp and papermaking process, there was also niche knowledge conveyed on a potentially high-value use of byproducts, which are less established compared to existing method. This was the carbon fibre example which was outlined in Section 7.1.3.

The level of engagement in the workshop was as follows:

- Six stakeholders across the industry were active on the mural board, voting for levels of efficiency, drivers and/or barriers.
- Five stakeholders actively contributed to verbal discussion.

7.3 Drivers & Barriers

The drivers and barriers influencing this measure were identified through a combination of the literature review, stakeholder interviews and sector workshop.

7.3.1 Drivers

Table 22 below shows the main drivers for Measure 7. The most significant drivers are shown in bold as voted for by stakeholders in the workshop.

Table 22: Drivers for paper measure 7

Description	PESTLE	COM-B
Financial benefits	**Economic**	**Opportunity – physical**
Improved resource efficiency of other industrial sectors and potential reduction of environmental impact	**Technological**	**Capability – physical**
Reduced burden on waste management systems	Technological	Capability – physical

Financial benefits

Whichever industry uses the by-products from the PPI could realise financial benefits. For by-products that may be used by companies in other industries, for example carbon fibre production (see Section 7.1.3), the mill producing the by-product may generate revenue from selling it. However, the exact scale of these financial benefits is unknown and will depend on many factors, not least the cost of processing the by-product and demand for the by-products. This potential downside is reflected by the barrier 'Cost implications of handling by-products'.

Despite identifying that this driver was the most significant, with four workshop votes, stakeholders also discussed the fact that there is limited further room for further financial benefits. Stakeholders stated this was due to the UK PPI having historically invested significant efforts into reducing costs wherever possible to remain financially competitive. The implication of this is limited potential for further identification of cost saving exercises. However, one stakeholder did also state that there could be room for further improvement, without being able to provide specifics of where these savings may originate from.

Improved resource efficiency of other UK sectors and potential reduction of environmental impact

It is advantageous to turn a wasteful by-product of one industry, into a valuable flow for another industry. There have been instances where the by-products of paper production have been proven as suitable for use in the production of construction sector materials such as cement.[267] Where other sectors can use the by-products produced by processes within the PPI, these

[267] Simão, L. et al, "Waste containing clinkers: valorisation of alternative mineral sources from pulp and paper mill", Process Saf. Environ. (2017). Available at: link

sectors will have a reduced need to produce virgin materials, achieving improved resource efficiency.

During the workshop, a stakeholder suggested that the chemical industry is an industry which is currently exploring means of improving the sources of their feedstocks. Specifically, the chemical sector is exploring methods of reducing the environmental footprint – assumed to be in terms of GHG emissions – of their feedstocks. An example of byproduct use in the chemical sector was found in the literature, where waste lignin derived from the kraft (chemical) pulping process was used as a feedstock in producing nylons.[268] This example has limited relevance to the UK PPI, given that no chemical pulp mills are located within the UK territory. However, given the UK does still use virgin chemical pulp, which is imported elsewhere, it is still noteworthy.

Reduced burden on waste management systems

By-products such as rejects, which comprise foreign materials not usable by the paper or pulp manufacturer, must be disposed of by the pulp or paper mill that receives them. A stakeholder disclosed that the most cost-efficient use of rejects is to currently incinerate them for energy recovery This is not a highly resource efficient means of handling by-products and results in material being removed from circulation, likely requiring new materials to be manufactured. If these rejects can be used by the commercial entities that handle them, there will be a reduced burden on waste management infrastructure.

7.3.2 Barriers

The barriers for Measure 7 are shown in Table 23. The most significant barriers are shown in bold as voted for by stakeholders in the workshop.

Table 23: Barriers for paper measure 7

Description	PESTLE	COM-B
Restrictions on land spreading	**Environmental / Political**	**Capability – psychological**
Moisture content of sludge and rejects	**Technological**	**Opportunity – physical**
Economic feasibility	**Economic**	**Opportunity – physical**

Restrictions on land spreading

Having been identified at the workshop, this barrier was identified as the most significant of all presented. It was found that the paper sludge produced from effluent treatment sites is nutrient

[268] Slowing, I.I, “New process turns paper manufacturing waste into valuable chemicals”, AMES National Laboratory, (2020) [Online]. Available at: link

rich and as such is often used for land spreading or sent for composting. This is carried out to reduce the mass of byproducts being sent for incineration or landfill, a target that is mandated. However, there are risks associated with land spreading paper sludge. For instance, due to the high carbon to nitrogen ratio of paper sludge, if the sludge is applied incorrectly, it can lead to an imbalance of the soil nitrogen levels.[269] Furthermore, stakeholders also discussed that land spreading of paper sludge could lead to adverse smell complaints being raised by dwellers located close to the spreading source. However it’s worth noting that each deployment of paper sludge to land requires specific approval from the environmental regulator where the proposals must justify agricultural benefit and any local concerns are addressed.

Moisture content of sludge and rejects

The moisture content of some sludge waste can be too high for reuse.[270] It is not immediately clear what the limiting technical factor is which leads sludge to have a moisture content that is too high, though this can be address by dewatering equipment such as presses. The barrier could be related to the intended applications of the sludge requiring low moisture material, or processing machinery being unable to accept sludge with high moisture levels. However, there was no evidence found to suggest this so there is a high level of uncertainty in this statement. Rejects are also cited in the CPI study as being commonly high in moisture content.[271]

A stakeholder stated that the main factor driving the moisture content of sludge is the state of the equipment being used at a pulp and paper mill. More advanced equipment will be capable of reaching a lower average moisture content level, as opposed to less-advanced equipment, which will likely reach a lower average moisture content.

Economic feasibility

When determining whether or not using by-products is cost effective, it may become apparent that the use or sale of by-products is not cost effective to market conditions or equipment costs. This would likely be the case if the cost of preparing/processing the byproduct for subsequent use, outweigh the potential revenues or profits from its sale.

An online source analysed the by-products in the Swedish markets, one of which is paper activities.[272] The barrier to the reuse of byproducts is reported as the lack of economic incentives to monetise the byproducts, as they are currently unprofitable. The work of Cherian and Siddiqua further reinforced cost as a barrier, stating that the initial capital expenditure of setting up the infrastructure to handle by-products was significant.[273]

[269] CPI, “Code of Good practice for land spreading paper mill sludges”, (2015) [Online]. Available at: link
[270] CPI, “Process wastes from the paper industry”, (2021). Available at: link
[271] CPI, “Process wastes from the paper industry”, (2021). Available at: link
[272] Material Economics, “A net-zero transition for EU Industry – what does it mean for the pulp and paper industry?”, (2019). Available at: link
[273] Cherian, C and Siddiqua, S, “Pulp and paper mill fly ash: a review”, Sustainability, (2019). Available at: link

7.4 Levels of efficiency

Table 24: Levels of efficiency for paper measure 7

Indicator: percentage of by-product recycled or reused			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value	78%	71-80%	71-80%
Evidence RAG	Red-amber	Red	Red

7.4.1 Current level of efficiency

The CPI published a report on wastes of the PPI in 2021.[274] The material flows the study refers to as wastes can also be referred to as by-products. By-products will be referred to only hereafter. It presented tabular data for the different by-products produced at sampled mills, using recycled paper. The data is shown in Table 25.

Table 25: Data on by-product production from mills using recycled paper taken from CPI report[275]

Product type	Wet tonnes pa from sludge	Average wet tonne rejects/paper production tonne
Hygiene	179,214	18,709
Packaging	149,426	108,097
Print & Graphical	135,721	11,000
Total	464,341	137,806

Each subsequent heading will discuss the material by-products individually.

Liquors and sludges

The same report by the CPI gave the treatment route destinations of paper sludge. [276] Of the paper sludge generated, 0% is landfilled, 42% is used as animal bedding and 58% as land

[274] CPI, "Process wastes from the paper industry", (2021). Available at: [link]
[275] ibid.
[276] ibid.

spread. This gives a 100% level of efficiency for paper sludge. For rejects, 69% are sent to landfill, 28% used for refuse derived fuel (RDF) or solids refuse fuel and the remaining 3% used in land remediation.

The generation of liquors and sludges was also covered in the work of Cherian and Siddiqua.[277] The source states that 35% of wood chips entering a pulp mill become sludge and rejects, where the sludge should not be confused with black liquor or other liquors.[278] According to the report, most of the sludge generated are landfilled, with some used for energy generation. The wording 'most' would imply that there is some material that is reused or recycled, without quantifying exactly how much. Whilst it does not provide an exact value, it indicates that the reuse and recycle rate is low as most of the sludge is landfilled.

The CPI industry article and the journal article by Cherian and Siddiqua present contradictory values. The CPI article has an IAS of 5 and is applicable specifically to the UK sector. Whilst the journal article by Cherian and Siddiqua is peer-reviewed and has an IAS of 4, it is not UK-specific and also published in 2019, compared to 2021 for the CPI article. Given the UK-specific stance of the CPI report and its higher IAS score, this source was used for drawing any conclusions for this measures level of efficiency.

Summarising the literature studies for the current level of efficiency:

- Sludge – the peer reviewed journal study, which was geographically agnostic, stated that that close to 0% of sludge generated is currently reused and recycled from a material perspective. This excludes where it is used for energy generation.[279] However, this directly contradicted the CPI source, which stated that the UK landfills 0% of its sludge. The CPI source did not state what proportion of sludge is incinerated, which would not be classified as recycling or reuse. As was discussed previously, as the journal article was agnostic to geographical location, data from the UK based CPI report was used. As such, the summarised level of efficiency for sludge is 100%.
- Rejects – only 3% of rejects are sent to reuse applications, which are those sent for land remediation, according to the CPI study. The remaining 69% are sent to landfill and 28% sent for use as RDF.[280]

Summary

Creating one final value for the level of efficiency is done by comparing the absolute tonnages produced, as reported in the CPI study.[281] 464,361 total wet tonnes of paper sludge are produced per annum, by the paper mills surveyed. By contrast, 137,806 wet tonnes of rejects are produced per annum, by the paper mills surveyed. By dividing each of the reject and sludge tonnages by the total tonnage, the relative proportion of by-products from the UK PPI is approximated for paper sludge and rejects as 77% and 23%, respectively. The level of

[277] Cherian, C and Siddiqua, S, "Pulp and paper mill fly ash: a review", Sustainability, (2019). Available at: link
[278] ibid.
[279] ibid.
[280] CPI, "Process wastes from the paper industry", (2021). Available at: link
[281] ibid.

efficiency for paper sludge is assumed to be 100% and rejects as 3%. A weighted average of both these values is then calculated to give an approximate current level of efficiency of 78%.

The workshop sought to confirm whether this level of efficiency, 78% was representative. Three votes were received from stakeholders. One in the 60-70% range with medium confidence, one in the 71-80% range with medium confidence and one qualitatively stating that ‘only very small [levels of byproducts] are not going for recycling, reuse or RDF use’. As there was no consensus from voting at the workshop, the level of efficiency derived from literature sources was retained.

The data source which was used to estimate an overall level of efficiency was from a UK institution, published very recently. It was taken from surveys of the UK’s pulp and paper mills, which as primary data means there is high confidence in its validity. A red-amber evidence RAG rating was given to this level of efficiency. This evidence RAG rating was selected as whilst the literature source giving the value was of a high quality, workshop attendees did not corroborate it.

7.4.2 Maximum level of efficiency in 2035

No literature sources were found which discussed to what extent by-products may be reused or recycled to a higher level.

During interviews, one stakeholder estimated that 50% of by-products could be reused or recycled, however they did not elaborate on which by-products this statement was referring to so cannot be used when creating levels of efficiency. Another stakeholder noted that most mills have zero landfill targets so are continuously investigating routes to recover materials, indicating that there is scope for potential future improvement. Only one vote was cast for this measure during the workshop, with low confidence, in the 71-80% range.

In the absence of data, the maximum level of efficiency for this measure was reported as 71-80%. Given the lack of stakeholder and literature data, a red evidence RAG rating was given for this measure.

7.4.3 Business-as-usual in 2035

No quantitative data was found for the BAU scenario of this measure from the literature.

One stakeholder stated in an interview that if there is improved collection and sorting of recovered paper, minimal rejects will arrive at UK paper mills. However rejects form the minority of UK by-products which will limit the impact of this development on the ultimate level of efficiency for this measure. Efforts also need to be focused on the paper sludge by-product, which is the highest by-product produced in tonnage terms.

At the workshop, there were four votes cast. One was cast in the 60-70% range, two were cast in the 71-80% category (with medium confidence) and one did note vote on a level of efficiency but stated, with medium confidence, that there could be a higher level of efficiency achieved than the current level of efficiency.

71-80% was selected as the BAU level of efficiency for this measure. This was chosen as two votes were cast in the 71-80% range category and one comment stated that the BAU level of efficiency may be higher than the current level of efficiency which is 78%. Given the lack of data from the literature, a red evidence RAG rating will be given.

8.0 Measure 8 – Efficient incorporation of water in paper and pulp production

8.1 Paper resource efficiency measure

8.1.1 Description

The reduction in total use and consumption of water in the pulp and papermaking processes.

Unlike other sectors considered in this project, water is a key element of the pulp and papermaking process, with many pulp and paper mills located next to water sources to ensure the necessary volumes are accessible. In pulp making, water is used as a carrier for the fibres, with the pulp mix being as much as 99% water and 1% fibre at certain instances of the manufacturing process.[282] Given the connection between fibre and water, it's important to consider the efficient incorporation of water in paper and pulp production.

There are two important and very distinct terms that are pertinent to this measure:

- Water usage – the total volume of water that is withdrawn from a source; and
- Water consumption – the total volume of water that is withdrawn from a source **but not returned to the same or equivalent source.** For example, water can either be lost through evaporation during processing or due to inefficiencies in machinery such as leaks.[283]

The UK PPI currently uses 77 million cubic metres of water annually (as of 2015 data), sourced from surface water, municipal sources and groundwater. Of the water used, 10 million cubic metres is consumed within the UK annually.[284] It is important to note that the paper and pulping processes incorporate different volumes of water into their processes, with pulping being the more water intensive process.

Sources have stated that a projected reduction in water availability will be a significant challenge facing the PPI in future, though this is extremely location dependent[285] [286] Therefore, efforts to reduce both water consumption and use through resource efficiency are important. For example, reducing the water usage would mean a reduction in water processed through pumping equipment that requires power to operate. Pumping equipment that is powered by electricity derived from fossil-fuel sources such as coal or gas produces GHG emissions. Therefore, improving water usage efficiency conserves water resources and could also reduce GHG emissions. On the other hand, if more water can be returned to its source in the same

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282 Witherspoon, C, "The paper recycling process explained", (2023). Available at: link
283 ibid.
284 CPI, "The economic value of the UK's paper-based industries", (2022). Available at: link
285 CPI, "2022-23 Annual Review", (2022). Available at: link
286 Hermosilla, D, et al. "Towards sustainable water use in the paper industry", (2010). Available at: link

condition, then it may be reused which in turn may lead to an improvement in the PPI's overall water resource efficiency.

8.1.2 Measure indicator

The indicator selected to measure the efficient incorporation of water in pulp and paper production was the '**percentage reduction of water usage compared to a 2023 baseline**'.

No other indicators were considered for this measure as no others were found within historical and current literature. During interviews, stakeholders did not suggest any alternative indicators to the indicator above which was presented to them.

8.1.3 Examples in practice

Deposit control

The company IMERYS is tackling water losses in pulp production with its technologies. An issue faced during pulp production is the presence of 'stickies', for example, adhesives or inks in recycled pulp production or wood pitch in virgin pulp production. Stickies can deposit on machinery and cause poor dewatering of the pulp product. This leads to increased water use and consumption.[287] To avoid this, the company offers a talc and bentonite-based technology that reduces the risk of dewatering and enables a reduction of water usage and consumption.

Superheated steam

In current standard paper mills, heated cylinders evaporate water from the newly manufactured paper, and air removes water vapour from the atmosphere. In a new concept, the water vapour evaporating from the heated cylinder is heated and pressurised, creating a superheated steam that carries heat and moisture away from the paper. It is posited that this steam could then be used in the papermaking process in place of water, since new technologies being developed use steam and heat to press and form paper rather than traditional methods. In this way, rather than using 100 litres of water for one kilogram of fibres, it would be 100 litres of vapour, using just 0.1 litres of water.[288]

Recycled paper

Water use and consumption associated with virgin pulp production is much higher than with pulp from recycled paper. This is because the process of deinking and pulping recycled paper requires less water than growing and harvesting trees, and transporting and processing them for virgin fibres. A more detailed breakdown of the water usage and consumption for making recycled versus virgin fibres was not identified in the literature review.[289] Increasing the

[287] IMERYS, "Sustainable pulp bleaching and deposit control", (2023). Available at: link
[288] CEPI, "The Two Team Project", (2013). Available at: link
[289] Esmaeeli, A and Sarrafzadeh, M-H "Reducing freshwater consumption in pulp and paper industries using pinch analysis and mathematical optimization", *Jrnl. Of Water Process Engineering* 53. Available at: link

proportion of recycled pulp fibres used will result in a lower overall water use and consumption.[290]

8.2 Available sources

8.2.1 Literature review

The literature review identified seven sources that discussed the efficient incorporation of water in the pulp and papermaking process as a resource efficiency measure. These comprise:

- Two academic papers;[291] [292] and
- Five industry reports.[293] [294] [295] [296] [297]

The literature for this measure was of high quality with an average IAS of 5 (out of 5). Three of the sources were relevant to the UK PPI, with the remaining five being related to the EU or territorially agnostic. The majority of sources were recently published, in the last nine years, with only two being published ten years ago or before. There were five industrial reports, which were mostly scoped specifically at a UK PPI level. This is perhaps due to the apparent public perception that the UK PPI is a major consumer of water, and it uses a large volume of water but does not replace it.[298] The sources provided good indications of the levels of efficiency currently being achieved. One area of the literature that would benefit from further research is the technologies that will enable further improvements in water consumption levels within the UK.

8.2.2 Interviews

Two interviewees (a trade association and a manufacturer) spoke to this measure. They spoke to the levels of efficiency, with one originating from a research background and the other from industry. Engagement was very positive, with one stakeholder saying it was one of two major issues facing the paper and pulping industry currently, attesting to its importance. Both stakeholders commented that the UK PPI is a leader relative to other territorial pulp and paper industries, in terms of its water consumption being one of the lowest.

8.2.3 Workshop

This measure received strong engagement from one stakeholder, with one other stakeholder also engaging. The discussion that resulted, mostly from one stakeholder, provided a good

[290] Suhr et al. (2015) Best Available Techniques (BAT) Reference Document for the Production of Pulp, Paper and Board. Available at: link
[291] Hermosilla, D, et al. “Towards sustainable water use in the paper industry”, (2010). Available at: link
[292] Bajpai, P, “Recycling and Deinking of Recovered Paper: Preprint”, (2014). Available at: link
[293] CEPI, “The Two Team Project”, (2013). Available at: link
[294] CPI, “2022-23 Annual Review”, (2022). Available at: link
[295] TwoSides, “Print and Paper, Myths and Facts”, (2021). Available at: link
[296] CPI, “The Economic Value of the UK's paper-based industries”, (2022). Available at: link
[297] ASPAPEL, “Sustainability Report 2021: Decarbonised bi-circularity of the paper industry”, (2021). Available at: link
[298] Twosides, ”Print and Paper – Myths & Facts”, Twosides (2021). Available at: link

qualitative evidence base on where the UK PPI has been making efforts in previous years to reduce its water usage. There was also discussion on the necessary nuance between water usage and water consumption, with a stakeholder making it clear that the UK PPI has low water consumption. This implies that of the water the UK PPI uses, it returns a large portion of it in either the same or an improved condition, where improvements to the water quality can be made if the water quality moving into the system is low. The techniques used to improve the water quality, before it is returned to its source, can include filtration, flotation and biological treatment.[299]

The level of engagement in the workshop was as follows:

- One stakeholder, a manufacturer, was active on the mural board, voting for levels of efficiency, drivers and/or barriers.
- Two stakeholders actively contributed to verbal discussion.

8.3 Drivers & Barriers

The drivers and barriers influencing this measure were identified through a combination of the literature review, stakeholder interviews and sector workshop.

8.3.1 Drivers

Table 26 below shows the main drivers for Measure 8. The most significant drivers are shown in bold as voted for by a stakeholder in the workshop.

Table 26: Drivers for paper measure 8

Description	PESTLE	COM-B
Economic benefits	**Economic**	**Opportunity – physical**
Regulation	**Legal/political**	**Capability – psychological**
Water availability	Environmental	Opportunity – physical
Less stress on water recycling equipment	Technological	Opportunity – physical

Economic benefits

By incorporating novel technologies associated with water reduction, there is the potential to reduce the cost of paper or pulping production. One study stated that by using superheated stream drying (see 'Examples in practice' section above), a 30% total cost saving could be

299 Twosides, "Print and paper – myths and facts", Twosides (2021). Available at: link

achieved.[300] This savings come from the drastic reduction in water handling and treatment costs, reduced energy costs in heating water, and an eventual fall in the capital cost of machinery that would have much shorter forming and drying sections.

During the workshop, the stakeholders pointed out that whilst water is currently relatively low in cost, there is always potential for the price to spike. If a spike in the cost of water were to occur, there would be a proportionally greater driver for this measure to be realised.

Regulation

The UK Government's National Framework for Water Resources is driving more collaboration for paper and pulping mills to reduce their water usage and consumption.[301] This collaboration is in the form of water companies discussing their demand for and supply of water.[302] At present, water companies are required by the Environment Act to collaborate on a regional level and produce water management plans to address supply and demand issues. Collaboration takes place between the paper and pulping mills and any other entity which consumes water within a given region. If conversations between users of water lead to targets on water usage reduction, to ensure all collaborators have adequate access to water they require for their processes, water usage may reduce, driving this measure.

Water availability

With pressing concerns around water scarcity in parts of the UK, there is an incentive for the PPI to reduce its water use and consumption. Future scarcity creates a risk for the PPI, so reducing water consumption and use will reduce this risk, ensuring it can continue operations should water availability reduce.

Less stress on water recycling equipment

Water must be recovered when used within the paper production process, to reduce the level of water consumption. By reducing the water usage, there is lower stress level on the water recovery equipment, reducing its energy usage levels. The associated economic and CO_2e emissions benefits will be realised by the paper mill as a result. Further research is recommended to investigate the link between reduced water usage and energy saving benefits as none was identified in the literature review.

8.3.2 Barriers

The barriers for Measure 8 are shown in Table 10. The most significant barrier is shown in bold as voted for by a stakeholder in the workshop.

Table 27: Barriers for paper measure 8

Description	PESTLE	COM-B

[300] CEPI, "The Two Team Project", (2013). Available at: link
[301] CPI, "2022-23 Annual Review", (2022). Available at: link
[302] Ibid.

Cost of investment	**Economic**	**Opportunity – physical**
Technical limitations	Technological	Capability – physical
Lack of direct incentive to improve equipment efficiency where no water scarcity exists	Social	Opportunity – social

Cost of investment

With improvements likely to originate from step changes in machine efficiency, during filtration for example, the machinery will require initial investment from individual paper mills.[303] For instance, and if commercially proven, the superheated steam example outlined in the 'Examples in practice' section, will require new machinery which will require capital expenditure for the paper or pulp mills.

Stakeholders viewed this, and technological development as the most significant barrier to achieving this measure. According to a stakeholder, the age of the equipment used for water recovery/handling during the pulp and papermaking process is the most significant factor when considering the potential for water reuse/recovery. The cost of purchasing new equipment will be a significant investment and this may prevent pulp and paper mills from purchasing it. A stakeholder supported this barrier. During the interview, they noted that economic barriers were the most significant barriers commercial entities face in achieving further resource efficiency of water usage.

Technical limitations

Technical limitations in normal pulp and paper mills dictate that some level of water consumption is maintained. This is due to contaminants such as colloidal organic matter and salts accumulating in the processing loop and reducing the water quality.[304] Using this water would lower the machine's efficiency and impact the whole process's efficiency.

Lack of direct incentive to improve equipment efficiency where no water scarcity exists

Water scarcity is not experienced in every region where paper mills are located. With limited regulation in place currently, there is limited incentive for UK paper mills to reduce their usage levels.

[303] TwoSides, "Print and Paper, Myths and Facts", (2021). Available at: link
[304] Hermosilla, D, et al. "Towards sustainable water use in the paper industry", (2010). Available at: link

8.4 Levels of efficiency

Table 28: Levels of efficiency for paper measure 8

Indicator: percentage reduction of water usage compared to a 2023 baseline.			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value	0%	Not available	Not available
Evidence RAG	Not applicable	Not applicable	Not applicable

8.4.1 Current level of efficiency

As the indicator for this measure is an index, relative to current levels, the estimated level of efficiency is set at 0%, serving as a baseline for subsequent scenarios. The evidence RAG rating for this efficiency level is therefore not applicable.

8.4.2 Maximum level of efficiency in 2035

There are several reports providing quantitative levels of efficiency:

- The 2022-23 CPI annual review states that of the water used in the UK PPI, 10% is consumed (as per Section 8.1.1, water consumption is the percentage of water that is used but not returned to the same or an equivalent source).[305] The source also reports that water usage has been reduced by 80% since 1991, that is, over a period of 32 years.
- One academic textbook states that using waste paper to produce primary products, will save 30,000L of water, per tonne of recycled paper used.[306] The source IAS is 4 as it does not disclose how these savings can be achieved, despite being published in a peer-reviewed journal. Furthermore, there was no indication of what the absolute usage values were, so a level of efficiency was not calculated using data from this source. However, it does provide a qualitative confirmation that use of recycled feedstock uses less water during pulping compared to virgin sources.
- A novel technology reported in a report by CEPI states that by introducing dry fibres into a region with agitated steam, 1/1000th of the water used today could be used. This would imply a 99.9% reduction in water usage.[307] However, rolling out this technology would require significant testing and it was also unclear whether this technology could apply to all types of pulp. As such, it was not considered to be applicable to the national, industry wide scope of this study.

[305] CPI, "2022-23 Annual Review", (2022). Available at: link
[306] Bajpai, P, "Recycling and Deinking of Recovered Paper: Preprint", (2014). Available at: link
[307] CEPI, "The Two Team Project", (2013). Available at: link

- A stakeholder at the workshop also discussed the Best Available Technologies (BAT) report. This outlines the potential ranges of water use at pulping mills, depending on the of technologies used, with each having a varying effectiveness.[308] The possible range is 5-20 cubic metres per air dried tonne of pulp produced but is hugely dependent on the pulp type and the product being made. There was no quantitative data gathered on what technologies are used by the different UK pulp and paper mills and in what proportions.

There was no literature found which provided an accurate figure for what the maximum reduction of water usage could be by 2035. One value was provided, in the UK CPI Annual Report, with changes from 1991 to 2023, but gave no future trend.[309] Another lab-scale technology stated that a very large reduction of water usage in pulping could be achieved, but without providing comment on whether this figure would be true if the technology was commercially used.[310] The BAT report stated that a reduction of water usage could be achieved if the worst performing equipment was changed for the best performing equipment. Only one vote was received for the maximum level of efficiency section in the workshop, which was in the ‘Don’t know’ category.

As only a ‘Don’t know’ vote was received from the workshop and the literature evidence is inconclusive, it has not been possible to report a maximum level of efficiency for this measure.

8.4.3 Business-as-usual in 2035

No quantitative literature values representing a BAU scenario were found in the literature.

One vote, with medium confidence, was received from a stakeholder, which was given as 10-15%. The stakeholder also remarked in this vote that a reduction in water usage would only be possible with a complete re-design of the water production facility. It can be reasonably expected that undertaking a complete re-design would be costly in terms of machinery investment requirements and the staff time required to implement these changes.

Due to the low levels of evidence, it has not been possible to report a BAU level of efficiency for this measure.

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[308] Serge, R, *et al.* “Best Available Techniques (BAT) reference document for the production of pulp, paper and board”, Institute for Prospective Technological Studies (2015). Available at: link
[309] CPI, “2022-23 Annual Review”, (2022). Available at: link
[310] CEPI, “The Two Team Project”, (2013). Available at: link

9.0 Interdependencies

This report has discussed each of the measures identified for the Paper sector and presented estimates for the maximum and BAU level of efficiency they could achieve independently, that is, not considering any interdependencies or interactions between measures.

However, in practice these measures are likely to occur in tandem, and the levels of efficiency that are reached in each will depend on progress against other measures. The precise nature of these interdependencies should be considered when using any of the level of efficiency estimates from this report in further research or modelling exercises that attempt to produce an estimate of the cumulative impact of these measures over time.

A summary of the key interactions/interdependencies between the measures in this report with other measures in the sector, and with measures in other sectors is presented below.

Note, the estimates for the current level of efficiency will, by their nature, reflect the interactions and interdependencies between measures as they currently occur.

9.1 Interdependencies within the sector

Measures 4 & 5

- Measure 4 – Lightweighting of paper process
- Measure 5 – Use of recovered fibre in the pulping process

With a lower mass of material being used, there will likely be a lower mass of waste arising at the end of life. As was shown in Measure 5, where there is a lower mass of waste available for collection, the mass of material available to use for recycled pulp also reduces. The size of this change would depend on the % reduction in mass of a product due to lightweighting as well as the number of products the change would apply to.

There is also a consideration on the reduction in a products mass if more recovered fibre is used in the pulp for a product. As was identified in Measure 5, if recovered fibre is using for a product, due to the fibres degrading, a greater mass of recovered fibres should be used to meet the same functional requirement.

Measures 6 & 7

- Measure 6 – Improvement of the production yield ratio
- Measure 7 – Utilisation of byproducts of the pulp and papermaking processes

If the production yield is improved significantly, there will likely be a lower volume of byproducts produced during the process as the inputs are converted into the valuable output product. There will, as a result, be a lower volume of byproduct available for use via the methods outlined in Measure 7.

Measures 1 & 5

- Measure 1 – Collection of waste paper and board for recycling
- Measure 5 – Use of recovered fibre in the pulping process

Whilst technical limitations are the key limitation to further use of recovered paper as feedstocks, the mass of material available is still a limitation in further use. If there is a significant change in the collection of waste paper and board, there could be a change to the use of recovered fibre within the UK PPI. This would be due to the link, as shown in Measure 5, between the collection rate of paper and board and the recycled input rate used in PPI products. The work by Van Ewijk showed, based on modelled data, that if the collection rate decreases, so would the recycled input rate and the converse would be true also. This is the only evidence found which suggests the direction of any potential shift. The magnitude of any potential shift cannot be predicted.

Measures 2 & 3

- Measure 6 – Improvement of the production yield ratio
- Measure 7 – Utilisation of byproducts of the pulp and papermaking processes

There is a potential interaction between the production yield and the level to which byproducts can be reused. For instance, if the production yield is improved there may be a change to the mass of paper sludge that is produced during pulping. As such, the magnitude of byproduct that is available to be reused may reduce. If it were to fall below a critical level, there could be insufficient material available to continue using it in reuse applications, such as land spreading. There was no evidence found to discuss the likelihood of this occurring or the scale at which it would happen.

Measures 5 & 8

- Measure 5 – Use of recovered fibre in the pulping process
- Measure 8 – Efficient incorporation of water in paper and pulp production

The level of water that is used during production of PPI products, when recovered paper is used as a feedstock, varies to the levels used if virgin wood is used for feedstock.

Measure 1 & 7

- Measure 1 - Collection of waste paper and board for recycling
- Measure 7 - Utilisation of byproducts of the pulp and papermaking processes

A stakeholder raised the interaction between these measures. They stated, at the workshop, that if there is a better collection system implemented which gives lower contamination rates, the level of rejects that will be generated will dramatically reduce. As such, there will be a lower opportunity to recycled or reuse rejects.

9.2 Interdependencies with other sectors

Plastic, Glass and Paper Sector

As was discussed in Measure 2, there are crossovers between the plastic, glass and paper sectors when material substitutions are made. Material substitutions made in the paper industry will lead to a reduction in material inputs to the paper sector and an increase of other sectors, such as the plastics or glass sector. Substitution of plastic products for fibre based ones will also lead to an increase in paper volumes and a reduction in the use of plastics. Conclusive data was not found confirming the net change in material flows between each sector because of potential material substitutions. However, what was confirmed is that there are net material flow trades between each sector occurring. The potential GHG emissions impact of such substitutions will depend on many factors including the nature of the product, the location of production when using both materials and the lifespans of each product, amongst other products.

Construction and Paper Sector

In Measure 7, cross-over between the construction and paper sectors was identified. During pulping, byproducts are generated which were shown to have the potential to be used as substitutes for raw material inputs in the manufacture of construction sector products. As some of the byproducts listed were shown to be potentially of use in the manufacture of cement, there is also a link between the paper and cement sectors.

Glossary and abbreviations

BAT	Best available technology
BAU	Business-as-usual
CPI	Confederation of Paper Industries
CTO	Crude tall oil
CSR	Corporate social responsibility
DES	Deep Eutectic Solvents
DRS	Deposit Return Scheme
EOL	End-of-Life
EPR	Extended producer responsibility
GHG	Greenhouse gas
GWP	Global warming potential
HGV	Heavy Goods Vehicles
HWRC	Household waste recycling centres
IAS	Indicative applicability score
IEA	International Energy Agency
LCA	Lifecycle assessment
LPB	Liquid packaging board
MRF	Materials recovery facility
RE	Resource efficiency
PFAS	Per- and Polyfluoroalkyl Substances
PIL	Patient Information Leaflet
POM	Placed on the Market
PPFA	Paper and Pulp Mill Fly Ash
PPI	Pulp and paper industry

PPWD	Packaging and Packaging Waste Directive
PPWR	Packaging and Packaging Waste Regulation
RAG	Red-Amber-Green
RDF	Refuse Derived Fuel
RIR	Recycled input rate
SBTi	Science Based Target Initiative

Appendix A: IAS Scoring Parameters

Table 29: Methodology for the calculation of the IAS

Number of ‘high’ criteria	Number of ‘low’ criteria	IAS
Indifferent	3 or more	1
<= 1	2	2
>= 2	2	3
<= 2	1	3
>= 3	1	4
<= 1	None	3
2	None	4
>= 3	None	5

Table 30: IAS Scoring Parameters

Criteria	High	Medium	Low
Geography	Specific to UK	Non-UK but applicable to the UK	Non-UK and not applicable to the UK
Date of publication	< 10 years	10 to 20 years	> 20 years
Sector applicability	Sector and measure-specific, discusses RE and circularity	Sector and measure-specific, focus on decarbonisation	Cross-sector
Methodology	Research methodology well defined and deemed appropriate	Research methodology well defined but not deemed appropriate / Minor description of research methodology	No research methodology
Peer Review	Explicitly mentioned peer review	Not explicitly mentioned, but assumed to have been peer reviewed	Unknown

Appendix B: Search strings

- Papermaking AND resource efficiency
- Paper* AND resource efficiency
- Paper* AND material efficiency
- Paper* AND circular manufacture OR design
- Paper* AND recycle*
- Paper* AND on-site waste
- Paper* AND byproduct recovery
- Paper* AND reduce*
- Paper* AND waste water usage
- Paper* AND material substitution
- Paper* AND low carbon
- Paper packaging AND reus*
- Paper packaging AND recycle*
- Paper packaging AND lifetime extension
- Paper packaging AND lightweighting
- Print paper AND reus*
- Print paper AND recycle*
- Print paper AND lifetime extension
- Sanitary and household AND reus*
- Sanitary and household AND recycle*
- Newsprint AND reus*
- Newsprint AND recycle*
- Pulping AND resource efficiency
- Pulp* AND resource efficiency
- Pulp* AND material efficiency
- Pulp* AND circular manufacture OR design
- Pulp* AND recycle*
- Pulp* AND production yields
- Pulp* AND reus*
- Pulp* AND material substitution

- Pulp* AND recycled pulp
- Pulp* AND recovered fibre
- Pulp* AND chemical reduction
- Barking AND material efficiency
- Barking AND process efficiency
- Debarking AND material efficiency
- Debarking AND process efficiency
- Paper printing AND digital AND substitution
- Paper* AND digital OR substitution
- Paper* AND lightweight*
- Mechanical pulping* AND Production Yields
- Mechanical pulping* AND process raw material usage
- Mechanical pulping AND coproducts AND reuse
- Mechanical pulping AND coproducts AND recycling
- Chemical pulping* AND process raw material usage
- Chemical pulping* AND Production Yields
- Chemical pulping AND coproducts AND reuse
- Chemical pulping* AND coproducts AND recycling
- Chemical usage* AND pulping AND efficiency
- Chemical usage* AND pulping AND reduction
- Process efficiency *AND pressing AND papermaking
- Process efficiency *AND screening AND paper making
- Material substitution* AND pulping AND chemicals
- Material substitution* AND pulping AND wood
- paper sector AND lightweight* AND resource efficiency
- Lifetime extension of cardboard products
- lifetime extension cardboard design

Appendix C: Literature sources

Table 31: List of literature sources for the paper sector

Title	URL	Author	Year	IAS
On the Conversion of Paper Waste and Rejects into High-Value Materials and Energy	link	Abushammala et al.	2023	5
Getting Value from Pulp and Paper Industry Wastes: On the Way to Sustainability and Circular Economy	link	Amandio, M.S.T.	2022	5
Why does recycled paper cost more than brand new paper?	link	Andberg print	2020	3
Eural	link	Arjowiggins	2023	3
Why use recycled papers?	link	Arjowiggins	2023	5
Sustainability Report 2021: Decarbonised bicircularity of the paper industry	link	ASPAPEL	2021	5
Recycled paper for printing: is it the right choice for your business	link	B&B Press	2023	3
The British paper industry of today	link	Back, S.	2021	4
Recycling and Deinking of Recovered Paper: Preprint	link	Bajpai, P.	2014	5
Biermann's Handbook of Pulp and Paper	link	Bajpai, P.	2018	5
Apple to drop plastic packaging by end of next year, no leather cases for iPhone 15	link	Beals, R.K.	2023	3
Membrane Operations in the Pulp and Paper Industry for the Recovery of Constituents: A State of the Art Review	link	Benavidez, D. et al	2023	5
Comparison of Morrisons' Reusable Paper Bags and Plastic Bags for Life	link	Blazejewski, T. et al.	2019	5
Increasing pulp yield in kraft cooking of softwoods by high initial effective alkali concentration (HIEAC) during impregnation leading to decreasing secondary peeling of cellulose	link	Brännvall, E.	2018	5

Milk & More to increase reuse of bottles by 15% as glass prices soar	link	Butler, S.	2022	4
Resource efficiency in the pulp and paper industry: Making more from our natural resources	link	CEPI	2014	4
The two team project	link	CEPI	2014	5
Paper-based Packaging Recyclability Guidelines	link	CEPI	2019	4
Future pulp paper and recycling mill 2030	link	CEPI	2021	4
Key statistics 2022: European pulp & paper industry	link	CEPI	2022	5
Age of fibre - the pulp and paper industry's most innovative product	link	CEPI	2015	5
Pulp and paper mill fly ash: a review	link	Cherian, C. and Siddiqua, S.	2019	4
Sustainability of reusable packaging–Current situation and trends	link	Coelho, P. et al.	2020	5
Sustainability of reusable packaging – Current situation and trends	link	Coelho, P. et al.	2020	5
Resource efficiency in the steel and paper sectors	link	Confederation of Indian industry	2019	3
Dematerialization Through Electronic Media?	link	Coroama, Moberg, and Hilty	2014	5
Code of good practice for landspreading paper mill sludges	link	CPI	2015	4
Paper: the sustainable, renewable and recyclable choice – Annual review 2018-19	link	CPI	2018	4
Recycled content in corrugated packaging	link	CPI	2020	4
The UK Paper Industry - Innovation and the Bioeconomy	link	CPI	2020	5
Recovery and Recycling of Paper and Board - Fact Sheet	link	CPI	2020	5

Process Wastes from the Paper Industry	link	CPI	2021	5
2021-22 Annual Review	link	CPI	2022	5
2022-23 Annual Review	link	CPI	2022	5
The Economic Value of the UK's paper-based industries	link	CPI	2022	5
Recycling of coffee cups	link	CPI	2020	5
Design for recyclability guidelines	link	CPI	2022	5
Papercycle	link	CPI	2023	5
Evaluating Chemical-, Mechanical-, and Bio-Pulping Processes and Their Sustainability Characterization Using Life-Cycle Assessment	link	Das, T.K. and Houtman, C.	2004	4
Waste Paper as a Valuable Resource: An Overview of Recent Trends in the Polymeric Composites Field	link	De Oliveria, D. et al.	2023	5
Resources and Waste Strategy Monitoring Progress	link	Defra	2022	5
Consultation outcome – Government response	link	Defra	2023	5
Extended producer responsibility for packaging: who is affected and what to do	link	Defra and Environment Agency	2022	5
Decarbonizing the pulp and paper industry: A critical and systematic review of sociotechnical developments and policy options	link	Del Rio et al.	2022	5
Functional barrier paper packaging that facilitates recycling	link	Delfort Group	2023	4
Strategies for Improving the Efficiency of Paper Manufacturing	link	DESKERA	No date	3
Rethinking packaging	link	DHL	No date	3
Energy Recovery from Waste Paper and Deinking Sludge to Support the Demand of the Paper Industry: A Numerical Analysis	link	Di Fraia, S. et al	2022	5
Lightweighting in Packaging: The Pros and Cons	link	Dillon, M.	2023	3

Sustainability in the printing industry starts with raw materials	link	DRUPA	2023	5
Circularity	link	DS Smith	2023	4
100% recycled white tissue paper	link	Eco-Craft	2023	3
100% Recycled cardboard boxes	link	Ecopackables	2023	3
Is recycling creating a toxic chemical problem?	link	ENDS report	2021	5
Paper to Protect the Planet	link	Environmental Paper Network	2018	4
A global comprehensive review of literature related to paper recycling: a pressing need for a uniform system of terms and definitions	link	Ervasti, I. et al.	2016	5
Substitution effects of wood-based products in climate change mitigation	link	European Forestry Institute	2018	5
Proposal for a regulation of the European Parliament and of the Council on packaging and packaging waste	link	European Commission	2022	5
Packaging waste - EU rules on packaging and packaging waste, including design and waste management	link	European Commission	2022	3
Circular by design - Products in the circular economy	link	European Environment Agency	2017	4
European Declaration on Paper Recycling - Monitoring Report 2020	link	European Paper Recycling Council	2020	5
European declaration on paper recycling	link	European Paper Recycling Council	2021	4
Revision of the packaging and packaging waste directive	link	European Parliament	2023	5
Green Paper: Packaging and Sustainability: An open dialogue between stakeholders	link	EuropPEN - The European	2011	4

		Organisation for packaging and the environment		
Banana midrib as substitute for pulp production	link	Fadarina et al.	2019	4
Mechanical design and performance testing of corrugated paperboard packaging for the postharvest handling of horticultural produce	link	Fadiji, T. et al.	2018	5
Agricultural Residues (Wastes) for Manufacture of Paper, Board, and Miscellaneous Products: Background Overview and Future Prospects	link	Fahmy, Y. et al.	2017	5
Recycling vs Reuse for Packaging: Bringing the science to the packaging debate	link	FEFCO	2022	5
Forever chemicals in the food isle: PFAS content of UK supermarket and takeaway food packaging	link	Fidra	2020	5
Studies assess PFAS, OPEs, and plasticizers in paper & board	link	Food Packaging Forum	2023	5
Menstrual Products: A comparable Life Cycle Assessment	link	Fourcassier et al.	2022	5
Reusable plastic crates vs. single-use cardboard boxes - two packaging systems in competition	link	Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT	2022	5
Less is more	link	Friends of the Earth Europe	2013	3
The Frugal Bottle	link	Frugalpac	2020	4
Product sustainability: back to the drawing board	link	Fuchs, S. et al.	2022	3
Pulp and Paper Wastewater Treatment - Innovative Treatment for Effluent Water Management	link	Genesis Water Tech	2021	2

Industrial decarbonisation of the pulp and paper sector: A UK Perspective	link	Griffin, P.W. et al.	2018	5
Alternatives to wood pulp for paper making	link	HABER	2023	5
Pulp and paper mill wastes: utilizations and prospects for high value-added biomaterials	link	Haile et al. (Bioresources and Bioprocessing)	2021	5
Alternative technologies for biofuels production in kraft pulp mills - potential and prospects	link	Hamaguchi, M., Cardoso, M. and Vakkilainen, E.	2012	5
Production of high yield bleached hardwood kraft pulp: breaking the kraft pulp yield barrier	link	Hart, P.W.	2011	5
Catalytic upcycling paper sludge for the recovery of minerals and production of renewable high-grade biofuels and bio-based chemicals	link	He, S. et al	2021	5
Considerations for cartonboard lightweighting	link	Heinke, I.	2019	3
Towards sustainable water use in the paper industry	link	Hermosilla, D. et al.	2010	5
Consumers' Sustainability-Related Perception of and Willingness-to-Pay for Food Packaging Alternatives.	link	Herrmann, Rhein, and Sträter	2022	5
What Happens to Cellulosic Fibers during Papermaking and Recycling?	link	Hubbe, Venditti, and Rojas	2007	5
ICFPA Sustainability Progress Report	link	ICFPA	2023	4
Sustainable pulp bleaching and deposit control	link	Imerys	No date	3
Fruit and nuts create a natural range of coloured papers	link	impress	No date	4
The facts about paper recovery & recycling	link	impress	No date	4
Best Available Techniques (BAT) reference document for the production of pulp, paper and board	link	Institute for prospective	2015	5

		technological studies		
Paper industry overview	link	International Energy Agency	No date	3
Paper waste byproduct creates carbon fibres	link	Jacoboson, M.	2020	3
Mailing Box 50	link	Jakodan	2023	3
Coffee cup recycling - CUPCYCLING - turning coffee cups into beautiful luxury papers	link	James Cropper PLC	2023	4
Discrete Event Simulation Approach for Energy Efficient Resource Management in Paper & Pulp Industry	link	Keshari. A et al.	2018	5
Why paper products made with recycled fibres are the most sustainable option	link	Kimberly-Clark	2022	5
Paperwork: Comparing Recycled to Virgin Paper	link	Kinsella, S.	2012	3
Assessment of emerging energy-efficiency technologies for the pulp and paper industry: A technical review	link	Kong, L., Hasanbeigi, A. and Price, L.	2016	4
Bio-based materials for barrier coatings on paper packaging	link	Kunam, P.K. et al.	2022	5
Paper and biomass for energy?: The impact of paper recycling on energy and CO2 emissions	link	Laurijssen, J.	2010	5
How to Calculate the Weight of Glass	link	Leadbitter glass	2023	3
Why Use Cloth Nappies?	link	Little Lamb	No date	3
The top ten factors in kraft pulp yield	link	MacLeod, M.	2007	5
True packaging sustainability: Understanding the performance trade-offs	link	McKinsey & Company	2021	4
Perspectives on paper and forest products in 2022: How can CEOs navigate today's era of transformational change?	link	McKinsey & Company	2022	3
The potential impact of reusable packaging	link	McKinsey & Company	2023	3

Metsä Board minimises environmental impact of packaging with simulation platform	link	Metsä	2021	5
Mobile Facts	link	MobileUK	2023	4
Proposal of Sustainability Indicators for the Waste Management from the Paper Industry within the Circular Economy Model	link	Molina-Sanchez et al.	2018	5
Advantage StretchWrap Life Cycle Assessment	link	Mondi	2021	4
Higher yield and less waste from pulp production	link	Nedmag	2023	3
Optima Co-Develops First Paper Packaging for Feminine Hygiene Products", (2021). Available at: link	link	NonWovens Industry	2021	5
Exploring Consumers' Understanding and Perception of Sustainable Food Packaging in the UK.	link	Norton et al.	2022	5
Advances in pulp and paper technology and the implication for the paper industry in Nigeria	link	Ogunwusi, A.A. and Ibrahim, A.D.	2014	5
The myth of 100% recycled content	link	Packaging corporation of America	2021	3
DS Smith and Krones aim to replace plastic shrink wrap with fibre-based ECO carrier	link	Packaging Europe	2022	3
International paper adds new basis weights to lightweight board	link	Packaging News	2015	5
PaperChain (consotrium) - website	link	Paper Chain	2023	4
Digital solutions from the Papermaking 4.0 portfolio lead to optimized energy efficiency with significant cost savings	link	PaperFirst	2022	1
Virgin vs recycled paper	link	Papernet	2023	3
Why are my paper prices so volatile?	link	PaperplusUK	2019	4
It's paper, but not as we know it!	link	PG Paper Company Ltd	2018	5
Supercalendered and lightweight coated paper	link	PG Paper Company Ltd	2023	4

Waste paper for recycling: overview and identification of potentially critical substances	link	Pivnenko, K. et al.	2015	5
Packaging Preserves Our Resources	link	Pro Carton	No date	3
Paper making in a low carbon economy	link	Rogers, J.G.	2018	5
The pulp and paper overview paper	link	Roth, S. et al.	2016	5
Process intensification in mechanical pulping	link	Sandberg, C.	2017	5
Energy efficiency in mechanical pulping - definitions and considerations	link	Sandberg, C., Ferritsius, O. and Ferritsius, R.	2021	5
Recycled paper vs virgin paper; reduce the carbon footprint of your business	link	Savi, A.	2010	3
Potential use of wood ash in South African forestry: A review	link	Scheepers, G.P. and du Toil, B.	2016	5
ScotRail App	link	ScotRail	2023	5
Best Available Techniques (BAT) Reference Document for the Production of Pulp, Paper and Board	link	Serge, R. et al.	2010	5
Wastes from pulp and paper mills - a review of generation and recycling alternatives	link	Simao et al.	2018	5
Waste containing clinkers: valorisation of alternative mineral sources from pulp and paper mill	link	Simão, L. et al,	2017	5
Show me the goods: Assessing the effectiveness of transparent packaging vs. product imagery on product evaluation	link	Simmonds, G. et al.	2018	5
Material economics: A net-zero transition for EU industry	link	SITRA, University of Cambridge	2020	5
Renewable & alternative energy sources for strategic energy management in recycled paper & pulp industry	link	Sonsale, A. et al.	2021	4
Heavy Oil Recovery and Upgrading	link	Speight, J.G.	2019	5

Novel biobased products from side streams of paper and board production	link	Spyros Bousios	2016	5
Barrier coatings	link	Stora Enso	2023	4
Top 10 pulp and paper trends in 2023	link	Stratus-Insights	2023	5
Understanding Cargo Shipping Costs And Rates In 2023	link	Sugam Group	2023	3
Paper and paperboard containers	link	Sumimoto, M.	1990	4
Allocation in the Life Cycle Assessment (LCA) of Flax Fibres for the Reinforcement of Composites	link	Summerscales, J. and Dissanayake, N.P.	2017	5
Packaging & Resource Efficiency	link	SUNTROY	2023	4
Packaging advice: Plastic vs Paper Packaging: The Pros and Cons	link	Swiftpak	2023	3
Life cycle greenhouse gas emissions of e-books vs. paper books: A Japanese case study	link	Tahar et al.	2018	5
Dimensional Stability Issues of Lightweight and New Paper Grades: Causes and Remedies, 18PaperCon	link	TAPPI	2023	4
Life Cycle Assessment of Disposable and Reusable Nappies in the UK	link	The Environment Agency	2023	5
Is Paper Packaging Really More Sustainable than Plastic?	link	The Grocer	2023	5
Is paper really better for the Earth than plastic?	link	The Grocer	2023	5
Morrisons to remove plastic 'bags for life' and trial paper alternative	link	The Guardian	2019	5
Cardboard versus plastic	link	Tri-pack	2020	3
Print and paper: Myths and facts	link	Two Sides	2021	4
Paper Packaging: The Natural Choice	link	Two Sides	2021	4
Paper production and sustainable forests	link	Two Sides	2021	4

Paper recovery and recycling	link	Two Sides	2021	4
Virgin fibres from sustainably managed forests are needed to maintain the paper cycle	link	Two Sides	2023	4
Packaging Preferences Unpacked – Consumers Prefer Paper-Based Packaging	link	Two Sides	2023	5
MPs call for ban on all plastic waste exports	link	UK Parliament Committees	2022	5
Resource efficiency	link	UPM Paper	2030	3
Circular economy	link	UPM Paper	No date	2
Energy efficiency and lightweighting - main challenges for containerboard makers	link	Valmet forward	2015	4
Energy efficiency and lightweighting - main challenges for containerboard makers	link	Valmet Forward	2015	4
Global Life Cycle Paper Flows, Recycling Metrics and Material Efficiency	link	Van Ewijk, S., Stegemann, J.A. and Ekins, P.	2017	5
Forming architectured paper by printing a starch patterned grid: a new low-cost approach for lightweighting packaging	link	Viguie, J.	2021	5
Facts & Trends: Fresh & Recycled Fiber Complementarity	link	WBCSD, NCASI	2015	5
The complete guide to recycled paper	link	Wigston paper	2022	3
The paper recycling process explained	link	Witherspoon, C.	2023	3
Industrial decarbonisation & energy efficiency roadmaps to 2050	link	WSP	2015	5
Reusable versus single-use packaging: a review of environmental impacts	link	Zero Waste Europe	2020	5

Appendix D: List of discarded resource efficiency measures in the paper sector

Table 32: List of discarded resource efficiency measures for the paper sector

Theme	Sub-theme	Measure name	Measure indicator	Reason for De-prioritisation
Manufacture	Process efficiency	Reduction in process energy usage through technological efficiency improvements	% reduction in energy usage	Energy efficiency is out of scope for this study
Manufacture	Production efficiencies	Reducing chemical usage in the kraft pulping process	% reduction in chemical usage during kraft pulping process	Scope of the measure was too restricted. UK has limited chemical pulping undertaken so limited evidence from literature and stakeholders.
Sale & Use	Lifetime extension / Reuse	Reducing raw material demand by lifetime extension of products	% reduction in fibrous raw material usage in manufacture	No evidence of this measure being carried out

Appendix E: UK paper mills

The paper mills which produce these products within the UK are outlined in Table 33.

Table 33: UK paper mills (2023)[311]

Mill Name	Location	Primary Product Type	Production Capacity (tonnes)	Fibre Types
UPM Caledonian	Irvine, Ayrshire	Graphic Paper	260,000	Wood pulp
Palm Newsprint	Kings Lynn, Norfolk	Graphic Paper	400,000	Recycled
Higher Kings Mill	Cullompton, Devon	Graphic Paper	30,000	Recycled
St Cuthberts Paper Mill	Wells, Somerset	Graphic Paper	1,000	Wood pulp
DS Smith Kemsley	Kemsley, Kent	Packaging	800,000	Recycled
SAICA Manchester	Trafford, Greater Manchester	Packaging	450,000	Recycled
Smurfit Kappa Townsend Hook	Townsend Hook, Kent	Packaging	260,000	Recycled
Smurfit Kappa SSK Birmingham	Birmingham, West Midlands	Packaging	230,000	Recycled
Sonoco Stainland	Halifax West Yorkshire	Packaging	70,000	Recycled
Romiley Board Mill	Stockport, Greater Manchester	Packaging	50,000	Recycled
Holmen Paperboard	Workington, Cumbria	Packaging	220,000	Wood pulp
Pelta Medical Papers	Beetham, Cumbria	Packaging	45,000	Wood pulp

311 Adapted from CPI, "*Grid Connection Assessment, Electrification of UK Paper Mills*", (2022). Available at: link

James Cropper	Kendal, Cumbria	Packaging	50,000	Wood pulp/ Recycled
Weidmann Whiteley	Otley, West Yorkshire	Specialty	10,000	Wood pulp/ Recycled
Hollingsworth & Vose	Cheltenham, Gloucester	Specialty	12,000	Glass
Carlson Filtration	Barnoldswick, Lancs	Specialty	2,000	Wood pulp
Glatfelter	Lydney, Gloucestershire	Specialty	17,000	Abaca/ Wood pulp
AhlstromMunksjo Chirnside	Chirnside, Scottish Borders	Specialty	15,000	Abaca/ Wood pulp
Devon Valley	Cullompton, Devon	Specialty	7,000	Abaca/ Wood pulp
Fourstones Paper Mill	Hexham, Northumberland	Specialty	6,500	Recycled
Huhtamaki	Lurgan, Northern Ireland	Specialty	20,000	Recycled
Vernacare	Bolton, Greater Manchester	Specialty	9,000	Recycled
AhlstromMunksjo Radcliffe	Bury, Greater Manchester	Specialty	15,000	Abaca
Portals Bathford	Bathford, Somerset	Specialty	4,000	Wood pulp
Kimberly Clark Flint	Flint, North Wales	Hygiene	30,000	Recycled
Essity Stubbins	Bury, Greater Manchester	Hygiene	55,000	Recycled
Sapphire Paper Mill	Glenrothes, Fife	Hygiene	40,000	Recycled
Northwood Tissue (Chesterfield)	Chesterfield, Derbyshire	Hygiene	30,000	Recycled
Northwood Tissue (Disley)	Disley, Stockport	Hygiene	30,000	Recycled

Northwood Tissue (Lancaster)	Lancaster, Lancashire	Hygiene	11,000	Recycled
Essity Prudhoe	Prudhoe, Northumberland	Hygiene	100,000	Recycled/ Wood pulp
Kimberly Clark Barrow	Barrow, Cumbria	Hygiene	120,000	Wood pulp
Kimberly Clark Northfleet	Northfleet, Kent	Hygiene	80,000	Wood pulp
Essity Oakenholt	Oakenholt, North Wales	Hygiene	70,000	Wood pulp
Essity Manchester	Trafford Park, Greater Manchester	Hygiene	50,000	Wood pulp
Essity Tawd	Skelmersdale, W Lancs	Hygiene	28,000	Wood pulp
Sofidel Leicester	Leicester, East Midlands	Hygiene	70,000	Wood pulp
Sofidel Baglan	Baglan, South Wales	Hygiene	60,000	Wood pulp
Sofidel Lancaster	Lancaster, Lancashire	Hygiene	30,000	Wood pulp
WEPA Bridgend Paper Mill	Bridgend, Mid Glamorgan	Hygiene	110,000	Wood pulp

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