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Analysis of Drivers Impacting Recycling Quality

Plant level data collection analysis on sorting and recycling of household packaging waste

Analyse des facteurs influençant la qualité de recyclage

Analyse des données recueillies auprès des centres de traitement sur le tri et le recyclage des déchets d'emballage ménagers

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Abstract

This study, based on a survey of twenty-five sorting plants for household packaging across Europe, examines the drivers and parameters that influence the quality, quantity and fate of household packaging recycling. The study examines the different drivers present for plant operators sorting and processing different material streams, the characteristics distinguishing higher quality recycling chains from lower quality recycling chains, and factors that tip the balance in favour of making quality improvements where there is only marginal financial benefit. It summarises findings in relation to the impact that policy and system design can have on the quality of recycling.

The factors found to be key to determining current quality of recycling were producer demand for secondary raw materials, the extent to which materials degrade in collection and sorting, and the scale and presence of products sharing relevant characteristics within collected waste streams. Where making improvements on quality had only marginal financial benefit, it was found that producer responsibility organisations (PROs) or other relevant authorities are likely to be able to improve qualities through influencing the scale of sorting operations, specifying sorting output fractions, as well as influencing producer behaviour in incentivising recyclability of their products and uptake of post-consumer recycled content.

Résumé

Cette étude, basée sur une enquête auprès de vingt-cinq usines de tri pour emballages ménagers à travers l’Europe, examine les facteurs et les paramètres qui influencent la qualité, la quantité et la destination lors du recyclage des emballages ménagers. L’étude examine les différents facteurs auxquels sont confrontés les exploitants d’usine qui doivent mener à bien le tri et le traitement de différents flux de matériaux, les caractéristiques distinguant les chaînes de recyclage de plus haute qualité des chaînes de recyclage de moindre qualité et les éléments qui font pencher la balance en faveur d'améliorations de qualité lorsqu’il n’existe qu’un faible avantage financier. Elle résume les conclusions relatives à l'impact que la politique et la conception du système peuvent avoir sur la qualité du recyclage.

Les facteurs qui se sont avérés essentiels pour déterminer la qualité actuelle du recyclage étaient la demande des producteurs de matières premières secondaires (MPS), la mesure selon laquelle les matériaux se dégradent lors de la collecte et du tri et l’importance et la présence de produits partageant des caractéristiques pertinentes dans les flux de déchets collectés. Lorsque la réalisation d'améliorations sur la qualité n'apportait qu'un faible avantage financier, il a été constaté que les organisations de responsabilité des producteurs (éco-organismes) ou autres autorités compétentes sont susceptibles de pouvoir améliorer les qualités en influençant l’ampleur des opérations de tri, en spécifiant les fractions de sortie de tri, ainsi qu’en influençant le comportement des producteurs en incitant à la recyclabilité de leurs produits et à l’utilisation de contenu recyclé post-consommation.

Executive Summary

Report context

This report has been produced for the Joint Research Centre (JRC) project on *Plant level data collection analysis on sorting and recycling of household packaging waste.* The aim of the project is to support the work of JRC in developing knowledge of the drivers and parameters, those both internal and external to sorting and recycling plants, that influence the quality, quantity and fate of household packaging recycling.

The project aimed to:

- Develop a definition of "quality of recycling" for household packaging plants in the EU in relation to dry recycling, plastics, paper and glass plants.
- Understand which factors impact the quality and quantity of recycling outputs, including particular consideration of:
    - material input composition and quality (including collection system and deposit return scheme arrangements);
    - loss rates and cross-contamination at each process stage and impacting factors;
    - equipment, process and technology;
    - management of plants;
    - product and industry standards; and
    - commercial and regulatory considerations (market impacts and PRO arrangements).

The findings will inform an understanding of which operationally and commercially practicable measures could be implemented in order to increase recycling quantity and quality across the various sorting plants, processes, technologies and commercial/regulatory contexts included in the study.

The project carried out study visits to 25 recycling plants across 11 EU countries. 12 of the plants focus on sorting and/or reprocessing specific types of plastics and 9 sort and/or reprocess a range of light packaging materials, with some of these plants also accepting some non-packaging dry recycling materials including papers. In addition, visits were also undertaken to 2 paper sorting and 2 glass sorting plants.

Data from these plants were collected and analysed, alongside insight from interviews with those involved in management (including quality management) at the plants.

Quality framework

'Quality' here refers to the extent to which, through the recycling chain, the distinct characteristics of the material are preserved or recovered so as to maximise their potential to be re-used in the circular economy. These characteristics include food-contact suitability, structural characteristics (i.e. uniformity and viscosity), clarity and colour, form, and odour.

Findings on key drivers at different types of plants in different contexts

Findings related to plastics sorting plants

Plastics require a chain of processes from the point of collection to the point where they become secondary raw materials. The chain of these processes is typically quite complex and differs according to the country, EPR scheme and individual business decisions (e.g. the choice by sorting plant owners to integrate reprocessing steps) . In all cases surveyed for this study there is more than one sorting plant involved in the recycling chain. The mixture of material types from which plastics are separated (paper and metals for example) also varies between surveyed plants depending on the collection scheme in place.

A key driver in the implementation of plant operation improvements associated with material quality is where the plant operator can realise the benefits of additional income from either improving the quality of a grade of material or separating materials into additional grades, and that income outweighs the investment cost of making those changes. In addition, the scale of sorting operations is a key varying factor between sorting plants, with plants at a larger scale having a better economic case for sorting more specific fractions (e.g. white/opaque HDPE). However, in a number of surveyed cases the plant operator does not realise the benefits of additional income from either improving the quality of a sorted fraction of material or separating materials into additional sorted fractions. The more significant driver in most of these cases is the need to meet the output specifications set on the grades of materials. In these cases it is typically the PRO that is contracting the operator and setting the specifications. The PRO could, therefore, drive further quality improvements by altering the specifications, though there were no specific instances of this having occurred recently from the plants that were surveyed.

At the plant operator level, as the cases for improving quality and quantities of material become more economically marginal, or in the cases where they do not experience this economic driver, then it would seem likely that PROs could play an important role in specifying or creating the economic drivers for:

- Further sorting into new sorted fractions;
- Improvements to the quality specifications of existing sorted fractions; and
- Tolerances for the amounts of target materials that can be sent for disposal rather than recycling.

Findings related to plastics reprocessors

Market forces are the primary driver of output qualities from plastic reprocessors. The material quality produced, and constraints on improving material qualities, varies between the reprocessors of different polymers. This is because of differences both in demand (size of demand and prices paid) for the secondary raw materials and also in the nature of the sorted material (polymer permeability, product variability and use).

- For rPET produced from bottles, market demand is high, particularly from bottle producers. rPET is relatively uniform, impermeable and not degraded in collection.
- The major challenge in PET recycling is the recycling of PET trays. rPET derived from trays has a low yield if processed on bottle lines and the rPET produced has a lower intrinsic viscosity than from bottles and is not suitable in large quantities for bottle production.
- There is an emerging PET tray line capacity in Europe, but the market for separated tray recycling is very much in its infancy, and reprocessing costs per tonne of output and losses are higher than for PET bottles.

- HDPE and PP are currently mostly found in single use packaging in the recycling chains that exist for the surveyed plants. In all plants studied, the majority of HDPE and PP were reprocessed into secondary raw materials for uses other than single use packaging. These secondary raw materials are used for the manufacture of items such as garden furniture, pipes, equipment cases and domestic items such as buckets. The exception to this might be some quantities of rHDPE that are recycled into HDPE non-food contact bottles. HDPE and PP are polymers that are 'absorbent' to some chemicals and compounds. In the plants that were surveyed as reprocessing these polymers, it was acknowledged that the secondary raw materials still had some of these contaminants in the polymers. Plants varied in the extent to which they took additional steps to improve the purity and reduce the odour of rHDPE and rPP outputs, with slightly higher prices available for these outputs. None considered more extensive odour reduction for their outputs, as the costs of decontaminating these polymers further would not be recovered by any increase in the sales revenues for the resulting material.
- PE films sorted in the surveyed plants are typically recycled into rLDPE that is used in the manufacturing of bin bags and construction films. The quality specifications for these outcomes can be met by the current plant processes. However, the costs of improving the secondary raw materials significantly to 'higher end' applications (e.g. transparent film packaging applications) was thought to be too high to be recovered by any additional revenues that could be obtained. Examples of investments that had been made to improve quality were focused on addressing deteriorating qualities of material obtained from sorting plants prior to its onward transfer to the reprocessing plant.

Findings related to paper sorters

Drivers to improve the quality of material output differed between the paper sorting plants studied, depending on how exposed they were to the benefit of additional material revenues. However, well established quality grades and a focus on maximising yields of the highest grades (de-inking grades) to meet the specifications of paper mills keep the quality of recycling relatively high. Plants consider themselves at the limits of what they can achieve with available technology.

Findings related to glass sorters/reprocessors

Drivers to improve the quality of material output differed between the glass sorting plants studied, depending on how exposed they were to the benefit of additional material revenues. However, this did not significantly impact on actual qualities produced, or on longer term investment choices (with large capital investments provided by the plants' owners). Strong demand from glass packaging manufacturers, exacting quality requirements for glass packaging re-melt and the fact that glass does not degrade in use, mean that the recycling chain can provide high quality outputs (provided sufficient subsidy is provided from producers). The biggest impact on quality outcomes (in particular, losses of target material) came from factors associated with product design and handling, which can create higher levels of rejects and fines.

Findings on key drivers across the whole recycling chain

Across recycling chains, the following factors are key in determining current qualities:

- Market demand for secondary raw material at different qualities (and virgin material prices);

- Material vulnerability to degradation (and degradation through product use or collection systems); and
- Product uniformity and presence in collected waste streams at sufficient scale to justify sorting.

High quality recycling chains exhibit:

- Strong market demand for high quality secondary raw materials;
- Prices paid for the secondary raw material that allow for the costs of the necessary recycling chain to deliver the quality required;
- Materials not vulnerable to degradation through use and collection; and
- Sufficient quantities of the material available with relatively uniform characteristics in context with the scale of the plant(s).

Within all the recycling chains studied there are examples of quality improvements that are on the margins of being economically viable under the current market conditions. Some of the examples found were:

- Sorters sorting green and opaque PET;
- Light packaging sorters sorting PET trays from PET bottles;
- Sorting natural or white coloured HDPE bottles from other colours of HDPE bottles; and
- Reducing odour and improving structural consistency of HDPE and PP outputs.

In those cases where quality improvements are on the economic margins at a plant, the factors key to increasing qualities of recycling within the plants studied are:

- Growth in market demand for higher qualities of material;
- Sorting and/or reprocessing at an appropriate (large enough) scale to justify sorting into more distinct material fractions and/or applying additional cleaning steps; and
- In cases where the plant is contracted by a PRO or is supplying material to a PRO, the introduction by the PRO of either new specified output fractions to be sorted and/or revised material specifications (standards).

Findings for policy and system design

Findings in relation to levers for market demand

Policy interventions appear to be important levers in raising the level of demand for higher quality grades throughout the recycling chains. These could include legislation regarding recycled content, support for cross-industry commitments, and more transparency and certification on use of recycled content in products.

However, the design of policy interventions needs to adequately take into account the achievability, both technically and economically, of the respective intervention, which will be specific to each packaging type and polymer type.

Findings in relation to product materials and design

The study reinforces the need to understand the impact of specific aspects of product materials and product design on the quality of recycling outputs. It highlights the problems posed by new materials such as biodegradable film, which may not be compatible with existing sorting and reprocessing plants.

Findings in relation to the types of collection systems

The study supports the view that, from a quality perspective, collection of plastics mixed with papers should be discouraged, as this mix causes increased losses of each of the respective materials to disposal and increases the potential for lower quality secondary raw materials. Whether the additional costs of separate collection are currently reflected in additional revenues from higher quality material output has not been assessed as part of this study. There are some examples of recycling chains within this study where plastic and metals packaging are collected mixed together without impacting on secondary material quality, where they are kept separate from the other material types (papers and glass).

Findings in relation to PRO contracts with sorting plants

PROs can play a role in incentivising plant operators to improve the quality of outputs above that which the market alone would determine, especially where the economic case for improving output qualities is marginal.

- Where PROs do not currently specify certain output grades, they could improve the likely quality outcomes for some materials by doing so (for instance, natural/white coloured HDPE, some specific sorted fractions of PP, opaque PET and PET trays).
- An alternative approach – setting overall recycling rates for plants – may similarly increase quality outcomes by either increasing capture into target grades or incentivising plants to output additional fractions for recycling (but allowing plants to do this in the most cost-efficient way). However, in both cases PROs would also need to ensure minimum standards are set and enforced appropriately to avoid negative impact on purities of grades.
- Where PROs currently buy material and set purity specifications on sorted fractions, paying some additional amount for material of higher purity to offset the increased disposal costs for the impurities removed at the sorting plants would counteract some of the current disincentive to exceed purity standards.
- Where PROs set specifications and buy material, they can target specific increases in qualities through raising quality standards, though corresponding payments will be needed to account for the costs of sorters in achieving the new specifications.
- The contracting phase is important in identifying what opportunities exist to improve output qualities (since in some cases a specific material quality is defined and targeted for the duration of the contract).

Findings in relation to technological innovation

For most materials, where there are opportunities to improve the quality of recycling, the technology is available to do so. An exception to this is the limitation of current paper sorting processes to sort smaller papers.

This study raised the potential of packaging 'embedded information' systems to improve sorting abilities and efficiencies of specific fractions of plastics, with relatively minor additional investment. In this case, the technology is available, but a common system needs to be agreed upon by producers and sorting plant operators.

From a quality perspective, a focus should be maintained on the research and development of improved or new technologies to tackle cleaning and quality challenges. However, for challenging materials where degradation is greater and producers are less willing to pay a premium for quality SRMs, the focus should be on developing cost-effective technologies to improve or replace existing processes, as cost is a critical constraint to the uptake of newer technologies.

Synthèse

Contexte du rapport

Ce rapport a été produit pour le projet du Centre Commun de Recherche (CCR) sur l'Analyse des données recueillies auprès des centres de traitement sur le tri et le recyclage des déchets d'emballage ménagers. L'objectif du projet est de soutenir le travail du CCR en matière de développement des connaissances sur les facteurs et paramètres, internes et externes aux centres de tri et de recyclage, qui influencent la qualité, la quantité et la destination du recyclage des emballages ménagers.

Le projet avait pour but de :

- Développer une définition de la « qualité du recyclage » pour les usines d'emballages ménagers dans l'UE qui traitent des déchets mixtes ou de plastique, papier et verre.
- Comprendre quels facteurs ont un impact sur la qualité et la quantité des matériaux en sortie, en prenant particulièrement en compte :
    - La composition et la qualité des matériaux entrants (y compris les systèmes de collecte et les dispositifs de consigne) ;
    - Les taux de perte et de contamination croisée à chaque étape du processus et les facteurs ayant un impact ;
    - Les équipements, processus et technologies ;
    - La gestion des installations ;
    - Les normes relatives au produit ou au secteur ; et
    - Les considérations commerciales et réglementaires (impacts sur le marché et dispositions des éco-organismes).

Les résultats permettront de mieux comprendre quelles mesures opérationnelles et commercialement viables pourraient être mises en œuvre pour augmenter la quantité et la qualité du recyclage parmi les divers centres de tri, processus, technologies et contextes commerciaux/réglementaires inclus dans l'étude.

Le projet a réalisé des visites d'étude dans 25 usines de recyclage parmi 11 pays de l'UE. 12 de ces usines se concentrent sur le tri et/ou le retraitement de types spécifiques de plastiques et 9 trient ou retraitent un éventail de matériaux d'emballage légers, certaines de ces usines acceptant également des matériaux à recycler hors emballages, y compris des papiers. En outre, des visites ont aussi été entreprises auprès de 2 usines de tri de papier et 2 usines de tri de verre.

Les données de ces usines ont été recueillies et analysées, de même que les perspectives issues d'entretiens avec les personnes impliquées dans la gestion (y compris la gestion de la qualité) au sein des usines.

Système relatif à la qualité

Ici la « qualité » fait référence à la mesure dans laquelle, à travers la chaîne de recyclage, les caractéristiques spécifiques des matériaux sont préservées ou récupérées, afin de maximiser leur potentiel de réutilisation dans l'économie circulaire. Ces caractéristiques incluent l'aptitude au contact alimentaire, les caractéristiques structurelles (c.-à-d. l'uniformité et la viscosité), la forme, la transparence, la couleur, et l'odeur.

Conclusions sur les facteurs clés pour les différents types d'usine dans différents contextes

Conclusions relatives aux usines de tri de plastique

Les plastiques nécessitent un enchaînement de processus depuis le point de collecte jusqu'au point où ils deviennent des matières premières secondaires. En général, cet enchaînement est assez complexe et diffère selon le pays, le programme (Responsabilité Élargie des Producteurs – éco-organisme) et les décisions commerciales individuelles (p. ex. le choix par les propriétaires d'usine de tri d'intégrer certaines étapes de retraitement). Dans tous les cas examinés pour l'étude, il y a plus d'une usine de tri impliquée dans la chaîne de recyclage. Le mélange des types de matériaux desquels les plastiques sont séparés (par exemple le papier et le métal) varie également entre usines examinées, en fonction du système de collecte en place.

Un facteur-clé dans la mise en œuvre des améliorations de fonctionnement de l'usine associées à la qualité des matériaux est en place lorsque l'exploitant de l'usine peut concrétiser les avantages sous la forme d'un revenu supplémentaires, soit en améliorant la qualité d'une classe de matériau, soit en séparant les matériaux en catégories supplémentaires et lorsque ce revenu surpasse les coûts investis pour réaliser ces changements. En outre, l'échelle des opérations de tri est un facteur variable clé entre les usines de tri, les usines plus importantes étant souvent dans une situation économique plus avantageuse pour trier des fractions plus spécifiques (p. ex. PEHD blanc/opaque). Toutefois, dans un certain nombre de cas examinés, l'exploitant d'usine ne perçoit pas ces bénéfices d'un revenu supplémentaire, en améliorant la qualité d'une fraction de matériau trié ou en séparant les matériaux en fractions triées supplémentaires. Le facteur le plus important dans la plupart de ces cas est le besoin de répondre à des spécifications de production définies sur les qualités de matériaux. Dans ces cas, c'est en général l'éco-organisme qui conclue un contrat avec l'exploitant et définit les spécifications. Par conséquent, l'éco-organisme pourrait entraîner d'autres améliorations de la qualité en modifiant le cahier des charges, bien qu'il n'y ait pas eu d'exemples spécifiques de ceci récemment dans les usines faisant l'objet de l'étude.

Au niveau de l'exploitant de l'usine, alors que la rentabilité d'une amélioration de la qualité et des quantités de matériaux devient économiquement plus marginale, ou dans les cas où ce facteur économique ne joue pas, il semblerait alors probable que les éco-organismes puissent jouer un rôle important dans la spécification ou la création de facteurs économiques pour :

- Un tri plus poussé donnant plus de fractions triées ;
- Un cahier des charges plus strict sur la qualité des fractions triées existantes ; et
- Des tolérances moindres pour les quantités de matériaux cibles destinés à l'élimination plutôt qu'au recyclage.

Conclusions relatives aux usines de retraitement de plastiques

Les forces du marché sont les facteurs principaux déterminant les qualités des matériaux en sortie des usines de retraitement de plastique. La qualité de matériau produite, et les contraintes liées à l'amélioration des qualités de matériaux, varient entre les usines de retraitement de différents polymères. Ceci est dû aux différences en termes de demande (volume de demande et prix payés) pour les matières premières secondaires, ainsi qu'à la nature du matériau trié (perméabilité du polymère, variabilité du produit et utilisation).

- Pour le PET recyclé (PETr) produit à partir de bouteilles, la demande du marché est élevée, en particulier venant des producteurs de bouteilles. Le PETr est relativement uniforme, imperméable et non dégradé pendant la collecte.
- Le défi majeur du recyclage de PET est lié au recyclage des barquettes en PET. Le PETr dérivé des barquettes est peu productif s'il est traité sur des lignes de bouteilles et le PETr produit a une viscosité intrinsèque plus faible que celui issu des bouteilles. Il ne convient pas en grandes quantité à la production de bouteilles.
- Il existe une capacité émergente de lignes de traitement des barquettes en PET en Europe, mais le marché pour le recyclage des barquettes triées n'en est qu'à ses balbutiements et les coûts de retraitement par tonne de production ainsi que les pertes sont plus élevés que pour les bouteilles en PET.
- À l'heure actuelle, dans les chaînes de recyclage existantes au sein des usines étudiées, on trouve le plus souvent les polymères PEHD et PP dans les emballages à usage unique. Dans toutes les usines étudiées, la majorité des PEHD et PP était retraitée en matières premières secondaires pour des utilisations autres que l'emballage à usage unique. Ces matières premières secondaires sont utilisées pour la fabrication d'articles tels que des meubles de jardin, tuyaux, enveloppes d'équipements ; et des articles de ménage tels que des seaux. L'exception à ceci pourrait être certaines quantités de PEHDr qui sont recyclées en bouteilles en PEHD n'entrant pas en contact avec les aliments. Le PEHD et le PP sont des polymères qui sont « absorbants » pour certains produits chimiques et composés. Dans les usines étudiées qui retraitent ces polymères, il a été reconnu que les matières premières secondaires présentaient encore certains de ces contaminants présents dans les polymères. Les usines varient dans leur approche quant aux mesures supplémentaires pour améliorer la pureté et réduire l'odeur des productions de PEHDr et de PPr, entraînant des prix légèrement plus élevés pour ces produits. Aucune n'envisageait une réduction de l'odeur plus poussée pour leurs produits, car les coûts de décontamination supplémentaire de ces polymères ne seraient pas compensés par une augmentation du chiffre d'affaires pour le matériau résultant.
- Les films PE triés dans les usines étudiées sont généralement recyclés en PE-LDr qui est utilisé dans la fabrication de sacs poubelles et de films pour la construction. Les processus actuels des usines permettent de satisfaire les spécifications de qualité pour ces productions. Toutefois, il est estimé que les coûts pour améliorer considérablement les matières premières secondaires et les amener aux niveaux d'applications « plus haut de gamme » (p. ex. les applications d'emballage à film transparent) sont trop élevés pour être récupérés par des recettes supplémentaires. Des exemples d'investissement qui avaient été faits pour améliorer la qualité étaient axés sur la résolution de la détérioration de la qualité des matériaux obtenus en sortie des usines de tri, avant leur transfert vers l'usine de retraitement.

Conclusions liées aux trieurs de papier

Les facteurs pour améliorer la qualité de la production de matériaux diffèrent entre les usines de tri de papier étudiées, en fonction du bénéfice qu'ils tirent des revenus complémentaires issus des matériaux. Toutefois, les catégories de qualité bien établies et la priorité mise sur la maximisation des matériaux de catégories plus élevées (catégories désencrées) pour répondre aux cahiers des charges des papeteries permet de maintenir une qualité du recyclage relativement élevée. Les usines considèrent qu'elles sont à la limite de ce qu'elles peuvent accomplir avec la technologie disponible.

Conclusions liées aux trieurs/retraiteurs de verre

Les facteurs pour améliorer la qualité de la production de matériaux diffèrent entre les usines de tri de verre étudiées, en fonction du bénéfice qu'ils tirent des revenus complémentaires issus des matériaux. Toutefois, ceci n'a pas d'impact important sur les qualités réellement produites ou sur les choix d'investissement à plus long terme (avec de grands investissements de capital fournis par les propriétaires des usines). La forte demande des fabricants de verre d'emballage, les exigences de qualité de la refonte du verre d'emballage et le fait que le verre ne se dégrade pas lors de l'utilisation, signifie que la chaîne de recyclage peut fournir des produits de qualité élevée (à condition qu'une subvention suffisante soit fournie par les producteurs). Le plus gros impact sur les résultats de qualité (en particulier, les pertes de matériau cible) provient des facteurs associés à la conception et à la manipulation du produit, qui peuvent créer des niveaux plus élevés de rejets et de pénalités.

Conclusions relatives aux facteurs clés parmi la chaîne de recyclage dans son ensemble

Parmi les chaînes de recyclage, les facteurs suivants sont essentiels pour déterminer les qualités à l'heure actuelle :

- Demande du marché pour des matières premières secondaires de qualités différentes (et prix des matériaux vierges) ;
- Vulnérabilité du matériau à la dégradation (et dégradation par le biais de l'utilisation du produit ou des systèmes de collecte) ; et
- Uniformité du produit et présence dans les flux de déchets collectés dans une proportion suffisante pour justifier le tri.

Les chaînes de recyclage de haute qualité présentent :

- Une forte demande de marché pour des matières premières secondaires de haute qualité ;
- Des prix payés pour la matière première secondaire permettant de compenser les coûts de la chaîne de recyclage nécessaires pour atteindre la qualité requise ;
- Des matériaux qui ne sont pas vulnérables à la dégradation due à l'utilisation et à la collecte ; et
- Des quantités suffisantes de matériaux disponibles avec des caractéristiques relativement uniformes par rapport à l'échelle de la (des) usine(s).

Parmi toutes les chaînes de recyclage étudiées, il y a des exemples d'améliorations de la qualité qui se situent en marge de la viabilité économique selon les conditions actuelles du marché. En voici certains exemples :

- Les trieurs qui trient du PET vert et opaque ;
- Les trieurs d'emballage léger qui trient des barquettes de PET des bouteilles PET ;
- Le tri de bouteilles PE-HD de couleur naturelle ou blanche séparées de bouteilles PEHD d'autres couleurs et
- La réduction de l'odeur et l'amélioration de la structure des polymères PEHD et PP en matériaux de sortie.

Dans ces cas où les améliorations de la qualité se situent dans les marges économiques d'une usine, les facteurs essentiels pour augmenter les qualités du recyclage dans les usines étudiées sont :

- La croissance de la demande du marché pour de meilleures qualités de matériau ;
- Trier et/ou retraiter à une échelle appropriée (assez grande) pour justifier le tri dans des fractions de matériaux plus spécifiques et/ou l'application d'étapes supplémentaires de nettoyage ; et
- Dans les cas où l'usine est sous contrat avec un éco-organisme ou lui fournit des matériaux, la spécification par l'éco-organisme de nouvelles fractions à trier et/ou un cahier des charges de matériaux révisé (normes).

Conclusions relatives à la conception de politique et de système

Conclusions relatives aux leviers sur la demande de marché

Les interventions politiques semblent être des leviers importants pour élever le niveau de la demande pour des catégories de qualité plus élevées dans l'ensemble des chaînes de recyclage. Celles-ci pourraient inclure la législation sur le contenu en matières recyclées, le soutien des engagements à travers l'industrie et plus de transparence et de certification sur l'utilisation du contenu recyclé dans les produits.

Toutefois, la conception d'interventions politiques doit prendre en compte de manière adéquate le caractère réalisable, techniquement et économiquement, de chaque intervention, qui sera spécifique à chaque type d'emballage et, le cas échéant, de polymère.

Conclusions relatives aux matériaux et au design des produits

L'étude souligne le besoin de comprendre l'impact, d'une part, des caractéristiques des matériaux utilisés dans les produits et , d'autre part, de la conception des produits (design) sur la qualité des matières recyclées. Elle met en lumière les problèmes posés par de nouveaux matériaux, tels que les films biodégradables, qui pourraient ne pas être compatible avec les usines de tri et de retraitement actuelles.

Conclusions relatives aux types de systèmes de collecte

L'étude soutient l'idée que, du point de vue de la qualité, la collecte de plastiques, mélangée à celles des papiers, devrait être découragée, car ce mélange entraîne des pertes pour chacun des matériaux respectifs et augmente le potentiel de matières premières secondaires de plus basse qualité. En revanche, il n'a pas été évalué dans le cadre de cette étude si les coûts supplémentaires d'une collecte séparée sont actuellement reflétés par des revenus supplémentaires générés par la production de matériaux de plus haute qualité. Il existe des exemples de chaînes de recyclage dans cette étude où les emballages en plastique et en métal sont collectés ensemble sans avoir d'impact sur la qualité des matériaux secondaires, lorsqu'ils sont maintenus séparés des autres types de matériaux (papier et verre).

Conclusions relatives aux contrats des éco-organismes avec les usines de tri

Les éco-organismes (organismes répondant aux obligations de responsabilité élargie des producteurs) peuvent jouer un rôle pour inciter les exploitants d'usine à améliorer la qualité des matières recyclées au-dessus de la seule demande du marché, surtout lorsque la rentabilité potentielle d'une amélioration de la qualité des matériaux en sortie est marginale.

- Lorsque les éco-organismes ne spécifient pas à l'heure actuelle de catégories spécifiques pour les matériaux en sortie, ils pourraient améliorer la qualité potentielle pour certains matériaux en le faisant (par exemple, PEHD de couleur naturelle/blanche, certaines fractions triées spécifiques de PP, de PET opaque et de barquettes en PET).

- Une approche alternative - définir des taux de recyclage globaux pour les usines - pourrait augmenter de manière similaire les résultats de qualité, soit en augmentant le captage de matériaux permettant d'atteindre les qualités cibles, soit en incitant les usines à produire des fractions recyclées supplémentaires (mais en laissant les usines déterminer elles-mêmes comment faire cela de la manière la plus économique). Toutefois, dans les deux cas, les éco-organismes devraient aussi veiller à ce que des normes minimums soient mises en place et appliquées de manière appropriée, afin d'éviter tout impact négatif sur la pureté des catégories.
- Lorsque les éco-organismes achètent actuellement des matériaux et définissent les spécifications de pureté sur les fractions triées, payer plus pour les matériaux de plus grande pureté pour compenser les coûts d'élimination plus élevés des impuretés éliminées aux usines de tri, compenserait certains des effets dissuasifs d'aller au-delà des normes de pureté.
- Lorsque les éco-organismes définissent les cahiers des charges et achètent des matériaux, elles peuvent cibler des augmentations spécifiques de qualités en élevant les normes de qualité, mais des paiements correspondants devront prendre en compte les coûts des trieurs pour atteindre les nouvelles exigences.
- La phase contractuelle est importante pour identifier les opportunités qui existent pour améliorer les qualités des matériaux en sortie (étant donné que dans certains cas, une qualité de matériau spécifique est définie et ciblée pendant toute la durée du contrat).

Conclusions en rapport à l'innovation technologique

Pour la plupart des matériaux, pour lesquels il existe des possibilités d'améliorer la qualité du recyclage, la technologie pour atteindre ces meilleurs niveaux est déjà disponible. Une exception à cela est la limitation des processus actuels de tri du papier pour trier les papiers plus petits.

Cette étude soulève également le potentiel d'inclure des systèmes « d'information incorporée », afin d'améliorer les capacités et les efficacités de tri de fractions spécifiques de plastique, avec des investissements supplémentaires relativement mineurs. Dans ce cas, la technologie est disponible, mais un système doit être convenu entre les producteurs et les exploitants d'usines de tri.

Du point de vue de la qualité, il convient de maintenir la priorité mise sur la recherche et le développement des technologies nouvelles ou améliorées, afin de faire face aux défis du nettoyage et de la qualité. Toutefois, pour les matériaux difficiles où la dégradation est plus élevée et les producteurs sont moins disposés à payer plus cher pour des matières premières secondaires de qualité, il convient de se concentrer sur le développement de technologies économiques pour améliorer ou remplacer les processus existants, car les coûts sont une contrainte critique à l'adoption de technologies plus récentes.

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Glossary

A glossary of key terms and acronyms is provided below.

Aseptic cartons	Cartons for liquids, fabricated from laminates of liquid packaging board, foil and polyethylene; also called 'beverage cartons' or 'tetrapak' (a trade name)
CITEO	French Producer Responsibility Organisation
Collected stream	Materials collected for recycling either presented separately, or mixed with other material types in the same container.
Contaminants	In collection systems: non-recyclable material presented in recycling collections
DRS	Deposit return scheme
DSD	German PRO organising the collection scheme for recycling of packaging, managed by Der Grüne Punkt – Duales System Deutschland AG. In summary, glass and paper/cardboard are each separately collected, and mixed light packaging (plastic bottles, pots, tubs & trays; metal containers; aseptic cartons) are collected from yellow bags or bins.
Ecoembes	Spanish Producer Responsibility Organisation
EfW	Energy from waste: incineration that includes energy generation from the combustion of the waste
EPR	Extended producer responsibility
HDPE	High density polyethylene
Impurity	The presence of materials and substances other than the target material in a sorted fraction or output secondary raw material.
Intermediate Sorted Fraction	A grade of material that has been sorted post collection but has not been sufficiently prepared to be a secondary raw material.
JRC	Joint Research Centre of the European Commission
LDPE	Low density polyethylene
Light Packaging Fraction (LPF)	A term used for the collected stream of plastic packaging and metal packaging common in Europe. In some areas this also includes papers, in some areas this includes some non-packaging items of similar materials also.
Material Types	Major material groups i.e. Plastic, Papers, Metals, Glass
MRF	Materials Recycling Facility
Non-target material	In sorted fraction: non-target material included in the output material. In collection systems: materials that are not targeted by the scheme, specifically referring to any materials that residents present for collection which are not specifically requested as part of that collection. This can include readily recyclable material that is not targeted as well as non-recyclable materials (contaminants).
PET	Polyethylene terephthalate
PO	Polyolefins (group of polymers including HPDE, LDPE and PP)
PP	Polypropylene
PRO	Producer Responsibility Organisation
Losses	Losses of target material at any stage prior to production of secondary raw materials
PS	Polystyrene
PTT	Pots, tubs and trays (plastic)
Purity	The lack of impurities in a sorted fraction

PVC	Polyvinyl chloride
Re-melt	The process of melting down glass cullets for manufacturing into new glass products
Reprocessor	A plant that carries out operations to produce at least one secondary raw material.
Residues	Material received by the plant but sorted to a fraction that will not be sent for recycling.
rHPDE	Secondary raw material made from recycled HDPE
rPET	Secondary raw material made from recycled PET
rPP	Secondary raw material made from recycled PP
rPE	Secondary raw material made from recycled PE film
Secondary raw material (SRMs)	Material that has been sorted and prepared so that it is suitable for use directly in new product manufacture, without further sorting or preparation, (such as a clean, dry polymer flakes, pellets, or compound)
Sorted material fraction, or 'sorted fraction'	Separate fraction of material sorted from an input stream; (in some cases, non-packaging products are included notably in the case of paper).
Sorter	A plant that carries out operations to sort a collected stream (or pre-sorted fraction) into two or more sorted fractions.
Initial Sorter	A sorter which has a collected stream as its input material
Secondary Sorter	A sorter which has a sorted fraction as its input material
Target materials	The main materials specifically targeted at any stage in the recycling chain: by a collection scheme, a sorting operation, a sorted fraction specification, or a reprocessor

Report background, aims and structure

This report has been produced for the Joint Research Centre (JRC) project on *Plant level data collection analysis on sorting and recycling of household packaging waste.* The aim of the project is to support the work of DG JRC and the Circular Economy and Industrial Leadership Unit in developing knowledge of the drivers and parameters, those both internal and external to sorting and recycling plants, that influence the quality, quantity and fate of household packaging recycling.

The project carried out study visits to 25 recycling plants across 11 EU countries and involved the following number and type of plants:

- 11 plants sorting collected streams of light packaging fractions (various mixtures including plastics only inputs) and sorting out at least one grade of plastic. Some of these plants also conducted some reprocessing operations;
- 2 plants conducting a second sort of specific plastic fractions output from sorting plants (mixed PET and mixed HDPE/PP);
- 8 plants primarily reprocessing sorted plastic fractions into secondary raw materials, whilst also conducting some sorting operations;
- 2 paper sorting plants; and
- 2 glass sorting plants.

This report provides analysis of the collected data in relation to investigating the project's key research questions (set out below). It is accompanied by another report 'Quality of Recycling: Towards an Operational Definition and Framework', which sets out a proposed operational definition of quality of recycling, and a framework for practically assessing the quality of recycling at the level of an individual plant or at the level of the recycling chain.

Background

The parameters that govern the quality, quantity and fate of household packaging that is sent for recycling are undergoing a period of reform, largely driven by policy changes at the European level. In July 2018, the European Union (EU) decided upon significant revisions to existing waste legislation, which it incorporated into the EU Action Plan for the Circular Economy (EU Action Plan). The EU Action Plan included six amendments to directives pertaining to waste management, including the Waste Framework Directive, Directive on Packaging Waste and the Landfill Directive. The amendments contain ambitious targets for EU Member states including:

- A recycling target of 65% for municipal waste by 2035 (with interim targets of 55% by 2025 and 60% by 2030);
- A recycling target of 70% for all packaging by 2030 (with an interim target of 65% by 2025 and specific targets for different packaging materials); and
- A binding landfill reduction target of 10% by 2030.

In the EU Action Plan, the directives also introduced:

- Reforms related to Producer Responsibility to ensure producers pay the full costs of end-of-life management of products; and
- A new measurement method for recycling performance, to create greater accuracy in the reporting of recycled material.

With this context in mind, it is the aim of this study to improve holistic understanding of the drivers and parameters that influence the quality, quantity and fate of household packaging recycling, and to define what is meant by "High Quality Recycling". This project has involved collecting and analysing data from sorting and recycling plants across Europe to form an evidence base when responding to key research questions, set out below. The analysis in this report contains information that will assist in the design of mechanisms to encourage a shift to higher quality recycling.

Research aims of the project

The key research aims the project has investigated are summarised as follows:

- To develop a definition of "quality of recycling" for household packaging plants in the EU in relation to dry recycling, plastics, paper and glass plants.
- To provide clear qualitative and quantitative descriptions of the relevant processes at a representative set of plants.
- To understand which factors impact quality and quantity of recycling outputs, including particular consideration of: material input composition and quality (including collection system and deposit return scheme arrangements); loss rates and cross-contamination at each process stage and impacting factors; equipment, process and technology; management of plants; product and industry standards; and commercial and regulatory considerations (market impacts and PRO arrangements).
- To develop an understanding of which operationally and commercially practicable measures could be implemented across the various sorting plants, processes, technologies and commercial/regulatory contexts in order to increase recycling quantity and quality.

Aims of this report

This report provides an analysis of the drivers that impact on the quality of recycling achieved at both sorting and reprocessing plants. Explanations are provided of the key factors found to be driving the current quality of recycling being achieved, both across the whole recycling chain and at the sorting and reprocessing plants that were studied during the project. The focus is on exploring factors that enable, or place constraints on, the production of higher quality (as compared to lower quality) outputs.

Thereafter, the potential for plants to implement refinements or changes to operations to improve the quality of recycling outputs is considered, alongside the key barriers to plants making decisions to produce higher outputs, and the potential levers to enable such decisions to be enacted.

Factors explored include those related to collection system types, Extended Producer Responsibility (EPR) scheme quality specifications and contractual arrangements with sorting plants, as well as broader market and economic factors (product design, market demand, technology). The report points to potential areas where changes in these external factors are likely to result in increases in the quality of recycling.

Structure of this report

This report is structured as follows:

- Section 1 provides an introduction to the recycling chain, the role of various types of EPR schemes and an outline of economic models that sorters and reprocessors work within;

- Section 2 outlines the key factors that determine the qualities of outputs currently produced by the plants visited during the study. Drivers that enable high quality or limit the production of higher quality outputs are discussed. Key opportunities are identified for increasing the quality of outputs at the plants visited and the nature of the barriers that currently prevent plants from making the changes or refinements to their operations that would enable producing higher quality outputs. The main groups of materials processed by the study plants are considered in turn:
  - Plastics sorting operations;
  - Plastics reprocessing operations;
  - Glass sorting; and
  - Paper sorting.
- Section 3 analyses how economic factors across the whole recycling chain drive or constrain the production of higher quality outputs. Case studies are provided to illustrate those factors which enable recycling chains to produce higher quality outputs.
- Section 4 examines evidence of the influence of policy and system design on the quality of recycling in respect of:
  - Impacts of collection systems;
  - How PROs affect sorting plant output specifications through tolerances for impurities and different fractions within sorted bales; and
  - How PRO payment structures impact the quality of recycling, in particular the role of PROs in guaranteeing prices for and buying materials from sorting plants, compared to plants selling these materials on the open market.

Therefore, following the general introduction to the concepts discussed in the report in section 1, the reader is directed to the following sections in respect of drivers for quality of recycling outputs:

- Themes applicable at an individual plant type level: Section 2;
- Overall system drivers analysis: Section 3;
- Impacts of policy and system design on different material streams: Section 4.

1. Introduction

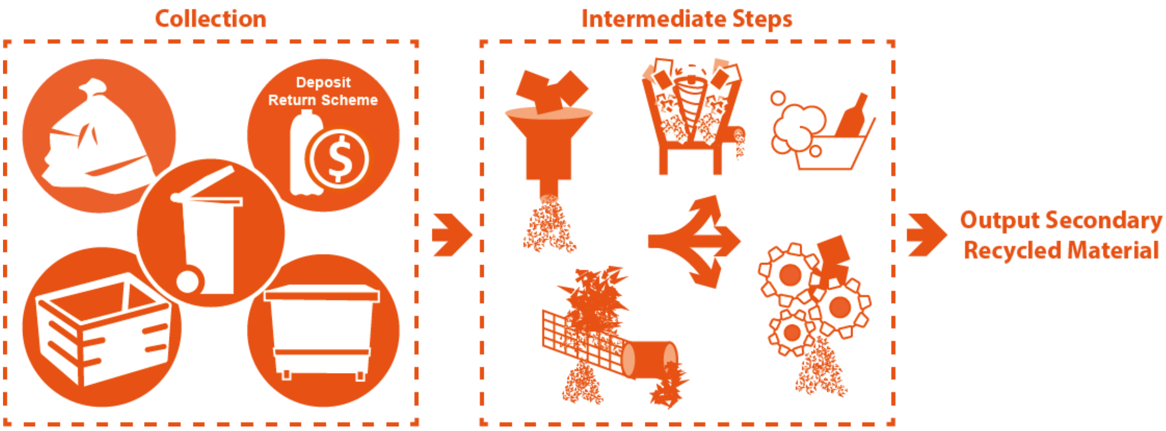
This section aims to define key concepts used in the report and introduces the roles of different actors in the supply chain.

1.1. Recycling chain

The production of recycling outputs involves different stages, collectively called a recycling chain (Figure 1-1). The different stages comprise:

- **Collection** (either separately, or mixed with other material types collected for recycling). For the purposes of this report, material at this stage of the recycling chain is defined as being a ***'collected stream'.***
- **Various intermediate stages of preparation** involving combinations of sorting into distinct material fractions (e.g. by specific material, sometimes by colour), washing, shredding, crushing or flaking. Material during these stages (having undergone some sorting, but prior to the production of a secondary raw material) is referred to in this report as ***'sorted fractions'***, up to the point of:
- The production of a **'secondary raw material'** suitable for use in new product manufacture, such as a clean, dry flake, pellet or compound; or glass cullet.

Figure 1-1: Stages of the recycling chain



For each secondary raw material there is a different recycling chain. The collection method and characteristics of different materials mean that the organisation of typical recycling chains differs both between materials and across regions and countries. The chain is particularly complex for plastics. There is a wide variety of processes that differ between materials and choice of processing strategy. There can also be a wide range of different amounts of business integration across the recycling chain, from as few as two or three entities (or business groups) across the chain to examples where the chain involves many more than that.

Outline descriptions of recycling chains for the main material types being considered are provided below.

Recycling chains: outline descriptions by material group

Typical recycling chains for plastics are provided in Figure 1-2 (focus on PET) and Figure 1-3 (focus on HPDE/PP). In Europe, plastics are predominantly collected in a 'light packaging fraction' (LPF) alongside metal packaging. In some EU countries DRS collections separate out a significant proportion of the plastic packaging that is generated as waste (primarily PET beverage bottles), which alters the composition of plastics collected in the LPF stream. Collected PET within the LPF in regions with DRSs therefore have a higher concentration of PET trays and dairy/non-beverage PET, though the extent of this impact depends on the scope and performance of the DRS.

Variations exist between countries, and in some cases between regions within a country, as to which material types are collected for recycling, how the material types are collected and which material types are collected mixed with other targeted material types. Some countries have a separate plastics collection excluding metals, some include non-packaging plastics and some include papers. This variation is illustrated in Table 1-1.

Table 1-1: Dry recycling collection schemes

	Germany (DSD)	**France**	**Greece**	**Sweden**
DRS	Beverage bottles and cans (plastic, metal and glass)			Beverage bottles and cans (plastic, metal and glass)
Door to Door Collections	2 streams:	1 stream:	1 stream:	3 streams:
	Plastics, Metals,	Plastics, Metals, Tetrapak, Papers	Plastics, Metals, Papers, Glass, Tetrapaks	Plastics
	Papers			Metals
				Papers
Bring Systems (on street containment)	Glass	Glass		

In some regions of Europe, fractions of plastics are sorted from mixed "residual" waste prior to disposal/energy recovery of the remaining fraction (i.e. general waste that has no separation for recycling during the presentation or collection of that waste). This study, however, focuses on plants sorting material from separate recycling collections.

The degree to which the first sorting plant (which receives the collected LPF stream) separates out distinct polymer and colour fractions, versus polymer and colour fractions being separated by a 'secondary sorting' plant varies between the study plants. In general, it is more likely that PET is sorted by polymer/colour at the first sorting plant, whereas it is more likely for HDPE, PP and PS to be sorted into specific polymers at a secondary sorting plant. Some of the study plants produce mixtures of HDPE and PP that are sent to reprocessors in this form. Some plants produce an output of a 'remainder' mixed plastics fraction also containing small plastic packaging, mostly of PP or PE. The variations in the degree of polymer/colour separation exist partly due to the scale of different sorting operations, and partly due to variations in sorting packaging fraction grades specified by different producer responsibility organisations (PROs).

Outputs from sorting plants can be sold on to different types of offtakers. Some sorting plants supply outputs to other facilities owned by the same company for further sorting and/or reprocessing. Whereas other sorting plants supply outputs to PROs, or sell directly to other sorters or reprocessors.

Figure 1-2: Recycling chain for plastics, focus on PET

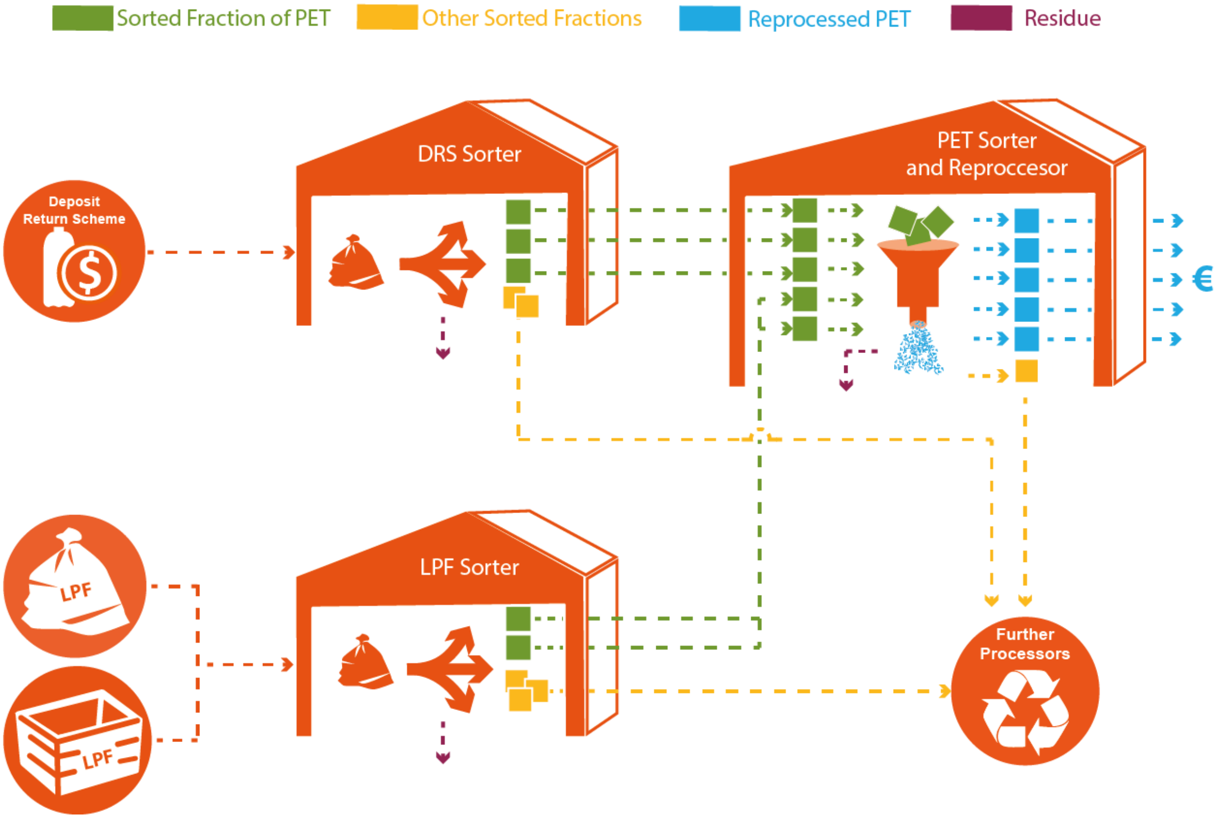
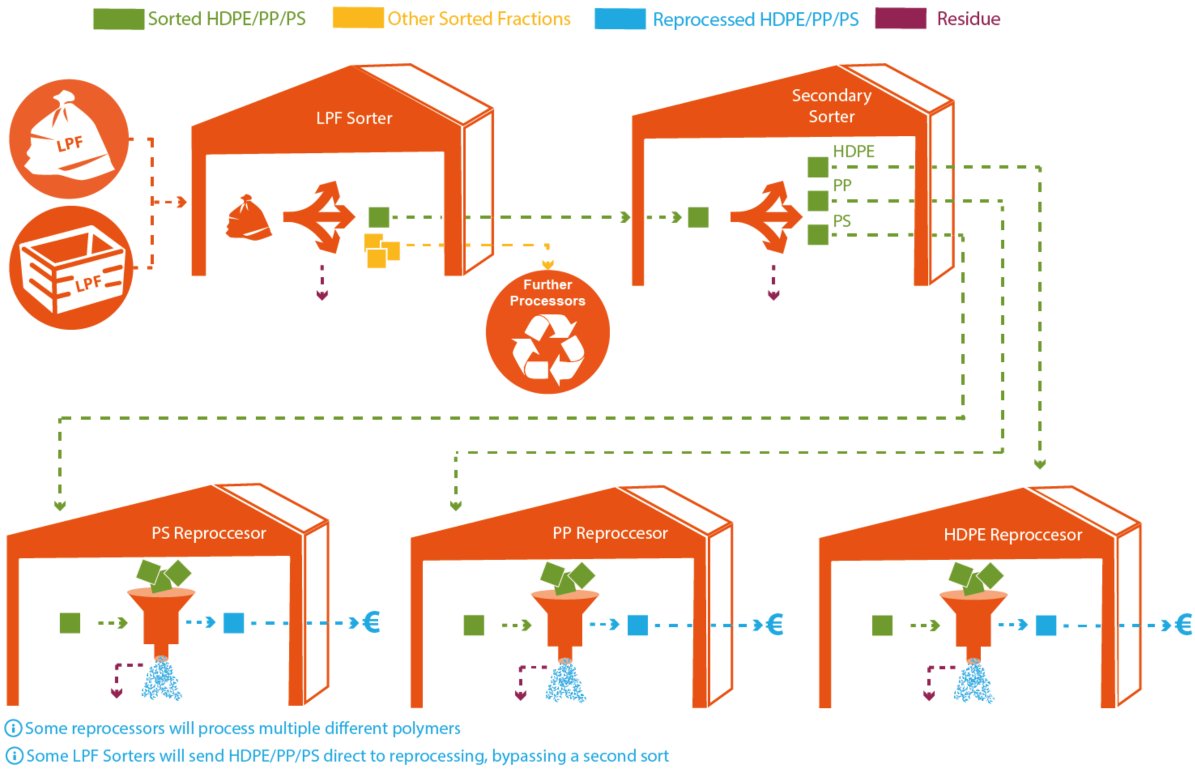


Figure 1-3: Recycling chain for plastics, focus on HDPE/PP



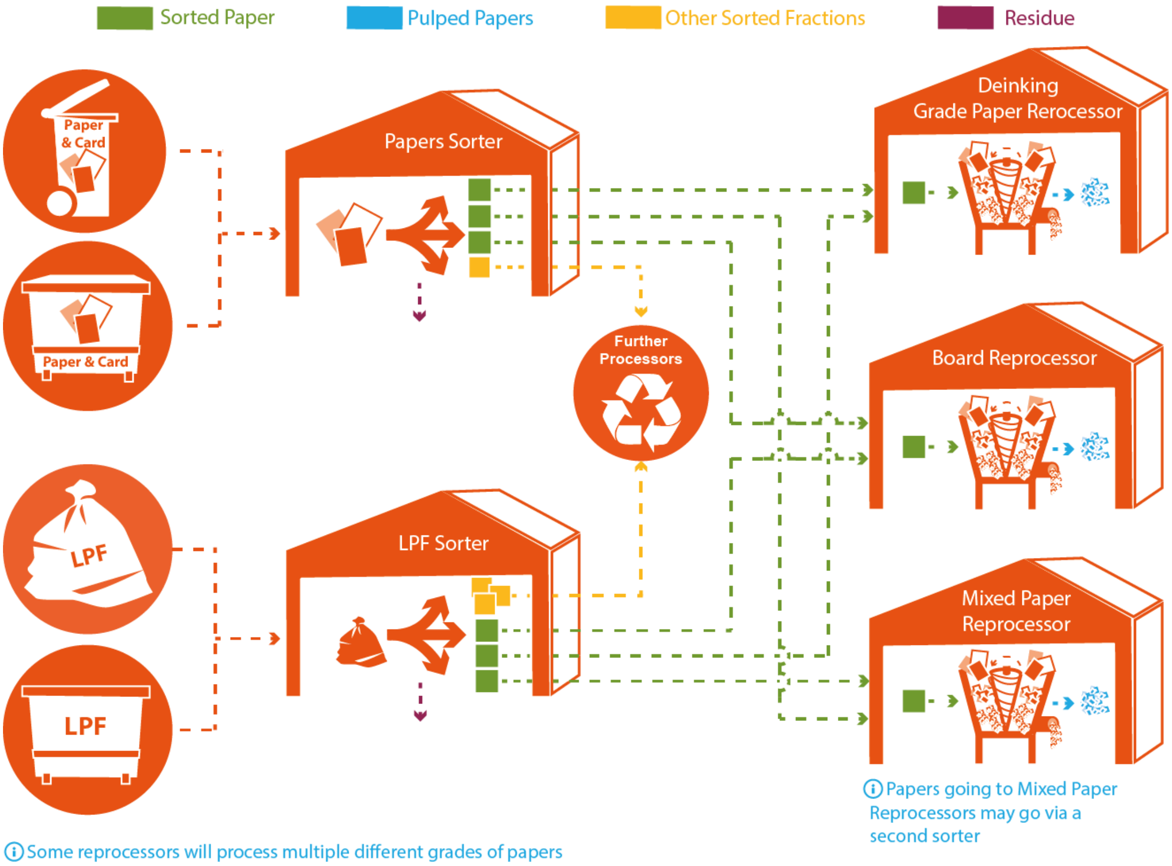
The typical recycling chain for papers (and cardboard) is illustrated in

Figure 1-4. In most countries included in the study, papers are collected separately from other materials, as a paper and cardboard mix. In some countries, papers are collected mixed with plastics and/or light packaging fractions.

At sorting plants (either dedicated paper sorting plants or light packaging fraction sorters) where the mix includes papers, the material tends to be sorted to separate out at least one grade that is suitable for acceptance by paper reprocessors (i.e. paper mills) and other offtakers. Paper reprocessors pulp the paper input, screen the material to remove non-target fibres, and carry out de-inking (to remove oil-based inks).

Paper reprocessors usually do not carry out additional sorting of de-inked or corrugated card board grades prior to processing, though it is understood that some reprocessors may carry out some further sorting of mixed papers grades prior to pulping (including to extract certain grades of paper in order to sell the material or feed into another facility owned by the same company). The sorted mixed paper and board output from one study plant was sold to a known reprocessor for the manufacture of board products without further sorting; for other plants, the extent of further sorting of mixed paper outputs was not known.

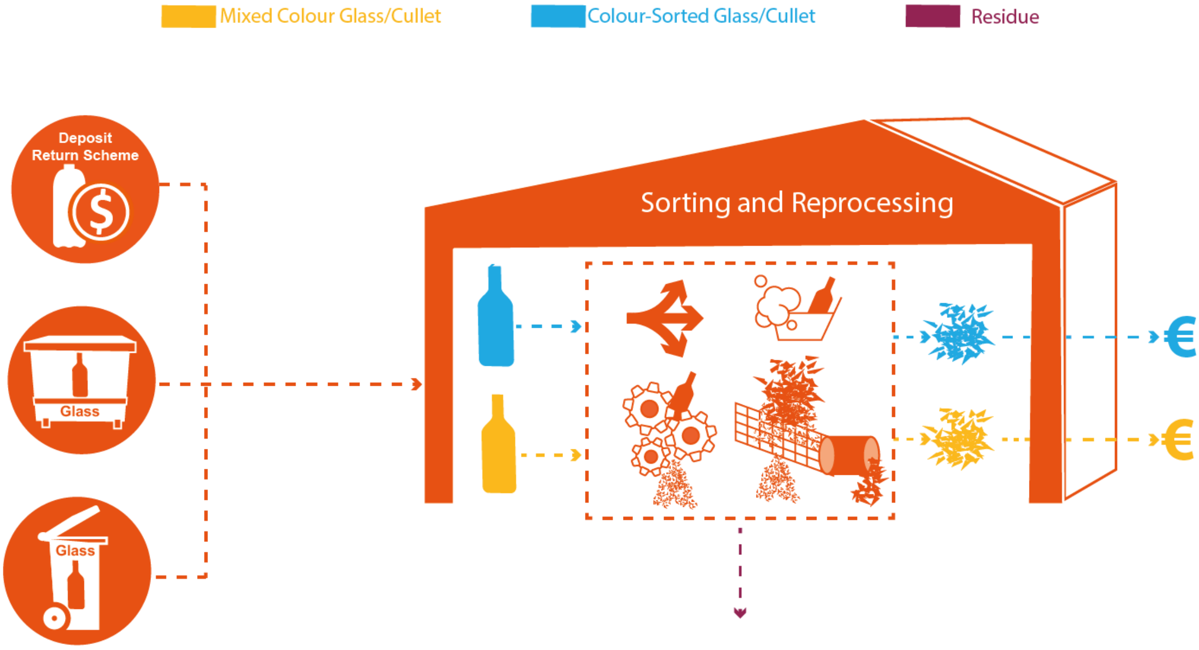
Figure 1-4: Recycling chain for papers



The typical recycling chain for glass is illustrated in

Figure 1-5. Most glass is collected through DRSs or separate glass collections. Colour separation at source is rare in household recycling collections of glass, and is becoming increasingly rare in bring site collection systems. In some countries, glass is collected mixed with light packaging and/or plastics. Most glass sorting facilities receive material from DRSs and/or separate collections. The study plants carry out sorting processes to remove unwanted impurities (such as ceramics) and to sort material into colours. From the study plants, the output colour-sorted cullet is supplied to re-melt applications for production of glass packaging or fibreglass insulation. Glass sorting processes produce a finer fraction of material with higher amounts of non-target material rejected earlier in the sorting process, that can (depending on additional investment and/or available markets) be further processed and sorted to feed back into re-melt applications.

Figure 1-5: Recycling chain for glass



The role of EPR schemes and PROs in the recycling chain

Extended Producer Responsibility (EPR) schemes for packaging waste are set up in most European countries to ensure the provision of collection arrangements for, and subsequent management of, packaging waste. The roles played by EPR schemes vary across different countries, but include combinations of some or all of the following features:

- Mechanism(s) for funding the collection of relevant materials, often via one or more PROs;
- The carrying out of collection of packaging waste streams (in some countries this function is carried out by municipalities);

- Contracting of sorting plants to sort material (in some countries this function is carried out by municipalities);
- Setting recycling targets for sorting plants (the amount of material output into saleable grades as a proportion of input material, sometimes customised to input composition information);
- Owning sorted packaging fraction outputs from sorting plants or buying these from sorting plants at agreed prices, and arranging for their onward sale/further processing;
- Setting quality standards for different sorted packaging fractions (either since the PRO(s) own the material, or to provide set standards to support the reprocessing sector).

To illustrate the degree of variation in how PROs operate across the countries where study plants were located, schemes in five example countries are summarised in Table 1-2.

Table 1-2: Examples of variation in PRO arrangements with sorting plants

Country	**France**	**Italy**	**Germany**	**Austria**	**Sweden**
EPR Scheme/PRO	CITEO	COREPLA	DSD	ARA	FTI
Owns sorting plants	X	X	X	X	Y
Provides material to sorting plants	X	Y	Y	Y	Y
Specifies choice of output fractions	X	Y	X	Y	X
Sets sorted fraction purity specifications	Y	Y	Y	Y	X
Owns/buys material	Y	Y (sells on in auction)	X	Y	X
Sets overall recovery targets	X	X	Y	X	X
Sets fraction-specific targets in contract	Y	X	X	Y	X
Variations	Plants have to bid for material from municipalities not PRO			Highly prescriptive and rigorous quality checks. Plants can sell some materials/ benefit from higher revenues	

1.2. Quality framework

Policy and legislation in the EU and Member States, in particular the revised Packaging and Packaging Waste Directive, has focussed on the quantity of recycling of each main material type, using recycling rates as a metric (material is either recycled or not recycled). There has been less focus on the *quality* of recycling, despite this being an important issue to consider. The main source of environmental benefit from recycling is in its ability to displace virgin material of the same kind. However, where the quality of recycling is insufficient, that direct replacement is not economically viable. Even when secondary raw materials do replace virgin material, it is often not economically viable for them to be recycled into the same products in a circular way. Recycling of a 'higher quality' may be needed in some areas to move towards a circular economy and enable higher overall recycling rates.

Higher quality recycling is not always economically (or even environmentally) preferable to lower quality applications in each specific instance. However, if there is too much supply and not enough demand in lower quality applications, and if markets for the lower quality outputs become saturated[1], there is likely to be an incentive to produce higher quality outputs in order to be able to sell the material.

This study seeks to provide a description of 'high quality recycling' in the 'Quality of Recycling: Towards an Operational Definition and Framework' report. The quality framework set out in that report seeks to move beyond simply a binary classification, (for example whether the material displaces demand for a virgin material or not). The framework attempts to describe the extent to which properties of the material being recycled are preserved, properties which are costly or unfeasible to recover once lost (i.e. transparency, colour form).

The framework is intended as a starting point for a practical, operational assessment of the quality of recycling at the level of individual sorting plants/reprocessors or whole recycling chains. Outputs from a plant (or from a recycling chain) can be graded against the quality levels defined in the framework to provide a description of the current quality of outputs, and to assess the impact on output quality of changes in the operation of one or more plants in the recycling chain. For example, a sorted fraction output which is of a lower quality (according to the framework) can be sent back through the process in order to be further sorted/treated in order to produce an output of higher quality.

The framework's descriptions of quality of recycling for PET can be found in Table 1-3 and for other materials (HDPE and PP, papers and glass) in Appendix A.1, along with a concise summary of the rationale for some the descriptions. For further detail, readers are referred to the 'Quality of Recycling: Towards an Operational Definition and Framework' report.

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[1] This is suggested by the disparity between pledges regarding increased collection and pledges regarding increased uptake of polyolefin recycled content evidenced within the Assessment report of the voluntary pledges under Annex III of the European Strategy for Plastics in a Circular Economy, available at https://data.consilium.europa.eu/doc/document/ST-7121-2019-ADD-1/en/pdf

Table 1-3: Framework quality levels for plastic - PET

Category	Quality/Value Dimensions	Rationale
A	Maintain/preserve IV, product type, transparency, colour; and food contact suitability	Preserves colour separation and suitable for use in the production of the same food-contact items
B	Maintain/preserve IV, product type, transparency, and colour	Preserves colour separation and suitable for use in colour-specific non-food-contact uses requiring high purity flake
C	Maintain/preserve IV, product type	Mixed colour bottle flake can be used for non-colour-sensitive applications that nonetheless require high enough IV (e.g. fibres and strapping). Separated trays can be separately reprocessed with lower losses compared to processing mixed with bottles
D	Other	Mixed, un-colour-separated bottle and tray flake that may need further sorting

*IV (intrinsic viscosity), measured in deciliters per gram (dl/g), is an important marker of quality. Bottle manufacture requires PET with high IV (0.75 dl/g and up to 0.84 dlg/g for carbonated soft drinks). Trays can made with PET of a lower IV (0.70) and textiles lower still (0.4-0.7).[2]

[2] Delta Engineering, PET, available from https://delta-engineering.be/pet?lang=hu; Equipolymers, available from https://www.equipolymers.com/pet-market.

1.3. Economic model of sorters and re-processors

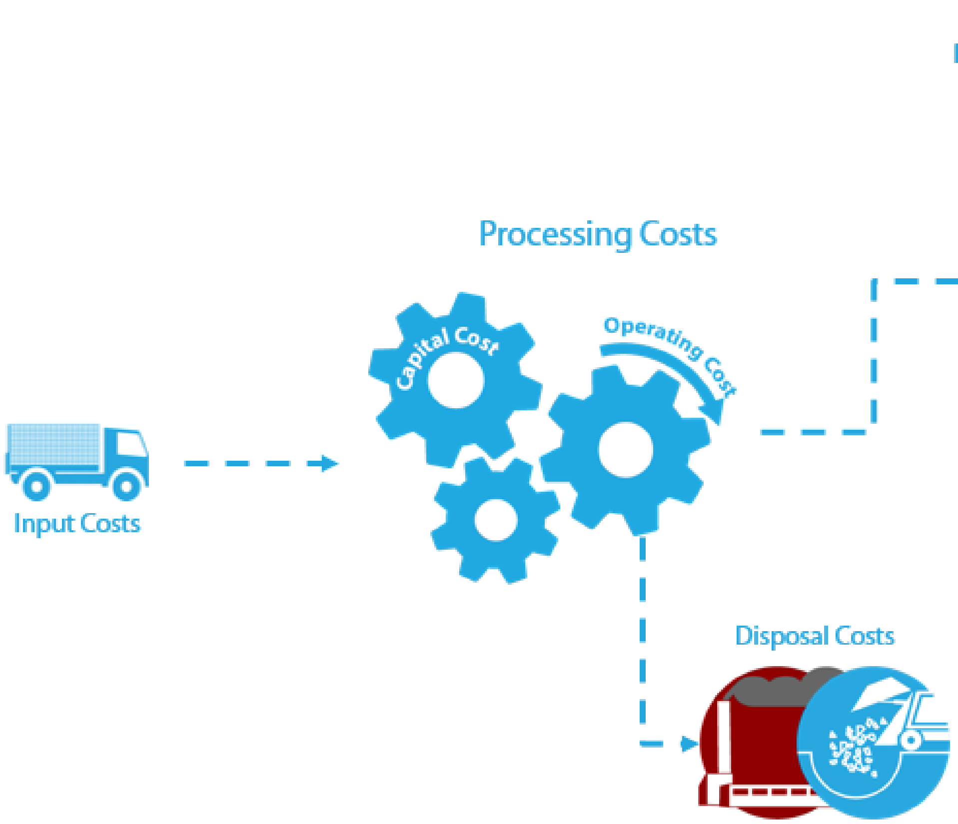
The quality of recycling achieved by sorting plants and reprocessors is strongly influenced by the economic context within which they operate. This context varies depending of the role of the plants in the recycling chain.

Plant operators either buy input material or are paid to process it. Operational costs are incurred in sorting and/or reprocessing the material, including paying off capital investments. Plant operators may sell outputs to offtakers under various arrangements (under contract to a PRO, on the open market, etc.), or the ownership of the material may reside with another actor in the recycling chain (i.e. PRO or municipality). Disposal costs will also arise for the reject fraction, which often fall to the plant operator.

The amounts of impurities (non-target material and contamination) in the input received by plants also impact costs, with higher amounts leading to greater amounts of reject material (with associated disposal costs) and lower quantities of saleable output, and/or increases in the cost of processing in order to achieve the required quality.

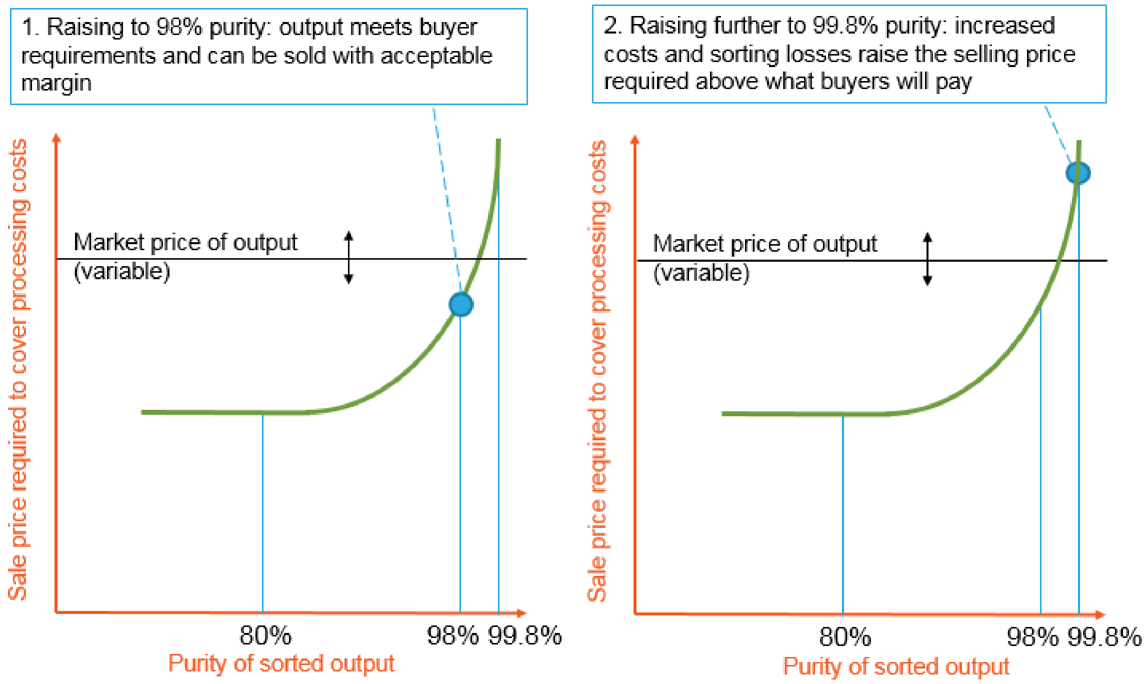
The economic features discussed above are illustrated in Figure 1-6.

Figure 1-6: Economic framework for sorting plants and reprocessors



From the point of view of sorting plants and reprocessors, if higher quality recycling outputs are to be achieved, it must be economically practicable to do so. The cost of improving the purity of sorted material fractions (and of increasing the amount of suitable material captured into these fractions) tends to follow a cost curve where, beyond a certain point, the removal of all or some of the remaining impurities can only be undertaken at considerable cost. Likewise, the costs associated with capturing a target material for a particular output also increase as you move towards recovering the last fraction of material (through the need to introduce additional sorting steps on reject streams). This dynamic is illustrated in Figure 1-7 below.

Figure 1-7: Illustrative Economic Viability of Producing Higher Quality Sorted Output



In order to make the additional sorting and/or processing steps economically viable, there needs to be sufficient change in the economic balance to enable this. The demand and value received from higher quality material needs to be sufficient to meet increased sorting and/or processing costs and to cover other potential changes in costs, as follows:

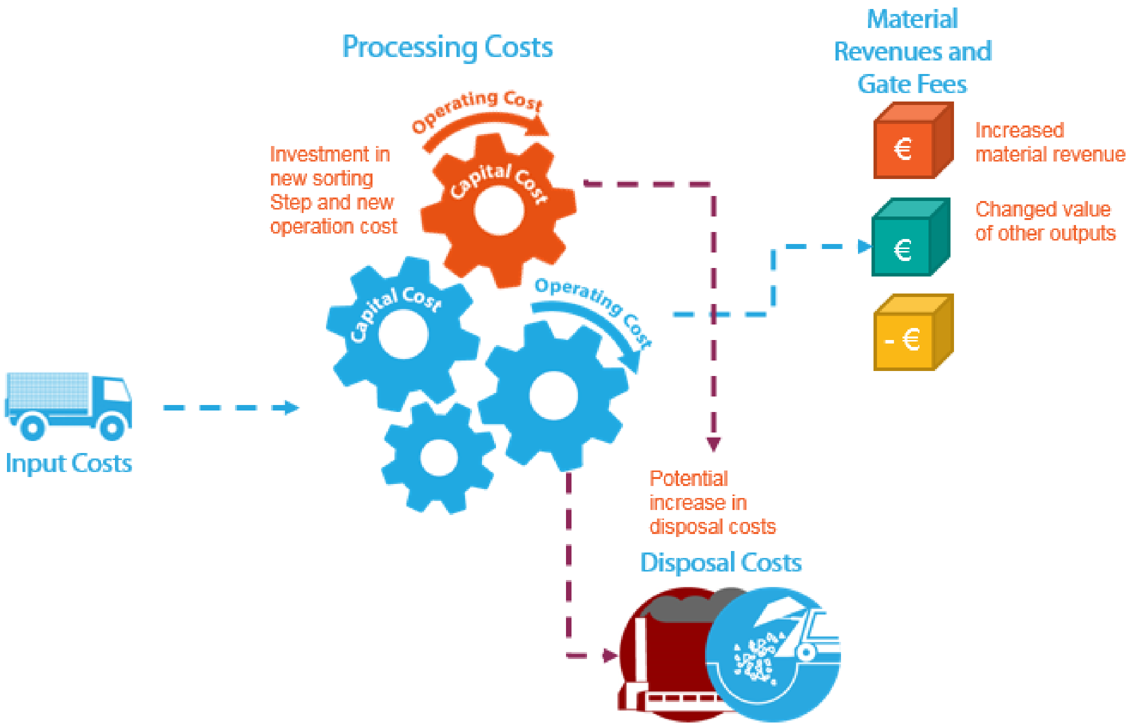
- Changes in disposal costs resulting from higher removal of impurities to enable a higher quality output, leading to higher tonnages going to disposal (conversely, increasing the capture of the targeted material reduces the amounts disposed).
- Changing revenues from other sorted fractions, due to how the increased quality affects the composition or level of impurities in other target sorted fractions. For example, separating transparent PET from a mixed colour PET fraction will make the mixed PET fraction darker, which has a lower sales value than lighter coloured mixed PET (with a higher transparent PET content).

Such increased material value would also need to be sufficiently reliable for a plant to consider that there is a business case for producing a higher quality output.

If quality is required to increase, by changes in legislation or by PROs, then plants would only be able to continue operating if increased costs are balanced out by additional revenues (or a change in payments).

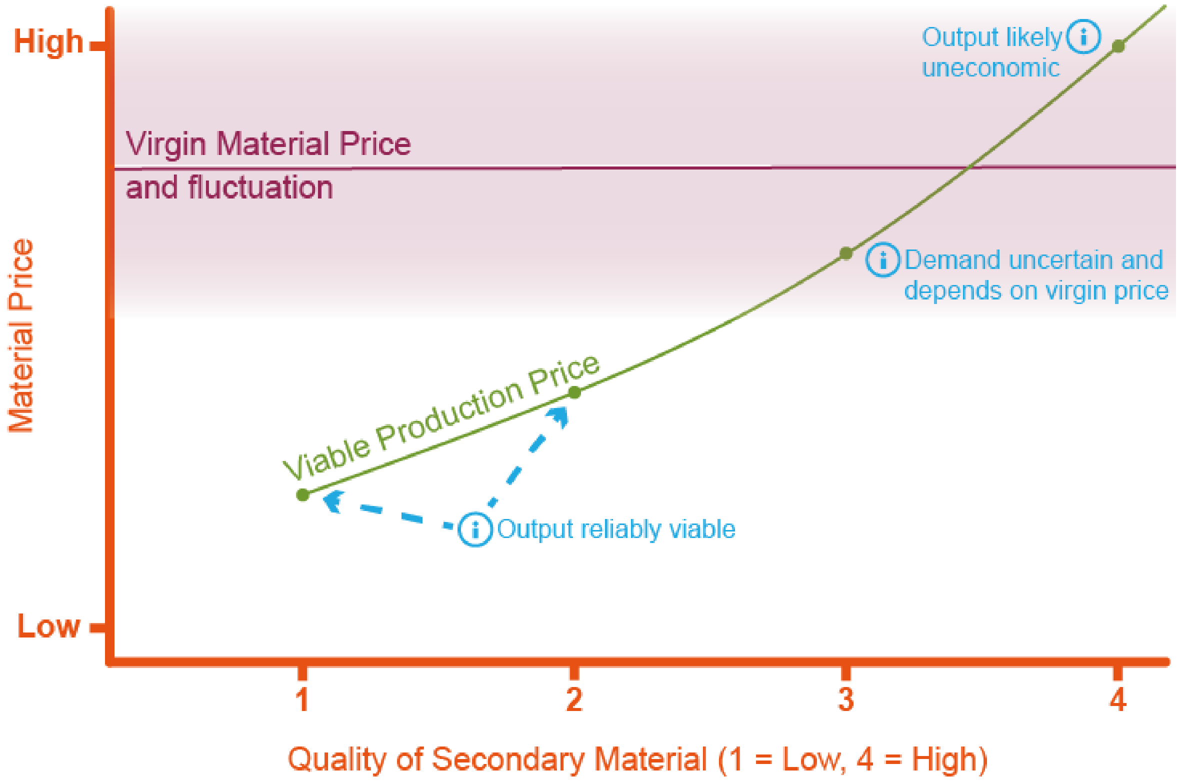
Figure 1-8 illustrates the key components of the economic model for increasing the quality of outputs at sorting plants.

Figure 1-8: Economics of increasing quality



The price of secondary raw materials is typically bounded by the price of the respective virgin materials, except in some specific circumstances where the secondary raw material is valued higher that virgin. In all cases, for the production of higher quality secondary raw material to be viable, the anticipated selling price for the improved material needs to be sufficient to cover the additional costs of production and meet the profit margin required by the plant operator. Conversely, where the additional costs and required margin to produce an improved secondary raw material exceed the prices of the relevant virgin materials, there is unlikely to be a suitable demand generated for the higher quality output (producers will choose virgin material instead). A further factor is that prices of virgin materials tend to fluctuate, and therefore the prices of secondary raw materials fluctuate. The associated uncertainty affects plant operator's confidence in demand for their outputs at prices required to make production viable and so investment decisions may be deemed "risky". This dynamic is illustrated in Figure 1-9 below.

Figure 1-9: Economic Viability of Producing Higher Quality Secondary Raw Materials



The bounding of secondary raw material prices by virgin prices has some important exceptions. For example, demand for secondary raw materials as opposed to virgin materials can be driven by legislation and public sustainability commitments from brands. In cases where demand is sufficient compared to the supply of that secondary raw material and substituting virgin material is unacceptable, then the price of the secondary raw material may exceed the market price for the virgin alternative. In the current market (at time of writing), this is understood to be the case for food-grade rPET for bottle production.

2. Analysis of drivers at individual plants

The findings in this section are based upon visits and interviews with 25 sorting and reprocessing plants. Findings are derived from plants from a wide range of locations, scales of operation, company types and roles in the recycling chain, although there are only a small number of examples of any particular type of plant. The findings reflect general drivers in relation to achieving high quality recycling for sorting plants and reprocessors in the EU, with particular relevance to the countries where the surveyed plants are located. However, conclusions drawn from specific plant visits and performance data referenced from individual plants may not be directly applicable to other plants beyond those studied.

This section is structured around material types (plastics, papers, and glass) sorted and/or reprocessed by the plants studied, in order to explore distinct themes across those plants, specific to their role in the recycling chain. An examination of how factors acting at the individual plant level play out across the whole recycling chain is presented in Section 3. A summary of the plants visited is provided in

Table **2-1**. Much of the information provided by the plants is commercially sensitive; plant identities are therefore anonymised by using a plant ID in place of the plant name, and a significant amount of detail on individual plants cannot be disclosed in this report. Case studies detailing specific plant information are included in Section 3.

Table 2-1: Plants included in the study, by type and location

Plant ID	Sorter (S) or Sorter and Reprocessor (S+R)	Plant type, by materials accepted for sorting / reprocessing	Location
D1	S	Plastic bottles, PTT, film, paper and board, metal containers, aseptic containers	France
D2			France
D3	S	Plastic bottles, PTT, film, paper and board, metal containers, aseptic containers, glass containers	Greece
D4	S	Plastic bottles, PTT, metal containers, aseptic containers	Denmark
D5			Hungary
D6			Spain
D7			Germany
D8			Austria
D9			Germany
P1	S (+R)*	Plastics, Mixed (direct from collections and sorted fractions)	Italy
P2	S+R	Plastics, Mixed (direct from collections)	Sweden
P3		Plastics, PET	Austria
P4			Germany
P5	S		Croatia
P6	S+R	Plastics, PET (bottles and trays)	Netherlands
P7	S+R	Plastics, HDPE/PP	Germany
P8			Germany
P9			Germany
P10	S (+R)*	Plastics, HDPE/PP/PS	Spain
P11	S+R	Plastics, LDPE Films	Austria
P12			Netherlands
F1	S	Paper	Germany
F2			Germany
G1	S+R	Glass	Germany
G2			France

*Companies also ran and provided insight into follow-on reprocessing operations

2.1. Plastics sorting plants

The group of plastics sorting plants analysed in this section are those that:

- Receive a collected material stream; or
- Are secondary sorters, receiving a mixed polymer bale and outputting bales of sorted packaging material.

Plants that fall under either of those two groupings are analysed together in this section due to the similarities in the economic model between them. The sorting plants in this section are typically contracted to sort material by either municipalities or a PRO(s), and they typically sell sorted outputs to PROs or reprocessors. Reprocessors (that also have sorting steps) are covered separately in Section 2.2. Plants that primarily sort material but carry out some reprocessing either within the same facility, or at another facility owned by the same company are included in both this section and Section 2.2.

The nature of plastics sorting plants is, to a large extent, determined by the prevalent collection systems in place for plastic packaging in the country where each plant is located. Most plastics sorting plants included in the study sort input material from LPF collections, which is usually a combination of plastic packaging, metal packaging, and often with aseptic containers. Input material from some collection schemes also includes other non-packaging plastics, and in some countries the collection mix includes papers. Where plastic packaging is collected separately from all other materials, this stream feeds directly into plastic sorting plants in these locations. In most cases, plastics sorting plant operators then sell on sorted fractions to secondary sorters and/or reprocessors. Some plants carry out further reprocessing steps on some outputs within the facility, or at another facility owned by the company.

Plastics sorting plants differ in scale, with smaller plants tending to output a smaller range of sorted fractions. There are two key dimensions to the quality of outputs from the sorting operations at plastics sorting plants:

- The number and range of the separate sorted packaging fractions the plant produces, which is largely influenced by the overall process design of the plant (established when the plant is built, subject to any subsequent significant reconfigurations or additions to the process).
- The purity levels of the sorted outputs, which is largely influenced by variations in the effectiveness of different sorting methods and process designs (for example, manual positive pick producing higher quality outputs) and from ongoing quality management and quality control stages.

The main variation in quality drivers for sorting plants depends on the nature of their contract with PROs or municipalities, in particular the extent to which they are exposed to material revenues and/or have yield targets for specific fractions set within the contract. The set of defined output fractions with associated purity specifications (i.e. standards for sorted plastic packaging) are a very important determinant of the choice and purity of sorted fractions from sorting plants and the quality of output bales, particularly where PROs also buy or own the resultant sorted fractions output.

The resulting different quality drivers acting on sorting plants in the study are summarised at a high level in Table 2-2.

Table 2-2: Quality drivers on plastics sorting plants (including LPF sorters but excluding plastics reprocessors with minimal sorting)

Plant ID	Plant type, by materials accepted for sorting / reprocessing	Location	Main Drivers			
			Sales revenue from improved quality outputs	***Meeting contract specification yields of specific fractions***	***Overall Recycling Target***	***Only really meeting offtakers specification***
D1	LPF + papers	France	Minor	Major		
D2		France	Minor	Major		
D3	LPF + papers and glass	Greece	Major			
D4	LPF	Denmark				Major
D5		Hungary	Major		Minor	
D6		Spain				Major
D7		Germany			Major	
D8		Austria		Major		
D9		Germany	Minor		Major	
P1	Plastics, Mixed	Italy	Minor	Major		
P2		Sweden	Major			
P5	Plastics, PET	Croatia	Major		Minor	
P10	Plastics, HDPE/PP/PS	Spain	Major			

Sales revenue from higher quality outputs

The choices by plant operators on the output fractions produced at the plant and the quality of these fractions are heavily influenced by the extent to which there is sufficient additional material revenue received from achieving higher quality outputs.

Most improvements in output quality noted during the survey were driven by additional net revenues for the operator realised by improving quality or introducing additional grades. Where plants are exposed to market revenues for their sorted fraction outputs (through their contracts with municipalities or PROs), this is a key driver in determining what sorted fractions the processes are designed to output and in making improvements to increase quality. Plants that would receive higher additional material revenue from higher quality outputs have an ongoing commercial driver to improve quality (either by changing output grades or improving purities) where this would result in sufficient additional revenue to cover the increasing processing and other costs.

Benefiting directly from higher revenues incentivises plants to make adaptations where there is increased revenue from different outputs, but also leads to plants opting not to sort some fractions due to insufficient revenues.

Whether there are higher revenues from sorted fractions with lower levels of impurities depends on the plant and material. Some plants selling outputs to the market outside of PRO arrangements were exposed to pressure to meet and exceed common international quality standards for some materials (notably PET outputs, but also others) in order to ensure a range of buyers for the material. However, some plants indicated that offtakers were content to receive material at lower than the purities specified by the PRO. Levels of impurities (within bounds) may be a relatively minor influencer on market prices.

Meeting contract specifications on grade yields

Where a PRO prescribes a wider range of sorted fractions, this will lead to fractions being separated to a greater degree than may otherwise have been the case (for instance, PET trays, opaque PET, colour sorted film grades, specific PP fractions).

Where PROs specify a yield requirement for a particular fraction at a particular quality, there is often little drive to improve quality beyond that specified in the contract and often a financial incentive to not exceed the purity standards specified. This is particularly true in cases where the operator has minimal exposure to material revenues. To improve the quality beyond that specified would likely entail costs in upgrading the process, or running the current process at a slower speed. The removal of more impurities from the sorted packaging fractions (beyond the specified purity standard) would result in lower sorted material fraction weights, which in turn may reduce revenues to the plant operator. In addition, the removed impurities would end up in the residue stream, meaning disposal costs would increase. Therefore, for plants that produce material based on grades and qualities specified in a contract and sold to PROs, the focus on quality needs to be at the point of revision of purity specifications and at contract renewal. In the absence of the PRO making subsequent amendments to the specifications for the quality of sorted packaging fractions, further improvements to quality are unlikely to be made by the plant.

Recycling targets

Recycling targets (a target to ensure a certain fraction of input material is recycled) set within sorting plant contracts can act as a strong driver to increase the quality of recycling output where the economic driver is not sufficiently strong. Targets can encourage additional capture of target material into sorted fractions, and can make the difference between materials sent to disposal or to recycling where the economics are more marginal.

However, targets can also lead to pressure to lower the purity of outputs (within the bounds of what reprocessors will accept) if the recycling target is measured on the basis of output contained in saleable grades, as there is then an incentive not to remove impurities beyond what is minimally acceptable.

Meeting offtaker specifications

Some plants included in the study had very little incentive to improve quality, having neither pressure from recycling rate targets nor specific grade or yield targets. In these cases, plant operators considered the quality of outputs sufficient so long as they met offtakers' required specifications (whether PROs or reprocessors). So long as these qualities were economically achieved, there tended to be little incentive for the plant operator to consider improvements in grades or outputs during the time period of the arrangement with offtakers (e.g. contract length with PRO).

Other factors

Some plants had more specific factors constraining the quality of outputs that they produced; for instance, there were limitations of physical space or the construction of the plant made it difficult or impossible to expand existing equipment (for example to widen process belts) or install new sorting or processing units.

Summary

Though there is considerable variation in the drivers for quality experienced by different sorting plants, in many cases the main secondary raw material outputs from the recycling chains ended up at a similar quality. In some cases, the overall quality outcome would not be improved by increasing purities of sorted fractions from sorting plants beyond minimum standards set by PROs or reprocessors, because sufficient further sorting steps to control for quality are typically conducted at a later stage of the recycling chain.

Most plants had already made process changes to improve quality or quantity where there was a relatively clear economic case. Most remaining opportunities for further improving quality and quantity were higher risk and/or with a weaker economic case, where the material income driver was less influential in the decision.

Where the economic case for improving qualities was more marginal, other drivers became stronger determinants in the outcomes for both sorted fractions and purity levels of sorted fractions:

- In response to PROs specifying output grades, plants were set up to output a wider range of fractions;
- In response to PROs setting recycling targets, grades were being sent for recycling that might otherwise have gone to disposal. Conversely, in the absence of recycling targets, further sorting of the reject fraction that could have been done was not being done;
- Where plants were not exposed to the benefit from material revenues and operated to set yield targets, there was no incentive to make further changes;
- Plants did meet the purity specifications demanded by PROs and in some cases these were higher than what is acceptable to reprocessors. However, where PROs bought the material, there was no incentive to increase the purity of sorted fraction grades beyond minimum standards.

Additionally, a key determinant of whether additional fractions were sorted was the scale of plant operation. Larger scale plants gained from economies of scale, thus the additional costs of further sorting steps were lower per tonne of material sorted.

Key findings

- In some cases, the overall quality outcome was not improved by improving purities of sorted fractions from sorting plants beyond minimum standards set by PROs or reprocessors, because further quality control sorting steps are typically conducted at a later stage of the recycling chain.
- A key driver in the implementation of plant operation improvements associated with material quality is where the plant operator can realise the benefits of additional income from either improving the quality of a grade of material or separating materials into additional grades, and that income outweighs the investment cost of making those changes. The majority of improvements noted during the survey were driven by additional net revenues for the operator by improving quality or introducing additional grades. However, these more straightforward, relatively easy, quality and quantity decisions have mostly now been made; remaining opportunities for further improving quality and quantity are higher risk and/or with a weaker economic case, and therefore the material income driver becomes weaker.
- The scale of sorting operation is a key varying factor between sorting plants, with plants at a larger scale having a better economic case for sorting more specific fractions (e.g. white/opaque HDPE).
- In a number of surveyed cases the plant operator does not realise the benefits of additional income from either improving the quality of a sorted fraction of material or separating materials into additional sorted fractions. The more significant driver in most of these cases is the need to meet the output specifications set on the grades of materials. In these cases it is typically the PRO that is contracting the operator and setting the specifications. The PRO could, therefore, drive further quality improvements by altering the specifications, though there were no specific instances of this having occurred recently from the plants that were surveyed.
- At the plant operator level, as the cases for improving quality and quantities of material become more economically marginal, or in the cases where they do not experience this economic driver, then it would seem likely that PROs could play an important role in specifying or creating the economic drivers for:
  - Further sorting into new sorted fractions;
  - Improvements to the quality specifications of existing sorted fractions; and
  - Tolerances for the amounts of target materials that can be sent for disposal rather than recycling.

2.2. Plastics reprocessing plants

The plastics reprocessors studied sold directly to users of secondary raw materials rather than to PROs. They tended to be set up to produce material of a certain quality or range of qualities to meet the specifications of different manufacturers utilising the secondary raw materials ("Convertors"). It is the requirements of these convertors that determined the material qualities that plastics reprocessors needed to produce.

Producing a higher quality grade output from a pre-sorted fraction might entail:

- Further sorting of materials whilst still in packaging form using manual and mechanical methods;
- Conducting additional cleaning steps such as hotwashing;
- In the stages post washing, separation of flakes of different colour grades, removal of contaminants and improvements to the output flake to improve the potential clarity of products manufactured from the flake; and/or
- Further decontamination and polymer improvements during extrusion processes.

The major factors influencing the quality of material produced by plastics reprocessors include the additional revenue available from higher quality fractions, and the consistency and reliability of demand for higher quality outputs. The different polymers (PET, HDPE, PP and PE) also have different challenges regarding quality due to:

- The comparative level of variability in the sorted fractions (colours, product types, additives);
- Differing amounts of problematic product features (adhesives, multi-polymer layers, less compatible resins); and
- The permeability of the material (absorbing odours, chemicals and compounds which are hard to remove).

The factors that led reprocessors to *increase* the quality of material produced were:

- Changes or anticipated changes in demand for higher quality material; and
- A concern to position themselves as a producer of quality material.

Conversely, where opportunities to improve quality were *not* taken, the main reasons cited were the volatility of secondary raw material markets and a lack of confidence in seeing sufficient return on investments.

The main drivers or barriers experienced by different plants in the study are shown in, and notably vary by polymer. Each polymer is discussed in turn below.

Table 2-3: Quality drivers on plastics reprocessing plants

Plant ID	Material Reprocessed	Location	Main Drivers or Barriers for Increasing Quality of Outputs			
			Material degradation particular challenge	*No increases considere d possible*	*Costs required would be too high in relation to demand*	*Consistency of demand at higher price*
P1*	PET/HDPE/PP	Italy			Minor	Major
P2	HDPE/PP	Sweden		Y		
P3	PET	Austria		Y		
P4	PET	Germany		Y		
P6	PET trays	Netherlands		n/a		
P7	HDPE/PP	Germany				Major
P8	HDPE/PP	Germany				Major
P9	HDPE/PP	Germany				Major
P10*	HDPE/PP	Spain			Minor	Major
P11	PE Films	Austria	Y		Major	
P12	PE Films	Netherlands	Y		Major	
*Sorting plants studied whose operators ran and provided insight into subsequent reprocessing operations elsewhere						

PET

Demand from bottle producers for recycled PET (rPET) is high; the material is relatively uniform, impermeable and is not degraded through use or in the collection systems. The relative costs of cleaning the flake to a suitable standard can, in general, be recouped in the value received for good quality transparent and light blue bottle flake. Mixed colour flake also has output markets, with higher tolerances for some impurities. The yield of rPET from PET trays is low when trays are processed on bottle reprocessing lines. However, with prices and demand high for rPET, and a large amount of available input material, further development of PET tray reprocessing capacity is expected in the near future.

HDPE/PP

For HDPE and PP, market demand for higher quality material is weaker. Quality challenges are also higher due to the chemical variation in the polymer group, greater use of colour and greater absorbency of the material, and the collected material has higher levels of organic and chemical contamination than PET due to the product uses. The major markets for HDPE/PP secondary raw materials currently only require a limited degree of colour separation and typically have a higher tolerance for odour. There are some applications for recycled HDPE and PP that require higher quality material (e.g. packaging), but the variability of virgin material prices, and the corresponding risks to stability of demand, mean that there is not currently a reliable demand pull for higher quality recycled HDPE and PP. This market uncertainty limits investment in projects to improve HDPE/PP output quality. However, a premium does exist for high quality, natural or white HDPE outputs for use in packaging, and a smaller premium for other outputs with reduced odour and more structural uniformity suitable for more delicate product applications (e.g. thinner walled products/packaging). Some plants are geared towards producing these slightly higher quality outputs, and either have already made or are planning relevant investments. From the group of plants studied, the operators that have invested to raise the quality tended to be operating large scale plants. This may well indicate that reprocessors need to be operating at the larger scale for there to be a reasonable economic case to improve the quality of recycled HDPE and PP. Higher quality material would also have a wider choice of offtakers, providing more security in finding buyers. However, company positioning can also play a role where economics are marginal, with one reprocessor positioning itself in the market as a producer of higher quality material.

PE Film

PE film from household packaging is mainly used in dark coloured applications with tolerance for odour, such as refuse bags. The relatively low yields combined with the high challenges of film processing mean that there is currently no economic case for investing in additional sorting and cleaning steps to create a higher quality output (e.g. clear de-odourised film for packaging applications).

2.3. Paper sorting plants

Two paper sorting plants were visited as part of the study. Both were situated in Germany and provided the majority of their de-ink output to German mills. The findings presented below may have been different had the study sample been larger and/or had it included paper-sorting plants *without* close relationships with specific mills.

Both plants sorted material direct from household collections, with limited control over quality of inputs they received. Both plant operators also experienced increased challenges to quality with the change in composition of the input mix (a decrease in newsprint and growth of board grades, with an increase in smaller sized board and difficult to remove inks). The plants existing contracts differed in economic structure:

- One plant operator was paid a processing cost per tonne and had no ownership of material, but was working in the context of a long-term agreement (made by the plants' owner) to provide a reliable supply of de-inked paper into a specific mill.
- The other plant operator bid for material directly and sold its outputs onto the market, but the plant's owner bought most of its output to be used within the same company to supply their own mill.

Accordingly, though the quality of output in both cases was driven directly by the requirements of offtakers, paper mills and traders, there were differences in drivers reflecting the particular circumstances:

- The first plant operator placed a greater emphasis on stability and confidence of long-term demand (the prospect of increased revenues was secondary as they saw no benefit themselves).
- The other plant operator was more directly focused on optimising sales revenues in relation to costs.

The main drivers are shown in

Table 2-4.

Table 2-4: Quality drivers on paper sorting plants

Plant ID	Location	Main Drivers for Quality	
		Material revenues from higher quality	*Yield targets set by contracts*
F1	Germany		Major
F2	Germany	Major	

The two paper sorting plants sought to maximise yields captured into a 'de-inking' grade material (EN643 grade 1.11), and also produced a corrugated cardboard grade (EN643 grade 1.04) with either one or two lower quality accompanying mixed paper grades. Most of the material in the mixed grade was grey/white board and smaller sized papers, the material collected but neither sorted into either a de-inking or a corrugated cardboard grade. Mixed paper grades are therefore largely defined by the collection and sorting processes rather than the requirements of reprocessors. At both of the paper sorting plants visited as part of this study, it was observed that no effort was made to remove non-paper materials from this grade, resulting in high levels of impurities.

The markets for the higher quality EN643 grades 1.11 and 1.04 are well established: the material is used as a key input by mills producing newsprint, corrugated cardboard and testliner. Though attracting lower prices, the remaining mixed paper grades also have offtakers – one mill uses these to produce the back of white-fronted testliner. Tissue paper manufacturers also provide an outlet for lower quality and fine-sized mixed paper grades.

In both cases, the plant operators saw little need to change or improve the quality of the outputs they produced, since their current output meets key offtaker requirements. Small differences in the quality of de-inked grades can be tolerated by mills without being detrimental to the process because mills can subsequently increase the quality of the input to the required whiteness by mixing it with a different input grade from commercial or post-industrial sources.

The value associated with the de-inking grades is high enough to incentivise both plant operators to continually review and look to implement:

- Additional recovery cycles to increase its capture; and
- Cost-effective technologies to improve sorting efficiencies and yields into de-inked grades as they become available.

Plant operators from both plants were able to identify potential marginal improvements in yields that were not yet economically viable, for example additional NIR or air-separation steps to recover additional de-inking grades.

Both plant operators reported that there is a desire from mills to further address specific quality issues in the de-inked paper supply that cause problems in pulping, for instance excessive levels of cardboard remaining in de-inked grades, but an acknowledgement that this requires larger investment in sorting plants that may not be commercially viable.

2.4. Glass sorting and reprocessing plants

Two glass sorters/reprocessors were visited for this study. One primarily received streams of glass that were colour-separated at source, and one received a mixed colour glass input. Both were a similar scale of operation, processing 200-250 thousand tonnes of material per annum.

They both primarily produced cullet for re-melt for glass packaging manufacture. One study plant operator reported that the demand for colour-separated cullet for re-melt was high and growing (though, due to competition for input material, the amount they paid for input material was also rising). The other plant was owned by a glass manufacturer and the operator was paid a processing cost plus a margin.

Transport costs for glass are an important factor in glass recycling given the relatively low value of material per tonne. Therefore, the presence of major glass-using industries (either glass packaging manufacturers or fibreglass producers) in the region can act as a strong demand pull with regards to the quality of recycling.

The purity of material required for re-melt is very high (with limits in the grams per tonne) and is complex to achieve given the variation in input material. Due to the technology costs and the comparatively low value of the material per tonne, glass sorting plants need to be established at a very large scale to be viable. Investments in upgrading quality are thus also considerable (typically over €2M). Therefore, access to capital was noted as an important factor in enabling investment in quality.

The plant operator included in the study that was paid a processing cost plus margin was insulated from drivers to improve output quality over and above that currently specified. Since yield and quality targets were being met, there was little incentive to make further ongoing improvements in, for instance, a greater degree of colour separation or a reduction in losses of target material to the reject/fines fraction.

A summary of the main drivers for improving quality is shown in Table 2-5.

Table 2-5: Quality drivers on glass sorting plants

Plant ID	Location	Main Drivers for Quality	
		Material revenues from higher quality	*Yield targets set by contracts*
G1	France		Major
G2	Germany	Major	

Both plant operators sold the large majority of their output to glass packaging manufacturers and therefore already work to tight and established quality requirements. Thus, the study plant operators considered the reject/fines fraction as the main focus for further quality improvements. To recover additional glass from this reject/fines fraction into re-melt outputs, substantial additional investment is needed in an extra processing stage involving washing, drying, and sorting. The reject/fines fraction has considerably higher levels of impurities (it contains all the material rejected earlier in the sorting process) and even after processing the remaining impurities can mean it has to be mixed in with other cullet at relatively low proportions (in one plant, at a ratio of 5:95) to keep overall impurities acceptable for glass packaging re-melt. At one of the plants studied, the fines/reject fraction was sometimes sent to insulation foam production. In both cases, investment in further processing of the reject/fines fraction was planned in the near future.

3. Analysis of drivers across the recycling chain

This section presents key findings from the analysis of the relative contribution of different parts of the economic model (demand for outputs, cost of making improvements to plants and processes, access to capital investment) in driving or constraining the quality produced. An assessment is provided of the conditions required across the recycling chain in order to enable improvements in the quality of recycling outputs.

The term 'higher quality' in this context is defined as the balance of outputs higher up in the levels of quality outlined in Section 1.2, i.e. a greater degree of separation by product characteristics, or a relevant other marker of quality differentiating between possible output uses.

3.1. Achieving high qualities: findings from high quality recycling chains (PET bottles, glass packaging)

The production of higher quality recycling outputs is widespread in the PET and glass packaging sorting and reprocessing industries. Both PET beverage bottles and glass packaging are recycled such that the same, or similar, products are subsequently produced, i.e. circular production. In these cases, a combination of factors work together to make the production of higher quality outputs viable, summarised below and discussed further in Section 3.1.1:

- high level of market demand for outputs;
- the intrinsic nature of the material is largely impervious to absorption of contaminants;
- the materials are generally collected in a manner to enable sorting facilities to readily separate the relevant sorted packaging fraction; and
- the level of degradation in the material with each pass through the recycling chain is relatively low (compared to other sorted packaging fractions with typically lower quality fates).

However, even for PET and glass, in some cases the above factors are not in place, or other factors limit the amounts captured into higher quality, circular uses; this is discussed further in Section 3.1.2. Opportunities for marginal improvements in material that is captured into these higher quality streams are outlined in Section 3.1.3.

3.1.1. Factors enabling high quality recycling

A number of the plants studied sort PET into a quality that would be sufficient for reprocessors to produce rPET for bottle to bottle manufacture. Both of the glass sorting plants studied produce glass suitable for re-melt back into glass packaging Multiple drivers work together to enable this type of high quality recycling, as follows:

Demand from producers for the secondary raw material

There is high demand for high quality materials from beverage bottle manufacturers (both PET and glass). Sustainability commitments by consumer-facing brands have kept prices high for food-grade rPET polymer, whilst the price of virgin polymer has fallen lower, since producers are committed to purchasing secondary raw materials. Similarly, demand for glass cullet of high quality is high and sustained.

Intrinsic impermeability of the material

Compared with other plastics polymers, PET is relatively impermeable to odours and chemicals. It is therefore comparatively easier to clean PET to produce a secondary raw material with low levels of odour and contaminants than for other plastics polymers. Glass is not degraded in the recycling process, so long as impurities are kept to an acceptable level for re-melt processes.

The product uses are also relevant, since beverage/food packaging (the major use of PET bottles and glass packaging) results in relatively low levels of chemicals and organic contamination remaining in products in collected streams and sorted fractions.

Collection systems that avoid degradation of the material

DRS schemes provide material which already meets a key criteria for the production of food-grade secondary raw materials in that it is guaranteed to be >95% food contact.[3] In the case of PET bottles DRS schemes also provide material which is also free from non-bottle PET, thereby reducing processing costs. The higher costs associated with this type of collection are covered by the packaging producers. Glass is usually separately collected (again sometimes via a DRS), and in some areas is collected in colour-separated streams at bring sites.

Sufficient quantities of homogenous material to enable plants to operate on a large enough scale

Collected PET bottles and glass packaging have sufficient proportions of clear material for there to be an economic case across the recycling chain to sort the material into at least these two colour separations. PET bottles and glass are also relatively homogenous materials with low levels of variation and complexity in product design (use of adhesives etc).

Summary

The following factors contribute to maintaining economic conditions suitable for high quality recycling. In the case of PET:

- the majority of plastics sorting plants can separate PET beverage bottle streams by colour (either initially at the sorting facility or sometimes at another facility that carries out secondary sorting); and
- reprocessors can produce colour separated secondary raw material outputs; and

[3] Commission Regulation (EC) No 282/2008 controls the use of recycled plastic for food contact applications. Article 4 sets out the conditions for the authorisation of recycling processes. The European Food Safety Authority (EFSA) publishes scientific opinion papers evaluating the safety of specific recycling processes, and has also published a paper on the criteria they use for the safety evaluation of a mechanical recycling process to produce rPET, available from http://www.efsa.europa.eu/en/efsajournal/pub/2184. Regarding input material to the recycling process, this paper concludes 'The Panel considered appropriate that the proportion of PET from non-food consumer applications should be no more than 5% in the input to be recycled.'

- economically viable cleaning and decontamination processes allow the secondary raw material to be safely used in the manufacture of food contact packaging.

For glass, similar factors also maintain a flow of collected glass back into colour-sorted bottle-to-bottle re-melt.

For these materials, the role of PROs in improving quality may be fairly limited (beyond for instance harmonising or pushing up purity standards for these sorted fractions), since the economic drivers for setting up plants to produce these quality outputs are relatively strong.

The following case studies illustrate examples from surveyed plants that have shifted production towards higher quality PET outputs.

Case study 1: PET reprocessor shifting to food grade production

In response to increased demand from producers, the operator developed the plant to produce food-contact suitable pellet. The plant shifted from producing lower-grade flake for the strapping sector to producing colour-separated grades of food-contact pellet.

Illustrative change in output quality in the PET quality framework:

	Before	**After**
Grade A – Food-grade colour-sorted bottle pellet	-	80%
Grade B – Non-food grade colour-sorted bottle pellet	-	20%
Grade C – Mixed colour to strapping	100%	-

To produce the non-food-grade, the plant incorporated 20% material from German LPF collections (which is high in non-beverage materials).

Change in components of economic model:

Input material: predominantly from a collection system without a DRS.
Processing costs: significant capital investment and additional cleaning steps.
Outputs: higher value obtained from food-grade output pellet, and secondary output of (still high value) PET pellet for non-food grade uses.
Disposal: 5% additional loss of target material yield from the additional flake sorting step.

The plant operator was investigating opportunities for further sorting on the reject flake.

Case study 2: PET to secondary detailed colour sort

Mixed PET output was sent to a secondary sort operation in southern Europe. The the sale value of rPET to non-food-grade markets (film or textiles) is sufficient to make this detailed colour sort into four colour fractions viable, even though there is far less transparent and blue beverage bottle input material.

Illustrative change in output qualities in the PET quality framework:

	Input	**Output**
Grade A – Food-grade colour-sorted bottle flake	-	-
Grade B – Non-food grade colour-sorted bottle flake	-	50%
Grade C – Mixed colour and product type	10%	-

Change in components of economic model:

Input material: mixed PET sorted from household collections in a country with a DRS system. Household collection is low in beverage bottles and high in tray content.
Processing costs: lower labour costs, high quality manual sort.
Outputs: sorted fractions of clear, blue, green and opaque PET bottles (PET trays currently to disposal).

3.1.2. Factors limiting amounts captured into higher qualities

In those plastics sorting plants that produced a more limited amount of higher quality PET outputs, the factors limiting quality were identified as follows:

- Comparatively lower presence of beverage bottle PET within the PET sorted fraction, due to higher value PET having already been extracted earlier in the recycling chain (which makes production of food-grade output less viable);
- Insufficient differential in revenues between outputs of different qualities;
- Lack of processing options for a sub-fraction of the material (PET trays);
- Degradation of the material during collection.

Extraction of beverage bottle PET earlier in the recycling chain

In order for rPET to be suitable for use in beverage bottle manufacture, the rPET output from a plant needs to be produced from a PET stream that is over 95% material from food contact origins. Within the study group of plants, in situations where a PET stream had a low content of PET bottles and a higher content of non-bottle PET, it was often seen as not cost effective to sort out and produce a suitable food-grade output for bottle-to-bottle manufacture. Additionally, plant operators processing PET streams with a low content of clear bottles and a high content of non-bottle PET are producing material that will result in rPET that has to complete against rPET derived from a high bottle content. The lower yield and lower price of rPET derived from low bottle content material results in this particular PET stream being uneconomically attractive in the current market conditions.

Not enough of a differential in revenues between different levels of quality

Even where beverage containers were not being extracted from the light packaging stream prior to its input to the plant, some plant operators considered the additional sorting and cleaning stages required in order to produce food-grade PET as cost-prohibitive. For three of the five PET reprocessors that received sorted fractions of PET from areas without a DRS, it was not commercially viable to carry out monitoring, sorting and cleaning to remove non-food grade material from collected PET in order to make rPET suitable for food contact applications. However, as noted above, this should be set against the context that the plant operators are able to obtain relatively high prices for good quality rPET produced into other manufacturing outcomes.

Two of the five PET reprocessors in the study produced a food grade rPET output from PET sourced primarily from household collections, rather than through a DRS.

The following case study illustrates the economic model ***against*** shifting towards higher quality PET output.

Case study: Plastics reprocessor not sorting to food grade

For this reprocessor, the value obtainable for non-food-grade rPET was high enough that the additional cleaning cost to produce a food-grade suitable output was not recouped through additional revenues obtained. Change in components of economic model:

Input material: mixed plastics from an area without a DRS
Additional processing costs required: Estimated at 300 euros /tonne to clean to food-grade
Changed output: None – food-grade rPET not cost-effective to produce

Lack of reprocessing markets for a lower quality sub-fraction of the material

PET trays are more expensive to reprocess than bottles and produce a lower value rPET output at lower yields. rPET derived from PET trays can be tolerated at low levels within bottle reprocessing, but at higher levels this material causes quality issues in manufacturing new bottles. However, a lack of reprocessing options for PET trays has led to their inclusion in bottle grade outputs in some countries, so that they can be recycled to some extent. The presence of a proportion of PET trays in a PET sorted fraction reduces its quality and market value, and can make it harder to find offtakers.

3.1.3. Opportunities for marginal improvements in quality of outputs

For the higher quality streams being considered, several opportunities for marginal improvements in the quality of outputs were identified:

- Stricter standards relating to the exclusion of specific contaminants;
- Development of additional markets for lower value fractions; and
- Improvements in plant process design.

Stricter standards relating to the exclusion of specific contaminants

Implementation by PROs of stricter specifications relating to the exclusion of specific contaminants in sorted fractions could, in some cases, drive the production of higher quality outputs. Specifically, this could entail the exclusion of trays from PET bottle fractions and opaque PET from coloured PET fractions. However, this could also result in a reduction in reported recycling rates if, for example, PET trays are subsequently included in plant residues.

Development of additional markets for lower value fractions

Further development of additional markets for lower value fractions would act as a driver for higher quality outputs. For example, better markets for opaque PET would further incentivise the removal of opaque PET from mixed colour bottle PET. Similarly, if the reprocessing market for PET trays was sufficiently incentivised, this would increase the quality of recycling for both trays and bottle grades.

Improvements in plant process design

The process design of the plant is another important driver. For instance, processing different grades of PET separately at the same plant (either in batches or on different lines) allows for greater capture of rejects from the processing of one sorted fraction into the correct fraction. This approach was found to be a common feature of reprocessing operations that produce high quality outputs whilst achieving high capture rates, allowing for material of the incorrect grade or fraction to be reincorporated in the correct process line, rather than being sent into the residue stream.

3.2. Findings from economically marginal cases

There are some materials for which the study plants demonstrated distinct variations in terms of output produced, particularly in relation to higher quality sorted fractions and reprocessing routes. The quality improvements that were identified as marginal cases include:

- The separation of green PET from other colours of PET;
- The separation and subsequent cleaning/decontamination of natural/white HDPE; and
- Improving structural consistency and reducing odour in HDPE and PP outputs.

Several factors were identified as being important in enabling <u>some</u> plants to produce higher quality outputs of these materials:

- The size of the plants in relation to the scale at which these materials arise in plant inputs;
- The degree to which plants position themselves in the market as producers of quality outputs; and
- PRO specifications that set recycling targets, and/or define more specific sorted packaging fractions and higher purity rates.

Scale of material arisings and sorting / reprocessing plants

The amount of each material stream being input to a plant and the size of the plant are important factors in improving output quality in economically marginal cases. For example, demand for natural/white HDPE in the packaging sector is understood to be growing. Two of the larger plants surveyed (located in different countries) had responded to increased demand by generating a sorted fraction of natural/white HDPE, with one plant sorting it from the collected stream of mixed plastic packaging, and the other from a sorted fraction of HDPE/PP. Conversely, in smaller sorting plants, natural/white HDPE tended not to be separated out from mixed colours of HDPE.

At the reprocessing stage the quality of HDPE and PP recycling outputs can be increased through more advanced filtration/extrusion processes and/or hotwashing the flake. Scale was also a identified as a critical factor in the level of additional quality improvement steps for plants reprocessing HDPE and PP. The large scale of one plants' reprocessing operation enabled investment in fine mesh filtration (improving the structural consistency) and hotwashing steps (reducing organic/fibre impurities and odour). Conversely, the lack of sufficient scale was also the key reason why one reprocessing plant was *not* investing to reduce odour in the secondary raw material HDPE output. The interaction between scale and price differentials was also evident: the smaller scale plant considered that investing in improving the quality of HDPE and PP outputs would only become viable for them once producers were willing to pay the higher prices needed; this was anticipated to occur in the next 3 to 5 years.

The case studies that follow illustrate how scale (in terms of arisings of the material and the size of the plant) drives decisions around producing higher quality recycling outputs of natural/white HDPE.

Case study: Additional sort on HDPE

This company currently runs a sorting plant producing sorted fractions from mixed plastics for their own reprocessing operations. It has recently sourced third-party sorting on the mixed HDPE output to produce a white/opaque grade in addition to a darker output.

This has resulted in a portion of material output at a higher (colour-sorted) quality, without any detriment to the quality of the remaining sorted fraction.

Illustrative change in output qualities in the HDPE quality framework:

	Before Change (% of HDPE output)	**After Change (% of HDPE output)**
Grade B –Colour-sorted	-	10%
Grade E – Mixed colour, odour tolerant	100%	90%

Change in components of economic model:

Input material: Sorted mixed plastic fractions from earlier sorting plants.
Processing costs: Increased capital and operating costs from adding an additional sorting step and quality control step to separate out a white opaque sorted fraction; lower labour costs, high quality manual sort.
Outputs: Higher revenues per tonne available for the separated out white opaque fraction from growing demand in the packaging sector. No change in revenue per tonne for remaining darker colour HDPE output. No change in disposal costs.

Market positioning in terms of quality of outputs

One plant that produces higher quality HDPE and PP outputs (but with higher loss rates than would occur if it were producing lower quality outputs) considered that the material revenues for the higher quality output were too unpredictable to base a business case upon. However, the company had a broader strategy of positioning itself as a producer of quality secondary raw materials, which was a powerful driver for decision making. The plant was planning further investment in an additional hotwashing process in order to further improve the quality of the outputs. Further details on this case study are provided below. In the context of the current high supply of low-grade HDPE and PP outputs, focusing more on higher quality output may help plants ensure that they will be able to reliably sell their outputs.

In a further example, one plant had invested in a robotic sorting unit to improve the quality of the small packaging papers output, largely driven by the need for the plant to demonstrate innovation and quality in the tendering process for contracts let by PROs to sorting plants.

Case study: Quality improvements in HDPE

This plant has an extrusion process designed to produce higher (more structurally consistent) grades of HDPE and PP that can be used in some packaging applications (e.g. bottles and paint pots), though losses of target material in the process are higher as material is put through a finer mesh filtration.

The plant is planning a third processing line containing a hotwashing step to further reduce odour.

These steps improve the quality level in turn:

a) Recovering structural integrity of the material (shifting output from quality level F to D and E – see Appendix A.1) with some additional target material losses.
b) Reducing odour (shifting output towards quality level C, though without fully deodourising the output).

These changes are not made on the basis of a firm financial case. Revenues are 'not sufficiently reliable as a basis for an investment decision'. They may help ensure reliability of demand for outputs.

PRO specifications that drive higher quality recycling

The choice of sorted fractions at sorting plants located in Austria and Italy is taken by the PROs rather than the plant operators. This can mean, in marginal cases in particular, that PROs who set these fractions can intervene to ensure particular sorted fractions are produced where the economic case is more marginal, but for which reprocessing markets exist (such as white/opaque HDPE and opaque PET).

For some of the surveyed plants, it was found that recycling targets are an important incentive to maximise capture in target fractions or produce extra sorted fractions for recycling where the economic case for doing so is marginal. It was also found that some plants carry out additional sorting of the reject fraction to recover more target materials partly to meet recycling targets. Where a recycling target was not in place, the plant did not have the same incentive to sort additional HDPE and PP from the residue fraction.

For materials for which there are marginal economic cases for increasing the amounts and/or quality of recycling, EPR schemes (through PROs) can provide drivers for doing so through:

- Identifying and specifying the economically sensible range of sorted fractions for output to reprocessing markets.
- Arranging for the aggregation of sufficient quantities of input material into plants of sufficient capacity, such that the factor of scale can make production of the higher quality recycling outputs operationally and commercially viable; this could also be achieved by arranging for sorted packaging fractions from various initial sorting facilities (that would not necessarily have to be large in scale) to send material to a secondary sorting/reprocessing plant that can achieve a larger scale in terms of the quantity of material and capacity of the plant.
- Setting appropriate recycling targets to incentivise the production of marginal economic higher quality output fractions.
- Designing tendering processes for the sorting/processing of material that include quality as part of the evaluation criteria (either by specifying production of higher quality grades, or by evaluating bids also on the basis of the qualities of fractions).

3.3. Findings from emerging higher quality recycling chains (PET trays)

There are some materials for which markets for higher quality outputs have only recently developed or are currently in the process of development, for example PET trays. PET trays have been present in growing proportions in collected packaging recycling streams in Europe for a number of years. Their presence in bottle streams is slightly detrimental to the quality of flake produced, and there are high losses of the tray material when processed on bottle lines (as trays are more brittle than bottles and can break up into smaller particles and end up in the reject stream). For some plant operators, it is a challenge finding buyers for sorted PET fractions high in PET tray content, and where trays are separated out from bottles they are often sent to disposal.

Factors which may help the development of recycling chains for higher quality outputs from materials such as PET trays are:

- Availability of material for reprocessing;
- Increases in market demand and sufficient prices for higher quality secondary raw materials; and
- PRO specifications that drive higher recycling performance.

Availability of material for reprocessing

PET trays have been present in growing proportions in collected packaging recycling streams in Europe for a number of years. Where sorted from PET bottles to improve the quality of PET bottle fractions, PET trays exist in separated quantities suitable for reprocessing. Changes in the composition of packaging materials that make producing higher quality outputs more technical feasible (such as reducing the use of carbon black PET trays) could also be a significant driver.

Increases in market demand for higher quality secondary raw materials

A small number of separate processing lines have been set up that are designed for PET tray processing. The relevant plant operators expect that the capacity of those PET tray lines will be increased over the next few years. The reason for the growth at the moment is likely to be confidence from investors in both growing demand and in continued high prices for rPET, as more rPET derived from bottles is diverted into meeting growing demand in the bottle to bottle recycling sector (this factor is pushing up prices for both food-grade and non-food-grade rPET).

For example, one plant studied in southern Europe was being reconfigured to sort a bottle/tray mix from German MRFs into a separated tray fraction in addition to bottle grades, in the expectation that markets for the separated PET trays would become available in the near future. Another plant had started to separate out trays from bottles on a trial basis and were sending them as a separate output to the same reprocessor to which they were originally sending a mixed grade (see case study below).

PRO specifications that drive higher recycling performance

The role of PRO-specified recycling rates in driving higher quality has already been discussed in Section 3.2. Recycling targets in PRO specifications can help to drive higher quality outputs for materials where the market is still emerging (such as for

PET trays), even where gate fees charged by reprocessors may be similar to disposal costs.

Ambitions from EPR schemes to ensure more PET tray material is recycled are also likely to play a role in reprocessor confidence in being able to source sufficient suitable material for PET tray processing. However, the emerging PET tray reprocessing sector will arguably need to be driven by higher demand for the rPET derived from trays if this sector is to become fully established.

Case study: Separating out trays from a mixed tray and bottle grade

This plant is trialling separating out the mixed PET into separate outputs of bottles and trays, by running the mixed PET fraction back through the sorting process a second time. Though on a trial basis, this is expected to result in a net benefit to both sorter and reprocessor.

Illustrative change in output qualities in the PET quality framework:

Grade of Output (see Appendix A.1)	**Before (% of PET outputs)**	**After (% of PET output)**
Grade C – Mixed colour, product separated	-	100%
Grade D – Mixed colour and product type	100%	-

Change in components of economic model:

Input material: Collected stream of packaging materials including papers and glass.
Processing costs: Additional costs of re-running PET fraction through same sorting line (no additional capital costs as yet).
Outputs: Two separate sorted fractions: PET bottles and PET trays.

3.4. Limitations in market demand: findings from recycling chains tending to produce lower quality recycling (PP and PE film)

This section analyses the conditions that are fundamental in constraining the production of higher quality PP and PE film recycling outputs. Our findings from the plant surveys reflect the understanding from literature of particular challenges in processing PP and PE film. Materials that tend to be sorted/processed to lower quality outputs generally have the following properties:

- Higher degradation of the material when in use (e.g. related to absorbency of the material);
- Higher variability in products (compounded polymers, colour pigments, grades) and sizes (particularly with materials consisting of or readily breaking up into particles of smaller dimensions, and thus lost to fines fractions);
- Greater problems with impurities introduced by product design and use; and
- Available markets for material at lower qualities.

Thus, even where technology is available to improve outputs, the additional cost compared to material revenue benefit tends to be prohibitive to selling an output of higher quality.

The remainder of this section focuses on PE films in the recycling chain.

Recycling chains tending to produce lower quality recycling: PE films

LDPE films from household packaging are mostly recycled to applications that are less sensitive to colour and odour. Where plants sort films as a separate fraction, the material is often processed into a secondary raw material used to produce refuse sacks or into other LDPE compounds used in products such as irrigation pipes. Of three study plants that processed PE film, two of them processed film into rLDPE used in the production of refuse sacks, the other produced compounds for a range of injection moulded product applications.

Smaller pieces of films (less than an A4 sheet) tend not to be sorted into a separate film fraction, and are instead incorporated into a mixed plastics stream. Where this material is recycled, it is likely to be used in lower quality injection moulded applications.

LDPE film from household collections is more contaminated than feedstock available from commercial sources. Furthermore, PE films are low in density, so where film is obtained through household collection the weight of contamination is high relative to the film collected.

For the two study plants that reprocessed film to produce refuse bags, the additional costs of improving the quality significantly (carrying out additional steps to separate out clear film and processes to sufficiently clean for use in film packaging applications) was not commercially viable. The additional costs (and losses of material) would mean that the price required for the resulting rLDPE would be significantly higher than the prices currently paid for virgin material. This is illustrated in the case study below.

The low value of sorted PE films outputs (related to the lower yields and high processing costs of PE film) make the economic case for sorting household film more challenging for initial sorting plants. In recent years export options have reduced, with buyers within Europe become more demanding about quality, and prices paid have dropped. Though study plants were aware they could output a wider range of sorted film products, in general, they chose not to because of a lack of confidence in current markets and available revenues. One study plant was stockpiling a mechanical sorted grade of smaller sized (including multi-layered) films in the expectation of being able to identify chemical recycling opportunities in the future.

Case study: Constraint in LDPE film processing

This plant reprocesses collected LDPE film grades for the production of black refuse bags. The operator is aware of the opportunity to colour-separate and clean for outputs into packaging applications, but the costs of doing so would be too high compared to the available revenues.

Illustrative change in output qualities in the LDPE quality framework if this was to become economically feasible:

	Before (% of outputs)	After (% of outputs)
Grade B – Colour-sorted and suitable for odour-sensitive applications		35%
Grade E – Mixed colour	50%	10%

Change in components of economic model:

Input material: Sorted LDPE films, high levels of inks, colours and organic contamination.
Additional processing costs required: Estimated at €300/tonne.
Changed output: Production of higher quality output and a similar quality lower grade output. However, revenues available not sufficient to cover additional costs.
Disposal costs: Increased rejects (to disposal or lower grades).

3.5. Summary

This section summarises the main findings in relation to those enabling and constraining factors for producing higher quality recycling outputs, and the changes that would be required to facilitate the production of a greater quantity of higher quality recycling outputs in future.

The historic and current development in market demand for recycled outputs, alongside the development of good collection systems and reprocessing technologies at a viable cost, have been fundamental in establishing recycling chains that can be orientated to higher quality outputs. Major developments in improving the quality of sorted packaging fractions have primarily been driven by emerging market demand for those fractions.

The main constraints towards the production of higher quality outputs have been where the additional costs of sorting and reprocessing are not counterbalanced by the additional market value for the higher grade output. Some materials are more severely constrained than others. It is starting to become more viable to produce natural/white HDPE and higher quality outputs of HDPE and PP, but the situation is currently less viable for LDPE film.

Scale, in terms of the amounts of material included in input streams and the size of sorting/processing facilities, was identified as a key differentiating factor between plants when justifying investment in technologies required to produce higher quality outputs. The lower the ratio of material in collected streams and the lower the additional revenue from the higher quality fraction, the larger the sorting plant needs to be.

PROs play a key role in the organisation and structure of the recycling chain through determining, to a large extent, the choice of viable output fractions available to sorting plants. A PRO can play a potentially important role in respect of:

- Supporting the recycling of higher quality outputs where the financial case (for the plant) in doing so would otherwise be marginal;
- Supporting the development of reprocessing sectors with reliable supplies of input material; and
- Working to ensure that material sorted to a lower degree goes on to secondary sorting routes of sufficient scale in order that the investment in improving quality becomes commercially viable.

Technologies, ownership structures and other factors play more minor roles that vary between individual specific plants.

4. Impact of policy and system design on quality of recycling

4.1. Levers for market demand

A good level of market demand for secondary raw materials is necessary for development of high quality recycling. However, the secondary raw materials also need to be available at suitable levels of quality and at competitive prices. In response to the European Commission's call for voluntary pledges to increase recycled content as part of the EU plastics strategy[4], many pledges made by plastics converters and brand owners were on the condition that 'the recycled plastics are available on the EU market in sufficient quantity and suitable quality, at competitive prices'[5].

A driving factor in the development of bottle-to-bottle PET recycling and the establishment of DRSs has been the demand for rPET from consumer-facing bottle manufacturers. The Single Use Plastics Directive 2019 (SUP) applies targets across the whole industry for recycled content in beverage bottles; there has recently been a wave of new commitments made by individual brands to incorporate recycled content into PET bottles. [6]

Increased demand from packaging brands to incorporate more recycled content in their applications has also led to higher market demand (and higher than virgin material prices paid) for de-odourised natural and white opaque fractions of HDPE, which can be used in colour- and odour-sensitive packaging bottles. However, for less consumer-facing, business-to-business secondary packaging and non-packaging applications, such as users of film or darker HDPE, there are few drivers of market demand. Prices of secondary raw material are much less likely to exceed virgin prices, limiting the degree to which costs for additional cleaning and reprocessing can be recouped in additional sales revenue.

For those materials where a business case does not currently exist to develop higher quality recycling routes, initiatives to raise the level of demand would appear to be key in driving further high quality recycling.

From a policy perspective, it is possible to identify a number of market failures which affect the demand for post-consumer secondary raw materials:

- **Lack of full internalisation of externalities:** failure to fully internalise externalities associated with the extraction, processing and manufacture of all materials, both primary and secondary. Full internalisation should lead to a price differential between secondary and primary materials, with seconda having a reduced price compared to primary material;

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[4] https://circulareconomy.europa.eu/platform/en/news-and-events/all-news/european-strategy-plastics-deadline-pledging-campaign-boost-recycled-content-extended-30-september-2018

[5] Council of the European Union, Assessment report of the voluntary pledges under Annex III of the European Strategy for Plastics in a Circular Economy, March 2019, https://data.consilium.europa.eu/doc/document/ST-7121-2019-ADD-1/en/pdf

[6] Directive (EU) 2019/904 of the European Parliament and of the Council of 5 June 2019 on the reduction of the impact of certain plastic products on the environment, available from https://eur-lex.europa.eu/eli/dir/2019/904/oj

- **Relatively high search or transaction costs:** a lack of cross supply chain cooperation and transparency leads to high transaction costs. This is due to costs of engaging secondary raw material suppliers and the need for quality checks to ensure the supply meets demand. This is a particular issue in the early stages of market development;
- **Imperfect information:** a lack of accurate and clear information regarding the quality of secondary raw materials, and the potential for their use; and
- **Inappropriate standards:** the lack of accurate information highlighted above, particularly regarding quality, can result in limits being placed on the use of secondary raw materials which may be unnecessarily strict.

In a recent study, Eunomia considered a number of promising policy options to incentivise uptake of secondary raw materials, including:[7]

1. Material taxation;
2. Tradable credits for using secondary raw materials; and
3. A fee-rebate scheme.

Of these, a fee-rebate scheme was identified as the leading option. The fee-rebate system would involve the introduction of a levy on the use of in-scope materials, and offer a full or partial refund of the levy based on the amount of post-consumer recycled materials being used.

EPR scheme fee modulation can also incentivise uptake of recycled content. In France, CITEO already applies a 50% bonus to contributions by weight for PE where there is at least 50% recycled material, and it is proposed that the incentives are strengthened and broadened to PP and PS packaging.[8] Discussions with the French Ministry indicated that incentivising recycled content through EPR was politically more palatable than using the tax system to do so.[9] Fee modulation on its own, however, is not the best approach to explicitly incentivising recycled content. Other instruments are more appropriate, as discussed below.

4.2. Product materials and design

The choice of packaging materials and the design-for-recyclability of packaging can be influenced both by policy and EPR fee modulation as described in Section 4.1.

In respect of packaging materials and design, there are three distinct kinds of challenges to achieving higher quality recycling outputs, as evidenced within this study:

- Packaging made from materials which are detrimental to the quality of recycling when collected within the predominant recycling collection;

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[7] Eunomia Research & Consulting Ltd (2018) Demand Recycled: Policy Options for Increasing the Demand for Post-Consumer Recycled Materials, Report for Resource Association & WWF UK, October 2018. Available at https://www.eunomia.co.uk/reports-tools/demand-recycled-policy-options-for-increasing-the-demand-for-post-consumer-recycled-materials/

[8] Citeo & Adelphe (2019) Proposition de Citeo et Adelphe pour l'ecomodulation du tariff 2020, 29 May 2019

[9] Personal communication with Léonard Brudieu, Chef du bureau de la prévention des déchets et des filières de recyclage (REP), Ministère de la Transition écologique et solidaire, 18/06/2019

- Features or components of packaging of a certain material which are detrimental to the quality of recycling of that packaging material (e.g. PA layers in PET, density-adjusted PP in bottle caps; colour pigments in films and paper); and
- Packaging use which, as the result of its design, has detrimental impacts on the quality of recycling (for instance, hard-to-empty cosmetics containing high levels of volatiles and odorous components that permeate the polymer).

Products made from materials detrimental to the quality of recycling

A key example of a material that has detrimental impacts on the quality of recycling is biodegradable film. When collected and managed appropriately, biodegradable film can be composted. However, biodegradable film is often misplaced by consumers in plastic packaging collections, alongside plastic films. This causes significant issues and additional costs for film reprocessing, with one plant in the study refusing to accept material from countries where biodegradable film is widespread. Where these biodegradable film products are present in the market, it may be challenging to appropriately communicate with collection system users in order to exclude them from plastics collections, as biodegradable and plastic films have a very similar appearance. The same is true (though to a lesser extent) regarding other biodegradable polymers.

Therefore, from a quality of recycling perspective, the impacts of newly developed materials and products on the existing recycling chains (in terms of costs and quality of recycling outputs) ought to be taken into account when evaluating the contribution of the new materials to the circular economy. Additionally, support to the industry may be required where such materials are developed and start to penetrate the existing recycling chains, to assist in implementing measures to avoid detrimental impacts on the existing recycling chain and/or efforts to protect the quality of recycled outputs. In the longer term this would also mean ensuring effective separation of the new materials or products from existing collection streams, which would include providing clear and effective communication to consumers regarding how to dispose of materials through the correct collection routes.

Features or components detrimental to quality of recycling

Features or components of products that are detrimental to the quality of recycling are well-described in design-for-recyclability guidelines.[10] There is a further distinction between those features or components which are key to the functionality of the product (such as the use of barrier layers) and those which are just simply design driven (use of silicon caps). Multiple layers involving different materials present a challenge wherever they arise, particularly in plastics and glass streams. There was a perception among plant operators that the arisings in collected material streams of complex materials with such features or components (particularly for plastics) is increasing.

[10] Such as those published by PRE, e.g. 'PE-HD coloured containers guidelines' available from https://www.plasticsrecyclers.eu/downloads

Combined impact of product use, design and material

Some problems result from the combination of the material used for the packaging, the product contained within the packaging, and the design of the packaging material. For instance, where a container is designed such that it is difficult to empty of its product, the product contained by the packaging will remain present at higher levels during reprocessing. As well as increasing the amount of impurities, where the products are organic and chemical products, and the material is relatively absorbant (notably the polyolefins), the quality of the output is decreased and/or the cleaning challenges are more difficult.

In order to ensure a move towards products being designed so as not to be detrimental to the quality of recycling of materials within the existing recycling chain, a recyclability assessment is required. This assessment takes into account the intended product use and how residues of product (contained within the packaging) affect the quality of recycling.

In order to support the production of higher quality recycling outputs, efforts to increase (and require) the recyclability of packaging would be beneficial, with recyclability assessments conducted at the level of individual product types. Also, where feasible, design should look to develop mono-material replacements for multi-material multi-layer products that are currently hard or impossible to recycle (e.g. multi-material PET trays, film and flexible packaging), to assist in the production of higher quality recycling.

Fee modulation by EPRs can incentivise better design for recyclability. Where DfR guidelines produced by or in association with reprocessors exist, the packaging within the relevant fee categories can be subject to modulation, such that items which achieve:

- a YES for *all* relevant aspects are eligible for a bonus;
- a YES in some aspects, but a CONDITIONAL in *any* aspect are provided a standard fee; and
- a NO in any individual aspect are subject to a penalty.

Modulating by recyclability through reference to DfR guidelines should bring about rapid changes in packaging design over a relatively short time period.

4.3. Choice of collection systems

Where there is a high degree of material separation at source, this can reduce the costs of subsequent sorting and keep materials apart that would have a detrimental impact on quality, thereby benefitting the recycling chain and encouraging higher quality of recycling.

For example, for PET in particular, a high degree of separation at source via DRSs has positively contributed to high quality recycling outcomes. DRSs for PET bottles allow for cost-effective production of PET flake/pellets suitable for food-grade products; PET streams collected via DRSs already meet the requirement to guarantee 95% food contact origin (so require no further sorting to remove non-food-contact material) and are lower in PVC and chemical contamination due to the lack of non-food-contact bottles, trays and other non-target material impurities in the sorted fractions. The anticipated expansion of the DRS in EU countries over the next decade will increase the supply of high quality PET in a cost effective manner, which will contribute to meeting the extra demand for rPET created as a result of brand commitments and legislative targets.

The cost of reprocessing of PET bottles to food-grade standard is lower when the PET comes through a DRS than through a household collection. This may reduce the chances of PET beverage bottles that are collected in streams other than DRSs being processed into food-grade recycling outputs, although they will still often be separated by colour and be recycled into high quality non-food-grade rPET.

Collection schemes should be designed by PROs (or by the municipalities and/or contractors who undertake such activities on their behalf) so as to be cost-effective. Indeed, Article 8a(4) of the amended Directive 2008/98/EC requires Member States to design extended producer responsibility schemes so as to ensure that the financial contributions paid by a producer are sufficient to comply with its obligations while not exceeding the "necessary costs" of doing so. Each further degree of source separation can entail further collection costs, and these increases may not result in sufficient additional material revenue (and/or make enough of a quality difference) for this to be commercially feasible. EPR schemes may prioritise quantity over quality by, for example, aiming for maximum captures into recycling collections, driven by quantity-based targets. Therefore, systems designed to maximise participation and capture by collecting co-mingled materials may take precedence over more complex collection schemes that are able to produce purer input streams for sorting plants and reprocessors. However, incentives for generating high quality secondary raw materials could be implemented through the approach to fee modulation, as described in Section 4.1.

Specific collection scheme differences were explored with the sorting plants in the study. Separate collection of papers from plastic packaging and cans is already widespread and is considered to have had a positive impact on recycling outcomes, with similar capture rates for plastics and papers in both co-collected and separately collected streams. Co-collection of papers with plastic film leads to increased losses/rejects and impacts on the quality of both the plastic and paper output materials, and plant operators clearly expressed that they would prefer the separate collection of paper and plastics for this reason.

Therefore, the study supports the view that, from the perspective of quality of recycling, **co-collection of plastics and papers should be discouraged**. Whether the additional costs of separate collection are reflected back in additional revenues from higher quality material has not been assessed as part of this study. However, there are plenty of regions that have decided that separate collection is economically practicable.

Key findings from the plants surveyed in relation to the co-collection of non-packaging material in packaging collections were as follows:

- For paper, it is generally sensible to collect alongside packaging papers (cardboard).
- For non-packaging plastics that are co-collected with plastic packaging:
    - Some plants reported that as much as 50% of the input consists of materials for which there are no output markets. In some countries, this is partly due to the scope of collections in place, which encourages residents to put non-packaging materials of a similar kind (other plastic products) in the same collection as packaging material. Plants noted that non-packaging materials such as tapes, balls and ropes placed in collections caused

particular problems, as they become tangled in the machinery, increasing both operating costs and disposal costs.

- However, there was no clear link demonstrated between inclusion of these materials in collection and sorting efficiencies and qualities of packaging material output achieved.
- The extent to which including non-packaging items in recycling collections may help to increase the capture of packaging materials is unknown, and it could be possible that limiting the scope exclusively to packaging materials may have a negative impact on the overall capture of plastic packaging.

4.4. Choice of sorted fractions in sorting plant design and contracting

The degree to which various PROs specify sorted packaging output fractions for sorting plants varies. For example, the Austrian PRO, ARA, sets prescriptive specifications for a wide range of outputs, whereas others (such as DSD in Germany) provide a greater degree of flexibility in sorted packaging fraction outputs but have recycling targets. Where PRO specifications encourage or require sorting plants to separate and process material into a greater range of more specifically defined outputs, it helps to drive the production of higher quality recycling, as it preserves distinct characteristics (separation by colour and/or product type) of specific product groups.

However, it is important to note that sorting to a more specific fraction could happen at different points in the recycling chain. In particular, sorting materials on a larger scale improves the business case for investing in more efficient sorting into a greater number of more specific outputs (and also avoids plants carrying out less cost effective sorting at smaller scales, which would result in the plants needing to charge at a higher rate to the EPR scheme). Therefore, there is a strong case for secondary sorting facilities for some sorted fractions. PROs could ensure that plants above a certain scale are required to output a wider range of grades (for which reprocessing markets are available or are developing) and that smaller plants arrange for their sorted packaging fraction outputs to be aggregated. This approach would probably be more appropriate through the PRO and sorting plants, rather than being mandated at a policy level.

Evidence from the plants surveyed supports the notion that plants need sufficient throughput of a material (which is a function of both the amount of the material as a proportion of the input to the plant and the overall amount of input material to the plant) in order to justify the costs of investing in further sorting steps for fractions that are less abundant. This is also the case for the inclusion of additional quality refinement stages at sorting plants and reprocessors, e.g. additional quality control or hot washing of particular fractions. This is reflected by the fact that, amongst the surveyed plants, larger scale plants tend to separate out more fractions, notably separate colour and natural/white HDPE.

Amending plants so that they sort existing fractions into further sub-divided fractions can be counter-productive to overall recycling outcomes. One of the sub-divided fractions may be improved through the process, but if the other has an insufficient market it may need to be disposed of or sent to energy recovery, at least in the short term, when it might otherwise have been kept within a mixed grade that went to lower quality recycling. Materials currently with challenging markets in this respect include PET trays.

Moreover, for the recycling chain to work, there needs to be input materials available at the right price, sufficient reprocessing capacity and sufficient market demand for the outputs at a price that makes their production commercially viable. The study found examples of plant which have been developing reprocessing capacity in response to expanding demand for outputs and based on sufficient available input material.

Through specifying a greater number of output fractions, PROs can play a role in driving market demand for more specific sorted packaging fractions. However, this would need to be in parallel with the development of reprocessing routes for remaining outputs that have higher sorting/processing costs (for instance PET trays).

Another issue to consider in relation to aggregating of sorted outputs from smaller plants at a larger facility is that it may be more advantageous to have a single PRO in each country, rather that multiple PROs competing in the same sector. Multiple PROs could reduce the security of supply at scale for the larger facility.

Opportunities to specify sorted fractions broadly within the current economic environment include:

- Ensuring PET trays are separated from PET bottle fractions.
- Separation of opaque PET.
- Separation of white opaque HPDE.

The market economics of particular sorted fractions merits close attention in order to identify the scale at which a business case can be made for sorting the output in question. The economic factors will vary depending on the difference in market value between the mixed and more specific sorted fractions and the proportional arising of the specific fraction in the mix (e.g. arising of white opaque HDPE in a mixed HDPE stream). The potential fractions may vary depending on the products on the market. In Spain, yellow bleach containers are produced in sufficiently large quantities and are present enough in collected HDPE streams to viably be separately sorted for use in the production of new bleach containers.

4.5. Quality specifications for sorted fractions

Impurities in grades of material cause differing issues in the reprocessing of the different materials. Whilst some impurity related issues are limited to increasing the costs of processing and disposal, others have a detrimental impact through decreasing the quality of secondary raw material and/or increasing the losses of target material from the process. Removing impurities from a sorted fraction can also lead to increasing losses to reject fractions.

However, reject fractions can be further sorted/recirculated in order to reduce losses of materials by ensuring that they are captured correctly in the targeted sorted fractions.

Quality standards for sorted fractions play an important role in controlling the levels of impurities in the fractions. They set general and specific impurity limits that balance costs and losses of material in sorting with costs and losses of material during reprocessing, and ensure that a sufficient quantity of desired material is included in the sorted packaging fraction. They also provide clarity on the tolerance limits for specific impurities (e.g. biodegradables, colours) that are detrimental to the quality of the secondary raw material output, unless a further sort is done on the material. Sorting has an important, but limited, role in removing impurities detrimental to the quality of secondary raw materials as, whilst there are impurities that can be removed in sorting, others derive from product design and use (as discussed in Section 4.2).

The nature of the contractual agreements with PROs influences the quality of outputs produced at sorting plants. Plants selling material to PROs at set prices generally have an economic incentive to *not* exceed the quality standards, since exceeding the quality standard reduces the tonnages sold at material prices and increases the tonnage sent to disposal at cost. This factor was found to significantly influence the purity of sorted fractions at a number of the plants surveyed. The quality specifications that PROs set strongly determines and may limit the quality that reprocessors will receive during the timeframe of the sorting plant contract.

The limit on quality of outputs created by minimum quality specifications could be mitigated by allowing plants to partially gain from material sales, as was found to be the arrangement between one plant in Austria and the PRO, ARA. For another surveyed plant in Italy, the PRO has an online auction system to sell material. It might be expected that this would thus deliver a larger amount of higher quality outputs, but the lack of pass-through of the additional material revenue to the sorting plants removed the economic incentive for the plants to exceed the quality standards.

So long as the standards broadly suit the requirements of reprocessors, small variations may not have a significant impact on the quality of secondary raw materials produced. The plastics reprocessors surveyed carried out, to varying degrees, their own quality control at various sorting stages, and the operators noted that variations in impurities due to non-target material in the input did not generally have an impact on the qualities of the outputs they produce. However, higher arisings of impurities may increase processing costs and process losses. Reprocessors in the study have had to adapt processes and make investments to maintain quality standards when faced with a decrease in quality of inputs.

The standards have a role in determining whether costs (and losses) of improving material purities fall on sorters (prior to selling to the PRO) or on reprocessors (buying from the PRO). Where PROs determine these quality standards, they can also be increased in order to drive specific improvements in quality for a particular sorted fraction.

Plant operators that sell sorted packaging fractions direct to market tend to be competing with material from PROs, and therefore the quality specifications applied by the PROs in the EU also effectively set 'benchmark' standards for the quality of sorting packaging fractions on the market. Some plant operators selling outputs to the market outside of arrangements with PROs were exposed to pressure to meet and exceed common international quality standards for some materials (notably PET outputs, but also others) in order to ensure a range of buyers for the material. However, some plant operators indicated that offtakers were content to receive material at lower than the purities specified by the PRO. Market forces may be less reliable than EPR-set specifications in driving quality when the balance of other market forces shifts and other factors have a greater impact on prices available.

To maximise the capture of material into high quality recycling, PROs should focus on setting impurity standards for sorted fractions which attempt to strike the right balance between costs and losses of target material at sorters, and costs and losses of target material at reprocessors.

Where PROs buy material, opportunities should be investigated to provide financial bonuses or higher prices for material with lower impurities, either through directly paying higher prices or though passing on higher material revenues where applicable. In order for this to be an effective driver for reducing impurities and increasing the quality of outputs, the additional revenue for the plant should be at least equivalent to the extra disposal costs from extracting higher amounts of impurities. This would counteract the current disincentive to exceed quality standards that arises from existing PRO quality specifications, and would act as a driver for sorting plants to increase the quality of their outputs at a relatively early stage in the recycling chain.

4.6. Other contract design factors

Alongside quality standards and market forces, there are also several drivers for quality within contracts that are particularly important in developing markets where the economic drivers to improve the quality of outputs are marginal. These factors include recycling targets set within contracts and competitive tendering involving an assessment based on quality.

Recycling targets

Where the economic case is marginal, recycling targets have a clear role in incentivising sorting plants and reprocessors to produce higher quality outputs. Amongst the plant operators surveyed, it was found that recovery targets were a key driver for sorting separate fractions of PET trays and cartons. Moreover, at some plant operators it was found that the absence of recycling targets was a barrier to producing higher quality outputs with marginal economic benefits (for example, carrying out an additional sort on the residue stream to extract more target material, or creating a mixed PO grade).[11]

[11] Mixed PO grades are a mixture of HDPE, PP and LDPE, which can be recycled together.

Recycling targets do not usually make a distinction between lower and higher quality outputs. However, requirements to recover certain percentages of input at a higher quality level, based on an input composition, could tip the balance in favour of the plant producing higher quality outputs where otherwise the economic return on its own may not be a strong enough driver. Such recycling targets would need to take into account whether viable reprocessing routes are available for the higher quality outputs.

However, recycling targets can also lead to pressure to lower the purity of outputs (within the bounds of what reprocessors will accept) since, if the recycling target is measured on the basis of output contained in saleable grades, there is an incentive not to remove impurities beyond what is minimally acceptable.

Competitive tendering

When contracts with sorting plants are procured by PROs or municipalities, competitive tendering could be an effective means of incentivising higher quality outputs where they would otherwise be economically marginal. For example, one study plant had invested in a robotic sorting unit to improve the quality of its small packaging board output, and this was largely driven by the need to demonstrate innovation and quality in the tendering process. The inclusion of a quality component in the evaluation criteria for tendering processes for sorting plants can thus provide an incentive to plants to make investments and upgrade their operation and/or process to improve the quality of outputs.

4.7. Technological innovation

The plant operators surveyed generally considered new technology as having a relatively minor impact on the quality of outputs that they are currently focused on achieving. However, it is important to note that much plastics reprocessing and some glass reprocessing to higher qualities is dependent on historical technological development. Three main themes regarding technical innovation were identified at the study plants:

- Increased automation of sorting plants, in particular through optical sorting (generally displacing manual sorting and quality control);
- Development of fine-grained NIR sorting on flake and cullet (where this is impractical to be carried out manually); and
- Development of cleaning, extrusion and reprocessing technologies for plastics.

Sorting technology

In general, sorting technology was not found to significantly impact the quality of outputs, although it has enabled cost reduction in many areas in Europe through reducing reliance on manual labour. However, for those plants with access to low cost labour, NIR was either not seen as a current viable investment (in Hungary) or was only just becoming viable (in Croatia).

In some plants, sorting technology is used to increase the efficiency and effectiveness of manual labour, for example systems where operators can point at items on a screen which a robotic arm or NIR unit subsequently removes. Where increases in efficiency result in manual labour costs being reduced sufficiently, this can help to make the business case for separating additional distinct fractions to achieve higher quality outputs.

Developments in NIR for film sorting have increased the efficiency of the sorting of film fractions; again this has mostly been to substitute previous manual separation.

The surveyed reprocessors who receive material from sorting plants found that there had not been significant changes or increases in the quality of sorted packaging fractions arising from sorting plants through use of sorting technologies. One paper mill credited a decline in the quality of sorted papers to a switch to more automated sorting system.

Some of the sorters surveyed anticipate that the development of intelligent-embedded packaging materials will enable sorters to sort more effectively and efficiently, to replicate and in some cases go beyond the nuanced visual judgements of a human operator.

Fine-grained sorting technology

The development fine-grained sorting technology has enabled the more precise sorting of smaller flake and cullet sizes. For example, this has enabled colour sorting of plastic flake and of crushed glass.

However the uptake of this technology is constrained by the value of the additional material that can be sorted. For instance, the colour sort of flaked PE film is not currently seen as being viable and one of the glass reprocessors surveyed only extracted clear glass from crushed glass (and not other colours).

Cleaning and decontamination

Technology is not considered to be a limiting factor for cleaning and decontamination in any reprocessing sector. However, for cleaning HDPE/PP and PE, the cost of technology (compared to the benefit of producing higher quality fractions) is a barrier. Nonetheless, the historical development of cleaning and decontamination technologies has been important in achieving high quality recycling:

- Technology is well established for high quality PET recycling, paper manufacturing and glass packaging re-melt, and this is viewed as being fit for purpose. The historical development of advanced cleaning processes for PET flake, for instance, has been important in enabling the market for food-contact PET.
- Some areas where technologies are available but less widely applied relate to different types of extrusion and melt filtration for HDPE/PP, because associated costs are not viable compared to additional value. Indeed, for HDPE/PP, even

simple technologies like hot-washing are not applied at some plants. The development of advanced extrusion techniques has, nonetheless, made it technically feasible to produce higher purity and more structurally consistent outputs from HDPE and PP flake.

- Breakthroughs in technology which significantly reduce the costs of processes could clearly have an impact in making technical solutions for producing higher quality recycling outputs economically viable.
- Technology adaptation can also be applied by manufacturers to 'retool' (adjust machinery) so that they can process specific secondary raw materials, for instance certain rPO compounds. At present this is typically done in a way that is bespoke to particular proprietary secondary raw materials.

Recommendations

It is recommended that policy makers should seek to support the alignment of industry with packaging 'embedded information' systems such as digital watermarking. These systems could create step changes in sorting efficiencies of specific fractions of plastics with relatively minor additional investment. Several such initiatives exist including digimark and that demonstrated in the 'Holy grail' pioneer project.[12]

From a quality perspective, focus should be maintained on the research and development of improved or new technologies to tackle cleaning and quality challenges. However, for challenging materials where degradation is greater and virgin material prices are lower, the focus should be on developing technologies that have the potential to lower the costs of existing sorting processes, as this is a critical constraint to the uptake of sorting technology.

[12] https://www.digimarc.com/about/technology/about-digital-watermarking; https://www.newplasticseconomy.org/assets/doc/Holy-Grail.pdf

A.1 Appendix 1

A1.1 Quality framework levels for different materials

For further detail on the development of these levels, readers are referred to the 'Quality of Recycling: Towards an Operational Definition and Framework' report.

Table 2-6: Framework quality levels for plastic - PET

Category	Quality/Value Dimensions	Rationale
A	Maintain/preserve IV, product type, transparency, colour; and food contact suitability	Preserves colour separation and suitable for use in the production of the same food-contact items
B	Maintain/preserve IV, product type, transparency, and colour	Preserves colour separation and suitable for use in colour-specific non-food-contact uses requiring high purity flake
C	Maintain/preserve IV, product type	Mixed colour bottle flake can be used for non-colour-sensitive applications that nonetheless require high enough IV (e.g. fibres and strapping). Separated trays can be separately reprocessed with lower losses compared to processing mixed with bottles
D	Other	Mixed, un-colour-separated bottle and tray flake that may need further sorting

*IV (intrinsic viscocity) is an important marker of quality, bottle manufacture required PET with high IV. Trays are made with PET of a lower IV.

Table 2-7: Framework quality levels for plastic – HDPE, PP, PE

Category	Quality/Value Dimensions	Rationale
A	Specified polymer, structural consistency, colour, odour limit, product type origin (e.g. milk bottles) and food contact decontamination	This material can be recycled into food-contact packaging (N.B only production in UK currently)
B	Specified polymer, structural consistency, colour, odour limit, product type origin (e.g. bleach bottles)	This material can be recycled into same colour-specific, odour-sensitive product type (e.g. bottle packaging for HDPE)
C	Specified polymer, structural consistency, lightness, odour limit, may be modified by additives	This material has potentially wide application due to light colour, reduced odour-free and enhanced structural characteristics. (that otherwise might not exist due to product variation)
D	Specified polymer, structural consistency, lightness	This material has potentially wide application due to light colour, enhanced structural characteristics. (that otherwise might not exist due to product variation). But is more limited due to odour.
E	Specified polymer, structural consistency	This material is a darker output than 4 which additionally restricts uses to dark/carbon uses by can be used for in applications demanding more structural consistency
F	Specified polymer, lower structural consistency	
G	Polymer blend, meltflow index and other structural characteristics	This material is a polymer blend and so has wider structural variation and more limited product applications (i.e. to injection moulded applications). It can still be extruded to have colour differentiation and more consistent structural characteristics (impact strength etc.)
H	Polymer blend, variable meltflow index and lower structural consistency	

Table 2-8: Framework quality levels for papers

Category	Quality/Value Dimensions	Specifications (EN643)	Rationale
A	Maintain fibre characteristics, homogeneity of grade	De-inking grade (1.11) OCC[13] grade (1.04)	Suitable for recycling to the same grade of product Suitable for corrugated cardboard manufacture
B	Mixed fibre characteristics, some variation in grade	Mixed papers (1.02)	Suitable for manufacture of other grades of product (components of corrugated cardboard, tissue manufacture)
C	Mixed fibre characteristics, lower grade fibres	Not meeting a specified EN643 grade	May yet be suitable for products with less structural fibre requirements

Table 2-9: Framework quality levels for glass

Category	Quality/Value Dimensions	Rationale
A	Maintains colour, limits specific contaminants and other physio-chemical glass types	Suitable for input into colour-specific glass packaging manufacture, fully circular
B	Limits on specific contaminants and other physio-chemical glass types	May be suitable for input into darker colour glass packaging, or other re-melt markets, or use as abrasive
C	Limits on specific contaminants	Suitable for bespoke non-re-melt applications (i.e. water filtration)
D	Limits on overall contaminants	Suitable for some non-re-melt applications, such as use in ceramics or as fluxing agent in brick production
E	Wide tolerance for contaminants	Only suitable for aggregate uses, unlikely to displace virgin material

Since there is relatively little to distinguish on quality grounds between re-melt applications in terms of purities and decontaminants (though they have slightly different tolerances for individual contaminants), the main distinguishing feature appears to be the extent of colour preservation/separation.

[13] Old corrugated containers/cardboard

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