Deliverable 2.2

Analysis of boundary conditions for waste collection systems

TASK 2.1 IDENTIFICATION OF MAIN BOUNDARY CONDITIONS FOR BETTER-PERFORMING WASTE COLLECTION SYSTEMS

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Credits

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List of Acronyms

ANS	Acrylonitrile-Butadiene-Styrene
CAS	Civic Amenity Site
CCP	Carbonless Copy Paper
CFC	ChloroFluoroCarbon
CRT	Cathode-Ray Tube
EERA	European Electronics Recyclers Association
EFR	European Ferrous Recovery & Recycling Federation
ELV	End-of-Life Vehicle
EN	European Norm
EPS	Expanded PolyStyrene
EU	European Union
EUROFER	European Confederation of Iron and Steel Industries
EVOH	Ethylene Vinyl Alcohol
HC	HydroCarbon
HDPE	High-Density Poly-Ethylene
HCFC	Hydro-ChloroFluoroCarbon
HFC	HydroFluoroCarbon
HIPS	High impact Polystyrene
ISRI	Institute of Scrap Recycling Industries
LDPE	Low-Density Poly-Ethylene
LED	Led Emitting Diode
LLDPE	Linear Low-Density PolyEthylene
NCR	No Carbon Required
NIR	Near InfraRed
OPP	Oriented PolyPropylene
PA	PolyAmide
PCB	PolyChlorinated Biphenyl
PCT	PolyChlorinated Terphenyl
PE	PolyEthylene
PET	PolyEthylene Terephtalate
PET-G	PolyEthylene Terephtalate Glycol-modified
PMD	Plastic bottles and flasks, Metal packaging and Drink cartons
PP	PolyPropylene
PPW	Paper and Packaging Waste
PS	PolyStyrene
PUR	PolyURethane
PV	PhotoVoltaic
PVC	PolyVinyl Chloride
PVDC	PolyVinyliDene Chloride
RDF	Refuse-Derived Fuel
RFID	Radio Frequency Identification
UK	United Kingdom
US	United States
WCS	Waste Collection System
WEEE	Waste Electrical and Electronic Equipment

1. Introduction

About 500 kilogrammes of municipal waste per capita are generated every year in the EU. These wastes contain large volumes of valuable materials for Europe's industrial base. Proper collection of waste is a pre-condition for their optimal recovery. The current trend of increasing higher collection rates is promising, but progress is uneven between Members States and between regions. Good regional practices have the potential to serve as good practice examples for other regions. So far, however, results of existing studies and good practices have not been effective enough in supporting the implementation of better-performing systems elsewhere. The main objective of the COLLECTORS project is to overcome this situation and to support decision-makers in shifting to better-performing collection system.

COLLECTORS will therefore:

1. Increase awareness of the collection potential by compiling, harmonising and presenting information on systems for Packaging and Paper Waste (PPW), Waste Electrical and Electronic Equipment (WEEE) and Construction & Demolition Waste (CDW) via an online information platform.
2. Improve decision-making on waste collection by the assessment of twelve good practices on their performance on:
   (1) quality of collected waste;
   (2) economics;
   (3) environment;
   (4) societal acceptance.
3. Stimulate successful implementation by capacity-building and policy support methods that will increase the technical and operational expertise of decision-makers on waste collection.
4. Engage citizens, decision-makers and other stakeholders throughout the project for validation of project results and to ensure the usability of COLLECTORS-output.

The COLLECTORS project covers the following waste groups/streams:

- **Packaging and Paper waste from private households (and similar sources):**
  - Paper & cardboard (both packaging and non-packaging);
  - Plastic packaging;
  - Metal packaging;
  - Glass packaging;
- **Waste Electrical and Electronic Equipment from private households and similar sources;**
- **Construction and demolition waste with a focus on wastes that are managed by public authorities.**

2. Goal and scope of WP2

Boundary conditions and solutions for implementation of waste collection systems

Work Package 2 (WP2, Boundary conditions and solutions for implementation of waste collection systems) will analyse the role of the waste collection system within the waste recycling value chain, helping to turn waste into a resource, by identifying the boundary conditions for efficient and effective recycling. These boundary conditions are the specific assets of a waste collection system that enable the recycling value chain to produce more value, by producing more (quantitative) and/or better (qualitative) secondary materials.

Waste collection systems do not operate in isolation but are part of a social and economic reality. This means that optimal collection of waste requires seamless integration into the existing social situation as well as into the broader value chain.
In other words, the willingness of citizens to cooperate with the implemented system is essential and the collected waste needs to be useful for other value chain partners; especially, it needs to have sufficient quality. Therefore, focus for WP2 will be on the role of the waste collection system within the waste recycling value chain (see Figure 1), rather than on the waste collection system itself.

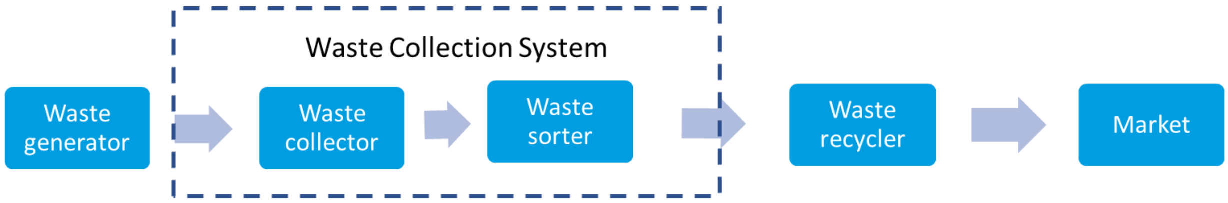


Figure 1: Waste Collection System within the waste recycling value chain

Furthermore, the introduction of the Circular Economy concept by the EU provided the framework to **shift from sustainable waste management**, being diverting waste from disposal over recovery to recycling ('waste push'), **to sustainable resource management** promoting the production of resources for which there is a market ('market pull') (see Figure 2). While the waste push is mainly promoting to shift large quantities of waste from disposal and incineration to low level or low value recycling, the market pull is trying to promote to produce high value secondary materials from waste.

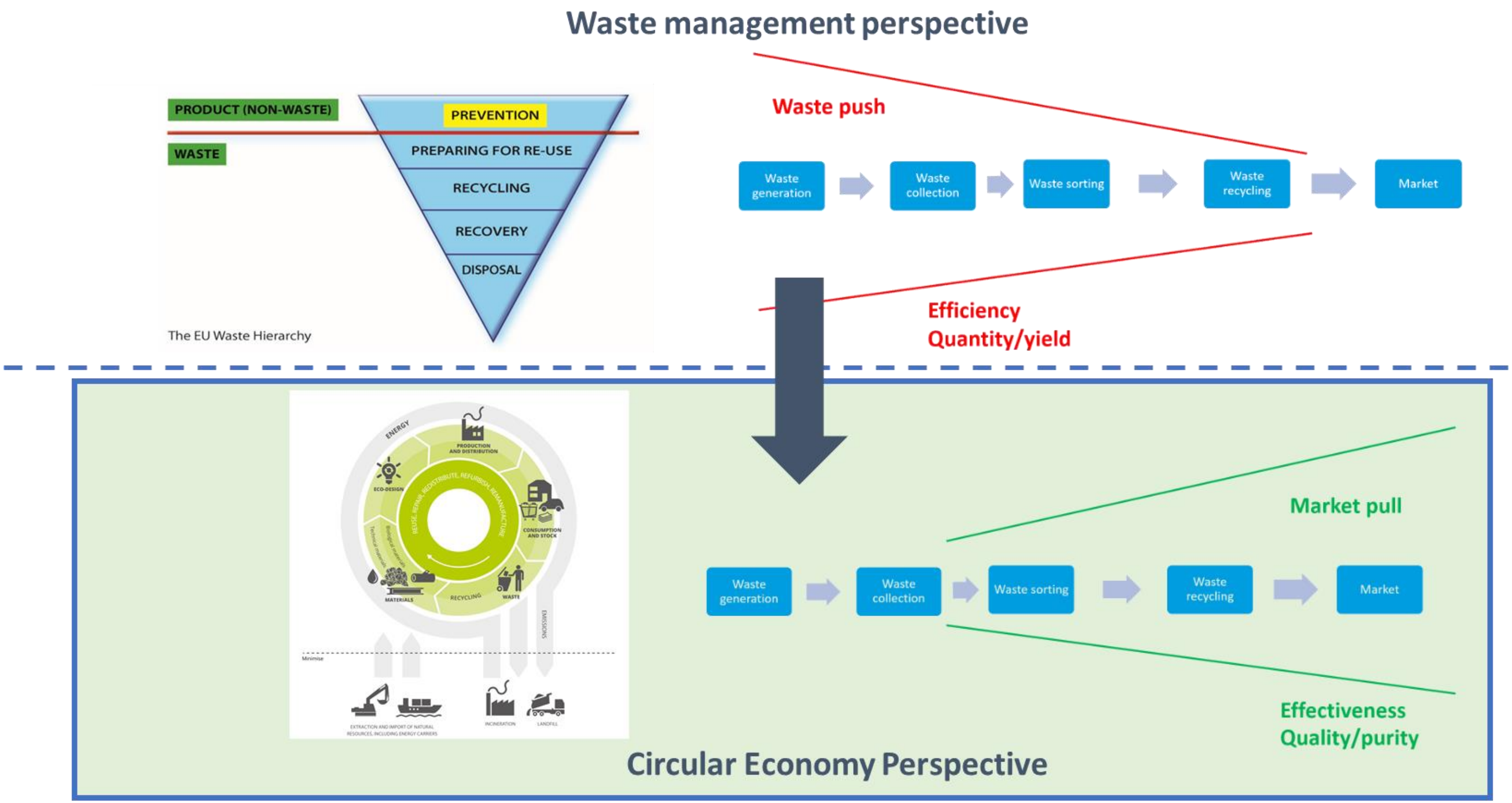


Figure 2: Circular Economy concept shifts recycling from waste push to market pull

The **objectives of WP2** are to identify the main boundary conditions for implementation of effective waste collection systems specifically from the perspective of recyclers on the one hand and from the perspective of citizens on the other hand, and then to gain insight into successful solutions and key elements for implementation.

Therefore, we will identify the boundary conditions for effective recycling of secondary materials at a generic European level in Task 2.1 (T2.1). These boundary conditions are the specific assets of a waste collection system that enable the recycler to achieve better quality, resulting in more value.

In Task 2.2 (T2.2) and Task 2.3 (T2.3) we will evaluate to which extent these boundary conditions have been met for specific waste collection systems (being the selection of 12 case studies), including listing specific solutions as applied in the case studies and potential solutions to improve the effectiveness of the waste collection system.
This will be done both from a technical and systemic point of view (in Task 2.2) and from a societal point of view (in Task 2.3).

The scope for Task 2.1 is the waste streams under investigation, being:

- Packaging and Paper Waste (PPW) from private households (and similar sources):
  - Paper & cardboard (both packaging and non-packaging);
  - Plastic packaging;
  - Metal packaging;
  - Glass packaging;
- Waste Electrical and Electronic Equipment (WEEE) from private households and similar sources;
- Construction and Demolition Waste (CDW) with a focus on wastes that are managed by public authorities.

For Tasks 2.2 and 2.3 the scope will be the selection of case studies as good practices for waste collection of these waste streams (5 for PPW, 5 for WEEE and 2 for CDW).

Alternative approach for CDW:
In contrast to PPW and WEEE, the collection of CDW is mainly in hands of private companies, being the building companies and contractors. The relevance of publicly organised waste collection systems is very different for CDW compared to PPW and WEEE, and mostly limited to providing a service to citizens for the collection of specific fractions of CDW that citizens want to get rid of. Accordingly, an alternative, pragmatic approach will be applied for CDW focussing on issues that are specifically relevant for local policy makers.
Therefore, the remainder of this report will only focus on PPW and WEEE.

3. Approach

As explained more in detail in D2.1 (Methodology Report), the identification of the boundary conditions for waste collection systems will be done on a generic level, being the EU level.

For this identification exercise, we will look at the recycling value chain from two perspectives:

(1) from a circular economy perspective: to what extent does the output of a waste collection system effectively meet the quality requirements for input for recyclers, and how can it be enhanced;

(2) from a societal acceptance perspective: to what extent do waste collection systems effectively fit with citizens' behaviour and opinions on waste recycling.

First, an introductory section provides a generic categorization of different waste streams. This categorization is meant to improve the understanding of some of the factors that have contributed to the success of separate collection and subsequent effective material recovery from waste streams such as paper and glass, whereas collection and recovery of materials from other waste streams still present major challenges.

3.1. Understanding waste streams

For a better understanding of collection and recycling boundary conditions, waste streams can be divided into two generic categories: **product-related and material-related flows**[1].Figure 3 shows different product-related and material-related waste streams and the links between them.

[1] http://www.europarl.europa.eu/EPRS/EPRS-Briefing-564398-Understanding-waste-streams-FINAL.pdf

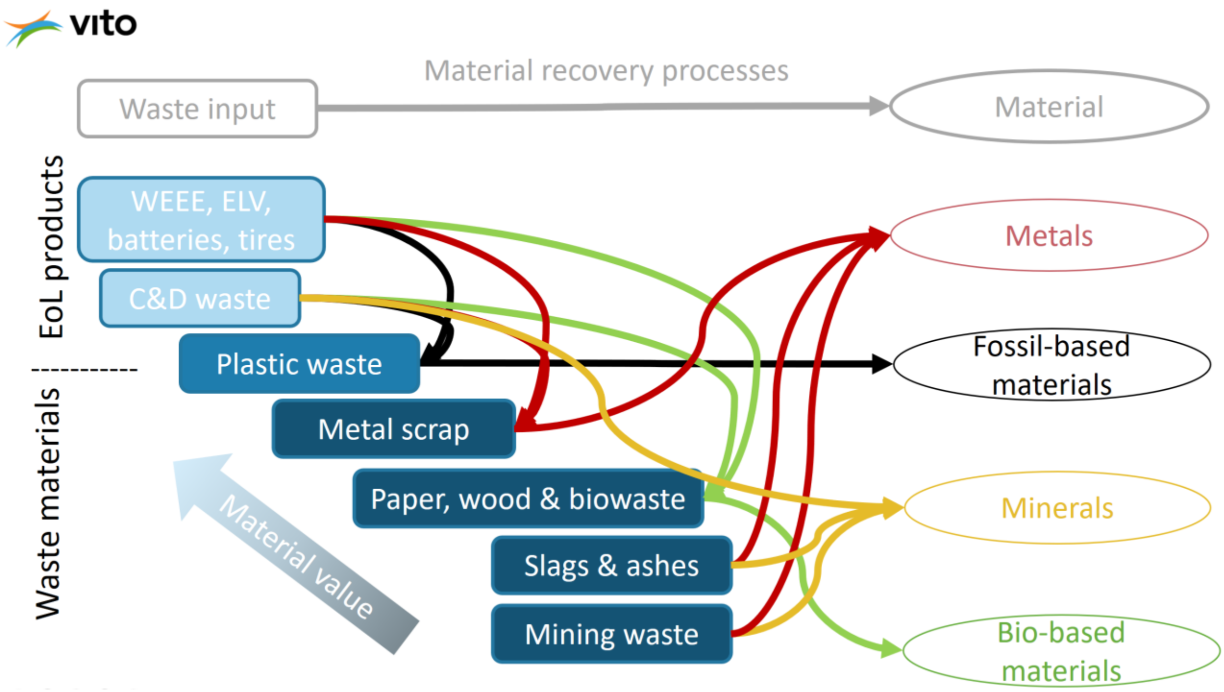


Figure 3: The recovery of materials from material and product related waste streams

The first category (product-related flows) considers streams that consist of **complex end-of-life products**, that combine different material types, for instance polymers, metals, wood or concrete. Examples are **waste of electronic and electric equipment (WEEE)**, including devices such as discarded laptops, refrigerators, dishwashers and micro-wave ovens, and **construction and demolition waste (C&D)**, consisting of end-of-life construction products such as roof tiles and window frames. After collection and prior to recycling, through product-specific treatments, the distinctive material types contained in the product, such as metals, minerals, organics and plastics, must be separated to be further processed in dedicated material-related waste treatments. These complex end-of-life products will thus, in general, require more preparatory processing through pre-treatments, such as depollution, disassembly and sorting, before yielding secondary resources, as compared to materials-related waste streams.

Waste plastics are to be considered at the interface between product and material-related wastes, since they can indeed be recovered from either plastic products (e.g. LLDPE bags and films, PET bottles, PVC pipes) or from products containing plastics among other material types (e.g. PC-ABS from back covers from LED TVs). At the same time, plastics are not just one material, but instead a family of hundreds of different materials with a wide variety of distinct properties and applications[2]. In order to make recovered plastics suitable for new applications, the different plastic types should be separated from each other, as if it were different material types.

[2] https://www.plasticseurope.org/application/files/5715/1717/4180/Plastics_the_facts_2017_FINAL_for_website_one_page.pdf

In general, **paper and packaging waste** can be categorized as material-related waste streams. Glass, paper and plastic packaging consisting of a single polymer (or a specific combination of polymers) can all be recovered as materials. According to the final concentrations of non-target materials, the recycled material, including most of its additives and fillers, will have recovered the original functionalities and properties. Material-related waste recycling results in secondary raw materials that can be used in a wide range of end-applications. If a secondary material provides the same functionality in the same application as the one that gave origin to the waste, this process is often called **closed-loop recycling**. In practice, it might be challenging to trace back the source and origin of a material in a product, and impossible to physically or chemically distinguish.

Waste treatment of **product-related waste flows** can result in both reusable products or product parts, as well as in fractions of different material types, that sometimes after additional sorting, separation and/or cleaning, will yield **material-related wastes** that can be further refined and purified in material-specific treatments.

In Figure 4, this concept is illustrated by the processing of a discarded washing machine in Flanders. The following material-related waste flows, distributed over different material type groups, are here obtained from this, discarded, complex product:

a) Metals:

This material category considers metal scrap, that can contain base metals (iron, aluminium, copper, lead, nickel, tin and zinc) and/or precious metals, among other. The metal scrap consists of different metal alloys and mixtures of alloys. The separate metals can be obtained in metal-specific treatment facilities, from metallurgical processing of the scrap. It is however not always possible to recover the functionalities of the alloying elements, and rising levels of impurities over consecutive recycling cycles might affect the final quality of the resulting metal or metal alloy.

In the example, the treatment results in (1) copper-rich flows composed of cords, cables, wires and coils, (2) low alloyed steel parts, sheets and frames, (3) stainless steel alloys from panels and drums, (4) cast aluminium from transmission subassemblies, and (5) a non-ferrous metal mix.

b) Biomass:

Textiles, paper, cardboard and rubber compounds will make up a fraction that is often characterized as refuse derived fuel (RDF), from which energy can be recovered. Some of the fossil fuel-based polymers, such as isolating foams, and residual waste from plastic sorting processes, will also be part of this RDF-fraction.

c) Minerals:

Glass from the washing machine doors, and concrete from the stabilizing counterweights will constitute a mineral fraction. Since the glass will be mixed with concrete and other mineral wastes and impurities, this fraction will not be fit to be recovered in the material-related waste stream of glass, but instead will serve as a constituent of building aggregates.

d) Fossil fuel-based polymers

Large sheets and components composed of one or a few polymers can be sorted per polymer type and sent to plastic recycling facilities for further cleaning and removal of impurities.

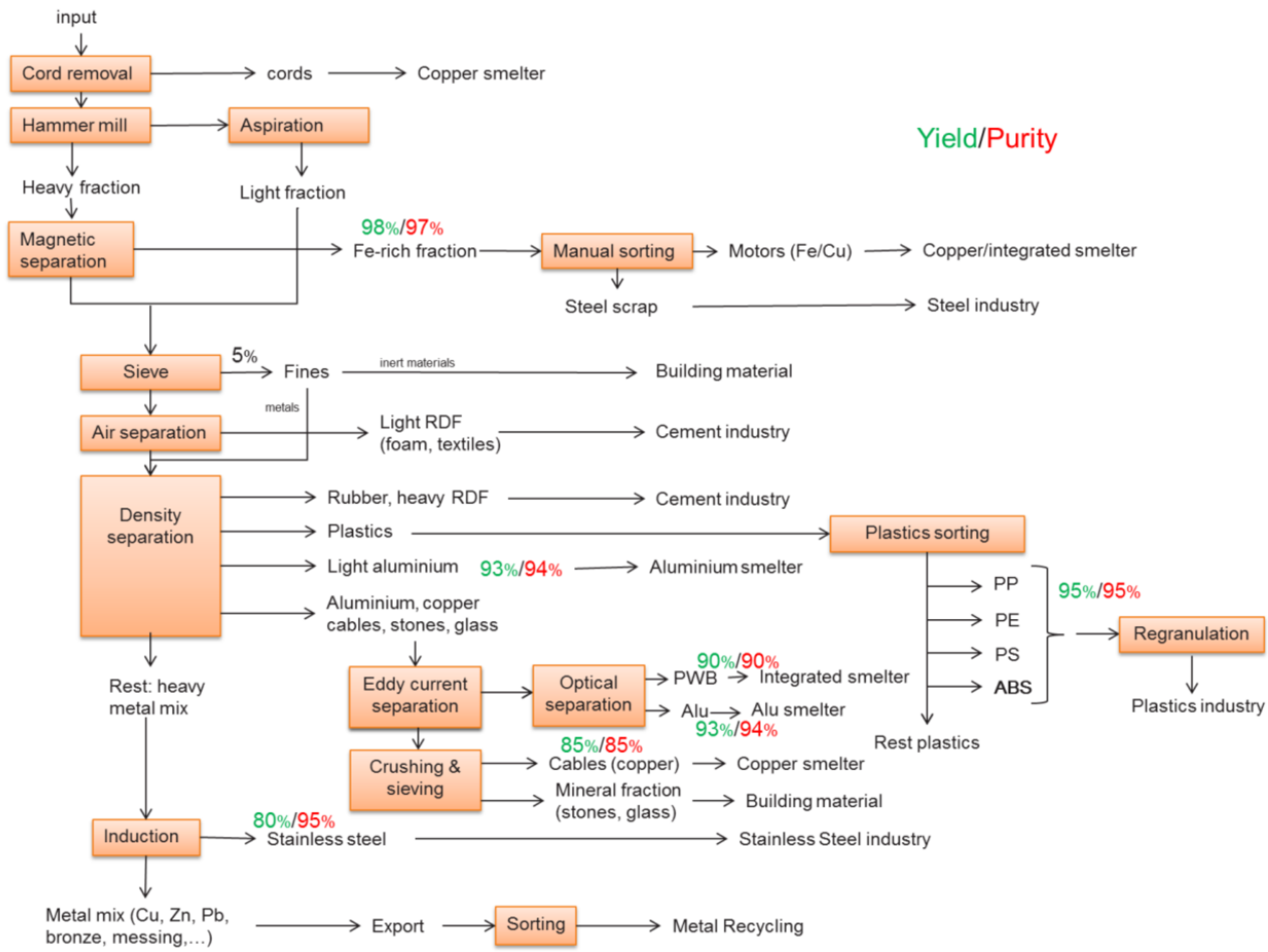


Figure 4: Example of process steps for discarded big household appliances in Flanders (Belgium)[3]

[3] Nelen D., Manshoven S., Vanderreydt I. (2014), Onderzoek inzameldoelstellingen en valorisatie AEEA, Steunpunt Duurzaam Materialenbeheer, Heverlee.

3.2. Circular Economy perspective

To identify the boundary conditions from the circular economy perspective, we will follow a 3-step approach for the generic analysis (see also Figure 5).

Step 1: Identification of generic boundary conditions

Based on available expertise in the consortium, we will identify the generic boundary conditions to be fulfilled for recycled waste streams to end up in actual end applications and subsequently select which of these conditions a WCS can contribute to.

Step 2: Analysis of the waste collection systems (WCS)

The inventory of the WCSs from WP1 allows us to analyse the information available for the most relevant waste collection methods for the respective waste streams and waste fractions.

Step 3: Overview of secondary materials and potential end applications for the recycled waste fractions

Finally, a qualitative overview will be made of the corresponding secondary materials and potential end applications where the collected and recycled waste generally ends up in, providing insights on how the waste entering the recycling value chain finally contributes (or can contribute) to a circular economy.

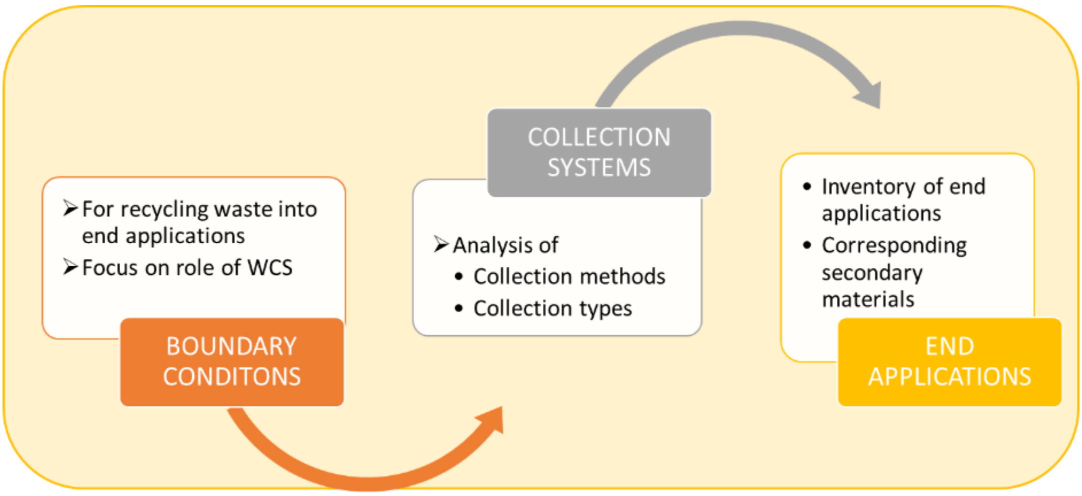


Figure 5: WP2 approach

3.3. Societal perspective

The generic analysis of the boundary conditions from a societal perspective identifies the assets of the waste collection system that anticipate on the behaviour and opinion of citizens on waste collection. This analysis will be done in a two-step approach.

Step 1: Identification of factors impacting citizens' behaviour

The identification of the assets that impact on citizen's participation in separate collection will be done on the one hand through the organisation of a focus group with citizens on this topic. On the other hand, we will analyse surveys on citizens' attitudes towards waste and main concerns around source-separated collection of waste.

Step 2: Study of the interrelation of factors

Through a review of existing academic literature, the interaction between these factors impacting citizens' behaviour will be analysed, including to what extent they are necessary or sufficient to drive virtuous behaviours.

4. Results

4.1. Circular Economy perspective

4.1.1. Step 1: Identification of boundary conditions

The role of a waste collection system in the recycling value chain

Recycling systems require waste streams being directed over two different chains: on the one hand there is a largely public waste service chain, that is meant to manage a supply of products and materials discarded by citizens, that leads to the safe disposal or, alternatively, from which materials can be recycled, often by handing over the waste to a private value chain that recovers valuable resources from waste, to be put on market. Waste services will come with a cost borne by society (ideally by the polluter), while value chain stakeholders aim to add value.

Within a recycling system the service chain focusses on the public obligation to remove waste, while the value chain is as a system of private commodities trading, with main activity to produce and sell materials with added value.

Within this context, the role of public policy and government is to provide a tight and customized connection between the waste service chain and the recycling value chain, that allows for a cost-effective flow of materials from the service to the value chain, observing at any point appropriate precautionary measures for protecting health and the environment. Such connection is made by imposing regulations, fees and taxes, the provision of permits to operate or grants, the implementation of the polluter pays principle, the provision of a suitable legal framework, and by coordinating the actions undertaken by the involved stakeholders. In general, policy should promote the transfer of waste from the service to the value chain in the earliest stage possible, in order to maximize the efficiency in public expenditure. If policy does not provide a good fit, added value is lost for the value chain, due to insufficient or inadequate waste supply, and simultaneously costs go up in the waste service chain, that is forced to pay for the processing, treatment and disposal of an avoidable waste volume. Policy should as well provide the appropriate framework for ensuring an environmentally and safe treatment of the waste and foresee means of enforcement.

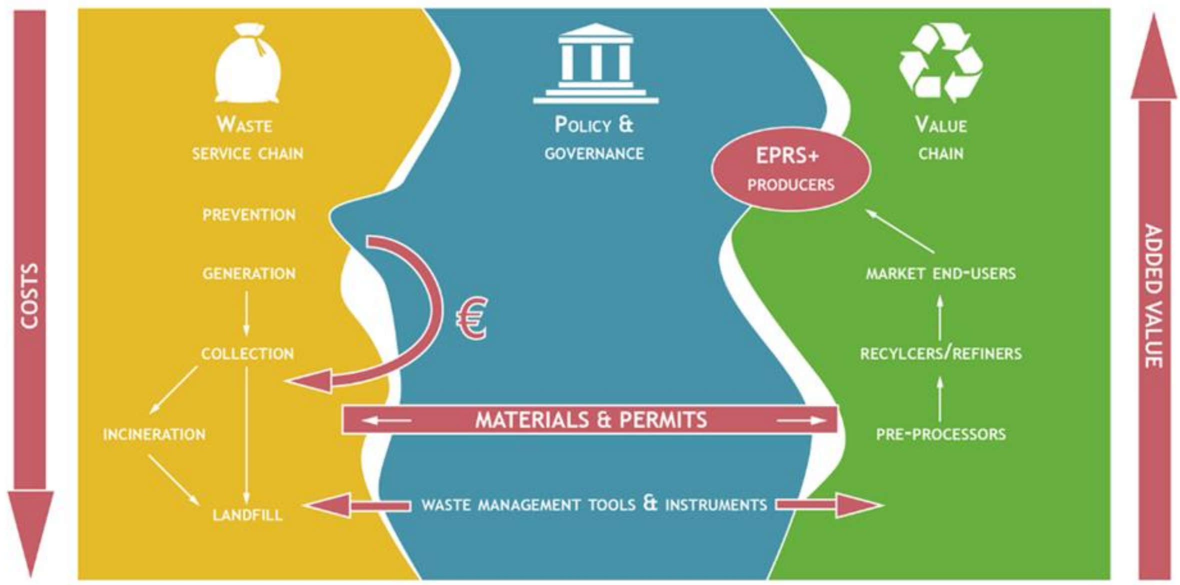


Figure 6: Framework for waste recycling[4]

Identification of boundary conditions

The identification of the main boundary conditions for a waste collection system from a circular economy perspective will show us how specific assets, that can be allocated to the waste collection system, can enhance the performance of the recycling value chain, by providing more or better recycling.

Based on our knowledge and expertise with respect to drivers and barriers for recycling and starting from the end market/demand side of the value chain (see Figure 7), we listed the boundary conditions that make that collected waste gets recycled into an end application.

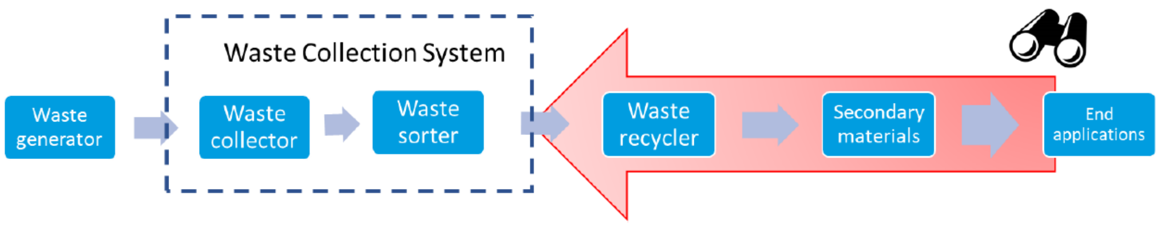


Figure 7 : Recycling value chain from CE perspective

These boundary conditions have been identified in a series of 3 brainstorm sessions:

1. A first session with waste management experts from VITO;
2. A second session with circular economy experts from VITO;

[4] Adapted from: Anne Scheinberg, Michael Simpson (2015). A tale of five cities: Using recycling frameworks to analyse inclusive recycling performance. Waste Manag Res, 33(11):975-85.

3. A third session with partners from the COLLECTORS project contributing to WP2 (being PNO, VTT, REH, ZWE, RSM and VITO).

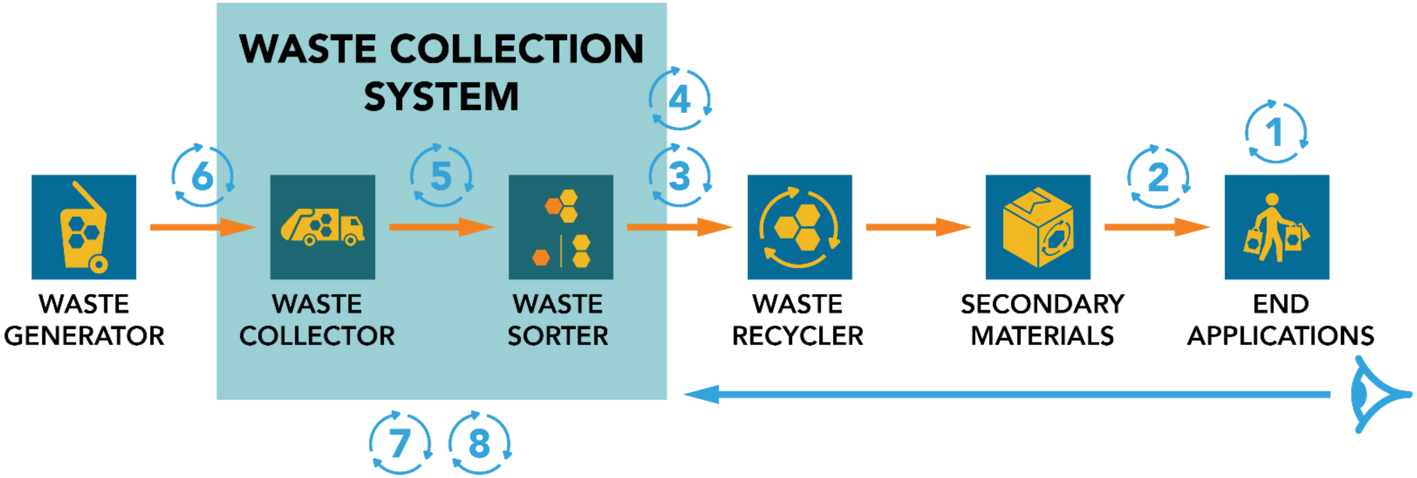
As outcome of these brainstorm sessions 6 boundary conditions have been identified that can be allocated to a specific link within the value chain and 2 boundary conditions that are overarching the total value chain, as illustrated in Figure 8.

The identified boundary conditions are:

1. Market/demand: a market, or at least a demand, should exist for the secondary materials or for end applications that can be made with secondary materials;
2. Manufacturing infrastructure: the manufacturing industry should have available the appropriate infrastructure (with feedstock flexibility) able to absorb/use the secondary materials;
3. Sorting and recycling infrastructure: the sorting and recycling infrastructure should be available to sort and recycle the collected waste into secondary materials meeting market specifications;
4. Supply: the supply of the (sorted) waste should be continuous and must reach a minimal nominal capacity;
5. Quality of waste: the (sorted) waste should meet some quality requirements to enhance recycling into marketable secondary materials; additionally, the quality level should show stability in correspondence with the flexibility of the recycling and manufacturing infrastructure to able to absorb the waste and secondary materials;
6. Traceability: the more information we have about the origin of products that have become waste, the more we know about the materials it is composed of and the higher the chance we can recycle it into high quality products;
7. Policy obligations: policy obligations (such as recycling targets) can support and help steering the recycling value chain in a certain direction;
8. Economics: the basic law of economics (overall revenues have to be larger than costs) has to be respected for each link in the value chain, or the value chain will stop working. A part of the revenues will be obtained from the marketed secondary raw materials, while policy and governance might have put in place waste management-related instruments and tools that allow to transfer additional financial resources, e.g. from fees, taxes and tariffs, into the value chain.

MAIN QUESTION

Which conditions enable the recycling value chain to produce more value, by producing more (quantitative) and/or better (qualitative) secondary materials?



1. **MARKET/DEMAND**
   for secondary materials or for end applications
2. **MANUFACTURING INFRASTRUCTURE**
   with feedstock flexibility to absorb/use sec. materials
3. **SORTING AND RECYCLING INFRASTRUCTURE**
   availability of this infrastructure
4. **SUPPLY**
   minimum amount
5. **QUALITY OF WASTE**
   quality requirements / uncertainty & stability
6. **TRACEABILITY**
   proxy for quality
7. **POLICY OBLIGATIONS**
   such as recycling targets
8. **ECONOMICS**
   costs ≤ revenues for each link in the value chain

Figure 8: Boundary conditions for recycling

In an additional step, we selected from these boundary conditions for recycling those conditions the waste collection system itself can contribute to (see Figure 9). So, these are requirements related to the waste collection system that enable (or hinder) the recycling value chain to produce more value, by producing more (quantitative) or better (qualitative) secondary materials, being:

4. Waste supply;
5. Quality of the waste;
6. Traceability.

Figure 9: Boundary conditions for recycling related to the waste collection system, indicated in red

4.1.2. Step 2: Analysis of waste collection systems included in the inventory (WP 1)

As part of Work Package 1 of the COLLECTORS project (WP 1 Inventory of waste collection systems), an inventory including information on 245 local waste collection systems (WCS) across Europe has been prepared: 135 WCS on Packaging and Paper Waste, 73 WCS on Waste Electrical and Electronic Equipment, and 37 WCS on Construction & Demolition Waste.

In the inventory, information on collection type and collection method has been included for all WCS. Further, we tried to gather information on the quality of separately collected waste fractions (impurities) and input and output fractions resulting from subsequent sorting & treatment steps. Main findings that are of relevance in the context of Work Package 2 are:

- Availability of information on **collection type** and **collection method** is quite **high for 135 PPW collection systems** included in the inventory, rather **basic for 73 WEEE collection systems** included in the inventory, and rather **low for 37 CDW collection systems** included in the inventory;
- Availability of information on the **quality of separately collected waste fractions (impurities)** and **input and output fractions resulting from subsequent sorting & treatment steps** is quite low for **all 245 collection systems** included in the inventory, regardless of waste fractions.

Therefore, the following subchapters focus on giving an overview of waste collection types and waste collection methods for PPW and WEEE only.

4.1.2.1. Packaging and Paper Waste

Data was collected for a total of 135 PPW waste collection systems. During data collection and also for the evaluation a distinction is made between glass, paper & cardboard, plastic, metal and composite material. The most important results for each fraction are presented in a separate table. Further, a distinction between **waste collection type** and **waste collection method** is made. Regarding the **collection type**, it will be distinguished here between single (separate) collection of a specific waste fraction on the one hand and co-mingled collection on the other hand that include two or more fractions at the same time (e.g. co-mingled collection of plastic, composite material and metal waste via a recycling bin). In contrast, the **collection method**, as it is defined here, describes whether a waste fraction is collected via door-to-door collection, bring points, civic amenity site (CAS) or other ways. Some systems apply several of these collection methods in parallel. The following tables are structured by providing statistical evaluation to each of the mentioned collection types and methods. The different waste fractions are each presented in a separate section.

Results for glass waste

Table 1 highlights some of the results of the analysis for glass waste. Of the 135 analysed collection systems, 125 apply a single collection scheme for glass. This represents around 93% of all analysed waste collection systems. Only a small minority (~5%) use a co-mingled collection (with other separately collected wastes) or a combination of single and co-mingled collection (~2%). This shows that a single collection is clearly preferred by municipalities for the collection of glass waste.

Within single (separate) collection schemes, the majority of systems (~30%) apply one collection method. Two or three collection methods in parallel are applied by around 18% and 8% respectively. It should be noted that for nearly half (~45%) of the analysed systems no information on the collection method could be found. This is an interesting outcome, especially when considering the increasing importance of recycling activities and increasing recycling targets.

Table 1: Overview of systems per collection type for glass waste

General overview	No. of systems	
PPW systems analysed in total	135	
Type of collection for glass waste	No. of systems	
Single collection	125	93%
Co-mingled collection	7	5%
Combination of single and co-mingled	3	2%
Single collection methods	No. of systems	
Systems with 1 collection method	37	30%
Systems with 2 collection methods	22	18%
Systems with 3 collection methods	10	8%
Systems without data on collection methods	56	45%

Table 2 presents the systems categorised in how many different waste collection methods are applied to separately collect glass waste. As it can be seen, collection via bring points is the by far most commonly applied collection method (~78%), followed by collection via civic amenity site (~14%) and door-to-door collection (~8%). Bring points are also of high importance in collection schemes that combine two or three collection methods.

Table 2: Used collection methods for the single collection of glass waste

Single collection of glass waste								
37 systems	**Door-to-door**		**Bring points**		**CAS**		**Other**	
Systems with 1 collection method	3	8%	29	78%	5	14%	0	0%
22 systems	Door-to-door + bring points				Bring points + CAS			
Systems with 2 collection methods*	6		27%		12		55%	
10 systems	Door-to-door + bring point + CAS				Bring points + CAS + other			
Systems with 3 collection methods*	6		60%		3		30%	

**Only the most important combinations of waste collection methods are presented here to maintain a clear overview. The values do not necessarily add up to 100%.*

Results for paper & cardboard waste

Regarding paper and cardboard waste, around 70% of the analysed systems apply a single collection type of this fraction (cf. Table 3). This is less compared to glass waste, but still represents the majority of systems. Co-mingled collection is applied by 24% of analysed systems and a combination of single and co-mingled collection is implemented by 6%. Similar to the single collection of glass waste, most systems (36%) use only one collection method for the single collection of paper and cardboard. Data availability is significantly better compared to glass waste, as no information could be found for comparably few systems (14%).

Within the single (separate) collection scheme (cf. Table 4), most systems use only one collection method for collection of paper and cardboard waste. In contrast to glass waste, civic amenity sites are the most commonly applied method (50%) rather than the collection via bring points (32%). Only a minority is applying door-to-door collection (18%) as only method. Civic amenity sites (CAS) are also commonly applied when two or three different collection methods are combined. Door-to-door collection in combination with collection via CAS is applied by 44% of the analysed systems. Additionally, collection via bring points in combination to collection via CAS is applied by 28%. This tendency is also reflected in the application of three different methods. Door-to-door in combination with bring points and CAS is applied by 73% of the systems that use three different collection methods in parallel. This indicates that CAS is the most common collection method for paper and cardboard waste.

Table 3: Overview of systems per collection type for paper & cardboard waste

General overview	No. of systems	
PPW systems analysed in total	135	
Type of collection for paper & cardboard waste	**No. of systems**	
Single collection	94	70%
Co-mingled collection	33	24%
Combination of single and co-mingled	8	6%
Single collection methods	**No. of systems**	
Systems with 1 collection method	34	36%
Systems with 2 collection methods	25	27%
Systems with 3 collection methods	15	16%
Systems with 4 collection methods	7	7%
Systems without data on collection methods	13	14%

Table 4: Used collection methods for the single collection of paper & cardboard waste

Single collection of paper & cardboard waste								
34 systems	**Door-to-door**		**Bring points**		**CAS**		**Other**	
Systems with 1 collection method	6	18%	11	32%	17	50%	0	0%

25 systems	Door-to-door + bring points		Door-to-door + CAS		Bring points + CAS	
Systems with 2 collection methods*	5	20%	11	44%	7	28%
15 systems	Door-to-door + bring point + CAS		Bring points + CAS + other			
Systems with 3 collection methods*	11	73%	2	13%		

**Only the most important combinations of waste collection methods are presented here to maintain a clear overview. The values do not necessarily add up to 100%.*

Results for plastic waste

With regard to the collection of plastic waste, the situation is reversed as 77% of the analysed systems use a co-mingled collection (cf. Table 5). Only a minority of 16% apply a single collection and 6% use a combined approach of single and co-mingled collection. No data could be found in regard to the collection type for 1% of the systems.

Table 5: Overview of systems per collection type for plastic waste

General overview	No. of systems	
PPW systems analysed in total	135	
Type of collection for plastic waste	No. of systems	
Single collection	21	16%
Co-mingled collection	104	77%
Combination of single and co-mingled	8	6%
No data	2	1%
Co-mingled collection methods	No. of systems	
Systems with 1 collection method	25	25%
Systems with 2 collection methods	22	22%
Systems with 3 collection methods	8	8%
Systems with 4 collection methods	4	4%
Systems without data on collection methods	45	43%

Within the single (separate) collection scheme, most systems either use bring points (40%) or civic amenity sites (40%) as collection method (cf. Table 6). However, it should be stressed that only 10 systems apply a collection with one method for the separate collection of plastic waste.

Within the co-mingled collection scheme, basically all systems either use door-to-door (48%) or bring points (48%) as collection method.

Table 6: Used collection methods for the single and co-mingled collection of plastic waste

Collection of plastic waste								
Single collection methods								
10 systems	Door-to-door		Bring points		CAS		Other	
Systems with 1 collection method	1	10%	4	40%	4	40%	1	10%
Co-mingled collection methods								
25 systems	Door-to-door		Bring points		CAS		Other	
Systems with 1 collection method	12	48%	12	48%	0	0%	1	4%

22 systems	Door-to-door + bring points		Door-to-door + CAS		Bring points + CAS	
Systems with 2 collection method	7	22%	9	29%	4	13%

Within the co-mingled collection of plastic waste, the situation is very diverse and a clear statement about waste fractions that are commonly collected together is difficult to make. The following list provides an overview of some of the more often found approaches:

- Co-mingled collection of plastic and composite material
- Co-mingled collection of plastic and metal waste
- Co-mingled collection of plastic, composite material and metal waste
- PMD collection (Plastic bottles and flasks, Metal packaging and Drink cartons)

The separately collected packaging wastes can be offered for collection both in dedicated bags or bins.

Results for metal waste and composite waste

Regarding metal, the data availability is insufficient to draw conclusions in regard to applied collections methods. However, some general remarks can be made.

For metal waste, only a minority chose a single collection approach (18%) or a combination of single and co-mingled collection (12%). This fraction is typically collected as co-mingled fraction (64% of systems). One might conclude that this is due to the connection to plastic waste, as both fractions are often collected together, when a co-mingled collection is implemented.

The situation is similar for composite material waste, as a majority of 65% of analysed systems apply a co-mingled collection. Only small minorities apply a single collection (7%) or a combination of single and co-mingled collection (1%).

4.1.2.2. Waste Electrical and Electronic equipment

For the waste fraction WEEE a total of 73 WCS were assessed. Similar to the assessment of PPW, different waste collection methods are distinguished. However, the methods differ to some extent and were defined as follows: municipal collection points (e.g. civic amenity sites (CAS)), retailer bring points, non-retailer bring points , door-to-door collection, pick-up on request and other. The latter includes waste collection events as well as mobile collection (not to be mistaken for door-to-door collection). Such a mobile collection might be conducted with specific waste trucks several times a year. The truck stays for 3-4 days at a given location which is communicated to the citizens, and a collective event can be very diverse and might be organised as a combination of waste collection and information event in a pedestrian zone, for example.

It should be stressed that the values presented in Table 7 are incomplete as data collection has proved to be extremely difficult for some of the systems. Nevertheless, some general statements can be made. Information collected shows a tendency can be seen in the application of civic amenity sites either as single collection method[5] or in combination with other collection methods. Information about the use of CAS could be found for around 85% of the assessed systems. A similar situation applies to non-retailer bring points with around 78% using this approach. A collection via retailer bring points seems to be another commonly applied approach, yet information about the number of participating retailers is rarely provided.

For the assessed WCS, a major part of collected WEEE quantities is collected via CAS, if this is implemented as a collection method. It should be pointed out again that sufficient data regarding waste amounts is only available for 45% of the assessed systems and that no general statements can be made. Within this selection of systems, largest proportions of collected WEEE are collected via CAS. For the other collection methods, no clear tendency can be identified.

[5] the WEEE Directive requests that retail bring point collect WEEE on a 1 to 1 basis and the recast of the Directive forces retailers of >400m² to collect small WEEE on a 1 to 0 basis. Probably only data sources from municipalities have been consulted in the WP1 database, hence, there is missing information about retail bring points usually provided by the PROs.

Table 7. Overview of systems regarding separate WEEE collection

General overview	No. of systems	
WEEE systems analysed in total	73	
Common types of collection methods for WEEE	No. of systems	
Civic amenity sites	62	84.9%
Other (e.g. mobile collection truck, collection events)	41	56.2%
Pick-up on request	31	42.5%
Retailer bring points	30	41.1%
No. of collection methods applied by a WCS	No. of systems	
1 collection method	7	9.6%
2 collection methods	11	15.1%
3 collection methods	31	42.5%
4 collection methods	16	21.9%
5 collection methods	7	9.6%
Limited data	1	1.4%

It further can be seen in Table 7 that the majority of systems apply several collection methods in parallel, with most systems applying three methods in parallel (~43%). Within this category, a variety of combinations do exist.

The analysis of individual WEEE categories is proving to be even more difficult as a variety of categorisations are used. Although the categorisation of WEEE is usually laid down in national legislation, there are sometimes different collection classes used for the collection, for example, via civic amenity sites. A comparative evaluation of the collected quantities is therefore not possible and has not been carried out.

4.1.3. Step 3: Overview of secondary materials and end applications

As ‘quality of waste’ is probably the most discussed boundary condition identified, the next paragraphs elaborate how the (sorted) waste relates to the corresponding secondary materials and end applications, and describe the quality requirements that allow recycling processes to produce marketable secondary materials, both for paper and packaging waste and for WEEE.

For each of the waste streams, following topics are discussed:

1. Secondary materials from the waste;
2. Sorting collected waste;
3. Qualities of sorted waste;
4. Market prices of sorted waste;
5. The waste recycling process;
6. End applications for different qualities;
7. Recycled content in end applications.

4.1.3.1. Packaging and Paper Waste

Paper & cardboard (both packaging and non-packaging)

Secondary materials from paper and cardboard waste

The recycling of paper and cardboard consists in the application of the natural fibres contained in products made predominantly from paper and board, in new products. Examples of **products from paper and board** are:

- newsprint and other graphic papers;
- case materials consist papers and boards mainly used in the manufacture of corrugated board. Included are kraftliner, testliner, semi-chemical fluting, and waste-based fluting (Wellenstoff). Also known as containerboard, corrugated case materials, cardboard, linerboard or corrugating medium[6];

Figure 10: Corrugated board

- carton board is stiffer and thicker than case materials. It has a medium to high compression and moisture resistance. Unlike cardboard, it is solid, and not fluted[7];
- wrappings and other packaging papers;
- sanitary and household paper;
- other paper and boards.

Sorting collected paper and cardboard waste

Collected end-of-life paper and cardboard products are processed in order to make available the contained fibres for their reuse in new applications. Depending of the collection system in place, the collected paper and cardboard is sorted in different grades. Unwanted materials (mainly non-paper components such as metal, plastic, glass, textiles, wood, stones, synthetic materials) can be removed before and during the sorting process. Pre-sorting treatments should focus on constituents that cannot be removed by dry sorting, such as coatings, laminates, spiral bindings. For unwanted materials maximum tolerance levels are defined by the paper producers.

As a result of the sorting process, the following main grades can be distinguished[8]:

[6] http://www.cepi.org/aboutpaper/glossary
[7] https://www.gwp.co.uk/guides/corrugated-board-grades-explained/
[8] These main grades refer to the CEPI classes I, II, II, IV, and also correspond to the EN 643 'European List of Standard Grades of Paper for Recycling and Board' official paper for recycling grade listing.

- mixed grades;
- corrugated and kraft[9];
- newspapers & magazines;
- other grades.

Qualities of sorted paper and cardboard waste

In order to be suitable for recycling, all sorted fractions should be free from '*any materials which represent a hazard for health, safety and environment, such as medical waste, contaminated products of personal hygiene, hazardous waste, organic waste including foodstuffs, bitumen and toxic powders, and similar*'[10]. Contamination with food, for instance, can cause odour problems and bacterial activity might affect the physical properties of the end product.

The paper industry manages standardized grade categorizations (EN 643)[10], such as:

- Group 1: ordinary grades, such as mixed paper and board;
- Group 2: medium grades, such as sorted office paper;
- Group 3: high grades, such as white newsprint;
- Group 4: kraft grades, such as unused corrugated kraft;
- Group 5: special grades, such as used beverage cartons.

The different main grades of paper and cardboard offered for recycling are further categorized according to, for example, the relative shares of specific types of paper or cardboard, or the presence of paper and board not fully complying with the grade definition, or of paper products not suitable for deinking. Examples of the subcategories are:

- Ordinary grade 1.04.00: Corrugated paper and board packaging = Used paper and board packaging, containing a minimum of 70 % of corrugated board, the rest being other packaging papers and boards;
- Medium grade 2.05.00: Ordinary sorted office paper = Paper, as typically generated by offices, shredded or unshredded, printed, may contain coloured papers, with a minimum 60 % woodfree paper, free of carbon and principally free from carbonless copy paper (ccp)/no carbon required (NCR), less than 10 % unbleached fibres including manila envelopes and file covers, less than 5 % newspapers and packaging;
- Kraft grade 4.01.01: Unused corrugated kraft = Unused boxes, sheets and shavings of corrugated board, with kraft liners only, the fluting made from chemical or chemo thermo mechanical pulp.

The standardized grading of the cleaned and sorted fractions allows to distinguish different waste paper and cardboard qualities. Each of the grades described in the EN 643 standard is associated with maximum tolerance levels of unwanted materials, i.e. materials that are unsuited for the production of paper and board, such as non-paper components, paper and board not according to

[9] Kraft paper or kraft is paper or paperboard (cardboard) produced from chemical pulp produced in the kraft process.
[10] http://www.cepi.org/system/files/public/documents/publications/recycling/2013/CEPI_EN%20643_brochure_FINAL_0.pdf

grade definition, paper and board detrimental to production and paper not suitable for deinking (if applicable).

Market prices of sorted paper and cardboard waste

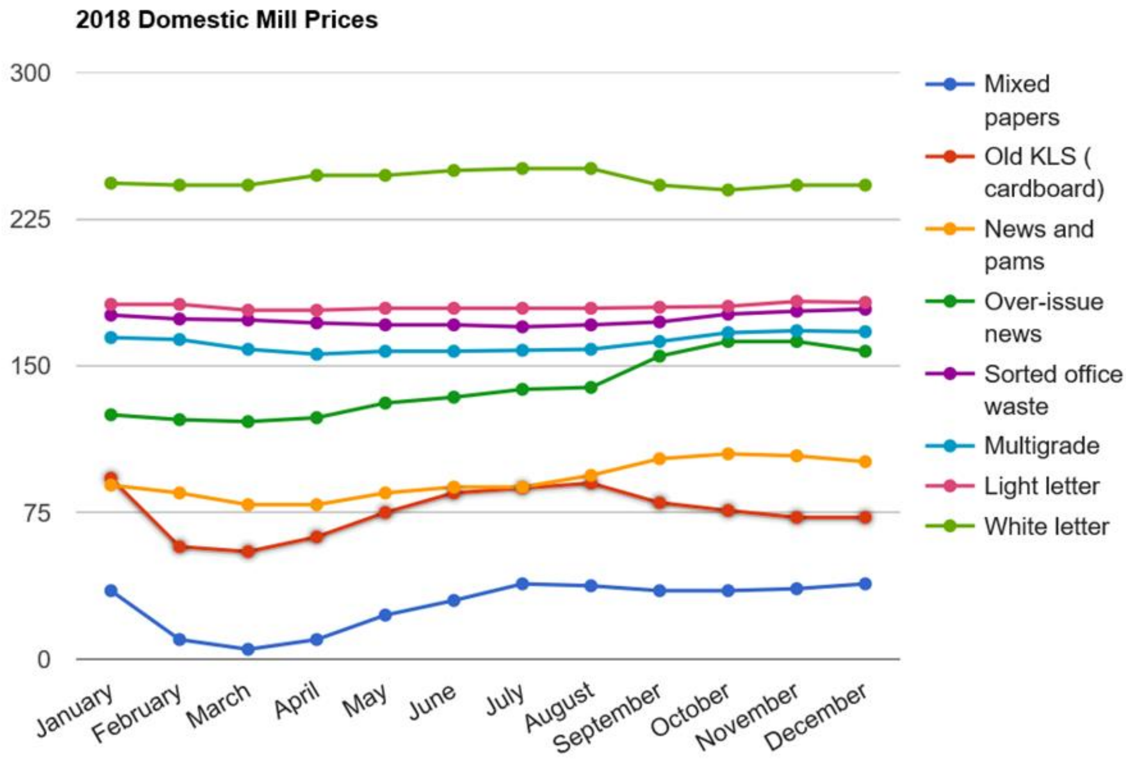


Figure 11: UK 2018 market prices (per ton, in £, ex works) for different grades of sorted paper and cardboard[11]

The paper and cardboard recycling process

The paper and cardboard recycling process usually considers (a combination of) the following processes[12]:

- **Pulping**: Waste paper is loaded into a pulper where it is mixed with hot water, alkali, and various solvents, detergents, and dispersants. This mixture is "cooked," which produces a "stock" of the resulting pulverized paper. The added chemicals dissolve and disperse adhesives, fillers, sizes, ink pigments, binders, and coatings, all of which eventually end up in one or another waste stream from the process.

[11] https://www.letsrecycle.com/prices/waste-paper/uk-domestic-mill-prices/2018-domestic-mill-prices/

[12] Woodard & Curran, Inc. (2006). Wastes from Industries (Case Studies), in: Industrial Waste Treatment Handbook (Second Edition), Butterworth-Heinemann, 2006, Pages 409-496.

- **Prewashing**: Gross amounts of ink, clay, and other materials are removed by prewashing, which consists of fine screening, partial dewatering, dissolved or dispersed air flotation, and/or settling.
- **Screening**: The prewashed stock is next subjected to both coarse and fine screening. The fine screens are sometimes operated under pressure.
- **Through-flow Cleaning**: Also called "reverse cleaning," this process is typified by a counter-current washing process. In one form, the stock flows down an inclined screen with several intermediate barriers. The stock is sprayed with water at each barrier, which washes substances such as ink particles through the screen.
- **Forward Cleaning**: Heavy contaminants that pass through the through-flow and fine screening processes are the target pollutants for the forward cleaning process. This process operates in a multistage sequence similar to that of the through-flow process.
- **Washing**: The washing process makes use of counter current flow washing to remove ink from the stock that has not yet been successfully removed. Equipment includes sidehill screens, gravity deckers, and dewatering screws.
- **Flotation**: Those colloidal substances, including inks that are resistant to screening and washing processes, are the target substances for the flotation process. Flotation does not make use of added water but may use coagulation chemicals, including organic polymers. In some instances, the flotation process is located ahead of the washing process.
- **Dispersion**: Those quantities of inks that are not removed by screening, through-flow cleaning, forward cleaning, washing, and flotation are dispersed in order to make them undetectable in the finished paper.
- **Bleaching**: Bleaching of the recycled pulp is highly specific to each individual mill. Bleaching can be done in the pulper, just after prewashing, or after flotation and dispersion. Bleaching chemicals can include chlorine, chlorine dioxide, peroxides, and/or hydrosulphites.

End applications for different paper and cardboard grades and recycled content

Table 8 represents the different end applications of main waste paper and cardboard grades[13]. The lighter the colour, the more the specific grade is used in the particular end application. For each end application a different fibre quality is preferred; highest quality fibres are required for newsprint and other graphic paper applications, lower qualities might be suitable for the production of sanitary and household tissues.

[13] Figures taken or calculated from CEPI Key Statistics 2017, available at http://www.cepi.org/system/files/public/documents/publications/statistics/2018/210X140_CEPI_Brochure_KeyStatistics2017_WEB.pdf

Table 8: End application of different waste paper and cardboard grades

Grade of paper for recycling → End application ↓	mixed grades	corrugated and kraft	newspapers & magazines	other grades
Newsprint	0%	0%	59%	3%
Other graphic papers	0%	0%	31%	12%
Case materials	52%	85%	0%	17%
Carton board	19%	2%	1%	17%
Wrappings and other packaging	23%	7%	2%	10%
Sanitary and household	3%	1%	6%	37%
Other paper and board	2%	4%	0%	3%
TOTAL	**100%**	**100%**	**100%**	**100%**

Not all collected paper and cardboard is utilised for papermaking. Recovered paper can be used in construction materials, such as insulation, bricks and furniture[14], for animal beddings or for composting. Also, as a less preferable waste treatment option, the calorific value of the fibres can be recovered, e.g. for providing energy to the paper production facility.

Some alternative applications of the paper fibres in the construction and manufacturing sector include[15]:

- Asphalt road surfaces that use old newspaper fibres to act as a thickener to hold the liquid bitumen in place around the aggregate, in order to avoid the bitumen to drain away, allowing the aggregate to be more easily dislodged by traffic[16];
- Car brake linings have been reported to use recycled newspaper fibres to hold the lining material together;
- In concrete repair, recycled newspaper fibres can be applied as a carrier for an electrolyte solution, which enables concrete–steel reinforced structures to be re-alkalised or desalinated, both responsible for the corrosion of the steel reinforcement.

[14] https://materialdistrict.com/article/paperbricks-bricks-furniture-newspapers/

[15] Pratima Bajpai (2014). Uses of Recovered Paper Other than Papermaking. In: Recycling and Deinking of Recovered Paper, Elsevier, 2014, Pages 283-295.

[16] Erlinda & Moran, M.S.R. & Austria, C.O.. (2009). Paper mill sludge as fiber additive for asphalt road pavement. Philippine Journal of Science. 138. 29-36.

Recycled content in end applications

Recycled paper and board cover a significant share of the industries' fibre needs for different paper and cardboard products, as is illustrated in Figure 12.

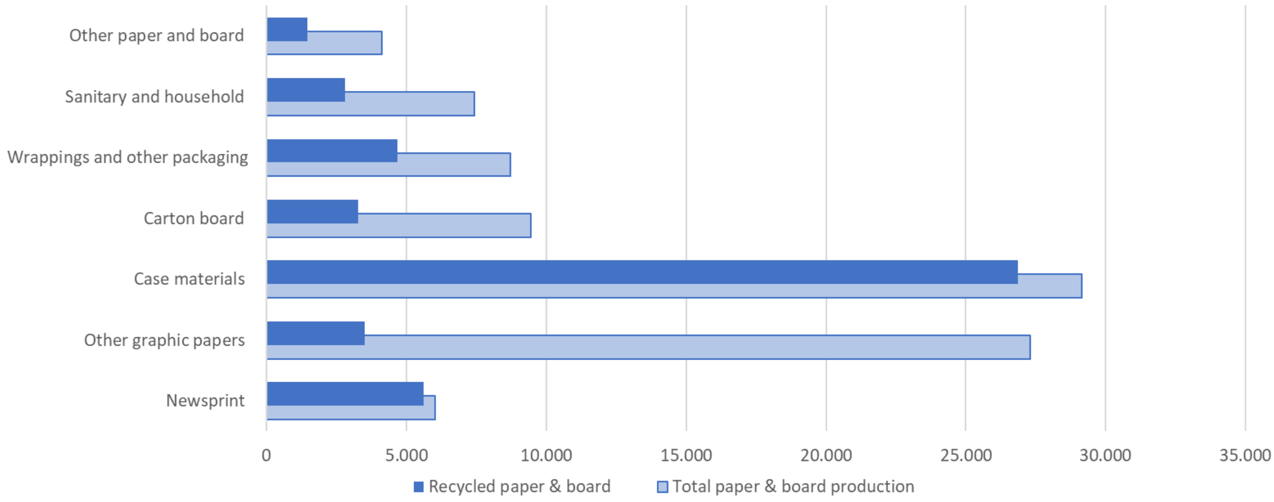


Figure 12: Share of recycled fibres in total paper and board production

Glass packaging

Secondary materials from glass packaging waste

The recycling of glass packaging consists in the use of discarded **glass bottles, containers and jars** as a substitute of primary raw materials in the process of glass production. The material used in glass packaging products is usually referred to as container glass or (furnace ready) cullet[17].

Sorting collected glass packaging waste

Since glass retains its colour after recycling, in general, a distinction is made between waste glass of different colours, clear (flint), amber (brown) and green being the dominant colours, while the category 'mixed' is also often marketed.

Waste container glass can be collected in different ways, as illustrated in Figure 13.

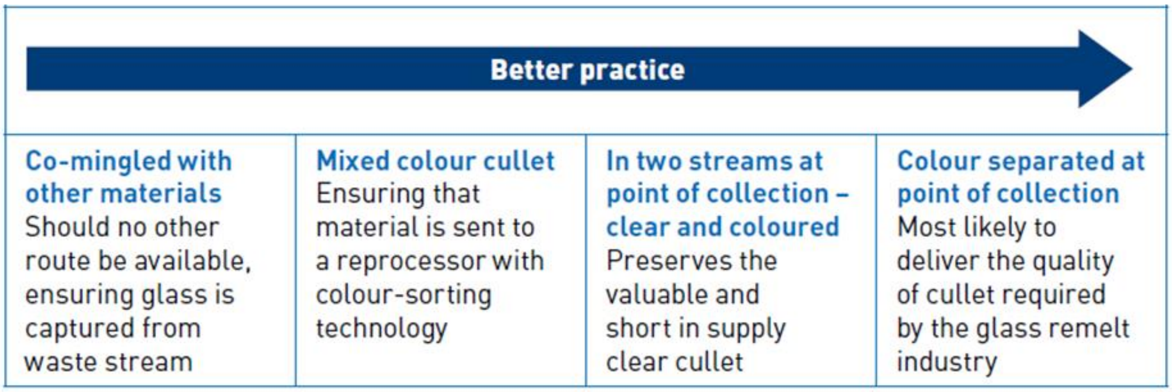


Figure 13: Container or packaging glass collection practices[18]

If the container glass collection does not distinguish different colours, colour separation or the removal of contamination with differently coloured glass can be achieved by high-tech optical colour sorting equipment. This technique allows to separate quality mixed glass into high standard cullet.

When closed loop container glass recycling is aimed at, special attention should be given to sort out or avoid the presence of glass types with different chemical compositions that can cause problems in the container glass manufacturing process, such as heat resistant glass, LED screens, light bulbs or drinking glasses[18].

[17] as defined in the Joint Research Center study in the preparation of the Regulation on End of Waste Glass 1179/2012
[18] http://www.wrap.org.uk/sites/files/wrap/Choosing%20and%20improving%20your%20glass%20collection%20service.pdf

Qualities of glass cullet

Glass containers are usually broken at the moment of disposal and will be further crushed or grind into so-called glass cullet before remelting. Finer and more homogeneous particle distributions are preferred by the glass industry.

Not all container glass cullet will be recycled into new bottles or jars, or even be remelted. The potential end applications of recovered glass will be determined by the particle size and size distribution, by the colour purity of the sorted glass cullet, and by the presence and levels of contaminants that might hinder the glass production process. Materials of which the presence in the sorted fraction should be minimized include ferrous and non-ferrous metal parts, stones and ceramics[19], and organic materials such as cork and paper.

The UK Waste & Resources Action Programme (WRAP) has published a standard, known as PAS 101, which provides a specification for recovered container glass and introduces a four-tier grading system for raw cullet quality – grades A to D – according to the degree of colour separation, contamination and particle size[20].

In the End Of Waste Glass Regulation 1179/2012[21] specifications on the quality of glass cullet resulting from recovery operations are mentioned, including the content of non-glass components.

Market prices of sorted glass cullet

The highest value will be obtained for fine cullet of pure clear glass with a homogeneous particle size distribution and minimal presence of contaminants (organic, inorganic, ferrous/non-ferrous metals). Colour preferences of local container glass producers, in combination with the availability of these preferred colours in the supplied waste glass, will determine the market price for each colour. In the UK for instance, there is a large supply of green coloured wine bottles, whereas local producers produce mainly clear glass[22]. An example of such price differences is given in Figure 14.[23]

[19] Often the term CSP (ceramics, stones and porcelain) is used
[20] http://www.wrap.org.uk/sites/files/wrap/MRF%20Output%20Material%20Quality%20Thresholds%20Report.pdf
[21] https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:337:0031:0036:EN:PDF
[22] https://www.letsrecycle.com/prices/glass/
[23] https://www.letsrecycle.com/prices/glass/glass-prices-2018/

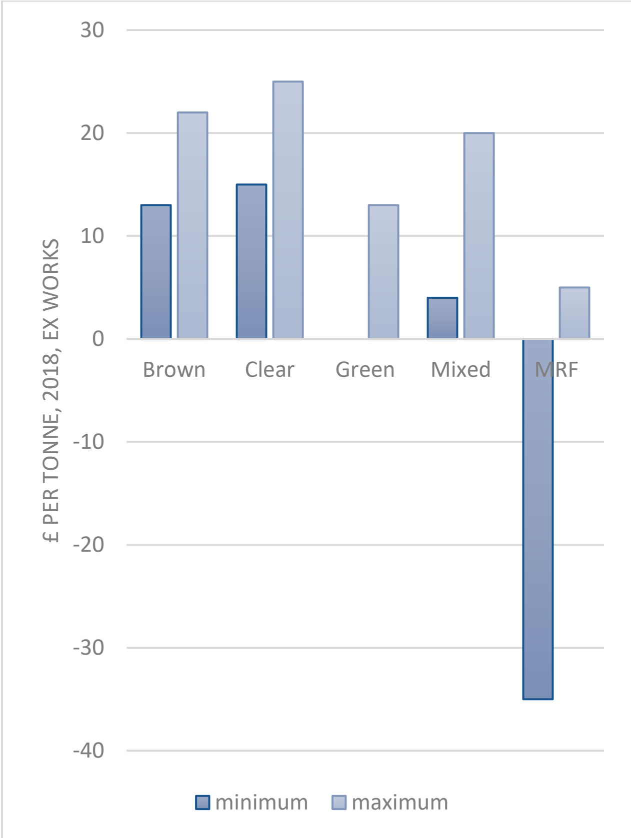


Figure 14: UK 2018 market prices (per ton, in £, ex works) for different grades of glass cullet

The container glass cullet recycling process

Homogeneous loads of sorted container glass cullet can be recycled in a closed loop system, in which the cullet are fed into the container glass production process at the moment of batch preparation:

This batch preparation stage involves weighing fine-ground primary raw materials – that include formers, fluxes, stabilizers and sometimes colorants – according to recipe required for the final product, and their subsequent mixing to achieve a homogenous composition[24]. Due to its abrasive nature and larger particle size, cullet is usually handled separately from the primary batch materials and may be fed, often after being pre-heated, to the furnace in measured quantities by a separate system[25].

Glass melting is one of the most important and energy intensive processes in the manufacturing of glass products, consuming 60 to 70% of the total energy used in glass production. As a general rule, every 10 % of extra cullet results in a 2.5 – 3.0 % reduction in furnace energy consumption, because the energy required to melt 1 ton of glass is lower than that required for 1 ton of sand[25]. Other

[24] http://ietd.iipnetwork.org/content/batch-preparation
[25] EC (2012). Best Available Techniques (BAT) Reference Document for the Manufacture of Glass.

authors[26] have estimated energy savings of around 8 MJ for every percent increase (by weight) in cullet use.

End applications for different qualities[27]

Container glass cullet is, in general, not suitable as a secondary raw material in the production of flat glass. Flat glass is mainly used in windows, doors, automotive glass, mirrors and in solar panels, i.e. applications for which very low maximum levels of contaminants must be observed. However, performant state of the art recycling installations are more and more able to meet the quality criteria of the flat glass industry to supply furnace ready cullet. (Vice versa, flat glass can perfectly be recycled in the container glass production.)

Colour sorted and clean container glass cullet can however be used for the production of new containers, bottles and jars, enabling closed loop recycling. The strictest maximum levels of colour contamination in container glass cullet apply for the manufacturing of clear container glass, whereas green glass has the highest tolerance for other colours. Typically, the maximum colour contamination limits for container glass cullet are:

- Clear glass: <2% to <6%
- Amber (brown) glass: <5% to <15%
- Green glass: <5% to <30%

Another possible end application of container glass cullet in the glass industry is provided by the production of mineral wool. Mineral wool is made of short fibres of glass (typically borosilicate glass or alkaline earth – alumina-silicate stone wool) and ceramic materials. It is used for insulation, filtering and firestop applications. For mineral wool, ferrous metal contamination levels are extremely low (<10 ppm). These and other possible end applications are summarized in Table 9.

Cullet type	Potential end application
Clear (flint)	Container glass (flint, brown, green)
Amber (brown)	
Green	
Mixed	
Mixed	Insulation mineral wool (short glass fibre)

[26] Ernst Worrell, Christina Galitsky, Eric Masanet, Wina Graus (2008). Energy Efficiency Improvement and Cost Saving Opportunities for the Glass Industry - An ENERGY STAR® Guide for Energy and Plant Managers.

[27] EC (2011). End-of-Waste Criteria for Glass Cullet: Technical Proposals. Available at: http://ftp.jrc.es/pub/EURdoc/JRC68281.pdf

Green, Mixed	Use in ceramic sanitary ware production
	Use as a fluxing agent in brick manufacture
	Use in sports turf and related applications
	Use as water filtration media
	Use as an abrasive

Table 9: Potential end applications for container glass

For some of the listed end applications that do not involve remelting, particularly the use as water filtration media and as abrasive, different and additional quality requirements can be demanded by the end user. For example, in an application as abrasive, corrosive constituents and adhesion-impairing contaminants must be avoided, whereas for water filtration it is important to establish the absence of medical or chemical refuse, hazardous or toxic substance, light bulbs and fluorescent lightning tubes.

Other possible end applications for glass cullet, mainly intended for the lower quality cullet, include its use in construction materials, for instance as an aggregate in concrete and asphalt mixtures, an aggregate in unbound base and subbase applications, as lightweight engineering material and a cementitious material.[28]

Recycled content in end applications

When using clean, furnace-ready, contaminant free, single colour cullet with a homogeneous particle size distribution, new glass containers can include up to 95% recycled content. In 2013, in the US, an average of 33.64% recycled glass was used in the production of all new glass containers.[29] In 2017, packaging glass producers estimate the ratio of cullet to primary raw materials being about 40%. Colours with higher maximum colour contamination limits, such as green glass, may contain more than 85% cullet, but clear glass must contain no more than 60% in order to avoid deviations in colour.[30]

For non-container glass end applications, colours are of less, or no concern, while tolerances for recycled glass are usually high. Foamed glass is an established commercial product that can tolerate 98% cullet in its manufacture. One producer of glass wool insulation reportedly uses up to 80% cullet[31].

[28] Mohajerani, Abbas & Vajna, John & Ho Homan Cheung, Tsz & Kurmus, Halenur & Arulrajah, Arul & Horpibulsuk, Suksun. (2017). Practical recycling applications of crushed waste glass in construction materials: A review. Construction and Building Materials. 156. 443-467. 10.1016/j.conbuildmat.2017.09.005.

[29] http://gpi.org/sites/default/files/GPI%20Recycled%20Content%20Report%2C%20September%202014.pdf

[30] https://www.wastematters.eu/uploads/media/DWMA_Closing_the_glass_recycling_loop.pdf

[31] Ernst Worrell and Markus A. Reuter (2014) Handbook of recycling : state-of-the-art for practitioners, analysts, and scientists, Elsevier Inc.

Metal packaging

Secondary materials from metal packaging

Metal packaging includes **steel and aluminium cans and foils, and metal caps, crowns, lids and closures**. When collected and properly sorted, they can be fed into metallurgical production processes, that recover both the base metals and part of the alloying elements, substituting for the corresponding primary metals from ore.

Sorting collected metal packaging waste

a) Aluminium packaging

Collected, completely emptied **aluminium beverage cans** can be separated mechanically from other materials and baled or briquetted for further metallurgical processing.

Apart from cans, aluminium packaging also includes **meal trays, rigid containers, aerosol cans, screw closures and cappings**. When separately collected, cleaned and sorted, the resulting aluminium fraction can be baled.

Aluminium is also present in packaging under the form of **laminated foil,** as a barrier material to plastics or cardboard. In many cases, separate packaging waste collection systems consider the collection of composite drinking cartons.

The aluminium of **blister packs, foil wrappers and metallized plastic film and paper** is not subject to separate collection but is often found in fractions that target aluminium packaging for recycling.

b) Steel packaging

Steel **drums and cans** are commonly used for containing food, pet food, personal care products, paints and aerosols[32]. Lacquers and polymer or metal coatings are frequently applied. When collected separately or together with aluminium packaging, steel-based packaging is easily sorted out from non-ferrous metals and other materials by magnetic separation. Sorted steel packaging scrap can then be cleaned and thermally treated to remove residues such as oil and paint. It can then be baled for metallurgical recovery.

[32] https://www.kidv.nl/6291/closing-the-loop-design-for-recovery-guidelines-steel.pdf?ch=DEF

Qualities of sorted packaging waste

a) Aluminium packaging

For baled aluminium **beverage cans**, European quality standards, in this case EN 13920-10:2003[33], can be applied. These standards set maximum moisture and volatile substance levels and limits the concentrations of silicon and a series of metallic impurities. Metal yield should be 88% or higher and must be free from burnt or oxidized cans and aluminium foil.

In case of used **aluminium packaging in general**, the standards EN 139205-14:2003 and EN 139205-15:2003 are applicable[33]. It is set that the bales shall contain maximum 5 % of steel packaging; be free of plastic, paper and blister packs; and have maximum 60 % of volatile components.

For **aluminium scrap in general**, European End-of-Waste criteria are in place (Council Regulation (EU) No 333/2011). Although most of the criteria are not relevant for separately collected aluminium cans, they also include maximum levels of foreign materials, such as combustible non-metallic materials such as rubber, plastic, fabric, wood and other chemical or organic substances. The scrap must be free from polyvinyl chloride (PVC) in form of coatings, paints, plastics.

b) Steel packaging

Most of the End-of-Waste criteria on steel scrap (Council Regulation (EU) No 333/2011) are not very relevant for **separately collected steel packaging**. Dedicated specifications were included for old thin steel scrap, predominantly less than 6mm thick, particularly on the analytical content of copper, tin, chromium, nickel and molybdenum, and establishing a maximum content of 1,5% of steriles.

However, in the '*End-of-waste Criteria for Iron and Steel Scrap: Technical Proposals*'[34] (JRC, 2010) steel packaging scrap criteria were considered. The proposed specifications referred specifically to **tin-coated packaging scrap**. They contained criteria on the presence of excessive moisture, metallic copper, tin devices (and alloys) and lead (and alloys), and defined minimum concentrations of free iron or alloy, or of metallic packaging.

Other specifications include the European **Steel Scrap** Specifications[35], developed by the European Ferrous Recovery & Recycling Federation (EFR) and European Confederation of Iron and Steel Industries (EUROFER). Currently, EUROFER is preparing a dedicated specification for packaging. The US Institute of Scrap Recycling Industries (ISRI) classifies non-ferrous metal scrap, **ferrous scrap**, glass cullet, paper stock, plastic scrap, electronic scrap and tyre scrap. This ISRI classification is commonly used in US and international trade. Many standard classifications for steel scrap have

[33] https://www.atm-recyclingsystems.com/fileadmin/materials/Aluminiumschrotte_EN.pdf
[34] https://core.ac.uk/download/pdf/38620550.pdf
[35] http://www.eurofer.org/Facts&Figures/ws.res/EurSteelScrapSpec.pdf

been developed by national industry associations, for example in the UK, Spain, Belgium, France, and Germany. [36]

Market prices of sorted metals

Pure used aluminium beverage can bales will obtain the highest market price of all metal packaging. Furthermore, the existing normative and international, national or even privately agreed standards and specifications will also contribute to the price setting, and are used as a reference for classification and quality control. The highest price for aluminium packaging will be achieved by collection and sorting systems that remove or avoid the presence of unwanted materials, especially of steel and plastic packaging.

In the UK, in 2018, prices for baled or densified and strapped aluminium cans varied between 900 and 1060 £ per tonne (ex-works),[37] whereas for steel cans prices were between 105 and 148 £ per tonne[38].

In most cases, metal packaging market prices are set in bilateral agreements or contracts in trade, which will often be based on a standard classification that is complemented with additional requirements suitable for the desired production process or product.[36]

The metal recycling process

a) Aluminium packaging

When separately collected or sorted out, **multi-laminate cartons** are treated to recover the paper fibres. After the removal of the fibre-based portion, pyrolysis technology could be employed for separating the aluminium portion from the polymer portion, but so far, the technology has not been realized on a large scale. The aluminium of **blister packs, foil wrappers and metallized plastic film and paper** will oxidize rapidly in a furnace and flash off without liquefying and is therefore difficult to recover.[39]

In general, **baled recoverable aluminium packaging** is shredded into small pieces, and steel contaminants are magnetically removed. Paint, ink and coatings are removed by blowing in hot air, in a delacquering kiln, before the packaging enters the furnace. The molten aluminium is finally cast

[36] http://ispatguru.com/steel-scrap/
[37] https://www.letsrecycle.com/prices/metals/aluminium-cans/aluminium-can-prices-2018/
[38] https://www.letsrecycle.com/prices/metals/steel-cans/steel-can-prices-2018/
[39] https://www.kidv.nl/6290/closing-the-loop-design-for-recovery-guidelines-aluminum-packaging-greenblu-sustainable-packaging-coalition.pdf?ch=DEF

into aluminium ingots. The ingots are then annealed and sent to a rolling mill or extruder. The recovered aluminium can be employed again in any packaging application.

b) Steel packaging

In a basic oxygen furnace, molten iron ore is the principal raw material. Molten ore can be mixed with varying quantities of steel scrap to produce different grades of steel. The molten steel from the furnaces passes through continuous casters and is formed into slabs, blooms and billets. These primary steel products are transformed into a wide range of finished steel products through hot and cold rolling processes.[40] Slabs are rolled into flat products, particularly steel sheets, that can be coated according to specific end-application requirements.

End applications for different qualities of aluminium and steel

a) Aluminium packaging

Two different main classes of secondary aluminium alloys can be distinguished, namely wrought and cast aluminium. An overview of the main differences is provided in Table 10.

Table 10: Some differences between cast and wrought aluminium alloys[41]

	Casting alloys	**Wrought alloys**
Recycling facility type	Refiner	Remelter
Aluminium scrap source	Allows for mixed scrap with varying compositions of different aluminium alloys	Requires primary aluminium, internal scrap and only clean, well-sorted external scrap, preferably based on closed-loop recycling systems.
Typical end applications	Cylinder heads, engine blocks, gearboxes and many other automotive and engineering components	Profiles, sheets, strips and foils

[40] https://corporate.arcelormittal.com/who-we-are/from-ore-to-steel
[41] http://www.world-aluminium.org/media/filer_public/2013/01/15/fl0000181.pdf

The bodies of aluminium beverage cans usually are produced from 3000-series wrought alloys. When mixed with aluminium scrap produced with other alloy series, the remelter will have to spend more resources in metallurgically adjusting the batch, and thus pay less per unit of mass[42].

Remelted aluminium scrap in the form of used beverage cans, has reportedly been used, in conjunction with TiH_2 blowing agent, to produce aluminium foam.[43]

b) Steel

Steel reprocessing operations, in contrast to alloyed aluminium production processes, are not very sensitive to the presence of impurities, because of the high furnace temperatures. This high temperature will vaporize plastic, glass, paper, and aluminium contaminants, that will leave the furnace as gaseous emissions. In general steel used for packaging is formable low carbon steel, which is produced in the basic oxygen steelmaking process. The presence of copper in the steel scrap, e.g. as alloying element of aluminium packaging or within radio frequency identification (RFID) tags, should be avoided, since it might affect mechanical and chemical properties of the steel.[44]

Recycled content in end applications

Steel cans consist of at least 25 % recycled steel scrap[36]. The basic oxygen steelmaking process, that produces low carbon steel suitable for packaging applications, limits the recycled content in steel packaging to a maximum of 30%[44].

Aluminium cans contain about 70% of recycled aluminium[45].

[42] http://mit.imt.si/Revija/izvodi/mit131/kevorkijan.pdf
[43] https://www.advancedsciencenews.com/aluminum-foam-from-scrap/
[44] https://www.kidv.nl/6291/closing-the-loop-design-for-recovery-guidelines-steel.pdf?ch=DEF
[45] https://www.aluminum.org/aluminum-can-advantage

Plastic packaging

Secondary materials from plastic packaging

Plastic packaging includes **PET** bottles and trays, **HDPE** bottles, **PP** bowls, cups and tubes, pouches of different polymers (**PE, PP, PET, PVC**) and combinations of materials (e.g. polymer(s) laminated with aluminium), crates, shock absorbers (**EPS**), and foils and wrappings. In many cases, the packaging will be printed or have printed labels, as well as coatings and barrier layers, lids, closures, caps and sleeves from a series of different materials (**HDPE, PVC, PVDC, EVOH, PA, PS, EPS, foamed PET, PET-G, OPP, silicone**, …).

Packaging containing **bio-based PE** and **PET** can be recycled together with their fossil counterparts.

Sorting collected plastic packaging

Biodegradable packaging however, is not meant to enter the recycling process. If it is collected separately and complies with the standard EN 13432, i.e. degradation requires maximum 12 weeks at 60°C, it can be processed in industrial composters.

Plastic packaging can be collected separately from mixed household waste,

- co-mingled with other packaging made of other materials that can easily be mechanically separated from each other, such as aluminium and steel cans, or multi-laminate drinking cartons;
- as plastic packaging only, co-mingling all possible polymer types;
- as a single type of packaging (e.g. only bottles) or a single type of polymer (e.g. PET);
- as a mix of two or more target polymers (e.g. PET, HDPE, LDPE, PE, PP) or packaging types (e.g. bottles and foils).

In all cases, the recycling process of plastic packaging requires intensive automatic sorting, often complemented by manual sorting activities. The sorting process of the collected fractions containing plastic packaging usually consists of[46]:

- bag opening, coarse milling and metal removal;
- film removal by wind sifting or ballistic separation;
- cascade of Near Infrared (NIR) sorting machines to sort the rigid plastics in plastic types;
- manual quality check and sorting;
- bunkers and bale presses;

[46] https://www.kidv.nl/6226/wur-handbook-for-sorting-of-plastic-packaging-waste-concentrates.pdf?ch=DEF

- storage of baled products.

An example of a sorting process, starting from collected bags in a system that collects co-mingled plastic bottles and flasks, metal packaging and drinking cartons, the so-called PMD, is given in Figure 15.

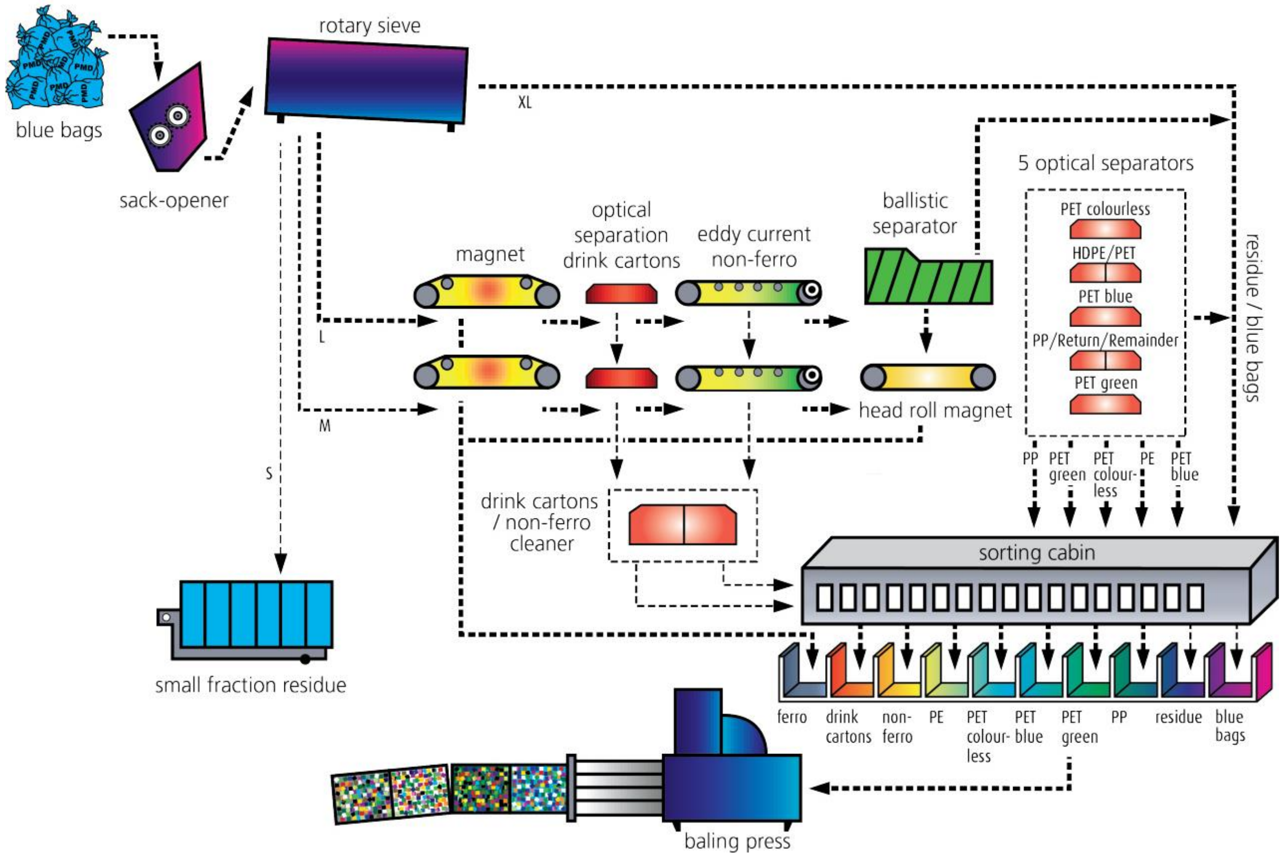


Figure 15: Sorting of PMD packaging waste[47]

Qualities of sorted waste

The bales of sorted plastic packaging waste, as shown in Figure 16, are traded to plastic recycling facilities, often outside of the EU. The preferred bale form is 1.8m x 1.2m x 1m, with larger bales too big to be handled by reprocessors' bale-breaking equipment and smaller balers difficult to store. Bale weights vary depending on polymer type and degree of compaction, but in general are about 200-325 kg[48]. In several countries, such as Germany and the Netherlands[49], quality standards have been developed for the main sorted fractions, such as PP, PET, PE, PS, EPS or mixed polymer bales.

[47] https://www.indaver.com/be-en/installations-processes/material-recovery/pmd/
[48] https://www.letsrecycle.com/prices/plastics/plastic-bottles/plastic-bottles-2018/
[49] https://www.nedvang.nl/kunststof-verpakkingsafval

In general, only a limited number of polymers is sorted out for recycling, being PET, LDPE, HDPE and PP the most common ones.

Figure 16: Colour sorted PET bottle bales

Plastics recyclers Europe has released a set of bales quality guidelines[50] to drive market transformation towards circularity. These guidelines can be applied to various collection systems in Europe, and aim at improving the quality of the collected and sorted plastics materials and in turn increasing the quality of input that reaches the recycling plants. They are made to provide an information benchmark to suppliers of any collected waste.

The quality of the plastics offered for mechanical recycling is determined by the content of impurities, the presence of prohibited impurities, colour, origin and source, moisture content. For end applications of rHDPE, rPP and rPET, the maximum content of impurities is often set at 5%. Examples of prohibited impurities are minerals, rubber, wood, film, hazardous waste, medical waste, glass, minerals, oxo or degradable material, food contamination, silicones, foams, PUR, PET-G, C-PET, etcetera. Specific criteria are in place for intended end applications that imply food contact.

[50] https://www.plasticsrecyclers.eu/bales-characterization-guidelines

Market prices of sorted plastic packaging waste

Well sorted, clear PET, LDPE and HDPE will achieve higher market prices, as shown in Table 11 (prices are only illustrative).

Table 11: Illustrative price differences between different (waste) PET types

	€/ton
Clear waste PET bottles	480
Mixed grade waste PET	300-420
Coloured waste PET bales	120-250
Primary PET	1380-1470

In all cases, the applicable standards and limit values for all the relevant parameters is contractually agreed upon between concerned parties. In Figure 17, UK 2018 market price trends are shown.

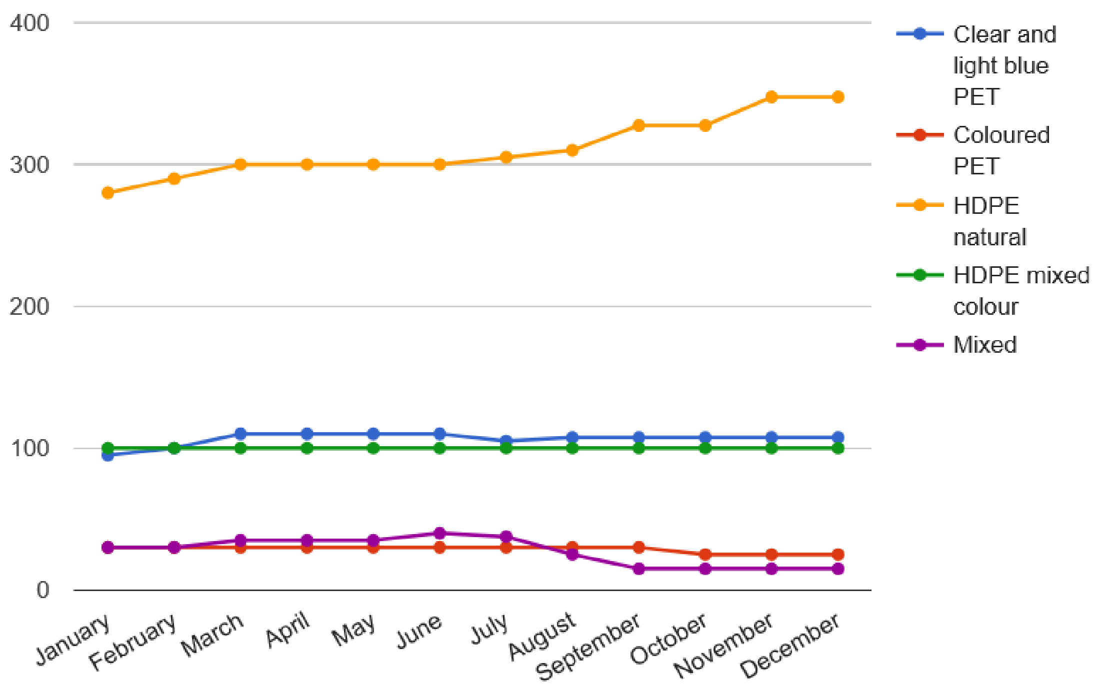


Figure 17: Baled colour sorted HDPE and PET bottle prices, for 2018, in £ per tonne[48]

The packaging waste plastics recycling process

Collected and sorted waste plastic is mechanically recycled into different intermediate or final shapes such as shredded plastic, flakes, agglomerates and regranulates, as well as profiles and sheets. In general, the process of mechanical recycling includes the following steps:

- **Pre-treatment:** The bales of sorted plastics are broken, and the plastic pieces are shredded and washed to remove contaminant substances such as paper labels, glue and other residues. Alternatively, a process called agglomeration is used, that consists of heating the plastic waste just below its melting point to reduce size, before cutting it into small pieces. The product is an irregular grain, often called crumbs or granules.[51] The production of recyclates like pellets, aggregates, regrind, and flakes taking waste plastic as input is performed by so-called reprocessors[52].
- **Extrusion and Pelleting:** Extrusion is a process used to homogenise the plastic pieces with heat. The output of the process of melting and extrusion can be a regranulate (pellet) or a profile. A pellet is the product resulting from the recycling process using an extruder. Is a standard raw material used in plastics manufacturing and conversion.[53] For extrusion, the plastic granules pass through a pipe with a rotating screw, which forces the granules forward into a heated barrel, where the melting occurs. Then, the melted plastic is cooled in a water bath and is later turned into pellets, which are easier to use when making new products.[51]
- **Manufacturing:** For the manufacturing of bottles, the plastic pellets are melted through a second extrusion and then forced into a series of mold cavities, called bottle preforms. In stretch blow molding, this preforms are reheated and stretched to the desired shape with the use of high-pressure air[51].

End applications for different qualities

In general, the transformation of both waste derived and primary plastic materials by application of processes involving pressure, heat and/or chemistry, into finished or semi-finished plastic products for the industry and end-users is called **plastic conversion**. Once a recyclate is in a suitable form and is of the required standard, it can be converted into a finished article.[53]

Depending of the sorting output quality, the polymers can be reused in different end-applications (see Table 12).

Table 12: Main end applications for recycled plastics from packaging[54,55]

Recycled plastic types	End applications Sector/products
rPET	- Packaging/bottles, trays, sheets - Fibres/fabric, automotive interiors - Other

[51] https://sciencing.com/recycling-process-plastics-8404184.html
[52] https://www.birchplastics.com/glossary-of-terms
[53] http://susproc.jrc.ec.europa.eu/activities/waste/documents/2014-JRC91637_ed2015.pdf
[54] http://publications.jrc.ec.europa.eu/repository/bitstream/JRC91637/2014-jrc91637%20.pdf
[55] https://www.plasticsrecyclers.eu/sites/default/files/2018-05/Study%20on%20an%20increased%20mechanical%20recycling%20target%20for%20plastics_BIOIS.pdf

rLDPE / rLLDPE	- Packaging/film, bags - Construction/insulation, carpets - Other
rHDPE	- Construction/pipes, membranes - Packaging/bottles, containers - Other
rPP	- Automotive/ car parts (bumpers, hidden parts) - Packaging/wrappers, containers, crates - EEE/dark products, printers, fans, irons
Mixed	- Packaging/pallets - Construction/floors, roofs - Other/furniture, benches

Some exemplary standard quality requirements and parameters for specific recycled polymers and for plastics wastes in general are listed in Table 13.

Table 13: Standard quality requirements and parameters for recycled polymers[54]

	Plastics waste (EN15347)	rPET (EN15348)	rPP (EN15345)	rPE (EN15344)
Required	Batch size	Max. particle size	Density	Bulk density
	Colour	Fine particle content	Impact strength	Particle size
	Form of waste	Colour	Colour	Colour
	History of waste	Water content	Melt mass-flow rate	Melt mass-flow rate
	Main polymer present	PVC content	Shape	Shape
	Other polymers present	PO content		
	Packaging			
Optional	*Polymer properties*	*Melt mass-flow rate*	*Bulk density*	*Density*
	Impact strength	*Intrinsic viscosity*	*Extraneous polymers*	*Contaminants*
	Melt mass-flow rate	*Alkalinity*	*Flexural properties*	*Filtration level*
	Vicat softening temperature	*Filterability*	*Filtration level*	*Residual humidity*
	Additives, Contaminants, moisture, volatiles	*Residual content*	*Recycled content*	*Izod impact strenght*
	Ash content	*Colour*	*Ash content*	*Ash content*
	Moisture		*Tensile strain at break*	*Tensile strain at break*
	Tensile strain at break		*Tensile stress at yield*	*Tensile stress at yield*
	Tensile stress at yield		*Volatiles*	
	Volatiles			

Recycled content in end applications

In general terms, the lower the presence of contaminants, the higher the maximum share of recycled material can be used in the production of new plastic products, while conserving compliance with the product's original quality requirements. In the Netherlands, it has been reported that PET bottles and trays have an average recycled content of 25 to 30%, although several brand owners have indicated to use at least 50% of rPET in their bottles.[56] Research shows that at least for PET bottles, a deposit scheme is the most efficient collection method, both in terms of quantity and quality of the collected material, allowing for high levels of recycled content in new bottle production[57].

[56] Rijkswaterstaat en Kennisinstituut Duurzaam Verpakken (2018). Verkenning 'Kunststof Verpakkingsafval als Grondstof' Technische en Economische Analyse - Eindrapportage.
[57] https://www.plasticsrecyclers.eu/sites/default/files/PRE_blueprint%20packaging%20waste_Final%20report%202017.pdf

4.1.3.2 Waste Electrical and Electronic Equipment

Secondary materials from WEEE

According to the categorization proposed in section 3.1, end-of-life electrical and electronic devices constitute a typical product-related waste stream. This means that the devices have to be processed in order to separate them into different material-related waste streams, from which applicable secondary materials can be obtained. Since WEEE contain a wide range of materials and substances, the list of potential secondary materials to be recovered from WEEE is large too.

On average, the most common materials present in WEEE are:

- Ferrous metals (e.g. iron, steel);
- Non-ferrous metals (e.g. copper, aluminium);
- Plastics;
- Glass; and
- Other

Metals may include precious metals. Other materials may be associated to specific products, such as the concrete block used in washing machines or fluids like oil or refrigerant gases, among others. Table 14 shows some examples of the content materials of specific types of WEEE.

Average data about the composition of the WEEE stream, including specific material compositions per WEEE type, is also available in the Urban Mine Platform®[58].

Table 14: Average composition of WEEE (source ESR)

Type of WEEE	Materials	Average composition (w%)
Refrigerators	Ferrous metals	59,6%
	Non ferrous metals	5,3%
	Plastics	29,1%
	Glass	2,2%
	Other (e.g. oil, CFC etc.)	0,7%
	Improper (non WEE)	3,1%
Washing machine	Ferrous metals	*39,3%*
	Non ferrous metals	*3,4%*
	Plastics	*15,9%*
	Concrete	*32,9%*
	Depolluted fraction	*0,5%*
	Other(e.g. rubber, glass etc.)	*8%*
Cathode ray tube TV	Ferrous metals	*10,7%*
	Non ferrous metals	*5%*
	Plastics	*16,4%*
	Glass	*59,3%*
	Other removed (e.g. capacitors, wood etc.)	*8,7%*

[58] http://www.urbanmineplatform.eu/homepage

It should be noted that a fast evolution of the technologies driving EEE products implies constant and fast changes in the composition and characteristics of EEE products, which sometimes poses a problem for the quantification and assessment of the actually amount of waste generated its composition and the best approach for the WEEE treatment. A very clear example of this situation is the transition from cathode ray tube screens (CRT) to Liquid Cristal Displays (LCD) to Light Emitting Diode displays (LED). Considering data from the last two decades, the figure below illustrates the volume (number of units and weight) placed on the market for screens in Europe. Whilst LCD screens have replaced CRT screens with an associated reduction in weight, as regards pieces, much more TVs are purchased per household (ProSUM final report[59]).

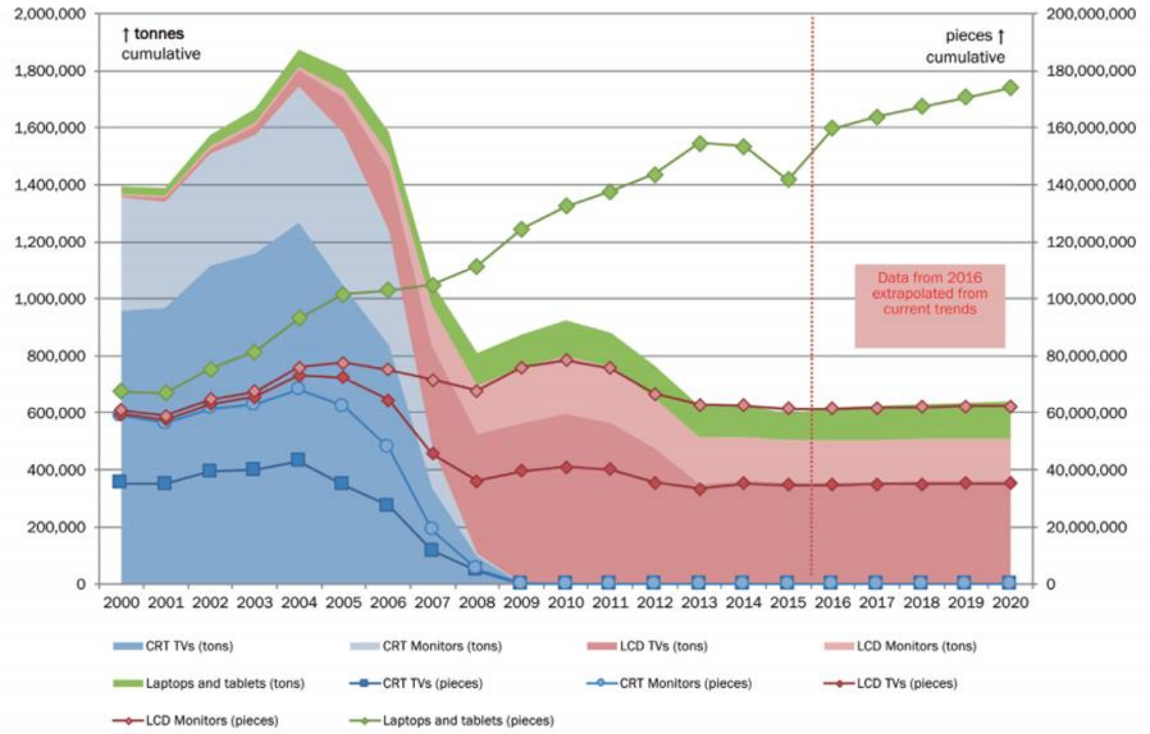


Figure 18: Quantities of screen appliances placed on market 2000 – 2020 in tonnes (left) and pieces (right)

[59] http://prosumproject.eu/sites/default/files/DIGITAL_Final_Report.pdf

Qualities of sorted WEEE

From 15 August 2018, the Directive 2012/19/EU on waste electrical and electronic equipment (WEEE), applies to all electrical and electronic equipment (EEE), categorized as presented in Table 15.

Table 15. Categories of EEE

1. Temperature exchange equipment
2. Screens, monitors, and equipment containing screens having a surface greater than 100 cm2
3. Lamps
4. Large equipment (any external dimension more than 50 cm) including, but not limited to: Household appliances; IT and telecommunication equipment; consumer equipment; luminaires; equipment reproducing sound or images, musical equipment; electrical and electronic tools; toys, leisure and sports equipment; medical devices; monitoring and control instruments; automatic dispensers; equipment for the generation of electric currents. This category does not include equipment included in categories 1 to 3.
5. Small equipment (no external dimension more than 50 cm) including, but not limited to: Household appliances; consumer equipment; luminaires; equipment reproducing sound or images, musical equipment; electrical and electronic tools; toys, leisure and sports equipment; medical devices; monitoring and control instruments; automatic dispensers; equipment for the generation of electric currents. This category does not include equipment included in categories 1 to 3 and 6.
6. Small IT and telecommunication equipment (no external dimension more than 50 cm)

Electronic and electric devices that are discarded by households are rarely or never collected in regularly scheduled door-to-door collection systems, although on demand pick-up services for big appliances are widely spread. Most WEEE is collected through bring systems that offer the possibility to drop-off discarded devices at a municipal or privately-operated recycling centre. Another frequently used option is the free of charge take-back of WEEE at retail shops when buying a new device (known as ‘1x1’) or when a new device is delivered to the buyer´s home. The recast of the WEEE Directive, issued in 2012, comprised a new requirement for distributors to provide for the collection, at retail shops with, or in their sales areas relating to EEE of at least 400 m^2 or in their immediate proximity, of very small WEEE (no external dimension more than 25 cm) free of charge to end-users and with no obligation to buy EEE of an equivalent type (known as ‘1x0’). The above means that in most cases of WEEE collection in a context of producer responsibility, WEEE will be sorted into different EEE categories at the moment of collection.

Figure 19: Containers for the collection of small WEEE (source: www.zicla.com)

Most WEEE collection systems also generate a flow of used appliances that are destined for preparation for re-use. These may be collected together with the WEEE for recycling and separated from it either at the point of collection or later at a central collection facility.

The collected WEEE can contain hazardous components or substances that have to be removed before further processing. Usually WEEE received at collection facilities are grouped according to their specific depollution and treatment requirements, they are then delivered to WEEE treatment plants equipped with the technology that provide such treatment. The most common grouping of WEEE considers:

- Cooling and freezing equipment.
- Large household appliances (excluding cooling and freezing equipment)
- Small household appliances
- IT equipment
- Screens
- Lamps

A pre-treatment for depollution often implies manual dismantling. Example of components or substances to be removed are[60]:

- Appliances containing ozone depleting substances (e.g. CFCs);
- PCB/PCT containing capacitators or other components;
- Chlorofluorocarbons (CFCs and HCFCs) or fluorocarbons (HFCs), or other hydrocarbons (HCs, isobutene, etc.);
- Plastics containing bromide fire retardants;

[60] https://www.recupel.be/media/1802/call-for-candidates-processing-2018.pdf

- Lamps from Liquid Cristal Display, switches, contact thermometers and relays containing mercury;
- Batteries;
- Toner cartridges, ink-containing receptacles and ink ribbons;
- Asbestos-containing components;
- Gas discharge lamps;
- Components containing refractory ceramic fibres;
- Appliances containing radioactive materials;

For different WEEE categories, such as cooling and freezing appliances, specific standards have been set regarding treatment requirements for depollution[61]. After depollution, the remaining fraction can be subject to recycling.

There are different types of technologies and treatment processes available for the treatment of WEEE. Figure 20 shows an example of the treatment followed by large household appliances[62].

Large Household Appliances

Manual dismantling and depollution		**Mechanical treatment and depollution**		**Mechanical treatment of output fractions and depollution**	**Endprocessing**
Removal of cables	Removal of PCB and electrolyte capacitors	Removal of motor	Removal of PCB and electrolyte capacitors	Additional treatment of fractions (usually mechanical processes that improve the purity of valuable fractions)	Refining
Removal of motors	Removal of batteries	Removal of cables	Removal of batteries		Material recovery
Removal of mercury containing components		Separation of ferrous fractions	Removal of circuit boards	Treatment of components (capacitors etc).	Incineration / Energy recovery
					Landfilling

Figure 20: Overview of treatment steps for the treatment of large household appliances

Specific treatment guidelines and standards have been developed to provide guidance on the collection, handling, storage, treatment, recycling and recovery of WEEE. The series of standards developed by CENELEC EN50625[63] deserve a mention in this respect, since they are the most updated set of requirements developed to comply with the European Directive on WEEE[64].

[61] For example the European Standard EN 50625-2-3 'Collection, logistics & treatment requirements for WEEE – Part 2-3 : Treatment requirements for temperature exchange equipment and other WEEE containing VFC' and TS 50625-3-4 'Specification for de-pollution – Temperature exchange equipment'.
[62] https://www.cwitproject.eu/
[63] http://ec.europa.eu/environment/waste/weee/standards_en.htm
[64] http://ec.europa.eu/environment/waste/weee/legis_en.htm

Market prices of sorted WEEE

The valuable materials that drive WEEE recycling vary between different WEEE categories.

Some categories of WEEE have a high content of metals and other valuable materials. As an example, fridges and white goods may contain an average of 60% of weight in metals (ferrous and non-ferrous). Printed circuit boards may contain precious metals such as gold or silver. On the other hand, in some cases an appropriate removal of hazardous substances may require a high investment in specific technologies[62]. These factors are considered drivers of the so called WEEE complementary flows.

In some cases, the cost for treating and removing hazardous materials outweighs the benefits provided by valuable materials. For example, it is estimated that one Cathode Ray Tube television may contain on average in its glass 1,5 kilo of lead[65].

For big appliances or white goods, most of the value is contained in steel and copper. Only in specific cases, like TV sets or WEEE mono-streams, it appears to be economically worthwhile to manually dismantle bigger plastic parts for polymer recycling, especially for PP. This plastic scrap from dismantling is baled and will have considerably higher market prices as compared to the mixed scrap from shredding, because of higher (polymer) purity and lighter colour.[66]

In the case of smaller devices, especially for IT like laptops and smartphones, the gold and other precious metal content of printed wiring boards are an important driver for material recovery[3].

The material value contained in WEEE and WEEE components, such as compressors and cables containing copper, or hard disk drives and printed circuit boards with precious metals, is one of the drivers of whole product and parts scavenging, and of illegal trade[67].

The WEEE recycling process

After possible depollution and the mostly manual removal of valuable parts and components, such as electromotors, frames and big plastic or steel parts, the WEEE is usually shredded. From the shredder output, different types of materials are sorted out for material recovery. The main categories of materials from WEEE are metals, plastics and glass.

The quality and composition of the output fractions obtained in the treatment process of WEEE influence greatly market prices. The quality is determined by the input material (quality of WEEE collected) and the treatment process. As an example, WRAP conducted a study in 2014 with the aim

[65] https://www.eera-recyclers.com/files/eera-crt-online.pdf
[66] https://www.plasticsrecyclers.eu/
[67] Federico Magalini, Jaco Huisman (2018). WEEE recycling economics - The shortcomings of the current business model. Commissioned by EERA.

to identify the value of recovering Printed Circuit Boards for UK WEEE recyclers. For this, a financial assessment was conducted taking into account treatment costs, technique recovery efficiencies, grade of PCB recovered by WEEE stream and value of PCB. The results are summarised in Figure 21.

Stream	Manual	Manual with Re-use	Semi-Auto Smashing	Semi-automated with Shredding
Stream A (LDA)	N/A	N/A	£1,139	£498
Stream C (Display)	£1,100	£8,283	N/A	N/A
Stream E (SMW)	£7,480	£11,425	£2,463	£1,038

LDA = Large Domestic Appliances
Displays = CRT and Flat Panel
SMW = Small Mixed WEEE, mostly IT

WRAP 2014

Figure 21: Financial assessment of PCB recovery techniques[68]

One of the conclusions of the project was that the main advantage of using a manual technique is that it can help recover the PCBs as a whole, minimising the potential loss of precious metals. The net benefit of using manual recovery is approximately £7,480 per tonne for Stream E (small WEEE) and £1,100 per tonne for Stream C (displays).

a) Metals

Most WEEE devices discarded by households have panels, sheets, covers, work tops, casings, pieces, drums and mechanical parts that mainly consist of metal alloys. Main metals include steel and stainless-steel alloys, aluminium, copper and precious metals. European standards and specifications exist on the final treatment of metal fractions from WEEE[69]. Table 16 provides an overview of the different grades used for trading metals sourced from WEEE[70]. The value of scrap metals offered for metallurgical recovery is determined by the specific type of alloy, the alloy purity, and the presence of not targeted metals and impurities. For international trading, often the US Institute of Scrap Recycling Industries (ISRI) classification is used to identify specific scrap metal compositions. The classification also allows to distinguish fractions from different sources, such as electronic equipment.

Table 16: Grades and destinations of metals from WEEE

Output metal stream	Grades	Destination	Specs	Price indication

[68] http://www.wrap.org.uk/sustainable-electricals/esap/re-use-and-recycling/reports/techniques-recovering-printed-circuit-boards-pcbs

[69] For example TS 50625-5 ‘Part 5 : Specifications for final treatment of WEEE fractions - Copper and Precious metals’

[70] http://www.recyclo.me/scrap-prices and ISRI scrap specifications (2018)

Aluminium scrap	Eddy Current Aluminium. ISRI code Tweak or Twitch	Aluminium refiners or remelters (see Table 10)	• Minimum density (e.g. >30 pounds per cubic foot) • Maximum impurity concentrations (e.g. max zinc & copper content; <5% non-metallic, <1% rubber/plastic)	Price group III in Al scrap: -10% to reference Al scrap price (1050 USD/ton in Nov 2018).
	Eddy Current Scrap (non-ferrous metal mix with up to 85% of Al. ISRI code Zorba.	Further separation, mainly in China[71]		Price group III in Al scrap: -10% to reference Al scrap price
Circuit boards (with precious metals)	Circuit boards or shredded circuit boards	Integrated copper smelter	• Gold content • Maximum metal concentrations (Al, Zn, Mg, Fe) • Max plastic content (e.g. 40%)	Estimated close to price group I in electronic scrap: +60% to reference electronic scrap price (3000 USD/ton in Nov 2018).
Ferrous scrap	Light iron. ISRI codes 200, 204, 207	Steel producer	• Cleanness • Off-grade material (other metals) • Residual alloys (Ni, Cr, Mo, Mg)	Price group I in ferrous scrap: +10% to reference ferrous scrap price (140 USD/ton in Nov 2018).
	Iron Frag. ISRI code 210.	Steel producer	• Average density 50 pounds per cubic foot	Price group III in ferrous scrap: -15% to reference ferrous scrap price.
	Iron Frag. ISRI code 211.	Steel producer	• Average density 70 pounds per cubic foot	Price group II in ferrous scrap: -7% to reference ferrous scrap price.
Copper scrap	Cables, motors and other copper rich components	(Integrated) copper smelter		Price group I in copper scrap: +10% to reference price (5000 USD/ton in Nov 2018).

b) Plastics

The shredder output is further mechanically sorted, yielding a fraction that contains a heterogenous mixture of different types of polymers with all kinds of additives, such as flame retardants, and contaminants like glass, wood, rubber and pieces of metal. Often plastic is the outcome of a negative sorting activity, meaning that the target fraction of the sorting is another material (e.g. copper), likely more valuable, and that plastic is a contaminant that needs to be eliminated through the sorting process. The average composition of WEEE plastics made available for recycling is given in Figure 22.

[71] https://www.recyclingproductnews.com/article/19742/dense-medium-separation-ideal-for-processing-sr-and-zorba

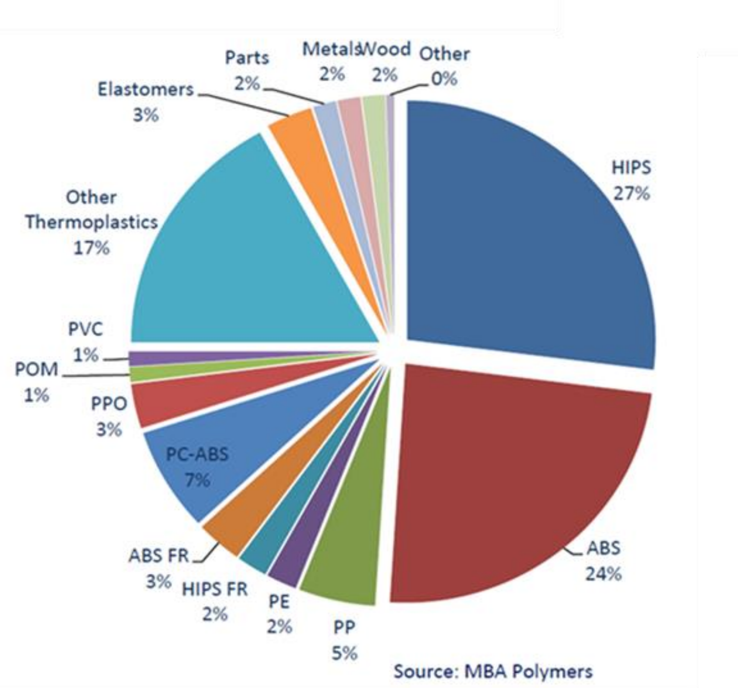


Figure 22: Average composition of WEEE plastics for recycling

However, different WEEE streams have very different plastic content in terms of quantity and quality. For instance, it results (PolyCE project findings[72]) that Cooling and Freezing appliances waste flow contains about 12.98% of plastics, mainly PS; that Large Household appliances waste flow contains about 6,82% of plastics, mainly PP; that TVs&screens and Small Household Appliance waste flow contains respectively about 16,42% and 36,4% of plastic, and these flows are characterized by a more complex mix of polymers.

This mixed and contaminated fraction of WEEE plastics is submitted to grinding before they are passed through a series of additional sorting phases, for example implemented through sink-float tanks with different densities, that allow separating PS, ABS, PP and PE. Additionally, a heavy fraction will be separated that will contain some of the hazardous substances (e.g. cadmium or brominated flame retardants), and that is disposed of. The separated polymers are then washed and dried and will undergo further separation steps to increase the purity of the targeted polymer and to remove non-polymer contaminants.[66]

It is in general however very challenging to separate the most frequently used polymers in EEE, particularly ABS (Acrylonitrile-Butadiene-Styrene), HIPS (High impact Polystyrene) and PC (Polycarbonate), and not economically viable. Therefore, these polymers are sometimes recycled together as a blend.[72] Currently, there are both technical and legislative barriers hindering WEEE plastic sorting. The technical issues include the difficult separation of polymers due to their similarity

[72] YV Vazquez, SE Barbosa (2016). Recycling of mixed plastic waste from electrical and electronic equipment. Added value by compatibilization. Waste management 53, 196-203

in terms of density and to the high variety of colours in post-consumer WEEE plastic flows. Lately, new technologies based on optic approaches are being developed and put in place for sorting different types of plastics. Results achieved so far by these technologies look promising.

From the legislative point of view, on one hand flame retardant related issues cause legal complexity; on the other hand a significant amount of WEEE plastic materials disappears from Europe to be treated outside European boundaries.

For now, most European WEEE plastics are recycled in Africa and Asia, or incinerated. It can be observed that within Asia, plastic scrap destinations changed because of the Chinese 'National Sword' initiative that bans the import of certain wastes to the country, displacing those flows towards other countries in the region. In 2017, the European Electronics Recyclers Association (EERA) estimated the total recycling capacity of plastics from WEEE in Europe to be only some 20 % of the total amount of plastics that are contained in the WEEE waste stream. There is an urgency to address this issue and the European Commission recently launched the Circular Plastics Alliance to foster the market of recycled plastics in Europe.

Evidence suggests that low-tech treatment processes, including manual disassembly and separation of WEEE, can achieve significantly better plastics recycling than highly mechanised and automated alternatives. In Europe however, and given the high WEEE amounts collected, these manual approaches carry relatively higher costs. It is however anticipated by experts that changes in regulation and/or the funding climate could '*possibly make low-tech, costly, yet high-quality plastics recycling much more attractive than it is at present*'.[73]

Some EU funded projects[74] like PolyCE and CloseWEEE are working towards improving the circularity of WEEE plastics. For instance, PolyCE project, adopting a systemic approach that involves all the actors operating along the WEEE value chain, aims to test some low-tech solutions as the introduction of collection clusters (e.g. product families defined taking into account the plastic content of the products) designed to increase the efficiency of the subsequent treatment steps; as well as to test the effectiveness of some new treatment technologies (e.g. innovative sorting equipment) and treatment procedures (e.g. manual dismantling additional steps) through demonstrator initiatives.

c) Glass and other materials

Monitors, screens and larger household appliances will contain glass of the most diverse chemistries and compositions. CRT glass contains lead and hazardous fluorescent coatings that must be treated appropriately. The diversity of the WEEE glass makes closed loop recycling not practicable.

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[73] Baxter, John. Wahlstrom. Margareta. Castell-Rüdenhausen, Malin Zu. Fråne, Anna (2015). WEEE Plastics Recycling. A guide to enhancing the recovery of plastics from waste electrical and electronic equipment. Nordic Council of Ministers 2015.

[74] https://www.polyce-project.eu/ ; http://closeweee.eu/

End applications for different qualities and the recycled content therein

Steel producers and non-ferrous metal refiners will integrate sorted scrap fractions from WEEE in their processes, and thus in the final and intermediate metal products and alloys.

Concrete counterweights of washing machines can be processed to be used as a construction aggregate.

Currently, only for a very minor share of post-consumer plastics from WEEE there reuse in new products is in place. Most of these plastics are downcycled in low value applications, such as outdoor furniture. The reapplication of WEEE plastic (similar to the original application, e.g. in new EEE) is to date still very low.

As regards displays, there is still a relevant fraction of cathode ray tube displays collected in Europe[75]. The share of glass containing lead in CRT tubes is close to 35% in weight. Most frequent destinations for leaded glass are construction materials such as tiles, ceramics, concrete blocks etc. However, due to different issues[76], currently there are not enough technologies and facilities to cover the demand of proper recycling of CRT leaded glass in Europe. This situation gives rise to stockpiling and compliance issues.

Lead-free glass from WEEE, e.g. from PV panels, can however be used for producing foam glass and glass beads. Sometimes, glass from certain WEEE categories can be used in construction aggregates or as sandblasting material.

[75] https://www.eera-recyclers.com/news/brochure-responisble-recycling-of-crt

[76] http://www.weee-forum.org/news/weee-forum-paper-on-crt-glass-issues-is-available-now

4.1.4. Conclusion

The overall process of collection, sorting and recycling tunes the product we discard as waste, be it packaging or EEE, into secondary materials, ready for trade on the market as input for new products.

The identification of the main boundary conditions for a waste collection system from a circular economy perspective shows us that the quality of the waste is a dominant factor in enhancing the performance of the recycling value chain, by providing more or better recycling. The potential of a waste collection system to contribute to better recycling mainly lies in providing waste fractions as much as possible in line with the quality requirements for the corresponding secondary materials. Although this probably would decrease the effort for the respective sorting or recycling, there might be a trade-off with increasing effort for collection.

Therefore, we analysed the relation between the (sorted) waste and the corresponding secondary materials and end applications and described the quality requirements that allow recycling processes to produce marketable secondary materials, both for separately collected paper and packaging waste fractions and for WEEE.

As a conclusion we drafted a table providing an overview per waste fraction of all possible collection methods, collected fractions, sorting outputs and recycling outputs (see Table 17).

As a next step (in Task 2.2 Assessment of implemented solutions in the 12 selected case studies for tackling systemic and technical boundary conditions), we will use this table for the analysis of the cases and to show the correlation between the collection methods for the fractions and the corresponding secondary materials and end applications.

Table 17: Overview of collection method, collected fractions, sorting outputs and recycling outputs for PPW and WEEE

Fraction	Container glass waste	Paper & cardboard waste	Plastic packaging waste	Steel & aluminium packaging waste	WEEE
Collection method	• Door-to-door • Bring point • CAS • Door-to-door + bring points • Bring points + CAS • Door-to-door + bring points + CAS • Bring points + CAS + other	• Door-to-door • Bring point • CAS • Door-to-door + bring points • Door-to door + CAS • Bring points + CAS • Door-to-door + bring points + CAS • Bring points + CAS + other	• Door-to-door • Bring point • CAS • Other • Door-to-door + bring points • Door-to door + CAS • Bring points + CAS	• Door-to-door • Bring point • CAS • Other • Door-to-door + bring points • Door-to door + CAS • Bring points + CAS	• CAS • Retailer bring point • Non-retailer bring point • Pick-up on request • Mobile bring point • Other
Collection output	• Mixed container glass co-mingled with other wastes • Mixed container glass • Clear container glass • Coloured container glass	• Newspapers & magazines • Cardboard • Mixed paper & cardboard • Paper & cardboard co-mingled with other wastes	• Plastic packaging co-mingled with other packaging waste • Plastic packaging only, co-mingling all polymers • Single type of packaging (e.g. only bottles) and/or a single polymer (e.g. PET) • Mix of two or more target polymers (e.g. PET, HDPE, LDPE, PE, PP) and/or packaging types (e.g. bottles and foils)	• Aluminium and steel packaging co-mingled with other packaging waste, often including drinking cartons • Aluminium beverage cans only • Metal packaging • Metal packaging co-mingled with other dry recyclables	• Temperature exchange equipment • Screens & monitors • Lamps • Large appliances • Small household appliances • Small IT
Sorting output	• Brown container glass cullet • Green container glass cullet • Clear container glass cullet • Mixed container glass cullet	• mixed paper & cardboard • corrugated and kraft • newspapers & magazines • other and special grades	• Mono-colour or mixed colour bales or bags containing a single polymer (PP, PET, LDPE, HDPE, PS, EPS)	• Baled or briquetted aluminium cans and/or aluminium meal trays, rigid containers, aerosol cans, screw closures and cappings	• Depolluted appliances • Parts from dismantling (cables, compressors, casings, coils & motors, circuit

				• Baled steel drums and cans • Baled drinking cartons	boards, drives, batteries…)
Recycling output	• Container glass (flint, brown, green) • Insulation mineral wool (short glass fibre) • Ceramic sanitary ware • Fluxing agent in brick manufacture • Sports turf and related applications • Water filtration media • Abrasive • Aggregate in construction materials • Reflective highway paint	• Newsprint • Other graphic papers • Case materials • Carton board • Wrappings and other packaging • Sanitary and household • Other paper and board • Construction materials (insulation, bricks and furniture) • Animal beddings or compost • Fibre applications in construction and manufacturing (in concrete, asphalt, brake linings)	• Mono-colour rPET • Mono-colour rLDPE / rLLDPE • Mono-colour rHDPE • Mono-colour rPP • Mixed plastic pellets	• 3000-series wrought aluminium alloys • Low carbon steel • Fibres	• Material-related waste streams for recycling: o Aluminium scrap, ferrous scrap, copper scrap, circuit boards o PP, PE, PS, ABS and mixes thereof o Glass and mineral fractions

4.2. Societal perspective

In terms of waste management and recycling improvement, the focus is mostly on technical conditions of the Waste Collection System. Yet, households' participation to the collection system is essential and depends on many social factors inciting citizens to adopt recycling behaviour. In this part, through the analysis of academic literature and European surveys, social factors influencing citizen's behaviour towards recycling have been analysed. Social factors are here defined as all influences that affect the behaviour of an individual or a group (Whishaw et al., 2006). Then, according to the Theory of Planned Behaviour (TPB, Ajzen 1985) it appears that the biggest driver for behaviour is the intention. In that sense, intention will not be considered as a factor in itself but rather we will consider the factors impacting on this intention. At first a list of the most relevant factors is compiled. Then, these factors are classified depending on how they drive citizen's behaviour.

4.2.1. Step 1: Identification of factors impacting citizens' behaviour

There are many factors impacting citizens' behaviour towards waste separate collection. Based on sociological and psychological studies, four different types of factors have been identified (Knickmeyer, 2018):

- Socio-demographic factors
- Socio-psychological factors
- Socio-economic factors
- Socio-political background

After analysis of academic literature and European surveys, 21 factors have been identified and organized within those four categories (see Table 18).

Table 18: Social factors influencing recycling

Socio-demographic factors (5)	Socio-psychological factors (11)	Socio-economic factors (3)	Socio-political background (2)
Family size	Perceived convenience and effort inside (e.g. lack of space)	Increased tariffs if waste is not properly separated	Laws and regulations
Household type	Perceived convenience and effort outside (e.g. facilities in the area)	Willingness to pay for recycling system	Acceptance of laws and regulations
Presence of children in household	State of knowledge and information	Financial incentives (Deposit, reduced tariffs)	
Marital status	Social norms: • Local culture and context • Influence of social group		
Social class	Moral norms		
	Attitude and environmental concern		
	Recycling habit		
	System trust and community (Reassurance that collected waste is effectively recycled)		
	Self/individual efficacy belief		
	Locus of control		
	Personal and general satisfaction		

Those factors can be organized within four categories (Hornik and al., 1995) depending on how they influence citizens to sorting their waste. The classification will be done such as not to be comprehensive but rather only include relevant factors. In this way, socio-demographics factors will not be considered since they have a quite low influence on citizens' behaviour (Oskamp and al., 1991) and because it has also been reported that their correlation with recycling is mostly unclear since studies offer contradictory conclusions regarding their influence on recycling behaviour (Miafodzyeva and Brandt, 2013). This division for relevant factors then includes the type of factors (incentive/facilitators) and location of the factor (interior/exterior).

The 16 factors have been classified within those 4 categories (see Table 19):

- Internal incentives (3 factors)
- Internal facilitators (7 factors)
- External incentives (3 factors)
- Internal facilitators (3 factors)

Table 19. Social boundary conditions for recycling

	Incentives	Facilitators
Internal	- Attitude and environmental concern - Locus of control - Personal and general satisfaction	- State of knowledge and information - Moral norms - Recycling habit - System trust and community (Reassurance that collected waste is effectively recycled) - Self/individual efficacy belief - Acceptance of laws and regulations - Willingness to pay for recycling system
External	- Increased tariffs if waste is not properly separated - Financial incentives (Deposit, reduced tariffs) - Laws and regulations	- Perceived convenience and effort in your area (facilities in the area) - Perceived convenience and effort at home (lack of space) - Social norms: ▪ Local culture and context ▪ Influence of social group

4.2.2. Step 2: Study of the interrelation of factors

The aim of analysing the interrelation of those factors is to understand how they impact together household's waste separation behaviour. Yet, social factors' influence is often quite complex to measure and most of the time, it is the presence of a set of different factors that influence citizens' behaviour without having one factor above the others. Considering this, and through the analysis of academic literature and European surveys, we will look at the most influencing factors and how they correlate to each other regarding households' waste separation behaviour.

The academic literature about citizen's behaviour towards recycling offers significant contradictory conclusions regarding the relevancy of the influence of social factors. It appears that their influence greatly varies depending on the local context whereas for some, the local context does not play any role (Miafodzyeva and Brandt, 2013). Yet, after an analysis of the various academic studies and European surveys, it appears that the 16 factors selected are the most present in those sources. The presence of all those factors therefore appears as essential to having citizens involved in waste separation. Among them, 4 factors seem to have an especially high influence on the recycling intention (Miafodzyeva and Brandt, 2013):

- Information (= State of knowledge and information)
- Environmental concerns (= Attitude and environmental concern)
- Social norms (= Local culture and context + influence of social group)
- Convenience (= Perceived convenience outside and inside)

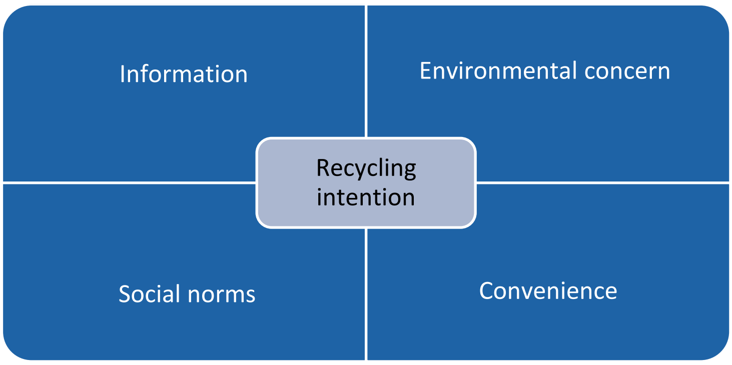

Figure 23. Most relevant social boundary conditions for recycling

The complexity of the specific interrelation of those factors does not allow us to define nor to calculate which specific part a factor is playing. Instead, this complexity should be recognized because no factor is acting on its own. For instance, a high convenience for recycling behaviour might not be sufficient if not complemented with environmental concern. As the general interrelation of social factors cannot be addressed through academic literature, specific interrelations due to the local context will be addressed through focus groups.

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4.2.4. Conclusion

Having citizens involved in the recycling process – and the waste separation – is the first step to an efficient WCS. In that sense identifying social boundary conditions impacting those citizens in their involvement in the recycling process is primordial. After analysis, many social factors are essential to drive citizens to separate their waste. Although some factors appear to be necessary to drive virtuous conditions, none of them is sufficient enough to act on its own. It is rather the combination of a different set of social factors – both incentives and facilitators – that will impact citizen's behaviour. Among them, 4 factors seem to have an especially high influence on the recycling intention (Miafodzyeva and Brandt, 2013):

- Information (= State of knowledge and information)
- Environmental concerns (= Attitude and environmental concern)
- Social norms (= Local culture and context + influence of social group)
- Convenience (= Perceived convenience outside and inside)

For the analysis of the cases (in Task 2.3, Assessment of implemented solutions in the 12 selected case studies for societal acceptance in dialogue with citizens), focus will be on these 4 main social factors to analyse why citizens participate in a waste collection system, and, maybe even more relevant, why not.