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Investigating Europe's secondary raw material markets

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Key messages

- Secondary raw material (SRM) markets are key to delivering a circular economy in the EU. These markets can ensure the **timely** circulation of **good-quality** recycled materials in the European economy, which **minimises** the need to extract **natural resources** as a result.

- This report develops a **new framework** for assessing SRM market functionality. Of the eight SRM markets assessed under this framework, only three are **well-functioning** (aluminium, paper and glass). These markets were established a long time ago, are international and open, and occupy a significant market share of their respective material supply.

- Five assessed SRM markets (wood, plastics, biowaste, aggregates from construction and demolition waste, and textiles) are **not well-functioning**. The main reasons are their small size, weak demand (even with increasing supply) and inadequate technical specifications.

- Despite the strong policy push to increase recycling and the steady supply of recyclates that has resulted from this, the supply side of SRM markets is challenged. The main problems are insufficient specifications such as the **end-of-waste criteria,** and the presence of **hazardous** substances in recycled materials. The demand side, on the other hand, is characterised by a **lack of trust** in SRMs. There is hesitance to invest in technologies that would integrate SRMs into raw material supply operations.

- A cross-cutting issue impacting market functionality is the **lack of adequate information** for interested stakeholders, and the absence of a **monitoring mechanism** to observe the market and propose improvements.

- There are a few pathways to help SRM markets function more smoothly. These include expanding or modifying **existing policy tools** at the EU level; for example, by including fee eco-modulation in extended producer responsibility schemes. Otherwise, pathways include extending the use of green public procurement; making recycling targets more effective or expanding them to more waste materials; further developing end-of waste criteria; and widening the scope of recycled content requirements.

- Entirely new policy measures also help. For instance, further developing harmonised, EU-wide **technical standards** for SRMs could be beneficial. It would also be helpful to create a level playing field for primary and secondary raw materials by considering **environmental externalities** through taxing primary raw materials or reducing the VAT on SRMs.

Executive summary

Secondary raw material (SRM) markets are crucial for a circular economy. This is because SRMs enable recyclables to re-enter the production value chain, which reduces dependency on primary resources as a result. This role is acknowledged in the EU circular economy action plan of 2020. However, if policy is to help establish or further develop such markets, we need to better understand the currently-fragmented SRM markets in the EU.

This report develops an assessment framework to describe the functionality of existing SRM markets. Applying the framework to selected SRM markets reveals specific reasons that explain why certain markets are functioning sub-optimally. The report also describes barriers preventing markets from reaching their full potential from a value chain perspective. Lastly, this report identifies potential measures that could effectively support SRM markets in the EU.

The SRM assessment framework is a criteria-based taxonomy for defining 'well-functioning' secondary markets. A well-functioning secondary market has:

- a significant share of the total market for that material (including the primary material market);
- representative prices properly reflecting demand-supply interactions;
- international or a wide scope of transactions;
- adequate economic drivers, even without support from (waste) policy;
- robust industrial capacity for recycling;
- good availability of market information;
- good product standardisation.

These criteria are applied to eight common SRM markets that are targeted by EU waste policy with the aim of improving their recycling (both qualitatively and quantitatively). Therefore, how these SRM markets function is very relevant to policy. The selected materials are:

- aluminium;
- paper and cardboard;
- wood;
- glass;
- plastics;
- textiles;
- construction and demolition aggregate waste;
- biowaste.

The 'maturity' of an SRM market is decisive in determining its functionality. More specifically, its size and material quality (from the industrial use point of view) play the most important roles. The well-functioning markets identified — namely, aluminium, paper and cardboard, and glass — can be models for less well-functioning markets.

All SRM markets could potentially benefit from the lifting of specific regulatory, economic or technical barriers that arise at different stages of the SRM value chain. Different barriers — regulation and legislation, technology and quality, industrial capacity/investments, economic factors (prices, costs, information, etc.), competition from energy use — are encountered across the value chain of various SRM markets.

In the product design phase, barriers are mainly associated with the lack of economic or regulatory incentives to put product recyclability at the forefront of the design concept.

In the supply of SRMs (waste generation, collection and processing stages), issues hampering market functionality stem from insufficiently harmonised technical specifications or end-of-waste criteria across the EU. If improved, these elements could reduce costs and increase manufacturers' confidence in the quality of SRMs.

When looking at the demand for SRMs, there are two main barriers. First, there is lack of trust in the steady supply and homogeneous quality of procured SRMs. Second, there is reluctance to invest in new and potentially expensive technologies that could better integrate SRMs into various production processes.

Lastly, a cross-cutting issue related to SRM governance is the lack of credible, in-depth and relevant information on SRM markets made regularly available to market shareholders. This information would enable shareholders to make informed decisions — but also enable better monitoring of developments in the SRM market. This is the case for primary raw material markets, in which data and information on commodities' availability, price, quality, traceability, trading platforms, etc. are readily available to stakeholders.

Various options are available to address these barriers effectively. In some cases, they can be implemented within policy frameworks already in place at the EU level. Examples are:

- introducing fee eco-modulation in extended producer responsibility schemes to incentivise designers to consider product recyclability;
- making recycling targets more effective or expanding them to cover more waste materials and waste streams;
- further developing EU-wide end-of-waste criteria to increase trust in SRMs and avoid legal uncertainty;
- widening the scope of recycled content requirements to increase demand for SRMs.

Ideas for further actions include introducing technical standards or certifications for SRMs to guarantee their quality to manufacturers. Another option could be to address the price competition between SRMs and primary resources. This could be done by using pricing instruments that consider environmental externalities; for instance, through a tax on primary raw materials, or a reduction in the VAT payable on SRMs.

1 Introduction

1.1 Objectives

The 2020 circular economy action plan (EC, 2020a) highlights that the improvement of secondary raw material (SRM) markets is a key component of the EU circular economy strategy. SRM markets are key to delivering a circular economy in the EU. They enable the timely circulation of good-quality, recycled materials in the European economy — minimising the need to extract natural resources as a result.

SRM markets report significant turnovers: the volume of traded recyclables within and across EU Member States is relatively high (EEA, 2021a). It is difficult to assess the turnover's exact magnitude, as detailed data for such markets do not exist. Only data on traded recyclables are reported by Eurostat. For example, in 2020, the economic volume of traded plastic, paper and cardboard, and glass waste stood at a little more than EUR2.8 billion ([1]).

SRM markets exist for many materials (metals, paper, wood, plastics, construction and demolition materials, biomaterials, etc.). Each of these markets is different in terms of its operational characteristics, historical and current developments, degree of closure of its material cycle, business and economic importance. While some markets have been well-established for a long time and are rather successful in providing a stable and relevant contribution to the circular economy, others still suffer from barriers to their further development. This remains the case even when they are targeted by strong waste and recycling policies at the EU and national levels.

The diverse features and dynamics of existing SRM markets are reflected in the insufficient state of knowledge on them, which reflects the weakness of publicly available information and monitoring systems and the considerable role of proprietary information and knowledge in the hands of industry and market operators. This state of information and knowledge often leads to these markets being analysed separately, ostensibly because there are no similarities or common features among them. The risk is that this can lead to a fragmented policy approach to developing and ensuring well-functioning SRM markets.

This report provides a unified view on the different SRMs by:

- developing an **analytical framework** for assessing SRM market functionality;
- testing the framework on **eight selected waste materials**;
- systematically mapping the **barriers** that prevent SRM markets from achieving full maturity from a value chain perspective;
- exploring **options for overcoming barriers**, which can be implemented at each stage in the value chain and across all types of SRM markets.

1.2 Approach and methodology

This report addresses the fragmentation and dispersion of information on SRM markets by proposing a unified approach to assess and improve how they function, regardless of the targeted material.

For this purpose, we develop an analytical framework, based on a set of criteria that address different aspects of market functionality. The framework is then applied to a series of specific materials to understand the existing SRM markets in Europe and the specific reasons for suboptimal functioning.

A deeper assessment of market characteristics can reveal the underlying reasons that SRM markets do not achieve 'well-functioning status' and deliver good-quality SRMs at competitive prices. This report adopts a 'value chain' approach, meaning that the identification and discussion of barriers follows the various stages of the SRM value chain. The reason for such an approach is that a sound analysis of SRM markets requires integrating a demand (or pull) perspective and the traditional waste supply (or push) view.

There are many policy approaches, instruments and tools that can help remove barriers at different levels of the value chain in both well- and, especially, less well-functioning SRM markets. Considering the existing EU policy framework for SRM markets, this report identifies effective ways to remove the barriers that prevent the development of SRM markets at different stages of the value chain.

(1) Recycling – secondary material price indicator - Statistics Explained (europa.eu)

1.3 Scope and definitions

A waste management system consists of all the activities and actions required to manage waste — from its generation to its preparation for reuse, recycling, recovery and final disposal. The activities may include collection, transfer, transport, sorting, recycling, treatment and temporary and final disposal by incineration or landfilling. Waste operations that start with (separate) collection and end with recycling will produce SRMs (see Box 1.1). SRMs are different from primary raw materials only because of their origin: waste for the former as opposed to the natural environment for the latter. SRMs can be offered to an SRM market, which is **an economic and logistical space linking waste management operations and the industrial raw material system.**

The scope of the SRMs assessed in this report includes all materials produced from waste through recycling. The conversion of waste to energy is outside the scope of this report. Some waste materials can indeed be used as an energy source; therefore, recycling and energy recovery might compete with each other in economic terms. In practice, however, such waste materials are rarely relevant sources of SRMs. This is because the bulk of energy recovery is linked to mixed, not separately collected, waste.

Box 1.1 What is a secondary raw material?

According to the Waste Framework Directive (EU, 2008), 'recycling' means any recovery operation by which waste materials are reprocessed into products, materials or substances, whether for original or other purposes. It includes the reprocessing of organic material but does not include energy recovery or reprocessing into materials that are to be used as fuels or for backfilling operations.

The above definition implies that only waste can be recycled. The status of waste is not defined by its chemical, physical or mechanical material properties or by its product composition or lifetime. Instead, in accordance with the Waste Framework Directive, it is defined by the fact that a holder discards or intends or is required to discard it. The recycling process ends at a single, determinate point at which a secondary raw material is produced. At this point, it is no longer waste, cannot be distinguished from a primary raw material and can be traded in the same way as all other commodities. Eventually, products that contain secondary raw materials as recycled content can be discarded as waste, from which materials can be recycled.

2
How well do SRM markets function in Europe? A criteria-based assessment

As with traditional commodity markets, there is no definition of or a set of standardised criteria for identifying a well-functioning secondary raw material (SRM) market. The idea of a well-functioning market is, often implicitly, associated with the concept of a competitive market. By definition, a competitive market has no operator with substantial market influence, a large number of transactions, prices fully reflecting demand and supply, full information available to participants, and standardised traded commodities or well-defined market segmentation. Although these features are rarely found in real-world markets, they are still important factors for judging whether a market is functioning well or not. The general conditions for establishing a market for raw materials are shown in Box 2.1.

However, SRM markets have intrinsic peculiarities with respect to traditional commodity markets. These include interaction with the primary material market (substitution), the potential for negative prices for materials regarded as 'waste', the sometimes inadequate or asymmetric information available to operators in less-developed or new SRM markets, the lack or limited availability of organised marketplaces, the often prevailing heterogeneity of the traded material, the externalities associated with both primary and secondary markets. Last but not least, SRM markets are under intense policy pressure to deliver recycling and recovery targets in the pathways towards a circular economy (Söderholm and Ekvall, 2020).

Therefore, while the idea that conventional competitive markets for (primary) commodities and other goods can be used as a reference model, it cannot be a standard benchmark for secondary material markets. Instead, the potential benchmark can be found in **relative terms** by identifying those SMR markets that perform better than others — and understanding why.

Box 2.1 End-market conditions for raw materials

The general conditions for establishing or expanding a market for materials, independently of their source or origin i.e. from the natural environment or from the anthroposphere, can be defined as follows:

Legal ownership of the material. If the material (virgin or waste) has no legal owner, no seller-purchaser relation is possible. Waste ownership can be a complex issue which deserves careful monitoring to avoid legal actions that might hinder further development of incipient markets. This is particularly the case for waste that is collected, and sometimes further processed, by public services.

Functioning rule of law. Environmental, waste, chemical and product legislation, emission standards, and industrial permitting procedures, among others, must be observed by all stakeholders involved in the secondary raw material production process.

Freedom of enterprise, freedom of establishment and freedom of contract. Both horizontal and vertical integration of activities throughout product and waste supply chains have the danger of monopolising markets.

Price setting in the market. Market prices are dynamic and should reflect actual market conditions.

Functioning competition. Competition is required to secure resource efficiency operations at company level at any time.

Profit as a signal. Profits and losses provide information and feedback on the outcomes of the production chain and allow adequate responses to the needs and pressures on the raw materials demand side.

Source: Kirchherr et al. (2017).

2.1 Developing criteria for defining a well-functioning SRM market

To assess whether an SRM market performs well (i.e. is well-functioning) or not, we need to develop a set of criteria that take into account the overall characteristics of material markets, as well as the particularities of markets developed around SRMs. These criteria should be based on the distinct, often implicit features of a well-functioning SRM market, which demonstrates:

- a significant share of the total market for that material (with respect to the primary material);
- representative prices properly reflecting demand-supply interaction;
- the international scope of transactions;
- economic self-sustainability even without the support of (waste) policy;
- robust industrial use capacity for recycling/recovery;
- good availability of market information;
- good product standardisation.

Based on these general features and our expert judgement, we propose a set of specific criteria. If fulfilled, an SRM market could be characterised as well-functioning. The criteria constitute an analytical framework that can be applied to any SRM market with the aim of assessing if the market approximates the idea of a well-functioning market or it is still some distance from achieving this status. The criteria used in the report revolve around four aspects and are shown in Table 2.1:

1. market size and growth (criteria 1-4);
2. role of policy drivers in market development (criteria 5-7);
3. prices (criteria 8-10);
4. technical specifications and barriers (criteria 11-12).

The criteria are not quantifiable or benchmarked, and the subsequent analysis is therefore largely qualitative. However, in Section 2.2, these 12 criteria are tested based on the information available on eight selected material markets — aluminium, paper and cardboard, wood, glass, plastics, textiles, construction and demolition (C&D) aggregate waste, biowaste — to assess their suitability for identifying a well-functioning market. These materials are all targeted, to varying extents, by the EU waste policy with a view to improving their recycling. Therefore, how their respective SRM markets function is very policy relevant.

Table 2.1 Set of criteria for defining a well-functioning secondary raw material market

Criterion	Description
Market size and growth	
1. High shares of supply and demand with respect to total market size	The SRM is relevant, in terms of share of material demand (as an industrial input or a final product), with respect to the total market (primary plus secondary) for that material.
2. Enough stable or increasing supply and demand	The supply/demand for the secondary material is not fluctuating depending on the supply/demand from single suppliers/demanders or from single market events. As a result, the price represents the fundamentals of the market and both demand and supply are possibly increasing.
3. Open international trade and high tradability	The material has an open international trade and, possibly, high tradability (value of the material is high compared with transport costs). This favours the stability of transaction flows and the capacity of price to represent demand/supply fundamentals (liquidity of the market).
4. High industrial capacity based on secondary material inputs	There is a large industrial capacity (plants and equipment) creating demand for the SRM as an input.
Role of policy drivers in market development	
5. Non-policy-driven supply and demand	The market can survive economically even without waste policies that exogenously push demand and/or supply or modify prices through, for example, taxes and subsidies.

Table 2.1 Set of criteria for defining a well-functioning secondary raw material market (cont.)

Criterion	Description
6. Included in compliance schemes for packaging waste or extended producer responsibility schemes	The material is involved in closed-loop circular schemes (voluntary or policy target-driven) that enlarge the demand and supply and then favour the stability and growth of the SRM market.
7. No competition from energy use	The SRM material is not subject to competing demand from energy recovery operations that can enlarge the market but (especially for a stable supply) can also displace the SRM market.
Prices	
8. Reference international or national prices	Similarly to what happens with major primary material markets, the SRM market is able to produce a price recognised by market operators as a reference for transactions and contracts. This remains the case whether the price is in international or national organised market platforms (e.g. organised commodity exchange markets) or a price is commonly-recognised through other market-related channels (e.g. online transaction platforms).
9. 'Organised markets' for trading (e.g. futures)	The material is transacted in international, organised market platforms or organised commodity exchange markets — also through forward, futures and option contracts.
10. Sufficient information available to both demand and supply actors	There is open and continuous information flow on supply/demand and the prices and factors influencing them. This is available via commercial sources and/or media channels.
Technical specifications and barriers	
11. Product specifications are standardised	The SRM is subject to agreed or formal (regulatory) definitions and standards that are accepted and recognised by operators as references for contracts and transactions.
12. No regulatory barriers to using SRMs as inputs in manufacturing	The SRM is not subject to adverse or discriminatory regulatory provisions for its use as an industrial commodity. Moreover, it is not subject to regulatory difficulties or barriers, for example in the end-of-waste process.

2.2 Applying the criteria to selected SRM markets

2.2.1 Aluminium

Market characteristics

Aluminium is a highly circular and highly recyclable material: it can be separated and used over and over again without losing its technical properties. Aluminium production is very energy-intensive, and the use of aluminium scrap saves significant amounts of energy. The recycling of aluminium accounts for 36% of aluminium metal supply in Europe. However, there is a need to achieve higher recycling rates because of the growing demand for recycled aluminium: it is expected to increase by 40% between 2019 and 2050, especially because of its use in electrical cars (European Aluminium, 2020). Today, around 20% of global demand for aluminium is covered by scrap (Spotlightmetal, 2019).

Furthermore, large quantities of aluminium are currently in stock and will be available for recycling in the future (European Aluminium, 2017).

The primary production of aluminium in Europe is stable, and the installation of new capacity is influenced by strict EU energy and climate regulations. The EU relies on imports to cover about 30% of its demand for primary aluminium. Recycling would also reduce companies' exposure to supply insecurity due to the EU's dependence on imports.

There are also trends influencing the recycling business in two directions (European Aluminium, 2020):

- export of aluminium products from Europe, resulting in lost resources;
- cheap imports rendering European investment in recycling uneconomic.

According to Material Economics (2018), the European demand for aluminium will grow to 450kg per person by 2050 from the current average of 250kg per person. In that report, it is also estimated that half of the growth in demand could be covered by recycling. In the future, the stock of recycled aluminium will reduce the need for primary aluminium production.

Is the secondary aluminium market well-functioning?

Secondary aluminium markets correspond well to the idea of well-functioning or mature markets (Table 2.2). The amounts of end-of-life aluminium recycled are already significant. Aluminium recycling rates are among the highest compared with those of other materials: in Europe, recycling rates are over 90% in the automotive and building sectors, and 75% for aluminium cans.

Table 2.2 Assessment of the secondary aluminium market

Criterion	Application
Market size and growth	
1. High shares of supply and demand with respect to total market size	Yes. Aluminium scrap used as feedstock in aluminium production (currently 20% of feedstock globally).
2. Enough stable or increasing supply and demand	Yes. Increasing demand for aluminium in future, especially in the transport sector.
3. Open international trade and high tradability	Yes. Aluminium is traded globally.
4. High industrial capacity based on secondary material inputs	Yes. Existing smelters use aluminium scrap as feedstock.
Role of policy drivers in market development	
5. Non-policy-driven supply and demand	Partly. EU energy and climate regulations support recycling, as a significant amount of energy is saved by using aluminium scrap.
6. Included in compliance schemes for packaging waste or extended producer responsibility (EPR) schemes	Yes. At the national level, most Member States have EPR schemes in place covering packaging (which will become mandatory by 2024). According to the statistics from European Aluminium and Metal Packing Europe, the recycling rate for aluminium beverage cans in the EU and EFTA was on average 75.8% in 2019 (which equals 488kt; Metal Packaging Europe and European Aluminium, 2021).
7. No competition from energy use	Yes.
Prices	
8. Reference international or national prices	Yes. Aluminium is traded globally.
9. 'Organised markets' for trading (e.g. futures)	Yes. Highest prices are for aluminium cans, extrusion scrap, lithographic sheets, aluminium cuttings and painted/insulated extrusion scrap. Aluminium scrap prices are more than an order of magnitude higher than those for bauxite, because of the low aluminium content of bauxite and the high costs of processing aluminium from bauxite.
10. Sufficient information available to both demand and supply actors	Yes. Commercial databases exist.

Table 2.2 Assessment of the secondary aluminium market (cont.)

Criterion	Application
Technical specifications and barriers	
11. Product specifications are standardised	Yes. Standard for aluminium scrap developed: analytical procedures for sampling and determination of aluminium content exist (EN 13920).
12. No regulatory barriers to using SRMs as inputs in manufacturing	Yes. Council Regulation (EU) No 333/2011 sets out the end-of-waste criteria for scrap aluminium and its use in manufacturing.
Overall result	**Well-functioning**

Note: EFTA, European Free Trade Area.

2.2.2 Paper and cardboard

Market characteristics

In 2018, the 27 EU Member States (EU-27) produced 42.9 million tonnes of paper and cardboard waste (Eurostat, 2021a). The major part (74%) of this waste was packaging waste (Eurostat, 2021b). Paper and cardboard are always recyclable, although for a limited number of recycling cycles due to shortening fibers, but the recycling process is more challenging when they are combined with other materials: all contamination and elements that are difficult to separate from the fibrous material decrease the pulp's quality and result in fibre losses during collection, sorting or the recycling process.

European legislation requires paper from municipal waste to be separately collected, as this is a prerequisite for recycling and fulfilling the recycling targets of the Waste Framework Directive (WFD). In the Packaging and Packaging Waste Directive (PPWD), a 60% target for recycling is currently (2020) applied to paper and board packaging (and has been since 2008). The target rises to 75% by 2025 (intermediate target) and 85% by 2030 (final target). To increase recycling rates, most Member States have created extended producer responsibility (EPR) schemes for packaging (which will become mandatory by 2024).

In current paper product production, almost 50% of the raw materials consumed are SRMs. Trading paper and cardboard waste is an important and stable activity (CEPI, 2020). Of all the paper and cardboard waste generated in the EU-27, 24% is exported to non-EU countries, 38% is traded between EU Member States, and the remaining 38% is treated domestically. This implies that the market for paper and cardboard waste is rather significant and open.

Technical requirements for paper and cardboard waste are set in the EN 643 standard, 'European list of standard grades of paper and board for recycling', which describes the grades of paper and cardboard that can be used by paper recycling mills. The described grades range from very specific homogeneous grades, e.g. cuttings from converting plants, to mixtures of different grades of paper and board resulting from household collection. No end-of-waste (EoW) system is yet in place.

Is the secondary paper and cardboard market well-functioning?

The market for recovered paper pulp corresponds well to the idea of a well-functioning market (Table 2.3). Paper fulfils most of the criteria (as defined in Section 2.1; see Table 2.1). This is not surprising because secondary paper and cardboard markets have been developed for a long time.

Two critical factors related to the maturity of SRM markets are market size and the quality of the materials. Paper scores well in both. Recovered paper already accounts for almost 50% of the raw material market for paper production, and there is a quality management system in place with technical requirements for feedstock for recycling. It is interesting to note that markets for secondary paper are also driven by the trend in replacing single-use plastics with other sustainable and environmentally-friendly alternatives, including both recovered paper and other fibre packaging solutions (Frost & Sullivan, 2019).

Table 2.3 Assessment of the secondary paper and cardboard market

Criterion	Application
Market size and growth	
1. High shares of supply and demand with respect to total market size	Yes. Paper and cardboard are used as feedstock in new paper production (currently 50% of new paper is based on SRM feedstock).
2. Enough stable or increasing supply and demand	Yes. Demand for paper and cardboard waste is stable.
3. Open international trade and high tradability	Yes. Paper and cardboard waste are traded globally.
4. High industrial capacity based on secondary material inputs	Yes. The paper and cardboard industry already uses SRMs to produce new paper and board.
Role of policy drivers in market development	
5. Non-policy-driven supply and demand	Partly. The market size for recovered paper is partially driven by recycling policies. The waste directives (WFD and PPWD) set requirements for separate collection and targets for recycling of paper and cardboard waste, which increases the availability of feedstock for recycling.
6. Included in compliance schemes for packaging waste or EPR schemes	Yes. At the national level, most Member States have EPR schemes in place covering packaging (which will become mandatory by 2024).
7. No competition from energy use	Partly. Energy recovery competes with recycling, but source-separated waste paper is rarely incinerated.
Prices	
8. Reference international or national prices	Yes. Paper and cardboard waste are traded globally.
9. 'Organised markets' for trading (e.g. futures)	Yes. Paper and cardboard waste are traded globally.
10. Sufficient information available to both demand and supply actors	Yes. Commercial information exists.
Technical specifications and barriers	
11. Product specifications are standardised	Yes. European Standards EN 13427 (Requirements for the use of European Standards in the field of packaging and packaging waste), EN 13428 (Requirements specific to manufacturing and composition — prevention by source reduction) and EN 13430 (Requirements for packaging recoverable by material recycling) define the requirements for packaging design. EN 13432 addresses packaging biodegradability.
12. No regulatory barriers to using SRM as inputs in manufacturing	Yes. However, no EU-wide EoW criteria exist.
Overall result	**Well-functioning**

2.2.3 Wood (construction and packaging)

Market characteristics

Construction waste

In the EU, about 70% of thewood produced is used in construction and furnishings (WoodCircus, 2021). The amount of non-hazardous waste wood arising from construction was approximately 8.6 million tonnes in 2018 (Eurostat, 2021a).

Currently, about one-third of waste wood is recycled, with large differences between Member States in recycling rates. The rest is landfilled or incinerated. In central and southern Europe, wood scrap is extensively used in manufacturing particle board. This is not the case in northern countries (for example, Finland and Sweden), where the particleboard industry relies on an abundance of higher quality wastes from sawmills. Examples of the challenges of using recycled waste wood as raw material are the logistics involved in its collection and transport and the need for sorting (Garcia and Hora, 2017). During use, wood quality may deteriorate under certain conditions and the resulting waste wood is not suitable for recycling or reuse. Furthermore, the pre-treatment of wood materials containing nails and paint is labour-intensive. Timber structures (e.g. beams) and interiors (doors, window frames, etc.) are reused today, albeit to a small extent.

According to the WFD, 70% by weight of non-hazardous C&D waste was to be reused or recycled by 2020. The directive also requires that Member States promote selective demolition to facilitate high-quality recycling and ensure that sorting systems are established for C&D waste (at least for wood, mineral fractions, metal, glass, plastic and plaster).

Wood waste from construction has a well-functioning market for use in energy production, and many countries have a clear objective to replace fossil fuels with bio-based materials. Standards for classifying wood waste as fuel have been developed to support the trading of solid recovered fuels (SRFs). Furthermore, an EoW concept has been developed for SRFs in Austria and Italy. This means that there is significant competition in the SRM market for wood from the energy production sector.

Wood packaging waste

Waste wood from packaging accounted for about 13 million tonnes in the EU-27 and the UK in 2017 (Eurostat, 2021b). According to Eurostat (2021b), the share of material recycled from wood packaging waste generated in the EU was approximately 31% (year 2019). This demonstrates huge, unexploited opportunities to recycle this waste stream in all EU countries.

Based on the PPWD, since 2008, a 15% target for recycling applied to wood packaging until 2020. The target rises to 25% by 2025 (intermediate target) and 30% by 2030 (final target). At the national level, most Member States have created EPR schemes covering packaging (which will become mandatory by 2024).

Is the secondary wood market well-functioning?

The market for SRFs has the potential to be well-functioning (Table 2.4). However, wood waste for recycling does not fully meet the criteria for a well-functioning SRM market in terms of the quantities (e.g. the share of SRM with respect to the total market) and the industrial capacity for producing SRM.

Table 2.4 Assessment of the secondary wood market

Criterion	Application
Market size and growth	
1. High shares of supply and demand with respect to total market size	No. Low share.
2. Enough stable or increasing supply and demand	No.
3. Open international trade and high tradability	No. Markets mostly operate at the national level.
4. High industrial capacity based on secondary material inputs	Partly. Only to some extent, for particleboard production.

Table 2.4 Assessment of the secondary wood market (cont.)

Criterion	Application
Role of policy drivers in market development	
5. Non-policy-driven supply and demand	No. The waste directives (WFD and PPWD) set requirements for separate collection and targets for recycling of wooden waste, which increases the availability of feedstock for recycling.
6. Included in compliance schemes for packaging waste or EPR schemes	Yes. For wooden packing waste, most Member States have EPR schemes in place covering packaging (which will become mandatory by 2024).
7. No competition from energy use	No. Energy recovery competes strongly with recycling.
Prices	
8. Reference international or national prices	No.
9. 'Organised markets' for trading (e.g. futures)	No.
10. Sufficient information available to both demand and supply actors	No.
Technical specifications and barriers	
11. Product specifications are standardised	No. A standard for SRF use has been developed, but that is not relevant to the SRM market.
12. No regulatory barriers to using SRMs as inputs in manufacturing	Yes. However, no EU-wide EoW criteria for wood exist.
Overall result	**Not well-functioning**

2.2.4 Glass

Market characteristics

In 2019, the EU-27 produced 16.4 million tonnes or 37kg/capita of glass waste (Eurostat, 2021a). Out of this amount, 32.5kg/capita was packaging waste (Eurostat, 2021b).

In 2019, 76% of packaging glass was recycled in the EU-27 (Eurostat, 2021b). Glass does not degrade during the recycling process, so it can be recycled indefinitely through melting and reprocessing without losing quality (Glass Packing Institute, 2021). Recycled glass can substitute up to 95% of raw materials in the glass production process. The majority of glass waste collected for recycling is used to produce new bottles and jars (FEVE, 2021). Post-consumer waste glass can also be recovered for uses that do not require re-melting.

The majority of glass produced and recycled is packaging glass. One limitation on recycling rates is that packaging glass cannot be mixed with other types of glass, such as windows, ovenware (e.g. Pyrex) and crystal. This is because the manufacturing processes for those types of glass and packaging glass are different.

European legislation requires glass to be separately collected for recycling. In the PPWD, a 60% target for recycling has been applied to glass packaging waste since 2008. The target rises to 70% by 2025 (intermediate target) and 75% by 2030 (final target). To increase glass recycling, most Member States have EPR schemes in place covering packaging (which will become mandatory by 2024), and many Member States have introduced deposit and refund schemes for glass bottles.

Glass is a low-cost but heavy material; transport is relatively expensive and the volumes traded of recovered glass or cullet are low compared to the overall volumes recycled. Since 2012, the European Commission has EoW criteria in place for cullet (EU, 2012a) to further facilitate its trade.

Is the secondary glass market well-functioning?

The market for cullet somewhat has the potential to be a well-functioning or mature market (Table 2.5). Cullet fulfils most of the relevant criteria (as defined in Section 2.1; see Table 2.1), except for the strong role of waste policies in the market development and the low tradability and lack of organised markets.

The two critical factors related to secondary material market functionality are market size and material quality. Glass scores well in both. Most recovered glass is used to produce new glass packaging, and there is a quality management system in place for the feedstock for recycling and EoW criteria for cullet.

Table 2.5 Assessment of the secondary glass market

Criterion	Application
Market size and growth	
1. High shares of supply and demand with respect to total market size	Yes. There is a relatively low volume of recovered glass or cullet traded. This is explained by the fact that glass is a heavy and low-cost material, so transport is relatively expensive. However, recycling rates for glass are high.
2. Enough stable or increasing supply and demand	Yes. The amount of glass waste generated in the EU is rather stable.
3. Open international trade and high tradability	Partly. International trading within the EU exists, but because of its low price and heavy weight, recycled glass is predominantly traded among neighbouring countries.
4. High industrial capacity based on secondary material inputs	Yes. Glass waste easily substitutes for virgin material in glass production.
Role of policy drivers in market development	
5. Non-policy-driven supply and demand	Partly. The market size for recovered glass is partially driven by recycling policies. The waste directives (WFD and PPWD) set requirements for separate collection and targets for recycling glass waste, increasing the feedstock available for recycling as a result. Given the high rates of recovered glass use, the recycling targets for glass packaging are set to be very high, at 75% by 2030.
6. Included in compliance schemes for packaging waste or EPR schemes	Yes. At the national level, most Member States have EPR schemes in place covering packaging (which will become mandatory by 2024).
7. No competition from energy use	Yes.
Prices	
8. Reference international or national prices	Yes. Statistics and information are available.
9. 'Organised markets' for trading (e.g. futures)	Yes. Trading platforms exist and also trading between glass producers.
10. Sufficient information available to both demand and supply actors	Yes. Commercial information exists.
Technical specifications and barriers	
11. Product specifications are standardised	Yes. A standard for cullet has been developed.
12. No regulatory barriers to using SRMs as inputs in manufacturing	Yes.
Overall result	**Well-functioning**

2.2.5 Plastics

Market characteristics

Recycling rates for plastic packaging wastes vary considerably across Europe, with the average being 42% in 2018 ([2]) (EU-27 and the UK; Eurostat, 2018). Recycling rather than incinerating plastics can reduce emissions by 1.1-3.0 tonnes of CO_2-equivalent per tonne of plastic waste managed (EEA, 2021b). Collection and recycling rates vary for different polymer types and even for the same polymers in different applications. There is a lack of reliable information on the recycling rates of plastic waste in waste electrical and electronic equipment, textiles and end-of-life vehicles (Huisman et al., 2017) ([3]). The sources of different plastic wastes as SRMs are summarised in Table 2.6.

Most of the demand for plastic comes from the packaging sector (approximately 40%), followed by the building and construction, automotive and electronics sectors (PlasticsEurope, 2019). Textiles also demand large amounts of plastics, but these are not covered by the available statistics.

There are still many uncertainties when it comes to data on the waste management of plastics. A study by Material Economics (2018) states that Europe generates about 45 million tonnes of plastic waste per year, which is 50% more than the 25-30 million tonnes typically reported (EC, 2022a). Plastic waste 'collected for recycling' does not always correspond to the amount that is actually recycled. Some fractions are exported, while others are lost to incineration or landfill (EuRIC, 2020). The revised PPWD (EU, 1994) sets stricter reporting rules for plastic recycling, which is likely to lead the EU's reported average plastic packaging recycling rate to drop (European Court of Auditors, 2020).

Table 2.6 Source of plastic waste as a secondary raw material

Subgroup of waste feedstock	Application or end-of-life product	Material group	Secondary raw material
Packaging waste	Plastic packaging e.g. bottles, bags	Thermoplastics (PET, HDPE, PVC, LDPE, etc.)	Mixed plastics, recycled monopolymer flakes, regranulates and regrinds, monomers, pyrolysis oil
Technical plastic waste	Automotive, EEE, building and construction products	Thermoplastics (ABS, HIPS, PC, etc.)	Mixed plastics, recycled monopolymer flakes, regranulates and regrinds, monomers, pyrolysis oil
Waste textiles	Carpets, clothing	Polyester, nylon, acrylic, polyamide	Recycled polyester, polyamide, nylon yarn, recycled polyester chips
Fibre-reinforced wastes	Wind turbine blades, boats	Thermosets	-

Note: ABS, acrylonitrile butadiene styrene; EEE, electrical and electronic equipment; HDPE, high-density polyethylene; HIPS, high-impact polystyrene; LDPE, low-density polyethylene; PC, polycarbonate; PET, polyethylene terephthalate; PVC, polyvinyl chloride.

([2]) The estimated recycling rate based on new calculation rules is 29%.

([3]) According to Huisman and colleagues' report, 'Gold, being the key value driver behind material recycling, primarily comes from printed circuit boards in LCD TVs, laptops, tablets, desktops and mobile phones and totals to 230 tonnes in-stock, roughly equal to 8% of the total annual world gold production. Other significant occurrences are plastics (26.5 million tonnes), copper (4.1 million tonnes), neodymium (12,000 tonnes), indium (300 tonnes) and silver (1,300 tonnes).'

Several factors hampering the production of high-quality secondary plastics have been brought up in recent reports. The main challenges are identified as follows (Material Economics, 2018; ETC/WMGE, 2019a; EEA, 2021b):

- Product complexity: plastic wastes are often heterogeneous streams containing different polymers and additives and potentially also other materials (metals, paper).
- Recyclability: polymers have different degrees of recyclability, and some polymers cannot be recycled in the same waste stream.
- Hazardous materials: plastics often contain additives, colourants, plasticisers and stabilisers, which make recycling processes challenging. Some frequently-used substances (e.g. flame retardants) are on the European Chemicals Agency's list of substances of very high concern. As a result, recycling becomes challenging due to the strict limits on their content in recyclables.
- Traceability: the low traceability of the chemical content of plastic products exacerbates this barrier and reduces the demand for recycled plastics. This is because there is uncertainty about which chemicals recycled plastics contain.
- Contamination: plastics may be contaminated during use e.g. by food waste or chemical substances that come into contact with plastics.
- Downcycling: this takes place both when the recycled content is of lower quality than the original product and when recyclates are used in products of lower value than the original (e.g. PET (polyethylene terephthalate) bottles to textiles). As a result, there are less subsequent recycling options.
- Price: the low price of primary materials and the costs of sorting and processing (including investment costs) put a price premium on products made from secondary plastics. Moreover, the volatility of primary material prices does not allow for a stable development of the SRM market.
- Degradation: during recycling, polymer length is degraded, which reduces the number of recycling loops. This varies from polymer to polymer, and the number of loops can be extended when virgin material is added to recycled plastic.
- Thermoset polymers have very limited (mechanical) recycling options and consequently very low recycling rates.

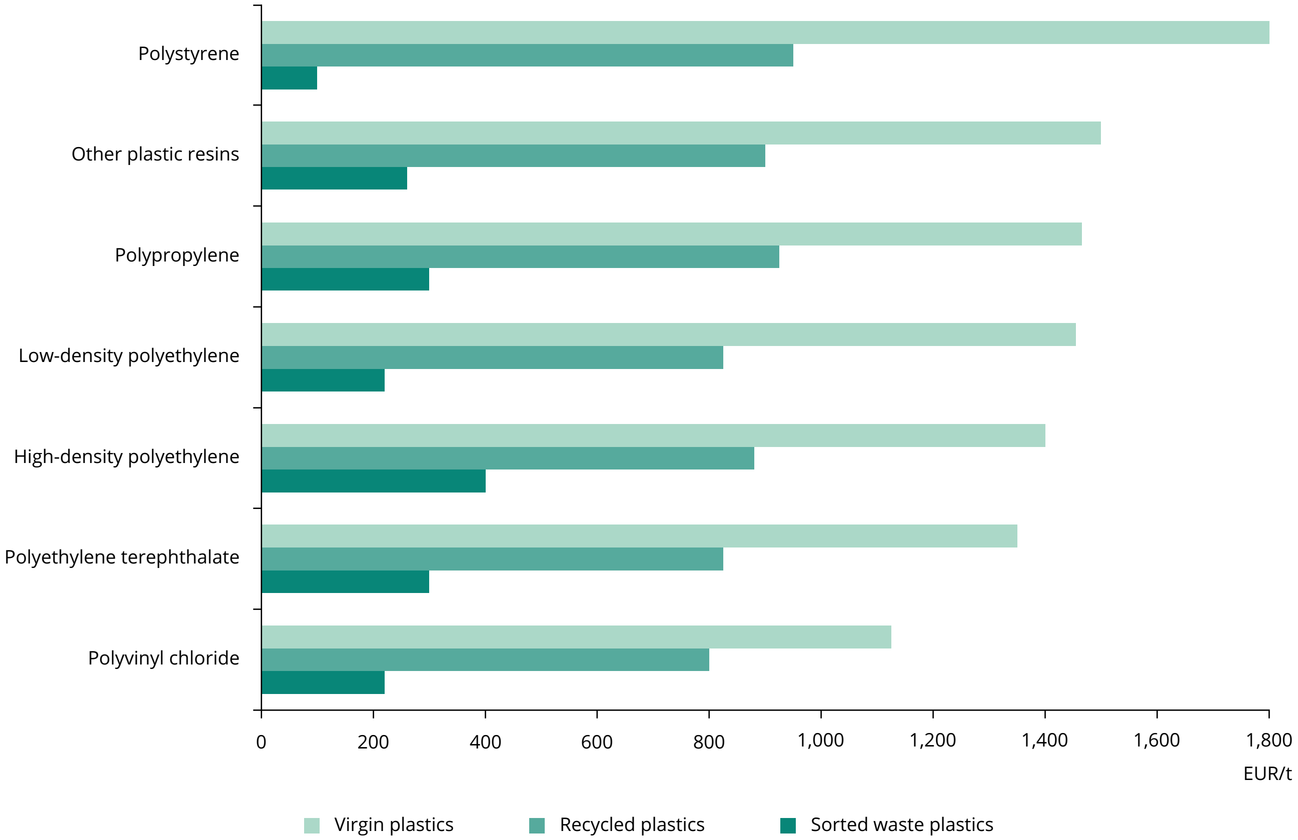
However, there is a growing demand to include recycled material in plastics. Several businesses and brand owners have set voluntary targets for recycled plastic content, and the Circular Plastics Alliance aims to put 10 million tonnes of recycled plastic content on the market by 2025 (Circular Plastics Alliance, 2022). There are several drivers behind this increase in demand for recycled plastic content, including (1) contributing to the targets set out in EU Single-Use Plastic Directive (EU, 2019a), (2) increasing the pace of transition to the circular economy, (3) ensuring a sustainable future for the industry, and (4) taking environmental responsibility seriously for customers.

One of the main challenges, according to companies that want to use recycled plastics, is finding sufficient and stable volumes of recycled plastics at the right quality. Safe and secure supplies of raw materials are important. Some also mention the lack of EoW criteria. This is seen as a barrier in the industry because it creates ambiguity around when waste ceases to be waste (Ljungkvist Nordin et al., 2019). However, the European Commission has announced that it will start to develop EoW criteria for plastic waste and textiles by 2022 and 2023, respectively (EC, 2022b).

The plastic recyclates most in demand are high-density polyethylene (HDPE), low-density polyethylene (LDPE), polypropylene and PET, which have a wide range of applications. PET from EPR schemes and deposit-return schemes (PET bottles) is a highly sought-after raw material, and from sectors other than plastic. This creates competition for recyclable PET. Demand for recycled PET (rPET) is much higher than supply, according to market reports from the German trading platform Plasticker (Plasticker, 2022). The high demand for PET is also due to demand from sectors other than packaging (e.g. textiles). PET is often used for food packaging (which means it complies with food grade quality requirements and has little hazardous content). This polymer is highly recyclable because PET bottles are often colourless. In addition, the short lifespan of packaging allows for a steady flow of material (Ljungkvist Nordin et al., 2019).

The price of recycled plastic varies from up to 90% of the price of virgin material to a negative value. The price of PET from bottles is currently just below the price of virgin material. The negative values are due to contamination, hazardous content or material degradation. Colour and odour are also important factors that have a significant impact on the price. The demand and price for regranulated engineering plastics such as polycarbonate, poly (methyl methacrylate), acylonitrile butadiene styrene, polystyrene and polyamide (PA6 and PA6.6) are consistently high if the quality is good (Ljungkvist Nordin et al., 2019).

Figure 2.1 Difference in value of unsorted, sorted and recycled plastics



Note: Data for unsorted mixed waste plastics are from an analysis of WRAP materials pricing reports for 2012-2015.

Source: OECD (2018), based on data from Hestin et al. (2015).

Box 2.2 PET recycling

Polyethylene terephthalate (PET) is presented here as a good example of a plastic with a well-developed market. PET is used in beverage bottles, food jars, some shampoo bottles and mouthwash bottles. Demand for PET was 3.9 million tonnes in 2017 (Plastics Europe, 2018) and 1.9 million tonnes of PET bottles were collected in 2017 (also recycled in textiles). The average recycled content in PET bottles in Europe has been around 11%, and the upcoming requirement on recycled content in the Single-Use Plastics Directive (EU, 2019a) will create a market for recycled PET. The directive states that at least 25% of the plastic in beverage bottles must be recycled by 2025 (for PET bottles), and 30% by 2030 (for all bottles). The high future demand for recycled PET is expected to drive prices for recycled PET higher than those for primary PET.

Is the secondary plastics market well-functioning?

To apply the framework developed, we focus on the most common plastic waste material — mixed plastics — as most municipal waste collection systems in the EU target mixed plastic polymers. Therefore, the results of this assessment can only refer to mixed plastics. For sub-markets of plastic SRMs, such as PET obtained from deposit-refund systems, the results of this assessment would be different.

Plastic recyclers operate in the same market as virgin plastic producers and often, recycling is not economically competitive. Plastic recyclers are in competition with resin producers and fluctuations in material quality and price significantly impact the viability of recycled plastic markets. In addition, virgin resin prices are linked to the price of oil, which is highly volatile. For plastics recyclers, the focus is on cutting costs and ensuring a high-quality material that can be used for high-value applications, such as food-grade packaging (Kosior and Mitchell, 2020; Pohjakallio, 2020). It is also crucial that recycled content is not downcycled — i.e. progressively used for lower value products — but used in products of similar value to the original (e.g. food packaging to food packaging). Promoting closed loop systems, in which plastic products are recycled and fed into the same product value chain, can alleviate some of the perceived risks concerning supply traceability, quality and availability.

The functioning of the secondary plastics market varies from polymer to polymer. The market for rPET is somewhat well-functioning. However, for most other polymers and especially for mixed plastics/composites, the market cannot yet be considered well-functioning. Overall, the market for secondary plastics is not well-functioning (Table 2.7).

Table 2.7 Assessment of the secondary plastics market

Criterion		Application
Market size and growth		
1.	High shares of supply and demand with respect to total market size	Partly. Large supply of plastic waste, but low demand due to poor quality, with the exception of certain plastic waste streams such as PET bottles.
2.	Enough stable or increasing supply and demand	Partly. Recycling targets for plastic packaging will increase the supply. There is also growing demand for recycled content from several brand owners. Nonetheless, the use of recycled plastic is still very low.
3.	Open international trade and high tradability	Yes. International trading for many plastic wastes (e.g. PET).
4.	High industrial capacity based on secondary material inputs	Partly. Technologies are still under development with the exception of certain polymers (PET).
Role of policy drivers in market development		
5.	Non-policy-driven supply and demand	No. Considerable push from legislation. The waste directives (WFD and PPWD) set requirements for separate collection and targets for recycling of plastic waste, increasing the feedstock available for recycling as a result. The requirement for recycled content in bottles creates demand (e.g. for PET).
6.	Included in compliance schemes for packaging waste or EPR schemes	Yes. At the national level, most Member States have in place EPR schemes covering packaging (which will become mandatory by 2024).
7.	No competition from energy use	Partly. Competition with use for energy recovery, but source-separated plastic waste is rarely incinerated.
Prices		
8.	Reference international or national prices	Partly. Only for certain polymers.
9.	'Organised markets' for trading (e.g. futures)	Partly. Trading platforms exist for certain plastic waste (PET).
10.	Sufficient information available to both demand and supply actors	Partly. Good market information is available for some plastics (e.g. PET).
Technical specifications and barriers		
11.	Product specifications are standardised	Partly. Standards exist for using primary polymers in various applications, but their applicability to plastic wastes is unclear.
12.	No regulatory barriers to using SRMs as inputs in manufacturing	No. Significant uncertainties related to EoW concepts (under development in some Member States and at the EU level) for certain plastic waste recovered from mechanical recycling processes requiring quality controls.
Overall result		**Not well-functioning**

2.2.6 Biowaste

Market characteristics

In 2018, the Ewa27 produced 87 million tonnes of biowaste (Eurostat 2021a) ([3]). This includes both biowaste that is separately collected and biowaste collected with mixed (residual) waste, but it excludes home-composted biowaste.

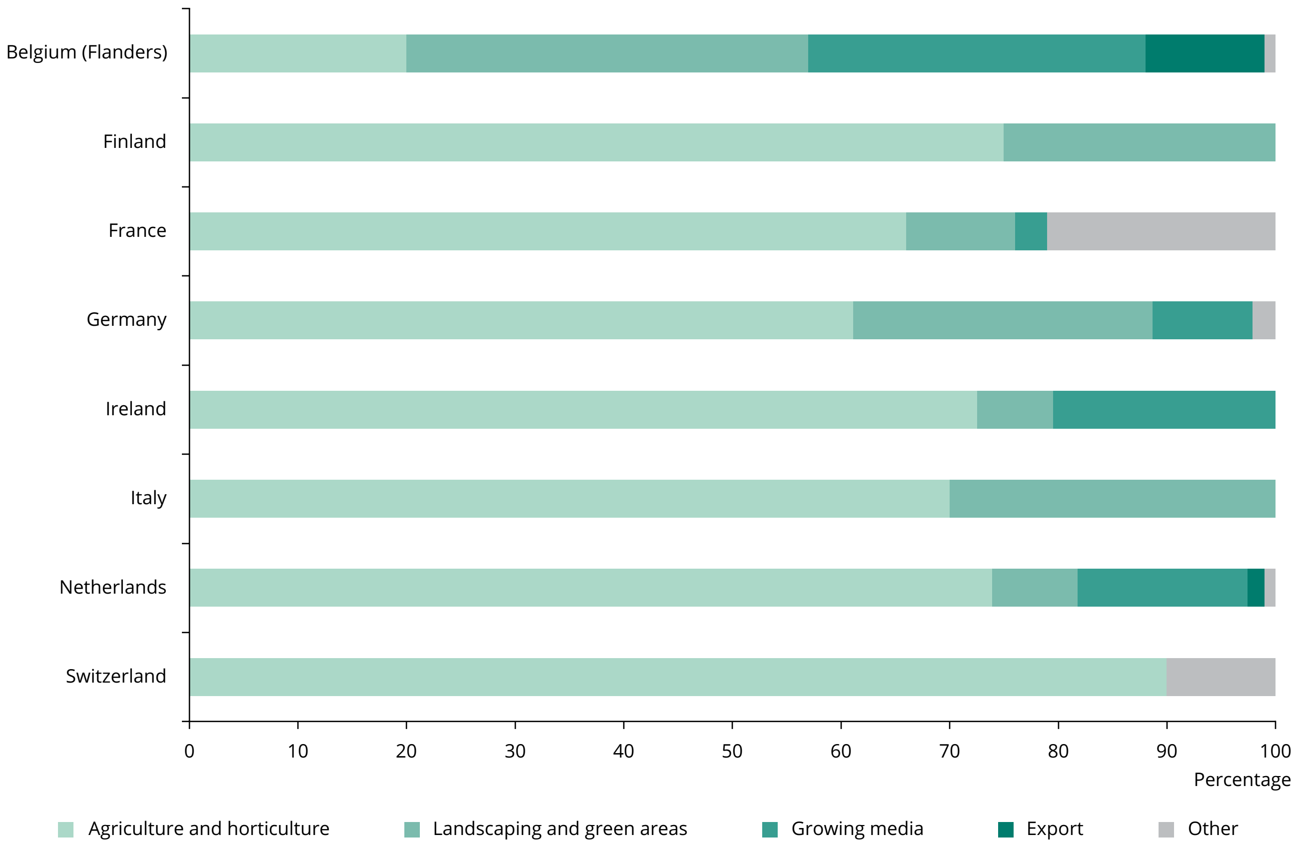
EU legislation requires municipal biowaste to be separately collected by the end of 2023, as this is a prerequisite for recycling. By the end of 2024, the Commission is to consider setting recycling targets for municipal biowaste. Moreover, according to the WFD, the share of municipal waste prepared for reuse and recycling, including biowaste, should be increased to a minimum of 55% of the total by weight by 2025.

The most common treatment methods for separately-collected biowaste are composting and anaerobic digestion. The resulting solid end products are compost (which can be used as fertiliser), soil improvers, and growing media constituents or digestate (which can be used as organic fertiliser or a soil improver). Anaerobic digestion also produces biofuel, which is outside the scope of this report. In addition to these treatment methods, however, various emerging technologies aim to valorise biowaste as a source for products or for energy recovery.

Figure 2.2 shows the different market sectors for compost from municipal biowaste for those countries and regions that have quantified information. Agriculture and horticulture seem to be the main markets, and this is also assumed to be the case in countries that do not have quantified market data.

The EU Fertilising Products Regulation (EU, 2019b) is intended to create a policy framework to encourage the use of organic fertilisers and soil improvers. This would decrease the EU's dependency on mineral fertiliser imports and contribute to a circular economy for nutrients. The regulation envisages harmonised rules for putting soil improvers, fertilisers and growing media on the EU market. Currently, some EU Member States have developed compost quality management schemes and certifications to enhance the market for recovered biowaste. Secondary fertilisers and soil improvers are not similar in quality to mineral fertilisers. Moreover, the market is very local, with short transport distances because of the product volume.

Figure 2.2 Market for compost from biowaste for selected countries/regions, 2018



Source: EEA (2020).

([3]) Calculated as the sum of waste codes W091, W092 and W093.

Is the compost market well-functioning?

The market for secondary fertilisers and soil improvers does not fit the criteria to be a well-functioning market (Table 2.8). Compost fulfils only one criterion (as defined in Section 2.1; see Table 2.1), related to quality management and standardisation.

Table 2.8 Assessment of the secondary compost market

Criterion	Application
Market size and growth	
1. High shares of supply and demand with respect to total market size	No. Low demand, due to poor quality of biowaste.
2. Enough stable or increasing supply and demand	No. Low demand.
3. Open international trade and high tradability	No. Local markets exist in some countries, but there is a lack of international trade or organised trading.
4. High industrial capacity based on secondary material inputs	Partly. Assessing the treatment capacity for municipal biowaste in Europe is difficult, as only a limited number of countries have data available on their installed and planned treatment capacity for this waste fraction.
Role of policy drivers in market development	
5. Non-policy-driven supply and demand	No. WFD sets requirements for separate collection.
6. Included in compliance schemes or EPR schemes	Not relevant.
7. No competition from energy use	Partly. Source-separated biowaste is rarely incinerated.
Prices	
8. Reference international or national prices	No.
9. 'Organised markets' for trading (e.g. futures)	No. Lack of organised and/or international markets and trade.
10. Sufficient information available to both demand and supply actors	No. No information available.
Technical specifications and barriers	
11. Product specifications are standardised	Yes. The European Compost Network Quality Assurance Scheme (ECN-QAS) is a standardised quality management system for compost and digestate products.
12. No regulatory barriers to using SRMs as inputs in manufacturing	No information available.
Overall result	**Not well-functioning**

2.2.7 Construction and demolition waste (mineral fraction)

Market characteristics

Construction and demolition (C&D) waste consists of numerous materials that can be recycled. However, the economically most valuable fractions (e.g. metals, plastics and glass) represent only a small percentage of all C&D waste (EC, 2018a). Aggregates can be produced from the mineral fraction of C&D waste; these are used in a range of product categories, such as bricks, floor and roof tiles, ceramics and concrete. In 2018, this mineral fraction of C&D waste amounted to nearly 300 million tonnes in the EU-27.

At the EU-27 level, 207 million tonnes of C&D waste were reported as recycled in 2018. However, recycling is largely based on low-grade recovery and use in, for example, road sub-bases (ETC/WMGE, 2020). Other applications include sand production, ready-mix concrete, concrete blocks, cement, ceramics and bricks, and low-cost adsorbent for wastewater treatment (Reis et al., 2021). Fine particles from crushed concrete can be used as an SRM in clinker production. Several technologies for producing aggregates for different applications are available. Therefore, it is assumed that the current low recycling rate for this type of application has more to do with market challenges than technical difficulties (Embureau, 2022).

With respect to the quality of recyclates, the aggregates produced from C&D waste must comply in all Member States with (1) specific regulations for the use of waste aggregates with limits on total content and/or leaching of pollutants, and/or (2) national EoW criteria (Velzeboer and Zomeren, 2017). These regulations and criteria aim to limit the risk of hazardous substances potentially present in the waste fraction diffusing into the environment.

Crushed concrete waste from construction to replace virgin aggregate requires selective demolition and treatment.

The price of virgin aggregate varies in Europe, depending on the availability of crushed stone. It is also relatively low and stable compared with other minerals and metals. The price of crushed concrete depends on the quality. Transport costs also affect the final costs.

Supply continuity seems to be secure for the next many years, at least in volume. To improve the quality, more selective demolition and source separation of materials is key. The potential introduction of material passports that describe the characteristics of materials and components in building products is also crucial. Unfortunately, such actions will make demolition more costly and create administrative burdens — especially considering the long lifespan of materials in buildings and infrastructure. Because of the often-low material value and the high relative weight of C&D waste, the production and use of recycled aggregates will necessitate infrastructure that allows good-quality recycled materials to reach potential clients in a cost-efficient way.

It can be concluded that waste feedstock in the form of C&D waste suitable for producing recycled aggregates is available in huge volumes. Commercial applications for recycled aggregates have been developed; technologies to convert the waste feedstock into a recycled aggregate are mature; and measurable quality criteria and quantitative pollutant limit values exist in the environmental regulations of all Member States. Therefore, it is theoretically possible to successfully produce secondary construction materials of a quality comparable to their primary equivalents.

Is the secondary aggregates market well-functioning?

There is a market for aggregates derived from C&D waste in roads, drainage and other construction projects. But the recycling potential of such waste is still under-used and varies among Member States. The market for aggregate from C&D waste generally does not meet the criteria to be well-functioning (Table 2.9).

Table 2.9 Assessment of the secondary aggregates market

Criterion	Application
Market size and growth	
1. High share of supply and demand with respect to total market size	Partly. High supply, but varying demand in the EU.
2. Enough stable or increasing supply and demand	Partly. High supply. Demand depends on quality and availability of virgin aggregate.
3. Open international trade and high tradability	No. Local market only due to transport costs, heavy weight and low price.
4. High industrial capacity based on secondary material inputs	Partly. Assessing the treatment capacity in Europe is difficult, as only a limited number of countries have data available on their installed and planned treatment capacity for this waste.
Role of policy drivers in market development	
5. Non-policy-driven supply and demand	No. WFD sets requirements for separate collection on site and targets for recycling of construction waste.
6. Included in compliance schemes for packaging waste or EPR schemes	Not relevant.
7. No competition from energy use	Not relevant.
Prices	
8. Reference international or national prices	No. Only local markets exist.
9. 'Organised markets' for trading (e.g. futures)	No. Lack of organised and/or international markets and trade.
10. Sufficient information available to both demand and supply actors	No. No information available.
Technical specifications and barriers	
11. Product specifications are standardised	Yes. Standards for quality developed.
12. No regulatory barriers to using SRMs as inputs in manufacturing	Partly. Unclear rules in regulation (or case-specific permits) hampers professional use of C&D waste as aggregate.
Overall result	**Not well-functioning**

2.2.8 Textiles

Market characteristics

This section refers to textile waste (where waste is defined as in the EU's Waste Framework Directive). This means that we only look at secondary value chains receiving separately collected waste material. Directly reused textiles, such as through charity organisations, are not part of this section's scope.

Average textile consumption per person amounted to 6.0kg of clothing, 6.1kg of household textiles and 2.7kg of shoes in 2020. Textiles generate significant amounts of waste. At the end of their life, textiles often end up in general waste and are incinerated or landfilled. When textile waste is collected separately, it is sorted and reused, recycled or disposed of, depending on the quality and material composition (EEA, 2022). In 2018, the EU-27 produced 2.17 million tonnes of textile waste (Eurostat, 2021a). European legislation requires textiles to be separately collected by 2025, as this is a prerequisite for recycling or reuse. By the end of 2024, the Commission is to consider setting reuse and recycling targets for municipal textile waste. Separately-collected textile waste today is a mixture of reusable and non-reusable textiles. Reusable clothes are sold mainly to foreign markets, where they are either sold or end up as waste in landfill. Non-reusable textile waste is often downcycled (e.g. as rags, upholstery filling or insulation) or is incinerated. Approximately 1% of textile waste is recycled into new clothes, as technologies for recycling clothes into virgin fibres are only starting to emerge (EEA, 2019).

Due to many technical challenges in fibre separation and fibre quality, little textile-to-textile recycling currently takes place. Two technology families can be distinguished — mechanical recycling and chemical recycling — and both face limitations and barriers. Chemical recycling causes environmental impacts due to the energy it requires and chemicals it uses. The major barriers to high-quality textile recycling include the diverse mix of materials — such as coatings, dyes and non-textile objects — and the mixing of different types of fibres. EU Member States mainly import textile waste originating from other Member States. Importing textile waste from non-EU-countries is rare. However, considerable amounts of textile waste are exported to non-EU countries. Of all textile waste generated domestically (in the EU-27), 53% is currently exported to non-EU countries, and 32% is exported to other Member States. This implies that the market for textile waste is rather significant and open.

Is the textile secondary market well-functioning?

The market for textile waste does not meet the criteria to be a well-functioning market (Table 2.10). Textile waste fulfils only the criteria related to international trade (as defined in Section 2.1; see Table 2.1) and to competition with energy use. Textiles score poorly on criteria related to quantities, such as the share of SRM with respect to total market size; the industrial capacity for producing SRM; the stability of supply and demand; and the presence of compliance schemes, such as EPR schemes.

Regarding the criteria related to the maturity of SRM markets (market size and material quality), textile waste is traded as an SRM for downcycling activities. Only a very small volume of textile waste is recycled into new textiles and enters the market for new products. However, trading textile waste among EU Member States is a rather stable activity, with significant volumes exported from the EU.

Table 2.10 Assessment of the secondary textile market

Criterion	Application
Market size and growth	
1. High share of supply and demand with respect to total market size	No. Low demand and downcycling of textile waste to other applications because of the poor quality of the textile waste collected.
2. Enough stable or increasing supply and demand	No. Low demand.
3. Open international trade and high tradability	Yes. Significant trade internationally.
4. High industrial capacity based on secondary material inputs	No. Limited textile-to-textile recycling.

Table 2.10 Assessment of the secondary textile market (cont.)

Criterion	Application
Role of policy drivers in market development	
5. Non-policy-driven supply and demand	No. WFD includes an obligation for Member States to collect textiles separately by 1 January 2025. Planned introduction of EU reuse/recycling targets.
6. Included in compliance schemes for packaging waste or EPR schemes	Partly. Only a few EU Member States have EPR schemes in place, but their introduction is planned at the EU level.
7. No competition from energy use	No. Significant share directed to energy recovery even after separate collection.
Prices	
8. Reference international or national prices	No.
9. 'Organised markets' for trading (e.g. futures)	No. Lack of organised and/or international markets and trade.
10. Sufficient information available to both demand and supply actors	No. No information available.
Technical specifications and barriers	
11. Product specifications are standardised	No. No common European product standards for textiles are set. But there are a few labels such as the EU Ecolabel and OEKO-TEX.
12. No regulatory barriers to using SRMs as inputs in manufacturing	No information available.
Overall result	**Not well-functioning**

2.3 Characteristics of well- and less well-functioning SRM markets

The framework presented in this report for assessing how SRM markets function is largely based on expert judgement. It is not possible, nor desirable, to develop rigid thresholds for the criteria in the framework. This is because the criteria are qualitative in nature and there is a lack of quantitative information and data. Moreover, the framework was applied to aggregated markets that might include well- and less well-functioning sub-markets (e.g. the plastics market is not well-functioning overall, but the sub-market for recycled PET is well-functioning). However, applying the analytical framework to eight SRM markets enables an overview of the key requirements needed for an SRM market to be assessed as well-functioning.

Table 2.11 summarises the framework criteria rating, as applied to the eight SRM markets. The green, yellow and red shading indicate, respectively, fulfilment, partial fulfilment and no fulfilment of the criterion.

The three markets assessed as well-functioning (aluminium, paper and cardboard, and glass) — as they fulfil almost all the criteria (green rating) — have been established for a long time. These markets already take up a significant market share of their respective commodity markets and are less dependent on the policy framework in place to regulate material supply. The SRMs are traded at competitive prices that reflect the cost of producing SRMs from waste. Technical specifications and standards for SRMs exist at either EU or national level, although EoW criteria are less well-developed and widespread overall.

However, the markets that are not functioning well (mainly plastics, biowaste, aggregates from C&D waste and textiles) also have common characteristics. These markets have an unstable supply of raw materials and their size is small compared with their primary market alternatives. The demand for these SRMs is weak, despite high and increasing levels of supply; prices do not reflect the balance between demand and supply; technical standardisation is weak; and there are regulatory barriers to using SRMs. These markets rely on policies to develop both supply (e.g. through waste recycling targets) and demand (e.g. through recycled content requirements). SRM markets producing low-cost recycled materials, such as compost or recycled aggregates, are difficult to expand on a large scale. This is because the transport cost cannot be recovered through the price at which the SRM is traded.

Overall, **the market size** and **material quality** (from the industrial use point of view) are the two dynamically-interconnected factors that dominate the emergence of a well-functioning SRM market.

2.3.1 What is relevant for decision-makers?

When it comes to SRM markets, policy instruments have traditionally focused on the market **'push'** by ensuring enough SRM supply through separate recyclable collection, recycling targets and other tools such as EPR schemes. This push element is the single most important factor for having established SRM markets for a number of materials (plastics, textiles, recycled aggregates from C&D waste, biowaste). On the other hand, materials such as metals — due to the technical characteristics reflected in their competitive prices — have long-established SRM markets, even without the policy push.

For both groups of SRM markets, however, policy measures in place to support the **'pull'** side of the market (i.e. the demand for SRMs) are weaker (the most relevant example being the requirements on recycled content). Looking at Table 2.1, it is easy to distinguish where policy interventions can make a difference:

- Regarding **market size and growth** (criteria 1-4), existing markets operate in somewhat favourable conditions. Policies may focus on the international dimension of the existing markets by removing barriers to trading recycled materials across borders and by promoting the development of adequate industrial capacity for processing them. This is especially true for waste materials that have a treatment process separate from that of their primary material processing alternative (e.g. biowaste).

- The **role of existing policies** is already strong in promoting market development (criteria 5-7). However, further efforts may well be needed; for instance, to address competition with energy recovery (only for relevant materials). Besides, the extension of EPR schemes to new materials (e.g. textiles) can help develop markets further.

- Applying the criteria on **pricing** (criteria 8-10) to the eight SRM markets shows that there is a lot of room for improvement across all the recyclables investigated. Market coordination and standardisation through dedicated steering institutions is needed, as are efforts to account for externalities when comparing prices of secondary and primary resources. On the other hand, the flow and openness of information should be reinforced so that all market stakeholders have access to the (currently limited) data that is necessary for making the right decisions.

- To address stakeholder insecurity over the performance of SRMs, **technical specifications and standards** (criteria 11-12) need to be developed for all SRMs. In general, the SRM production process should focus on the objective for SRMs; namely, to adequately substitute primary materials and to operate in manner similar to their primary material alternatives.

Table 2.11 Assessment of functioning of selected SRMs

	Aluminium	Paper	Wood	Glass	Plastics	Biowaste	C&D	Textiles
Market size and growth								
1. High share of supply and demand with respect to total market size	🟢	🟢	🔴	🟢	🟠	🔴	🟠	🔴
2. Enough stable or increasing supply and demand	🟢	🟢	🔴	🟢	🟠	🔴	🟠	🔴
3. Open international trade and high tradability	🟢	🟢	🔴	🟠	🟢	🔴	🔴	🟢
4. High industrial capacity based on secondary material inputs	🟢	🟢	🟠	🟢	🟠	🟠	🟠	🔴
Role of policy drivers in market development								
5. Non-policy-driven supply and demand	🟠	🟠	🔴	🟠	🔴	🔴	🔴	🔴
6. Included in compliance schemes for packaging waste or EPR schemes	🟢	🟢	🟢	🟢	🟢	Not relevant	Not relevant	🟠
7. No competition from energy use	🟢	🟠	🔴	🟢	🟠	🟠	Not relevant	🟠
Prices								
8. Reference international or national prices	🟢	🟢	🔴	🟢	🟠	🔴	🔴	🔴
9. 'Organised markets' for trading (e.g. futures)	🟢	🟢	🔴	🟢	🟠	🔴	🔴	🔴
10. Sufficient information available to both demand and supply actors	🟢	🟢	🔴	🟢	🔴	🔴	🔴	🔴
Technical specifications and barriers								
11. Product specifications are standardised	🟢	🟢	🔴	🟢	🟠	🟢	🟢	🔴
12. No regulatory barriers to using SRMs as inputs in manufacturing	🟢	🟢	🟢	🟢	🔴	No information	🟠	No information
Overall result	✓	✓	✗	✓	✗	✗	✗	✗

Note: 🟢 = Criterion verified; 🟠 = Criterion partly verified; 🔴 = Criterion not verified;
✓ Well-functioning; ✗ Not well-functioning.

Source: Authors' compilation.

3
Barriers to market development across the SRM value chain

A well-functioning secondary raw material (SRM) market is crucial for achieving circular economy objectives such as recirculating materials and maintaining the value of materials, even after they have been discarded as waste. A well-functioning market will deliver good-quality secondary materials to the right processes for closing material loops — avoiding the environmental, climate, socio-economic and supply security issues related to sourcing primary raw materials as a result. Such a market will send the right signals to both the supply side (incentives to improve the waste sorting and recyclable quality) and the demand side (steady supply of standardised, good-quality secondary materials delivered to manufacturers).

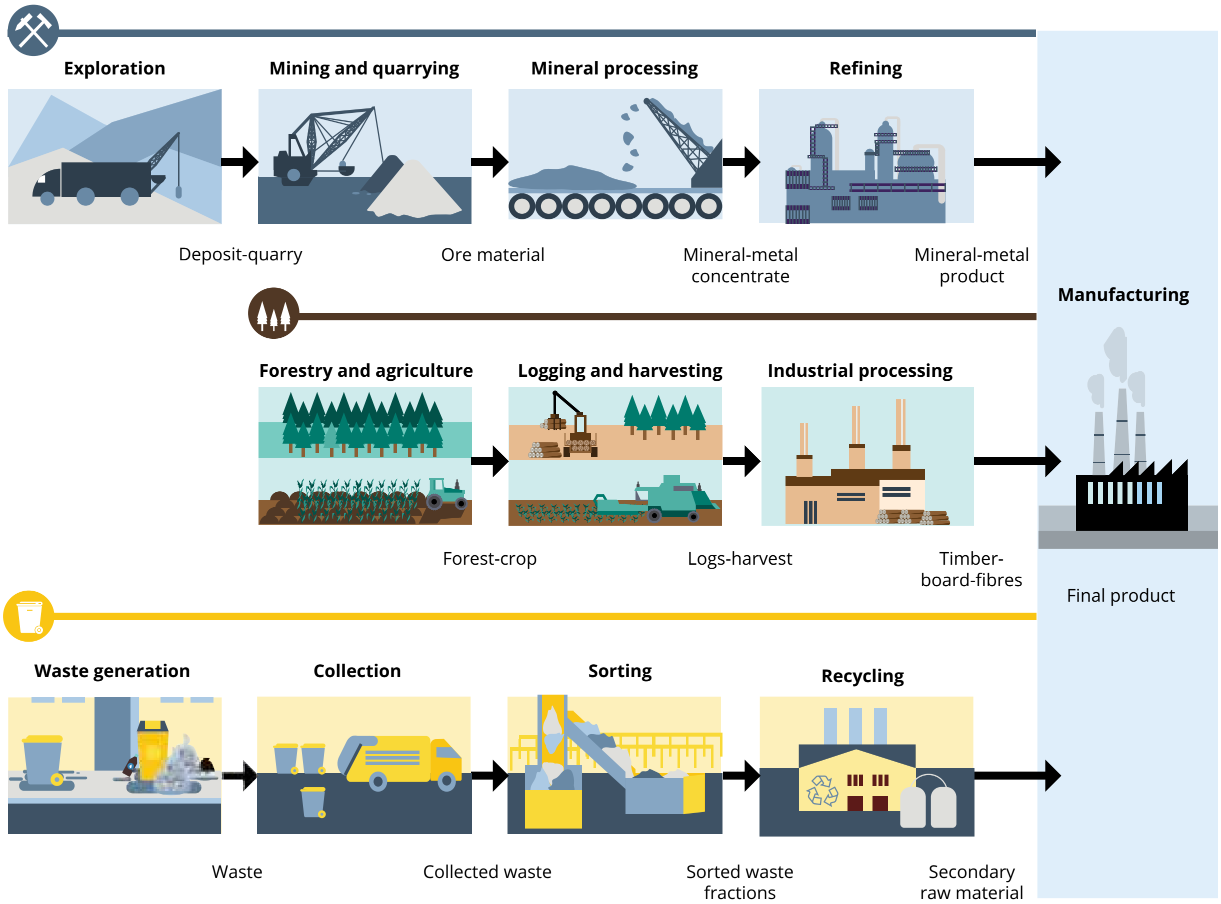
However, for SRM markets to achieve this potential, challenges specific to SRM markets need to be addressed. Contrary to primary commodity markets, SRM markets present challenges relating to the **quality** and **quantity** of the raw material. In this section, we present an overview of SRM market challenges, taking the perspective of the SRM 'value chain'. The value chain approach is an integrated perspective that points to the mutual interdependence between phases, even if each one is generally performed by different actors from different industrial environments (See Box 3.1).

Box 3.1 The SRM value chain

From a manufacturer's perspective, the source of the raw materials, i.e. the natural environment or waste, does not matter in principle. Given sufficient availability, purchasing decisions will be taken mainly or exclusively based on the raw material cost and the quality or technical properties of the material. If the SRM market — delivers cost-competitive and technically adequate SRMs, these will be taken up new product manufacturing.

Having that in mind, the sum of the SRM production processes can be seen as a value chain. Figure 3.1 shows both the primary and secondary material production processes that supply minerals, metals and biomass to manufacturing industries. At the point in a production process where recycled content is added to a primary feedstock, the two processing routes converge.

Figure 3.1 Primary and secondary material production processes



Source: Authors' compilation.

The SRM value chain includes waste generators (households, institutions and industries), waste collectors, and discarded product dismantlers, sorters, recyclers and traders. These actors are typically involved in one or more activity within the SRM value chain. All these activities have a cost. In compliance with waste regulations, and to ensure environmentally- and societally-sound waste management, part of these costs will be borne by local or national governments. Another part might be covered by producers; for example, through extended producer responsibility schemes.

As in a 'conventional' value chain, the generic rule — applicable to each individual process step — is that the worse the quality of the feedstock supplied, the lower the yield of the process and the higher the cost of production of a high-grade output.

There is a main difference between primary and secondary material production processes. In the first case, purchasers can be highly selective in choosing their feedstock qualities. In the second, the choices with respect to waste-based feedstock are restricted by the compositions and volumes of the wastes generated and collected. The quality of the waste-based feedstock is thus dependent on the typical drivers of waste management policies, such as legally-binding, weight-based collection and recycling targets, or environmental and societal concerns. In contrast, both the qualities and volumes of the raw material feedstock obtained from mining, extraction or harvesting will be mostly, if not entirely, determined by the purchaser's needs.

3.1 Challenges across the value chain

3.1.1 Method for assessing barriers

Challenges for and barriers to developing SRM markets are investigated through a value chain approach (see Figure 3.2). This includes two material cycle stages that are not part of the waste value chain but critically influence its functioning, namely:

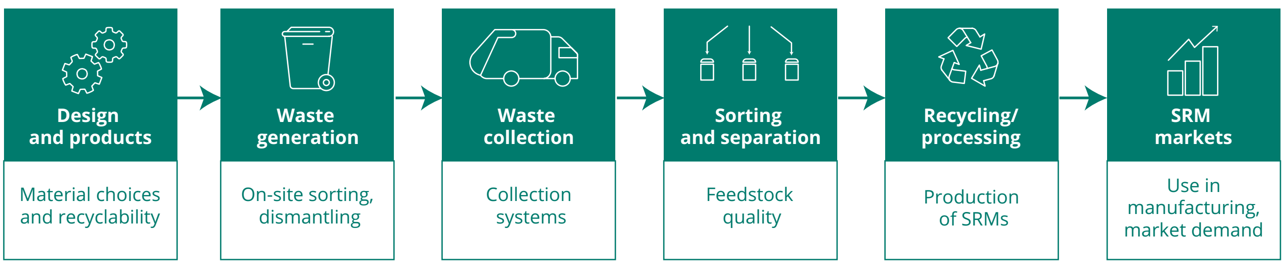
- Product design and manufacture: post-consumer waste consists of a mix of discarded end-of-use products, which themselves are built from a variety of diverse materials. The recovery of separate materials from the end-of-use products by recycling can be facilitated through the design of the product.
- Final demand: the supply of secondary raw materials, in quantities and of qualities that enable their use in manufacturing industries, will be realised only if there is sustained and sufficient demand for manufacturers' products that have recycled content in their parts and materials.

The types of barriers to be identified are grouped and further specified in terms of their different types and sources:

1. Regulatory: while environmental and waste policies are generally a critical factor for some SRM markets taking off and a permanent condition for their growth even in mature markets (see Chapter 2), these markets are subject to many specific regulations and rules, including some of a non-environmental nature. Some of them can hinder market development at some stage of the value chain. We also consider the **lack** or **weak application** of a regulation a barrier to SRM market development.
2. Technical (including the quality of SRMs): the lack of availability of, or lack of access to, appropriate technologies at different points (from waste collection to waste recycling, up to the use of SRMs in manufacturing applications) can hinder the working of SRM markets. In particular, the lack of appropriate quality performance checks in different phases of the value chain (waste collection, traceability of contaminants, standardisation of SRMs, etc.) can deliver materials that cannot be competitive with primary materials, for reasons of technical substitutability or cost.
3. Industrial capacity-related (and investment needs): in many new and emerging markets, although the supply of waste for recycling and the availability of SRMs have been boosted by policies, there may be significant shortages of processing capacity at some points of the chain. For example, the lack of recycling capacity for many plastics makes it difficult to manage large amounts of plastic waste arising from separate collection at the end user point. Various SRMs still suffers from a lack of this production capacity.
4. Economic (prices, costs, information, etc.): as suggested by the analysis in Chapter 2, some SRMs are not-competitive in term of costs compared to primary materials. This can happen even in the case of waste traded at negative prices, because the hindering factors described above at points (1), (2) and (3) can increase the costs for industrial users. In other cases, these markets are far from having full information available for all market actors. Information can be a critical barrier to developing competitive SRM markets, even when both demand and good-quality supply exist.
5. Competition from energy uses of the same waste feedstock: in some SRM markets, especially those linked to the bioeconomy, there can be strong pressures from demand for waste as energy feedstocks. This remains the case even if it violates the waste hierarchy and material recycling would be more economically valuable (e.g. green chemistry).

This analytical structure is used in the following sections to look at the same SRM markets examined in Chapter 2. The objective is to highlight the relevance of different types of barriers, and specific barriers, for different phases of the SRM value chain.

Figure 3.2 Value chain for secondary raw materials production



3.2 Barriers by phase of the value chain

3.2.1 Barriers specific to products and design

The design and manufacture of products defines the potential material uptake ('recyclability') at the end of their life, allowing the materials either to enter the SRM market through waste management and recycling processes or to be discarded after use. Thus, the design and production phase of the value chain determines the availability and quality of materials, the processing needs (cost) of an SRM feedstock, and the potential yield and quality of the recyclates entering the SRM value chain (Figure 3.3). Design and manufacture can also be very important for products using SRMs as inputs to optimise the SRMs' performances.

Regulatory barriers

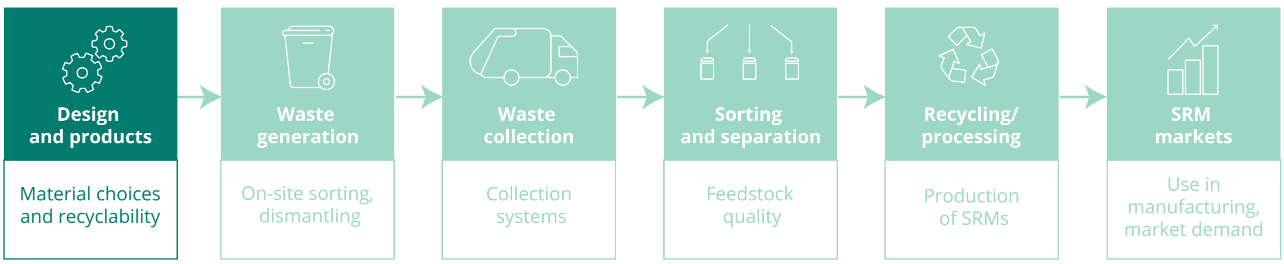
Regulatory tools to promote recyclability can enhance the quality and quantity of the waste generated, which would further increase the quality and volumes of the SRMs produced. Regulatory tools in place today do not always adequately support eco-design and, in particular, the optimisation of the end-of-life system (e.g. design for disassembly and recycling; OECD, 2016). Therefore, they also represent a significant barrier to the functioning of secondary markets (see Chapter 2). For instance, about 30% by weight of plastic packaging worldwide is destined, by its design, to landfilling, incineration or energy recovery after a short single use (Ellen MacArthur Foundation, 2017). Small-format, multi-material and uncommon types of plastic packaging are especially challenging to sort and treat.

The extended producer responsibility (EPR) scheme is a tool to enhance recycling of specific products and is mandatory for, for example, vehicles and electrical and electronic equipment (EU, 2000, 2012b). For packaging, EPR schemes will become mandatory as of 2024 (even if most Member States already have EPR schemes in place) and, for certain single-use plastic products, EPR schemes will have to be applied in 2023-2024 (EU, 2019a). The current EPR schemes, however, have no binding requirements regarding eco-design and recyclability. According to the amended Waste Framework Directive (EU, 2008, 2018), the eco-modulation of fees (based on certain product criteria, such as recyclability and material choices) is not mandatory. Most producer responsibility organisations collect fees based on product volumes put on the market without eco-modulation, which provides weak incentives for producers to adopt eco-design (Bio by Deloitte, 2014; Massarutto, 2014; Walls, 2006). Moreover, for some products (e.g. construction products with a long lifespan or containing parts from several manufacturers), EPR schemes are not applicable.

Apart from EPR schemes, there is a general lack of concrete and enforceable product requirements related to design for recycling (recyclability, disassembly and other key concepts are poorly defined by the EU legislation). The Packaging and Packaging Waste Directive (EU, 1994), for example, establishes the essential requirements to be met by all the packaging placed on the EU market, which have been translated into EN standards (including the standard for packaging recoverable by material recycling). According to a report by Euromia et al. (2020), these requirements are vague and the harmonised standards do not provide the added degree of clarity needed. This means that they are difficult to enforce, do not sufficiently operationalise the concept of recyclability and do not necessarily account for the range of packaging types that are now on the market.

Against this background, such regulatory barriers are significant hurdles for SRM markets because they tend to decrease the quality of recycled materials.

Figure 3.3 The design and product manufacture phase of the value chain determines the quality and quantity of feedstock for recycling



Economic barriers

Economic incentives to promote the use of waste-derived materials as feedstock in new products would enhance the quality and quantity of the waste generated. This would enable larger volumes, better quality and a more stable supply of SRMs for market uptake.

A study on plastic packaging estimated that around one third of all packaging solutions will not allow **economically** viable recycling (BKV and GVM, 2020) after the end of their life, because introducing recyclability in design and production can be hindered by economic considerations. In many cases producers and sellers are reluctant to invest in improved product design because of a variant of the investor-user dilemma. This describes the situation in which the investor will not achieve a financial return on their investment, as it is the user who benefits from the investment. This is often seen in investments in the energy efficiency of buildings (Schleich and Gruber, 2008): the landlord will not invest in energy efficiency if the investment costs cannot be passed on to the tenant, as the latter will benefit from the investment through lower energy costs. Similarly, packaging producers do not invest in recyclability because the resulting benefits for the recycling process will not be passed on to them but will just increase the benefits for the recycler. Because of this dilemma, products are not sufficiently designed in ways that would allow the recovery of secondary materials to be cost-efficient.

Investments in the recyclability of products often face another economic barrier because they do not increase consumers' willingness to pay. Especially in the business-to-consumer sector, consumers are unable to properly assess the recyclability of specific products and will not take such characteristics into account in their purchasing decisions.

3.2.2 Barriers specific to waste generation and collection

Waste is generated at the end of a product's life. Whether it is collected in a mixed material scheme or sorted at site for a separate collection system will have a significant impact on the production of SRMs and their market value (Figure 3.4). Although there are systems for sorting mixed waste fractions, the quality of the output from mechanical sorting plants is not considered to be as high as that from separately-collected waste streams. Thus, like design for recycling, the collection phase of the value chain will affect the quantities and qualities of SRMs put on the market.

Regulatory barriers

The collection of waste for recycling is supported by EPR schemes (when applied), along with collection and recycling targets and obligations set out in EU legislation. Current recycling targets are volume-based, do not focus on the quality of the waste collected and do not distinguish between materials (except for packaging).

The lack of collection obligations and/or EPR schemes for some waste streams, as well as the lack of quality-focused recycling regulation, negatively affect the continuity of the supply. This is a significant barrier to the development of SRM markets for some materials (Nordic Council of Ministers, 2018a). In these cases, the demand for SRMs is low, as manufacturers fear that they will not meet their need for a reliable, high-volume supply of materials of consistent quality. Some studies also identify the lack of landfill bans on selected recyclable materials (e.g. aluminium, certain construction and demolition (C&D) waste such as glass waste) as a barrier to their collection (European Aluminium, 2020; Heuts, 2020; Williams, 2020).

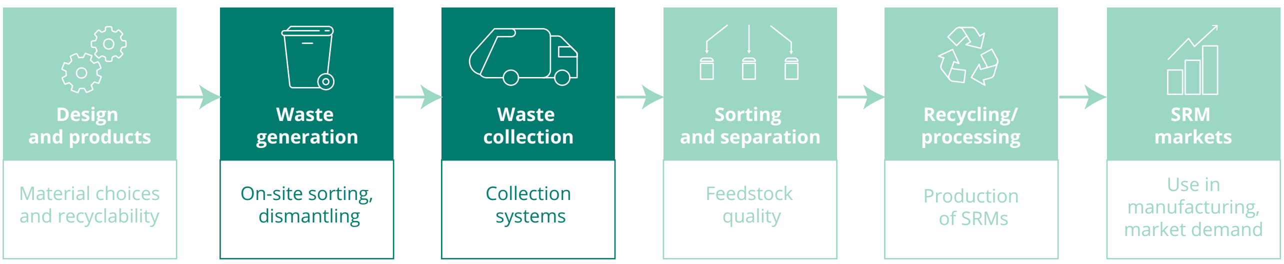
Economic barriers

The collection of waste normally accounts for the largest share of costs related to the production of SRMs. The often widely geographically-dispersed sources of waste lead to significant economic disadvantages compared to primary raw materials.

Technical barriers

SRM quality is highly dependent on the collection system. The quality of the collected waste is influenced by the presence of contaminants or foreign substances. The more homogeneous the waste, the easier it is for the waste material to maintain its technical properties during its second life, after it is recycled. This is the case for PET (polyethylene terephthalate), where the technical quality of recycled PET (rPET) that can be achieved at the end of the secondary PET production process is defined during the first step of the process, i.e. waste collection (see Box 3.2).

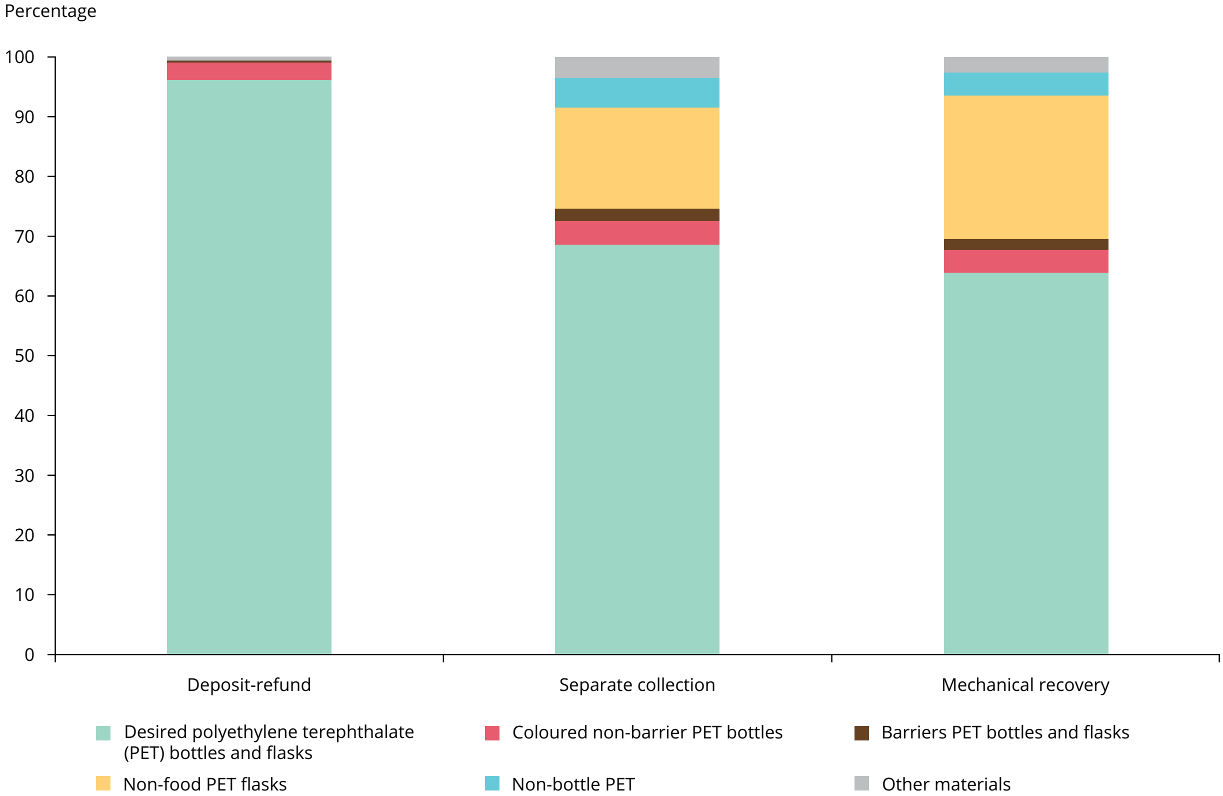
Figure 3.4 The waste generation and collection phase of the value chain determines the fate and recyclability of the waste, the quality of the SRM and the continuity of supply



Box 3.2 PET sorting and SRM quality

While sorted and cleaned PET (polyethylene terephthalate) bottles from automated deposit refund systems might contain nearly 100% PET, bottles obtained from the sorting of mixed, residual household waste will still contain over 30% of foreign materials and contaminants (Figure 3.5).

Figure 3.5 PET quality depends on the collection system



Note: PE, polyethylene; PP, polypropylene; PS, polystyrene; PVC, polyvinyl chloride.

Source: Thoden van Velzen et al. (2016).

When the sorted and cleaned bottles are further processed into food-grade PET pellets, the presence of contaminants will affect the visual and technical characteristics of bottles with recycled content, as well as the maximum achievable recycled content levels (Alvarado Chacon et al., 2020).

For other waste materials, such as recycled aggregates produced from C&D waste, the waste collection system directly affects the technical properties of the SRMs produced. When collecting C&D waste on site, mixing different materials or material qualities should be avoided. The fewer impurities and unwanted substances present in the material fractions obtained from selected demolition, the greater the potential to reuse the material as recycled content and the higher the share of recycled content in the final manufactured product. Similarly, recycled aggregates produced from different types of inert material present in C&D waste (bricks, mortar, ceramics, concrete and asphalt) collected as mixed waste can be used for backfilling or landscaping. (However, they often cannot be used in ready mix concrete, where the performance standards for the SRMs are higher). Selective demolition that leads to separate collection of concrete waste can supply the SRM market with recycled concrete that has higher performance standards and can fetch a higher price.

These examples suggest that the configuration of the waste collection system is directly linked to the properties of the SRMs produced after recycling and to the price of SRMs.

3.2.3 Barriers specific to recycling

Recycling is the process of converting a unit of waste into an SRM. This process is material-specific, but in general, the key stages include sorting processes and recycling processes (Figure 3.6). In sorting, the targeted materials are separated from other materials, aiming to generate a mono-material feedstock for the recycling process. The recycling process then changes the form of the waste into an SRM that can be used to manufacture new products. The separation and recycling phase will directly affect the quantities and qualities of SRMs put on the market. The output from the recycling process determines the market supply of SRMs.

Regulatory barriers

A key regulatory barrier to SRM supply is the lack of end-of-waste (EoW) criteria for most SRMs at EU level, which often results in different national classifications. The legal uncertainty over waste status may affect the investment decisions of both producers and users of recycled materials. At the same time, unharmonised national classifications can create some administrative and economic burdens, especially related to storage and shipment. This type of barrier is reported for plastic, flat glass, certain metals and C&D waste (Technopolis, 2016; Williams, 2020; zu Castell-Rüdenhausen et al., 2021).

The lack or inadequacy of standards for recycled materials is also identified as a relevant barrier to the development of SRM markets (affecting both the supply and the demand of recycled materials). For instance, in the construction sector, metal, wooden and concrete structural elements are not covered by standards suitable for recyclates (ETC/WMGE, 2020). Moreover, a need for quality standards for both inputs to recycling and recyclates has also been reported in the plastic sector (EC, 2018b).

Lastly, unclear, complex or incomplete legislative frameworks may hinder recycling activities and investments. For instance, the regulatory framework affecting plastics is not clear regarding the interface between chemicals, waste and product policy (EC, 2018b); under the Single-Use Plastic Directive (EU, 2019a), bioplastics are regulated in the same way as plastics made from fossil fuels because there is no legislative framework defining the former. This kind of barrier is particularly perceived as a problem by smaller companies for which the amounts are too small to justify the cost of employing experts to clarify the regulation (Nordic Council of Ministers, 2018b).

Technical and quality barriers

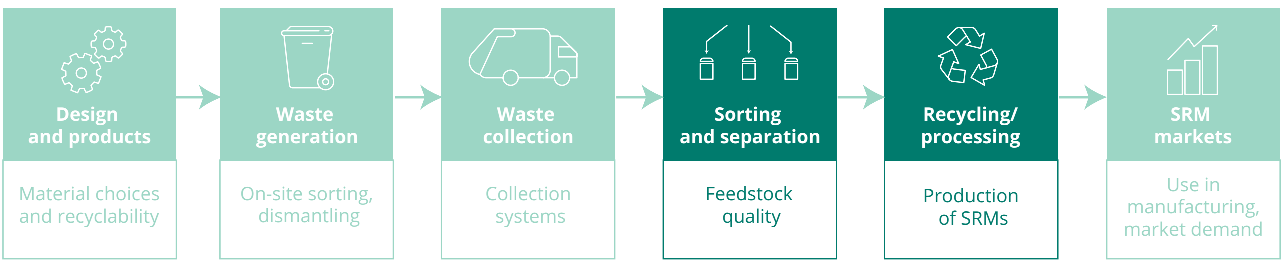
The failure to produce an SRM for which the quality or grade can be verified and guaranteed will reduce its possible applications and thus its economic value. Since one of the main objectives of the circular economy is to preserve the value of materials, the actual economic value of SRMs put on the market is a very relevant parameter. The economic value of an SRM is closely linked to the number and nature of recovered or retained functionalities i.e. its mechanical, physical and chemical properties. For this reason, mono-grade scrap steel compliant with the EU EoW criteria (EU, 2011) will be sold at higher prices than scrap mixes containing a diversity of grades and alloys. Similar price differences apply to plastics (e.g. mixed plastics or transparent PET), glass (e.g. flat glass and coloured packaging glass) and any other material designed for a specific performance.

The potential risks of the presence of hazardous substances (e.g. flame-retardants containing persistent organic pollutants in electronic waste) require costly monitoring and sorting. These risks also entail costs for process control and management of rejects.

Internationally-accepted standards have the potential to resolve these issues and give feedback to recycling operators on how to produce homogeneous, predefined and stable-quality SRMs. Yet currently, the standardisation of SRMs (and similar standardisation and legal issues, such as technical specifications and EoW criteria) in Europe is incomplete (not many materials covered) and fragmented (different standards in different parts of Europe). The challenges in developing such standards are the variety of material qualities and grades collected as waste, and the wide spectrum of uses for SRMs.

Examples of existing quality standards, EoW criteria and user specifications for selected waste materials are provided in Annex 2.

Figure 3.6 The separation and recycling phase of the value chain affects the quantities and qualities of SRMs put on the market. The output from the recycling process determines the market supply of SRMs



Economic barriers and investment demands

Recycling technologies are typically divided into mechanical, chemical/thermal and biological types. In many cases, mechanical technologies have low investment needs, whereas chemical/thermal and biological methods require more investment in controlling the process conditions. However, mechanical recycling technologies are a solution for only certain waste streams (e.g. plastics with mainly one polymer and aggregates from selective demolition). The reason is that, in many cases, it is not possible to produce sufficient clean streams cost-effectively (with a low impurity content) using only mechanical treatment methods (See Box 3.3). Typically, in recycling, a combination of sorting and processing technologies is used. In all technologies, the need for identification, sorting and pre-treatment of feedstock before treatment may require considerable investment, especially in the case of automatic and digital solutions.

The high investment costs of new technologies and complex business models are mentioned by several sources (e.g. Masi et al., 2018; Grafström and Aasma, 2021) as one of the key barriers to introducing new technologies for recycling. Risks due to potential contingencies or doubts about future waste material availability can also be barriers for investment. Decisions on big investments are typically made at a corporate level. Decisions on investments that show clear economic benefits from reduced operational or waste disposal costs can be taken by local managers in companies. Local managers are generally not empowered to make decisions about big investments (Pajunen et al., 2012; Tsamis and Coyne, 2015).

In the short run, the start-up costs are high. For example, they involve the installation of new process units, retooling machines, relocating factories, building new distribution and logistics arrangements, and retraining staff. Furthermore, developing and later maintaining a quality assurance system for recycled material also incurs high costs. The following barriers result in high investment costs:

- the need for extensive pre-treatment;
- the complexity of the recycling technology that ensures SRMs can be used in manufacturing;
- the requirements for a large supply of feedstock (scale of process);
- the need for new skills.

Setting up a recycling scheme for products requires a critical mass and a guarantee of future supply to justify the investment and setting up of new technology/separation plants specific to the particular properties of the waste to be recycled. Thermal technologies in particular require a minimum feedstock for processing. This means that only a limited number of plants can be developed. Moreover, the legislative permits for new technologies may take a long time to be granted and require the installation of emission monitoring and safe treatments for process residuals.

Box 3.3 Barriers to investment in critical raw material recycling

Recycling critical raw materials from waste (e.g. electronic waste) requires considerable investment in complex processes, comprising high temperature treatment (e.g. pyrometallurgical) and/or several refining processes (e.g. hydrometallurgical) with many steps. Consequently, in Europe, only a limited number of companies can end process complex streams containing critical materials; often, high feedstock flows are needed to recover rather small amounts of valuable metals. The waste electrical and electronic equipment (WEEE) recycling industry is characterised by a pyramid structure, with a very small number of refiners (fewer than 10 in Europe), a larger number (hundreds or thousands) in the dismantling and pre-processing phases, and much larger numbers in the initial collection phase. At the moment, critical raw materials contained in WEEE are characterised by very high losses during collection, pre-processing (e.g. for magnesium) and actual recycling (absence of recycling processes at industrial scale for neodymium, for example). Moreover, there is still little profitability in recycling some materials (e.g. lithium). The increasing value of some very scarce metals, such as indium or tellurium, may eventually justify the investment in large-scale recovery and in the recycling of certain electronic items (e.g. touch screens or photovoltaic panels). The considerable attention given to electric vehicles and the willingness to install a competitive sustainable battery value chain in the EU have increased the interest in investing in recycling key critical raw materials for use in batteries (e.g. cobalt and lithium; Baxter et al., 2014; Tsamis and Coyne, 2015; Redlinger et al., 2015,; Godoy León et al., 2022; Matos et al., 2022).

Competition from energy recovery from waste

When it comes to energy recovery, the lower investment needed for waste incineration compared with recycling is a particularly relevant economic barrier for SRM markets. Incineration plants require large investments and depend on sufficient waste feedstock being available for decades while competing for waste feedstock with waste sorting facilities. Overcapacity in the waste incineration market — for example, in Sweden or Germany — have resulted in financial problems in the recycling sector (Wilts, 2016).

3.2.4 Barriers specific to SRM market demand

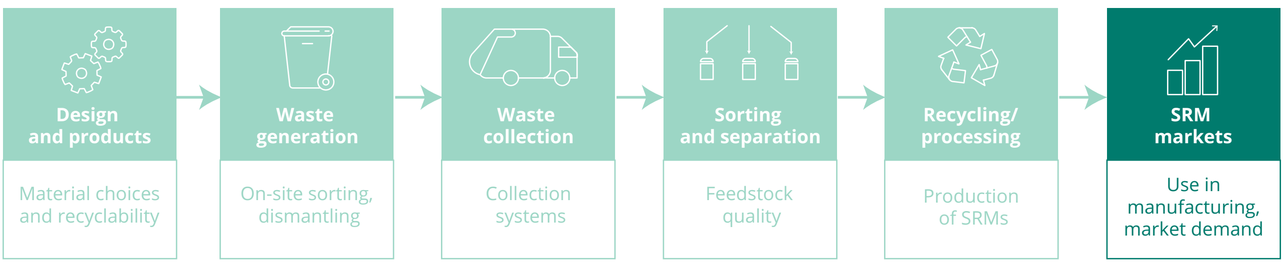
This section examines the potential barriers that may hinder the uptake of SRMs by their respective markets **after** the SRMs have been produced (see Figure 3.7). The barriers in question have to do with the markets' operation and characteristics and the market operators' perceptions.

Regulatory barriers

The share of the demand for many SRMs (such as biowaste, plastic, construction materials and textiles) with respect to total market size is low (Nordic Council of Ministers, 2018b). The regulatory tools that address the demand side of SRM markets more directly are mainly voluntary, with the most important being green public procurement (GPP) and the EU Ecolabel. By setting specific requirements (for example, for the content of SRMs in a product), GPP and Ecolabel criteria can help develop the market for recycled materials. However, evidence proving the effectiveness of GPP and the EU Ecolabel is currently scarce (EP, 2017; Kaufman et al., 2020).

Another regulatory aspect is that the supply of SRMs to commodity markets is not streamlined and warranties are infrequently given. SRMs need to fulfil the technical requirements for their use in new products, exactly as

Figure 3.7 The SRM markets create the demand for the materials, enabling the uptake of SRMs and the closing of the material loop



primary raw materials have to. However, manufacturers' trust in SRMs is lower. This is because SRMs are less standardised, available in less stable quantities and lack performance guarantees compared to primary materials.

Lastly, a range of regulatory barriers relate to policy areas other than the environment. SRMs are often contaminated with hazardous substances that prevent their use in certain applications, such as food contact materials and toys. These kinds of limitations restrict SRM marketability and decrease SRM prices.

Investments in industrial capacity

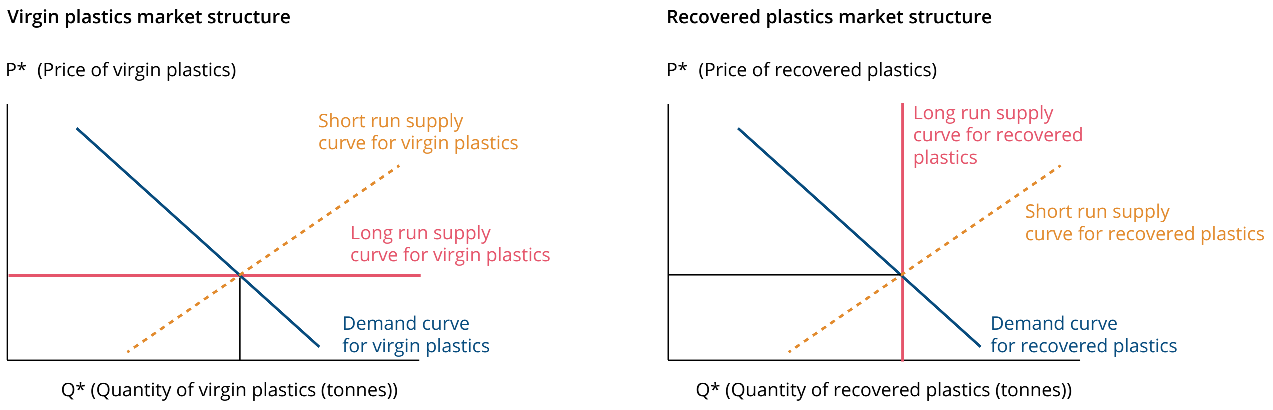
The investment needed to enable the use of SRMs as inputs varies for the different material streams. For example, producing goods from scrap metal (iron and copper) is an existing practice, as blast furnace and electric arc technologies take scrap metal as feedstock. However, to accommodate feedstock from SRMs for other materials, manufacturers sometimes have to modify the production process. This requires additional infrastructure and capacity. Especially for innovative technologies, the risks involved in committing capital to unproven technologies are high: new processes might cause problems in the current production system and conflict with earlier investment (Moors et al., 2005). Developing technologies to enable the uptake of SRMs also takes time. It usually takes years before new technologies are mature and become industry standards or are accepted as a best available technique (BAT).

Economic barriers

A key economic barrier for SRM markets is illustrated in Figure 3.8. For most virgin materials, there is a lack of differentiated demand for recycled materials. They are generally perceived as replacement materials for virgin raw materials with clear impacts on the market price mechanism. Taking the example of plastics, the price of virgin material depends on the production costs; mainly, the oil price. In clear contrast, the demand for recycled material is to a large extent disconnected from production costs and mainly depends on the price of virgin materials. **There is demand only if the price of secondary plastics is below the price of virgin plastics**. Similar differences in price elasticity can be observed for many other SRMs, leading to considerable uncertainty about the economic viability of investments in recycling infrastructures.

Comparing the market structures of the primary raw material sector on the one hand and the recycling sector on the other also highlights economies of scale as another economic barrier for SRM markets. The average size of companies producing most primary raw materials is often of completely different magnitude to that of recycling companies. The recycling sector is, to a large extent, still dominated by family-owned businesses (ASA et al., 2020) and often lacks the financial resources or access to capital needed to develop innovative technological solutions.

Figure 3.8 Market structures for primary and recovered plastics



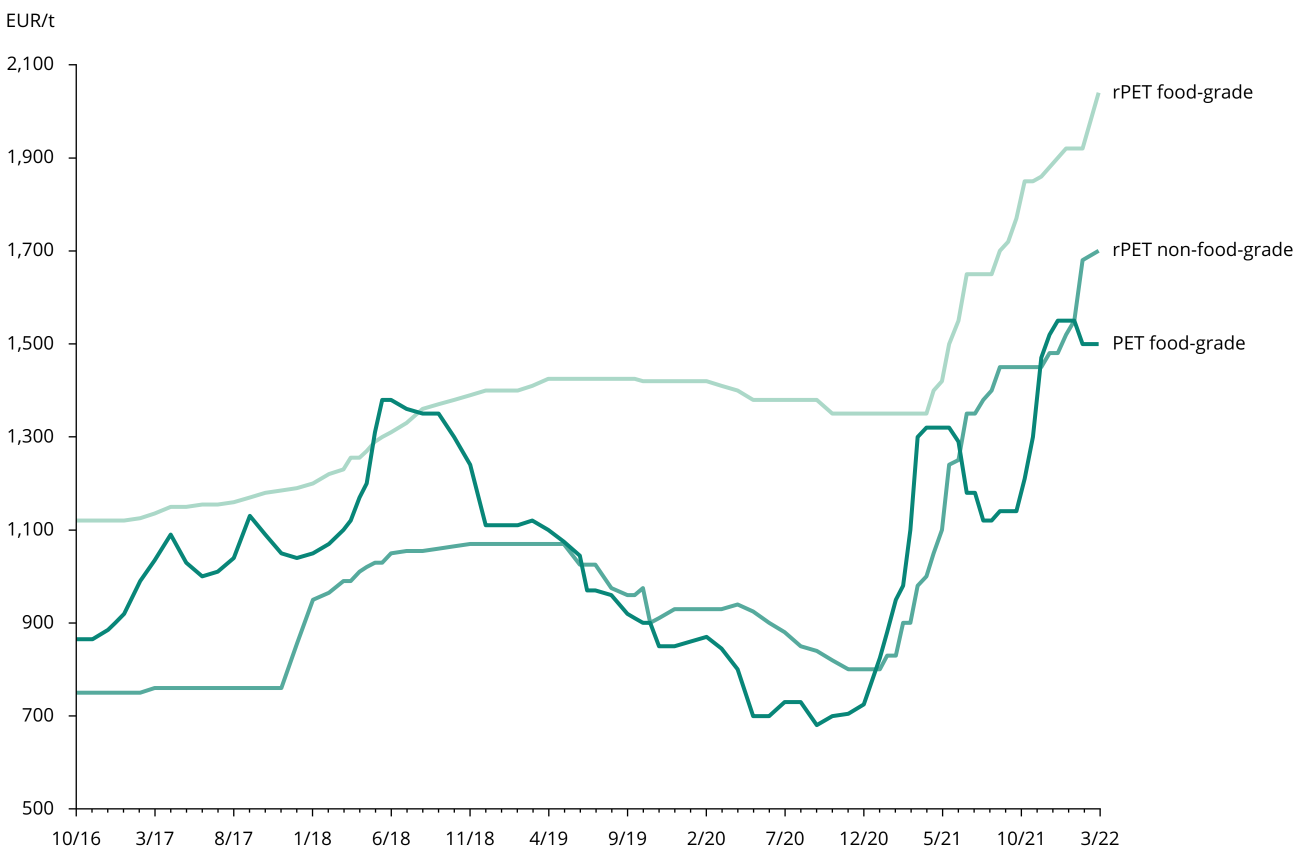
Source: WRAP (2007).

Looking at economic barriers, primary raw materials also often benefit from subsidies granted by public authorities. Taking the example of Germany, the Environmental Protection Agency publishes an annual report on environmentally-harmful subsidies showing that, for example, tax exemptions on oil save the virgin plastics industry around EUR1 billion (Umweltbundesamt, 2016). In general, many environmental externalities related specifically to mining are not incorporated in primary raw material prices, leading to massive market distortions and the overconsumption of primary raw materials. These externalities also explain why it is difficult for SRMs to compete on price with primary alternatives.

In the case of rPET, the industry is concerned that fixed targets on recycled content would result in fierce competition for recycled plastics. This would lead to distorted quality-price ratios and artificial price hikes. Already the market demand for food-grade transparent PET has led to rPET prices higher than the virgin equivalent (see Figure 3.9).

When looking at price competition between primary materials (see Box 3.4 for recent developments concerning plastics) and SRMs, stakeholders' established perceptions are also relevant. Stakeholders often perceive using SRMs in their production processes as riskier than using primary materials for many reasons. These include the insecurity of supply and the lack of standardisation, as well as inertia from established supply agreements with primary raw material producers. This perceived risk is translated into a lower willingness to pay for SRMs than for their primary alternatives.

Figure 3.9 **Market prices for rPET food-grade, rPET non-food-grade, and PET food-grade from October 2016 to February 2022**



Source: Kahlert and Bening (2022).

Box 3.4 The surge in the prices of energy and industrial primary commodities in 2021-2022

High prices for primary commodities (virgin materials) are expected to stimulate substitution with secondary materials, thus increasing the market for secondary raw materials (SRMs).

Since the second half of 2021, international prices of energy and primary commodities have been increasing under pressure from demand arising from the economic recovery following the COVID-19 crisis. The Russian invasion of Ukraine in February 2022 dramatically boosted these increases, especially in Europe, to generate an energy and commodity price shock of a size comparable to that of the early 1970s.

While the international nominal prices of energy commodities — especially natural gas in Europe — achieved exceptionally high levels, international prices of some industrial raw materials (e.g. timber, rubber and cotton) did not experience strong increases. In August 2022, prices were at levels similar to those of 2008 and well below their historical peak in 2011. The prices of metals and minerals, however, recorded sharp increases: in April 2022, their levels were the highest they had been over the last two decades (Figure 3.10).

Figure 3.10 Monthly prices of industrial raw materials and of metals and minerals, 2000-2022 (August)

Note: Monthly indices based on nominal US dollars, 2010=100.

Source: Authors' own calculations based on data from the World Bank (https://www.worldbank.org/en/research/commodity-markets).

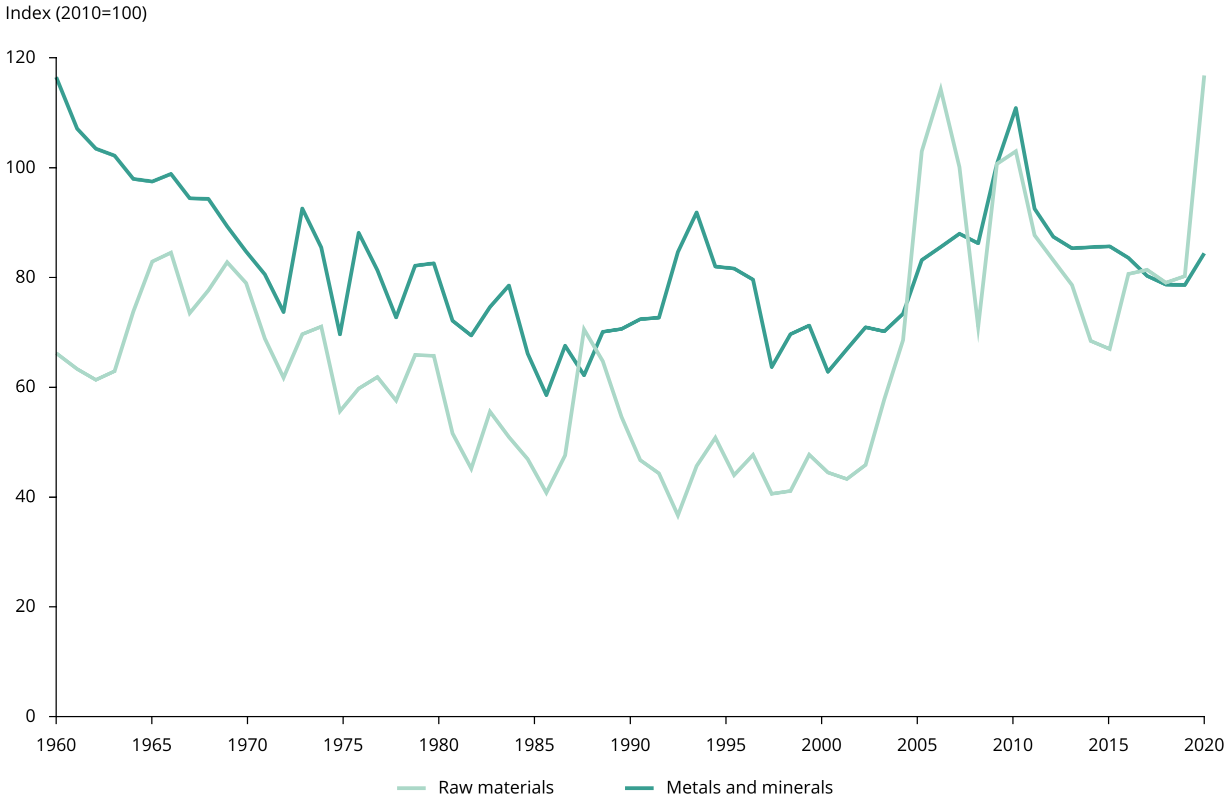
When looking at real prices (nominal commodity prices deflated by general price indices), which are traditionally considered indicators of economic scarcity, indices for industrial primary materials were, in 2021, well below the levels of the 1960s. This highlights the lack of structural, medium-term conflicts between supply of and demand for these primary commodities. The prices of metals and minerals, however, increased sharply and again achieved the peaks recorded in 2007 (Figure 3.11).

Therefore, in view of the exceptional current tension in energy markets, the prices of industrial primary commodities are generally increasing. However, there are no strong signals of an exceptional shock for the prices of metals and minerals, and even less so for those of industrial raw materials.

Box 3.4 The surge in the prices of energy and industrial primary commodities in 2021-2022 (cont.)

As a consequence, the primary materials market price signals in favour of recycling. SRMs are relatively weak, even in the present crisis — suggesting the importance of policies for developing SRM markets. The evolution of the energy and international security crises is unpredictable and may present serious risks for all the industrial production value chains in Europe and globally. In the presently highly uncertain geopolitical and geo-economic situation, the potential for sudden disruptions in supply in some international primary material markets cannot be ruled out.

Figure 3.11 Annual real prices of industrial raw materials and metals and minerals, 1960-2021



Note: Annual indices, 2010=100, real 2010 US dollars.

Source: Authors' own calculations based on data from the World Bank (https://www.worldbank.org/en/research/commodity-markets).

3.3 A summary of barriers by stage of the value chain

A summary of the major barriers identified at each stage of the SRM value chain is presented in Table 3.1.

Table 3.1 Major emerging barriers by phase of the secondary raw material value chain

Phase of the value chain	Product design and manufacture (upstream, 'recyclability')	Supply of SRM			Demand for SRM (substitution of primary material or new uses)
Type of barrier		In waste input availability/quality	In waste collection/sorting/dismantling	In waste recycling (manufacturing)	
From regulation and legislation	• Weak regulatory push for design for recycling and similar design considerations	• Lack of landfill bans • Possibility to export waste outside EU	• Lack of collection obligations and/or EPR schemes • No regulatory incentive to focus on recycling quality	• Lack of EoW criteria for most materials at EU level, different national classifications • Unclear, complex or incomplete legislative frameworks hindering recycling activities and investments	• Weakness of obligations to use SRMs • Weakness of GPP criteria and of enforcement in many countries • Conflicts with other regulations, e.g. health
From technology and quality		• Instability of waste supply and unreliability of its quality	• Collection of waste is a very costly process	• Insufficiency of technical specifications and standards for many SRMs	• Technical difficulties in introducing recycled materials as inputs • Distrust in recycled materials by manufacturers
From industrial capacity/investments				• Lack of capacity in immature SRM markets • Risk and uncertainty of investing in new processes/technologies • Uncertainty/instability of demand	
From economic factors (prices, costs, information, etc.)	• Lack of economic incentives to introduce recyclability in product design and manufacture		• High up-front investment costs • High costs of sorting for high-quality recycling	• High up-front investment costs • Instability of prices for SRMs and subordination to the primary market (prices) • Limited market power of small SRM producers (if no obligations to use SRMs)	• High overall prices of SRMs compared with virgin materials • Established perceptions of the risks of using SRMs
From competition from energy use		• Strong competition from highly subsidised energy uses			

4 Exploring solutions for further developing SRM markets

This chapter identifies potential pathways and priorities for removing or reducing barriers in one or more phases of the value chain identified in Chapter 3. The ideas presented in this chapter are particularly relevant to less well-functioning markets, as identified in Chapter 2. These markets are often born in response to the push of environmental and waste policies, but at their present stage of development or maturity, they are largely incomplete. Various conditions required to achieve 'well-functioning' status are still missing. This is because they have relatively low market shares compared to primary material-based equivalent markets and are unable to balance supply and demand.

The ideas on potential measures to remove barriers to market development are arranged according to the area in the value chain they address; namely, **product manufacture and design, supply of secondary raw materials (SRMs)** and **demand for SRMs.**

An overarching intervention **across** the three areas of focus concerns the need to improve information on and monitoring of SRM markets. There is still a large amount of proprietary and undisclosed information and knowledge in the hands of industry and market operators. Especially in less well-functioning or emerging markets, information is scant and fragmented: even simple metrics for the quantities processed and traded in the market and, even more so, for prices and economic values. Many policy approaches and tools — in particular, market-based instruments — critically depend on good information about the economic and industrial conditions in which the value chains are operating. This is because policy design and implementation should be based on the expected reaction of the stakeholders in the market addressed. In general, information on critical economic variables is poor, such as the prices of SRMs and how added value circulates along the value chain. Economic information is also scant and of poor quality in the SRM supply chain, from landfill and incineration gate fees for waste to market structure (industrial concentration, major actors, small and medium-sized enterprises) and the condition of international trade flows of waste and residues (ETC/WMGE, 2019b). As highlighted in the 2015 circular economy action plan (EC, 2015), there is also a need to improve the availability of data on SRMs. There are some relevant attempts to fill this data gap for selected waste streams (e.g. waste electrical and electronic equipment (WEEE), vehicles, batteries), such as the Horizon 2020 Europe project Prosum ([5]) or by the Raw Materials Information System ([6]). Efforts are being continued in the frame of the new Horizon Europe project Futuram ([7]).

Information on what kind of recycled materials are available and their environmental benefits (compared with virgin materials) and quality (compared with virgin materials), as well as producer/consumer options for improving the SRM, should also be further promoted. Networking and information activities would also strengthen the link between SRM market supply and demand.

Similarly, monitoring options need to improve so that the market penetration of SRMs can be measured. Harmonised methods for measuring and verifying the recycled content in products need to be further developed.

4.1 Measures to address barriers across phases of the value chain

Table 4.1 summarises the potential measures analysed in the following sections.

([5]) https://www.prosumproject.eu
([6]) https://rmis.jrc.ec.europa.eu
([7]) https://cordis.europa.eu/project/id/101058522

Table 4.1 Ideas for policy measures to improve SRM markets

Product manufacture and design	Supply of SRM	Demand for SRM
• Eco-modulated extended producer responsibility fees • Design for environment measures • Restrictions on substances inhibiting recycling • Green public procurement	• Recycling targets • Waste export restrictions • Harmonising collection schemes • Promoting material recovery over energy recovery • Standardising SRMs • End of waste criteria	• Recycled content requirements • Ecolabel/product passports • Tax on primary raw materials • VAT reduction on SRMs

4.1.1 Product manufacture and design

The lack of eco-design and, particularly, of design for recycling is a key barrier for the development of SRMs. Indeed, the way a product is designed determines to a large extent its potential for recycling and having good-quality SRMs.

First, SRM markets could benefit from the extended and harmonised application across EU Member States **of eco-modulated fees** for extended producer responsibility (EPR) schemes. The inclusion of eco-modulation in EPR schemes creates a strong incentive to design products for increased recyclability, as producers will pay less to producer responsibility organisations if they are putting more recyclable products on the market. Recyclability is only one criterion for eco-modulation in EPR schemes: other criteria promoting the quality of recyclables could address both the security of supply and the quality of the SRMs produced. Moreover, the influence of individual EPR schemes is limited and only international harmonisation can enhance the impact of modulated fees for global consumer products (OECD, 2016). With this in mind, coordination (at least) at the EU level is essential.

Second, there is a need to further encourage **design for environment (DfE)**, such as design for disassembly and recycling and integrating recycled materials in product manufacturing. Such legislation already exists in several waste streams (e.g. packaging, batteries, end-of-life vehicles and WEEE). However, these concepts are not always clearly defined and sufficiently operationalised by current legislation and standards, and they need strong implementation and (when appropriate) compliance enforcement. For example, the 'essential' requirements established by the Packaging and Packaging Waste Directive, which address packaging recycling and are to be met by all the packaging placed on the market, must be improved. This is because they are very vague, according to third party analysis (Eunomia et al., 2020). On the other hand, requirements for recycled content in new products placed on the market create a strong, artificial demand for SRMs which has the potential to further develop related markets. The sustainable product policy legislative initiative, proposed by the European Commission, widens the scope of the Ecodesign Directive (EU, 2009) beyond energy-related products. This makes the related framework applicable to the broadest possible range of products (EC, 2022d).

Third, as part of the concept of DfE, there is a need to minimise the use of **substances allowed on the market** that (significantly) hamper recycling and reuse or that can be substituted with more recyclable alternatives. For instance, the Single-Use Plastics Directive (EU, 2019a) prohibits oxo-degradable plastic (which negatively affects the recycling of conventional plastic) and single-use polystyrene food and beverage containers (which, in practice, are currently not recycled) from being placed on the market (Ellen MacArthur Foundation, 2017; EU, 2019a). Substitution in favour of more recyclable alternatives is difficult to achieve via legislation. However, more information on material recyclability and viable substitutions could be promoted, so that designers and producers are better-informed about alternatives.

Green public procurement (GPP) (see Box 4.1) is another tool for incentivising DfE. Specific GPP provisions concerning the recyclability and/or recycled content could further incentivise DfE and secure a steady long-term demand for SRMs. According to the 2020 circular economy action plan (EC, 2020a), the Commission intends to propose minimum mandatory GPP criteria and targets in sectoral legislation, which, by turning GPP into a binding regulatory tool, could increase its effectiveness.

4.1.2 Supply of SRMs

Several options are available that ensure the continuity and quality of the waste input supply to recycling. A potential measure in this respect is the extension of **binding recycling targets** to waste streams not currently covered to ensure a steady and high-quality supply and avoid downcycling. Such targets have been set by EU legislation for several waste streams. They can contribute to the stability of waste input supply and increase recycling. Introducing recycling targets to waste streams not currently covered, such as textiles and biowaste, which operate in markets that are not well-functioning may positively affect the corresponding

SRM markets. In addition, such measures can promote high-quality recycling and focus on maintaining material value and lowering environmental effects.

The potential to export waste outside the EU reduces the availability of waste input for EU SRM supply chains. Despite the waste import bans recently introduced by many Asian countries, the export of non-hazardous waste out of the EU for recycling still represents a substantial share of the overall separately collected waste, with the loss of valuable resources from EU industry and associated negative impacts on the environment and public health in destination countries (EEA, 2021a). A revision of the Waste Shipment Regulation (EU, 2006) is ongoing, based on the circular economy action plan (EC, 2020a), which calls for **limiting the export of waste that can be treated domestically**, thus supporting its reuse and recycling within the EU (EC, 2021). This measure could increase waste input supply stability and allow economies of scale, leading to more robust SRM markets in the EU. However, this hinges the increase in the availability of waste resources to be treated in the EU being matched by the development of adequate waste recycling capacity (to avoid waste being landfilled/incinerated); the challenges for waste management companies arising from lower prices for waste materials being addressed; and the demand for SRMs being supported (EC, 2020b).

Collection schemes based on EU legislation are implemented in different ways across Member States. A more **harmonised** development of an adequate collection infrastructure, awareness-raising and information campaigns, the use of economic instruments to reduce the generation of unsorted waste (e.g. 'pay-as-you-throw' schemes), and innovation in sorting systems and techniques can contribute to the better performance of collection and sorting schemes. This can improve the supply of recycled material.

Promoting material recovery over energy recovery is also important. For some important SRMs (e.g. wood), highly incentivising policies on renewable energy sources result in the diversion of waste and residues from material recovery and recycling chains towards energy recovery. In some cases, this occurs in a way that is inconsistent with the EU waste hierarchy (Zoboli et al., 2020). Better application of the circular economy criteria may contribute to solving problems related to the competition between alternative uses of waste inputs. For instance, according to the 2030 Biodiversity Strategy, only residues and non-reusable and non-recyclable waste should be used to produce bioenergy (EC, 2020c).

A barrier to the uptake of collected waste materials by SRM markets has been the lack of **standardisation** of SRMs, which would mean that their quality and technical performance could be guaranteed to final users, similarly to primary raw materials. A harmonised, EU-wide effort to standardise SRMs, especially those that operate in markets that are not well-functioning (see Chapter 2), would help address insecurities by manufacturers and increase trust in SRMs. Such standardisation efforts also come with the potential of decreasing the cost of producing SRMs and should be carefully investigated.

However, SRMs currently covered by technical specifications and standards would benefit from harmonisation. These standards may be more effective if they are uniformly imposed at the EU level (and possibly also at the international level) to ensure a level playing field. Moreover, more efforts are needed to **harmonise national end-of-waste (EoW) criteria** across all Member States to avoid the same product being categorised as no longer waste in one country but waste in another country (see Box 4.1.). EoW criteria, similarly to other certification mechanisms and standards, create confidence in the SRM and ensure a legal level playing field with primary raw materials.

Box 4.1 End-of-waste concept

The end-of-waste (EoW) concept means that a specific waste fraction can cease to be waste under certain criteria given in the Waste Framework Directive (EU, 2008). The criteria are that:

- the substance or object is commonly used for specific purposes;
- a market or demand exists for such a substance or object;
- the substance or object fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products;
- the use of the substance or object will not lead to overall adverse environmental or human health impacts.

If the criteria are fulfilled, the material will no longer be classified as a waste and will, instead, become a product subject to free trade and use (albeit for specific purposes). If no EoW legislation exists at the EU level, Member States can develop national EoW legislation for a certain waste material. EU-wide EoW criteria have been developed for only a few materials (scrap metal and cullet). In national EoW systems, national conditions for waste characteristics and use can be considered. However, it is important to note that, when waste reaches national EoW status, it ceases to be waste only in that Member State. The waste is still considered waste in other Member States and the regulation on shipments of waste still applies to it.

4.1.3 Demand for SRMs

Some of the barriers to improving the demand for SRMs, identified in Chapter 3, can be overcome using tools already described in the paragraphs addressing other parts of the supply chain. For example, technical specifications and standards for SRMs can change manufacturers' perception that these materials are a suboptimal replacement for primary raw materials. GPP criteria can not only enhance DfE aspects when designing new products but also be used to impose recycled content requirements on procured products, creating a strong demand for SRMs as a result. GPP criteria should also be flexible to account for rapid technological developments in the recycling industry and avoid the inertia arising from long-term contracts with primary raw material suppliers.

With specific regard to **recycled content requirements**, for many materials (such as biowaste, plastic, construction materials and textiles) the share of demand for SRMs with respect to total market size is low. Binding requirements related to minimum recycled content have been introduced for the first time by the 2019 Single-Use Plastics Directive for plastic bottles (EU, 2019a) and are considered set for further products and materials (plastic, construction materials, etc.; EC, 2020a). Recycled content requirements ensure that producers buy SRMs regardless of price, increasing the demand for SRMs and supporting investment in recycling as a result. However, their unintended consequences along the related value chains should be carefully monitored and addressed (e.g. potential risks, such as quality and product safety; sharply rising prices for recycled materials and the products made from them; and mere redirection of recycled materials from existing applications to regulated applications).

Apart from the above-mentioned GPP tool for non-mandatory recycled content requirements (that functions also as a "pull" measure increasing demand for SRMs), other options exist, such as extending the use of the EU **Ecolabel** (including a criterion for minimum recycled content) to further product groups or introducing product passports containing information such as recycled content for recycled materials and products.

To increase the demand for SRMs, one option is to shift the balance between the price of SRMs and the price of primary raw materials in favour of the former. As already mentioned, primary raw materials often benefit from subsidies, and their price does not reflect environmental externalities. These factors can be addressed either by increasing the price of primary raw materials or by reducing the price of SRMs. An example of a measure that serves to increase the price of primary raw materials is the introduction of a **tax on primary raw materials**. Such a tax, reflecting the environmental externalities of primary materials, might help reduce the cost disadvantage of recycled materials (Eckermann et al., 2015). The price of primary material does not reflect the environmental or climate costs of their extraction and processing. This gives them an unfair price advantage over recycled materials, which have a much lower environmental and climate impact. Unintentional negative effects would need to be considered, such as production moving overseas and disproportionate impacts on lower income groups (EEA, 2021c).

In terms of the second possibility for reducing SRM prices, an example of a potential economic incentive would be to **reduce VAT** on products containing recycled material. This would help reduce the costs of recycled materials.

Box 4.2 Green public procurement

Every year, public authorities in the EU spend the equivalent of 14% of the gross domestic product on purchasing works, goods and services — accounting for roughly EUR 2 trillion per year (EC, 2022c). Public procurement may therefore have significant leverage on the economy and in addressing social and environmental challenges.

EU green public procurement (GPP) criteria have been set for different product groups, most of which contain the materials covered by the present work. These criteria are not legally binding but, in practice, a number of Member States have either referenced the EU GPP criteria in their national action plans or adopted criteria that reflect them quite closely. Their level of implementation, however, significantly differs across Europe (EP, 2017).

Not all countries that have implemented GPP have established good monitoring systems to review their environmental effectiveness (Baron, 2016). Therefore, evaluating the actual impact of GPP on the environment proves to be difficult.

The environmental impact potential of GPP, regarding both eco-design and the demand for SRMs, may be significant, as highlighted by a study by the European Parliament (EP, 2017). GPP criteria are mostly shaped as product requirements (including services and works), while the most common criteria include thresholds for chemical substances and the recycled content in products — both of which support SRM markets. However, other studies have questioned the overall effectiveness of GPP (Halonen, 2021).

Abbreviations

Abbreviation	Name
ABS	Acrylonitrile butadiene styrene
BAT	Best available technique
C&D	Construction and demolition
CED	Cumulative energy demand
CRT	Cathode ray tube
DfE	Design for the environment
EEA	European Environment Agency
EoW	End-of-waste
EPR	Extended producer responsibility
EPS	Expanded polystyrene
EU	European Union
EU-27	The 27 EU Member States
GPP	Green public procurement
HDPE	High-density polyethylene
HIPS	High-impact polystyrene
ICT	Information and communications technology
ISRI	Institute of Scrap Recycling Industries
LDPE	Low-density polyethylene
OECD	Organisation for Economic Co-operation and Development
PC	*Polycarbonate*
PE	Polyethylene
PET	Polyethylene terephthalate
PJ	Petajoule
PP	Polypropylene
PPWD	Packaging and Packaging Waste Directive
PS	Polystyrene
PVC	Polyvinyl chloride
rPET	Recycled PET
SRF	Solid recovered fuel
SRM	Secondary raw material
TJ	Terajoule
VAT	Value added tax
WEEE	Waste electrical and electronic equipment
WFD	Waste Framework Directive

References

Alvarado Chacon, F., et al., 2020, 'Effect of recycled content and rPET quality on the properties of PET bottles, part I: optical and mechanical properties', *Packaging Technology and Science* 33, pp. 347-357 (https://doi.org/10.1002/pts.2490).

ASA, et al., 2020, *Statusbericht der deutschen Kreislaufwirtschaft 2020* (https://www.bvse.de/dateien2020/2-PDF/01-Nachrichten/01-bvse/2020/November/Statusbericht_der_deutschen_Kreislaufwirtschaft_2020.pdf) accessed November 2022.

Baron, R., 2016, 'The role of public procurement in low-carbon innovation', Background paper for the 33rd Round Table on Sustainable Development, 12-13 April, Organisation for Economic Co-operation and Development, Paris.

Baxter, J., et al., 2014, *Plastic value chains. Case: WEEE (Waste Electric and electronic equipment) in the Nordic region*, Tema Nord 2014:542 (http://norden.diva-portal.org/smash/get/diva2:721021/FULLTEXT01.pdf) accessed November 2021.

Bio by Deloitte, 2014, *Development of guidance on extended producer responsibility — final report prepared for the European Commission* (https://ec.europa.eu/environment/archives/waste/eu_guidance/pdf/Guidance%20on%20EPR%20-%20Final%20Report.pdf) accessed November 2022.

BIR, 2016, *Report on the environmental benefits of recycling*, 2016 edition, Bureau of International Recycling, Brussels.

BKV and GVM, 2020, Kurzfassung der Studie *Potenzial zur Verwendung von Recycling-Kunststoffen in der Produktion von Kunststoffverpackungen in Deutschland*, BKV, Frankfurt am Main, Germany.

Bocken, N. M. P., et al., 2016, ‚Product design and business model strategies for a circular economy', *Journal of Industrial and Production Engineering* 33(5), pp. 308-320 (https://doi.org/10.1080/21681015.2016.1172124).

CEPI, 2020, *Monitoring report 2020. European Declaration on Paper Recycling 2016-2020*, CEPI, Brussels.

Circular Plastics Alliance, 2022, 'Commitments and deliverables of the Circular Plastics Alliance' (https://single-market-economy.ec.europa.eu/industry/strategy/industrial-alliances/circular-plastics-alliance_en) accessed September 2022.

EC, 2015, , Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions 'Closing the loop — an EU action plan for the circular economy' (COM(2015) 614 final).

EC, 2016, *Study on the energy saving potential of increasing resource efficiency. Final report*, European Commission, Brussels.

EC, 2018a, Commission Staff Working Document 'Measuring progress toward circular economy in the European Union — key indicators for a monitoring framework' (SWD(2018) 17 final).

EC, 2018b, Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions 'A European Strategy for Plastics in a Circular Economy' (COM(2018) 28 final).

EC, 2020a, Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions 'A new Circular Economy Action Plan for a cleaner and more competitive Europe' (COM(2020) 98 final).

EC, 2020b, Waste shipment — revision of EU rules; inception impact assessment (Ares(2020) 1505101).

EC, 2020c, Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions 'EU Biodiversity Strategy for 2030: bringing nature back into our lives' (COM(2020) 380 final).

EC, 2021, Proposal for a Regulation of the European Parliament and of the Council on shipments of waste and amending Regulations (EU) No 1257/2013 and (EU) No 2020/1056 (COM(2021) 709 final).

EC, 2022a, 'Plastics', European Commission (https://environment.ec.europa.eu/topics/plastics_en) accessed September 2022.

EC, 2022b, 'The Commission starts to develop end-of-waste criteria for plastic waste', European Commission (https://environment.ec.europa.eu/news/commission-starts-develop-end-waste-criteria-plastic-waste-2022-04-05_en) accessed September 2022.

EC, 2022c, 'What is GPP?', European Commission (https://ec.europa.eu/environment/gpp/what_en.htm) accessed September 2022.

EC, 2022d, Proposal for a Regulation of the European Parliament and the Council establishing a framework for setting ecodesign requirements for sustainable products and repealing Directive 2009/125/EC (COM(2022) 142 final).

Eckermann, F., et al., 2015, 'Resource taxation: discussion for selected materials', Working Paper for discussion by ETC/SCP, ETC/WMGE and EEA, October 2015, European Environment Agency, Copenhagen.

EEA, 2017, *Circular by design — products in the circular economy*, EEA Report No 6/2017, European Environment Agency.

EEA, 2019, *Textiles in Europe's circular economy,* EEA Briefing No 10/2019, European Environment Agency

EEA, 2020, *Bio-waste in Europe — turning challenges into opportunities*, EEA Report No 4/2020, European Environment Agency.

EEA, 2021a, *Linking cross-border shipments of waste in the EU with the circular economy,* EEA Briefing No 14/2021, European Environment Agency (https://www.eea.europa.eu/publications/linking-cross-border-shipments-of) accessed September 2022.

EEA, 2021b, *Plastics, the circular economy and Europe's environment*, EEA Report 18/2020, European Environment Agency.

EEA, 2021c, *Reflecting on green growth — creating a resilient economy within environmental limits*, EEA Report 11/2021, European Environment Agency.

EEA, 2022, Textiles and the environment: the role of design in Europe's circular economy, EEA Briefing No 1/2022, European Environment Agency (https://www.eea.europa.eu/publications/textiles-and-the-environment-the) accessed November 2022.

Ellen MacArthur Foundation, 2017, *The new plastics economy: rethinking the future of plastics* (https://emf.thirdlight.com/link/faarmdpz93ds-5vmvdf/@/preview/1?o) accessed November 2022.

Embureau, 2022, 'Construction and demolition waste' (https://cembureau.eu/policy-focus/sustainable-construction/construction-demolition-waste/) accessed September 2022.

EP, 2017, *Green public procurement and the EU action plan for the circular economy*, European Parliament, Directorate-General for Internal Policies, Brussels.

ETC/WMGE, 2019a, *Are we losing resources when managing Europe's waste?*, ETC/WMGE Report 3/2019, European Topic Centre for Waste and Materials in a Green Economy (https://www.eionet.europa.eu/etcs/etc-wmge/products/etc-reports/are-we-losing-resources-when-managing-europes-waste-1) accessed November 2022.

ETC/WMGE, 2019b, *Plastics waste trade and the environment*, ETC/WMGE Report 5/2019, European Topic Centre on Waste and Materials in a Green Economy (https://www.eionet.europa.eu/etcs/etc-wmge/products/etc-reports/plastics-waste-trade-and-the-environment) accessed November 2021.

ETC/WMGE, 2020, C*onstruction and demolition waste: challenges and opportunities in a circular economy*, ETC/WMGE Report 1/2020, European Topic Centre on Waste and Materials in a Green Economy (https://www.eionet.europa.eu/etcs/etc-wmge/products/etc-wmge-reports/construction-and-demolition-waste-challenges-and-opportunities-in-a-circular-economy) accessed November 2022.

EU, 1994, European Parliament and Council Directive 94/62/EC of 20 December 1994 on packaging and packaging waste (OJ L 365, 31.12.1994, p. 10-23).

EU, 2000, Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles (OJ L 269, 21.10.2000, p. 34-43).

EU, 2006, Regulation (EC) No 1013/2006 of the European Parliament and of the Council of 14 June 2006 on shipments of waste (OJ L 190, 12.7.2006, p. 1-98). *Consolidated version of* 11/01/2021.

EU, 2008, Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (OJ L 312, 22.11.2008, p. 3-30).

EU, 2009, Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products (OJ L 285, 31.10.2009, p. 10-35).

EU, 2011, Council Regulation (EU) No 333/2011 of 31 March 2011 establishing criteria determining when certain types of scrap metal cease to be waste under Directive 2008/98/EC of the European Parliament and of the Council (OJ L 94, 8.4.2011, p. 2-11).

EU, 2012a, Commission Regulation EU No 1179/2012 of 10 December 2012 establishing criteria determining when glass cullet ceases to be waste under Directive 2008/98/EC of the European Parliament and of the Council (OJ L 337, 11.12.2012, p. 31-36).

EU, 2012b, Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE) (OJ L 197, 24.7.2012, p. 38-71).

EU, 2018a, Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste (OJ L 150, 14.6.2018, p. 109-140).

EU, 2019a, Directive (EU) 2019/904 of the European Parliament and of the Council of 5 June 2019 on the reduction of the impact of certain plastic products on the environment (OJ L 155, 12.6.2019, p. 1-19).

EU, 2019b, Regulation (EU) 2019/1021 of the European Parliament and of the Council of 20 June 2019 on persistent organic pollutants (OJ L 169, 25.6.2019, p. 45-77).

Eunomia, et al., 2020, *Effectiveness of the essential requirements for packaging and packaging waste and proposals for reinforcement: final report and appendices*, Eunomia, Bristol, UK

EuRIC, 2020, *Plastic recycling factsheet*, European Recycling Industries' Confederation (https://circulareconomy.europa.eu/platform/en/knowledge/euric-plastic-recycling-factsheet) accessed September 2022.

European Aluminium, 2017, *Market overview*, European Aluminium, Brussels.

European Aluminium, 2020, *Circular aluminium action plan — a strategy for achieving aluminium's full potential for circular economy by 2030*, European Aluminium, Brussels.

European Court of Auditors, 2020, *EU action to tackle the issue of plastic waste*, Review No 4/2020 (https://www.eca.europa.eu/en/Pages/DocItem.aspx?did=55223) accessed September 2022).

Eurostat, 2018, 'Recycling rates of packaging waste for monitoring compliance with policy targets, by type of packaging [ENV_WASPACR]', Eurostat Data Browser (https://ec.europa.eu/eurostat/databrowser/view/env_waspacr/default/table?lang=en) accessed November 2022.

Eurostat, 2021, 'Generation of waste by category, hazardousness and NACE Rev. 2 category [env_wasgen]', Eurostat Data Browser (http://appsso.eurostat.ec.europa.eu/nui/show.do?lang=en&dataset=env_wasgen) accessed December 2021.

Eurostat, 2021b, 'Packaging waste by waste management operations [env_waspac]', Eurostat Data Browser (https://ec.europa.eu/eurostat/databrowser/view/ENV_WASPAC/default/table?lang=en) accessed December 2021.

Eurostat, 2022, 'Circular economy — overview' (https://ec.europa.eu/eurostat/web/circular-economy) accessed September 2022.

FEVE, 2021, 'Record collection of glass containers for recycling hits 78% in the EU', European Container Glass Federation (https://feve.org/glass_recycling_stats_2019) accessed December 2021.

Frost & Sullivan, 2019, Emerging alternatives for single-use plastics in packaging — circular economy initiatives leading to increasing adoption of sustainable and environment-friendly alternatives for single-use packaging (https://store.frost.com/emerging-alternatives-for-single-use-plastics-in-packaging.html) accessed November 2022.

Garcia, C. A. and Hora, G., 2017, 'State-of-the-art of waste wood supply chain in Germany and selected European countries', *Waste Management* 70, pp. 187-197 (https://doi.org/10.1016/j.wasman.2017.09.025).

Glass Packing Institute, 2021, 'Glass container recycling loop' (https://www.gpi.org/glass-recycling-facts) accessed December 2021.

Godoy León, M. F., et al., 2022, 'Material system analysis: functional and nonfunctional cobalt in the EU, 2012–2016', *Journal of Industrial Ecology* 26(4), pp. 1277-1293.

Grafstrom, J. and Aasma, S., 2021, 'Breaking circular economy barriers', *Journal of Cleaner Production* 292, 126002.

Halonem, K. M., 2021, 'Is public procurement fit for reaching sustainability goals? A law and economics approach to green public procurement', *Maastricht Journal of European and Comparative Law* 28(4), pp. 535-555.

Hestin, M., et al., 2015, *Increased EU plastics recycling targets: environmental, economic and social impact assessment*, Final report prepared for Plastics Recyclers Europe.

Heuts, L., 2020, *FISSAC — Final publications regarding living lab for FISSAC model* (D7.3).

Huisman, J., et al., 2017, *Prospecting secondary raw materials in the urban mine and mining wastes (ProSUM) — final report* (https://doi.org/10.13140/RG.2.2.10451.89125).

Kahlert S., Bening C.R., 2022, Why pledges alone will not get plastics recycled: Comparing recyclate production and anticipated demand, Resources, Conservation & Recycling 181 (2022) 106279.

Kaufman, S., et al., 2020, *Effectiveness of product labelling schemes for the circular economy: a rapid evidence review for behavioural public policy*, Behaviour Works Australia, Monash University, Melbourne.

Kirchherr, J. W., et al., 2017, *Breaking the barriers to the circular economy*, Deloitte and University of Utrecht, Netherlands.

Kosior, E. and Mitchell, J., 2020, 'Current industry position on plastic production and recycling', in: Letcher, T. M. (ed.), *Plastic waste and recycling. Environmental impact, societal issues, prevention, and solutions*, Academic Press, London, p. 133-162.

Ljungkvist Nordin, H., et al., 2019, *Kartläggning av plastavfallsflöden, återvinningsmetoder och marknader: kunskapsunderlag för ett returraffinaderi*, Rapport C516, Swedish Environmental Research Institute, Stockholm.

Make it from Metal, 2022, 'Posts from Jonathan Maes' (https://makeitfrommetal.com/author/jonathanrmaes) accessed September 2022.

Masi, D., et al., 2018, 'Towards a more circular economy: exploring the awareness, practices, and barriers from a focal firm perspective', *Production Planning and Control* 29(6), pp. 539-550.

Massarutto, A., 2014, 'The long and winding road to resource efficiency — an interdisciplinary perspective on extended producer responsibility', *Resource Conservation and Recycling* 85, pp. 11-21.

Material Economics, 2018, *The circular economy — a powerful force for climate mitigation* (https://media.sitra.fi/2018/06/12132041/the-circular-economy-a-powerful-force-for-climate-mitigation.pdf) accessed September 2022.

Matos, C. T., et al., 2022, 'Material system analysis: a novel multilayer system approach to correlate EU flows and stocks of Li-ion batteries and their raw materials', *Journal of Industrial Ecology* 26(4), pp. 1261-1276.

Metal Packaging Europe and European Aluminium, 2021, 'Roadmap towards 100% can recycling by the year 2030' (https://www.canroadmap2030.eu) accessed November 2022.

Moors, E. H. M., et al., 2005, 'Towards cleaner production: barriers and strategies in the base metals producing industry', *Journal of Cleaner Production* 13, pp. 657-668 (http://dx.doi.org/10.1016/j.jclepro.2003.12.010).

Nordic Council of Ministers, 2018a, *Plastic waste markets — overcoming barriers to better resource utilization*, Nordic Council of Ministers, Copenhagen.

Nordic Council of Ministers, 2018b, *Recycling in the circular economy*, Policy Brief, Nordic Council of Ministers, Copenhagen.

OECD, 2016, *Extended producer responsibility — updated guidance for efficient waste management*, OECD Publishing, Paris.

OECD, 2017, *The macroeconomics of the circular economy transition: a critical review of modelling approaches,* OECD Working Paper No 130, OECD Publishing, Paris.

OECD, 2018, *Improving markets for recycled plastics: trends, prospects and policy responses, OECD Publishing*, Paris (https://doi.org/10.1787/9789264301016-en).

Pajunen, N., et al., 2012, ;Drivers and barriers of effective industrial material use', *Minerals Engineering* 29, pp. 39-46.

Plasticker, 2022, 'Home page' (https://plasticker.de) accessed November 2022.

Plastics Europe, 2018, *Plastics — the facts 2018. An analysis of European plastics production, demand and waste data* (https://plasticseurope.org/knowledge-hub/plastics-the-facts-2018-2) accessed September 2022.

Plastics Europe, 2019, *Plastics — the facts 2019*. *An analysis of European plastics production, demand and waste data* (https://plasticseurope.org/knowledge-hub/plastics-the-facts-2019) accessed October 2020.

Pohjakallio, M., 2020, 'Secondary plastic products: examples and market trends', in Letcher, T. M. (ed.), *Plastic waste and recycling. Environmental impact, societal issues, prevention, and solutions*, Academic Press, London, pp. 467-479.

Redlinger, M., et al,, 2015, 'Evaluating the availability of gallium, indium, and tellurium from recycled photovoltaic modules', *Solar Energy Materials and Solar Cells* 138, pp. 58-71.

Reis, G. S. D, et al., 2021, Current applications of recycled aggregates from construction and demolition: a review, *Materials* 14, 1700 (https://doi.org/10.3390/ma14071700).

Schleich, J. and Gruber, E., 2008, 'Beyond case studies: barriers to energy efficiency in commerce and the services sector', *Energy Economics* 30(2), pp. 449-464.

Söderholm, P., and Ekvall, T., 2020, 'Metal markets and recycling policies: impacts and challenges', *Mineral Economics* 33, pp. 257-272 (https://doi.org/10.1007/s13563-019-00184-5).

Spotlightmetal, 2019, 'Aluminium. Markets for steel and aluminium scrap' (https://www.spotlightmetal.com/markets-for-steel-and-aluminum-scrap-a-789883) accessed November 2021).

Technopolis, et al., 2016, *Regulatory barriers for the circular economy — lessons from ten case studies*, Technopolis, Amsterdam.

Thoden van Velzen, E. E., et al., 2016, *Technical quality of rPET: technical quality of rPET that can be obtained from Dutch PET bottles that have been collected, sorted and mechanically recycled in different manners*, Wageningen University Research Food & Biobased Research, Wageningen, Netherlands.

Tsamis, A. and Coyne, M., 2015*, Recovery of rare earths from electronic wastes: an opportunity for high-tech SMEs*, European Parliament's Committee on Industry, Research and Energy (https://www.europarl.europa.eu/RegData/etudes/STUD/2015/518777/IPOL_STU(2015)518777_EN.pdf) accessed November 2022.

Umweltbundesamt, 2016, *Umweltschädliche Subventionen in Deutschland Aktualisierte Ausgabe 2016*, Umweltbundesamt, Dessau-Roßlau, Germany.

Velzeboer, I. and van Zomeren, A., 2017, End of waste criteria for inert aggregates in member states, ECN (https://publicaties.ecn.nl/PdfFetch.aspx?nr=ECN-E--17-010) accessed November 2022.

Walls, M., 2006, *Working Group on Waste Prevention and Recycling. EPR policies and product design: economic theory and selected case studies*, Organisation for Economic Co-operation and Development (https://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV/EPOC/WGWPR(2005)9/FINAL&doclanguage=en) accessed September 2021.

Williams, R., 2020, *Emerging challenges of waste management in Europe — limits of recycling,* Trinomics (https://trinomics.eu/wp-content/uploads/2020/06/Trinomics-2020-Limits-of-Recycling.pdf) accessed November 2022.

Wilts, H., 2016, *Nachhaltige Innovationsprozesse in der kommunalen Abfallwirtschaftspolitik: eine vergleichende Analyse zum Transition Management städtischer Infrastrukturen in deutschen Metropolregionen*, PhD Thesis, Technische Universität, Darmstadt, Germany.

WRAP, 2007, *The determinants of recovered plastics prices in the UK*, Waste and Resources Action Programme, Banbury, UK.

WoodCircus, 2022, 'Project home page' (https://woodcircus.eu/index.php/about) accessed September 2022.

Zink, T. and Geyer, R., 2017, 'Circular economy rebound', *Journal of Industrial Ecology* 21(3), pp. 593-602.

Zoboli, R., et al., 2019, *Towards an Innovation-intensive circular economy. Integrating research, industry, and policy*, FEEM Report (https://www.feem.it/m/publications_pages/rpt-economiacircolare.pdf) accessed November 2022.

Zoboli, R., et al., 2020, *Energy and the circular economy: filling the gap through new business models within the EGD*, FEEM Report (https://www.feem.it/en/publications/reports/energy-and-the-circular-economy-filling-the-gap-through-new-business-models-within-the-egd) accessed September 2022.

zu Castell-Rüdenhausen, M., et al., 2021, *NONTOX framework analysis and activities to enhance plastic recycling*, Deliverable D5.1 (in press) (nontox-project.eu) accessed September 2022.

Annex 1. Evidence of the environmental benefits of SRMs: a summary

To enable the assessment of the environmental benefits of a circular economy, it is necessary to adopt a product perspective (EEA, 2017) instead of the materials perspective that is traditionally employed when assessing the impact of waste management policies in a linear economy context. From a materials perspective, the waste hierarchy is considered the guiding principle for policies on waste, which aims to maximise the share of waste that is treated according to the highest-ranked waste management option. The corresponding environmental ambitions are set in weight-based landfill, recycling and reuse targets.

In a circular economy, however, a product perspective should prevail. A product has a value that is associated with its functionality. When the functionality is lost, the product loses most or all its value. The product can be reused, using the remaining functionalities; it can be given a new functionality; it can be temporarily stored; or it can be discarded as waste. It should be noted that product functionality is not limited to technical performance but includes fashion trends, the provision of social status or identity and other non-material properties. A newly bought piece of clothing or electronic gadget can lose its functionality even when still unpacked. A circular economy, however, aims to maintain the functionality, and thus the value of products, for as long as possible. The fewer products we discard, the less materials we extract — and the better for our environment (Eurostat, 2022).

In a circular economy hierarchy, the most preferred option is to conserve the original product with all the related functionalities, including non-technical or non-operational ones. The corresponding strategies include design for longevity, independence from fashion trends, and product repair and reuse. An example is the reuse of railway tracks. Railway track steel is typically made of 1084-grade steel or equivalent hot-rolled steel. This is a medium carbon steel with 0.7-0.8% carbon and 0.7-1.0% manganese (Make it from Metal, 2022). Its reuse as railway tracks allows the complete conservation of all the functionalities provided by this specific type of steel.

At a lower level in the circular economy hierarchy, components or parts of a discarded product are either replaced or recovered, thus avoiding the production of entirely new products or product parts. A less preferred option consists of destroying the discarded product (e.g. by dismantling and/or shredding operations) to prepare it for mineral, metal alloy and other material extraction. These operations will allow only the preservation of the functionality of (some of) the materials the product is composed of, as happens in most recycling processes. The least preferred option is the recovery of pure chemical elements, as in the recycling of gold and precious metals from electronic waste.

When a product inevitably becomes waste, in a circular economy, it is subjected to a series of processes that decompose it into a series of separate fractions. These can include (1) reusable parts or components, (2) fractions that are rich in recyclables, such as minerals, metal alloys, polymers and other materials that can be further sorted, separated and purified into secondary raw materials (SRMs), (3) fractions with an interesting calorific value, which can be used as energy carriers, and (4) residual or hazardous fractions for final processing and disposal. The assessment of the corresponding environmental benefits cannot be based on weight, as is the case for the waste management targets. Instead, the environmental benefits will depend on the magnitude of the avoided impact associated with each of the primary raw materials that is substituted by reused or recycled ones.

Often, resource-intensive materials i.e. with relevant environmental burdens are present in very low concentrations, such as precious metals or rare Earth minerals. In other cases, they can be difficult to recycle from discarded products, such as metal alloying elements. The environmental benefits associated with recycling of a few milligrams of gold will easily outweigh those of hundreds of kilos of glass.

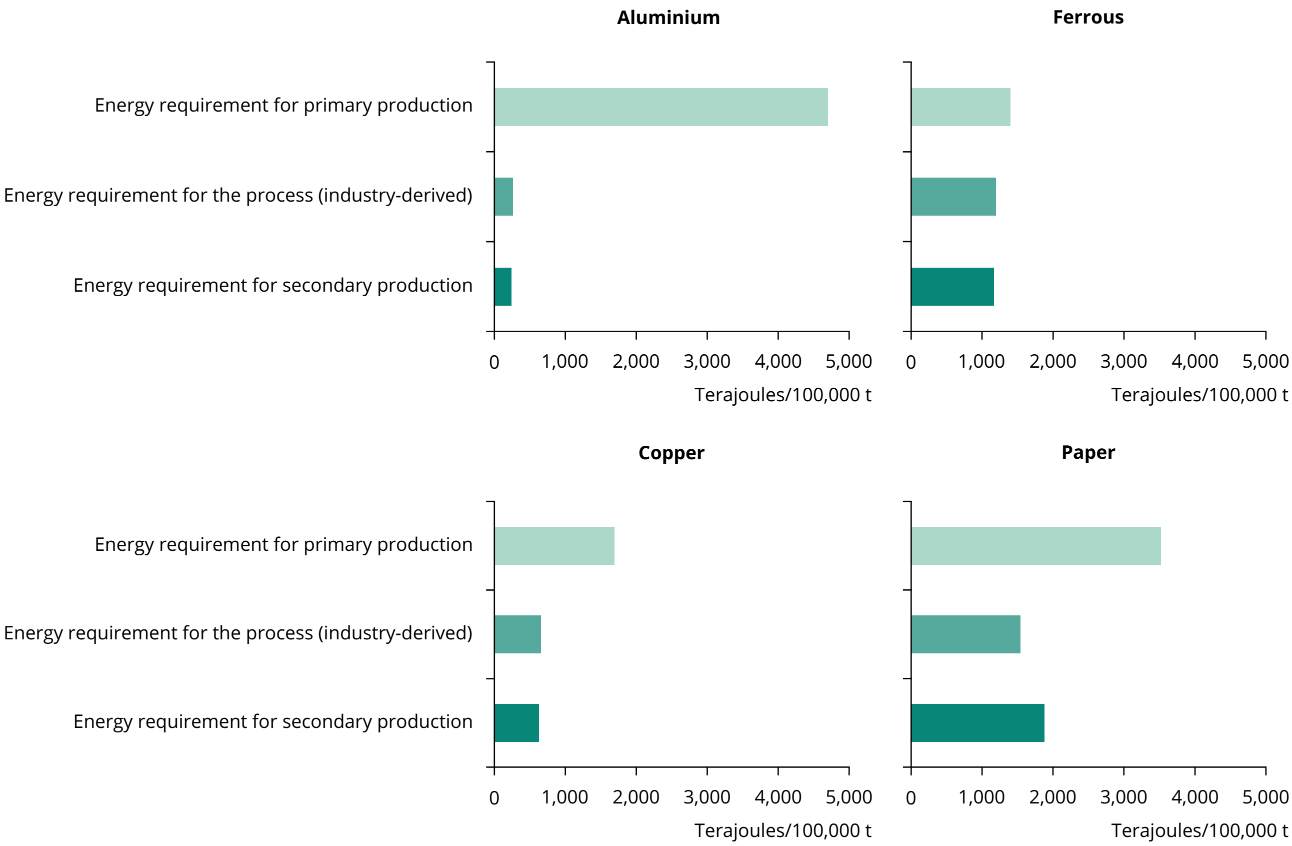
Moreover, the processes that are used to decompose the discarded product give rise to very diverse fractions to be managed at multiple levels of the waste hierarchy. Therefore, the environmental benefits from these waste treatment processes are determined by the extent to which new products, parts, metal alloys, polymers, minerals, fuels and other processed and primary materials are substituted. In some specific cases where the substitution potential is low, the net environmental impact of recycling may even be negative — leading to a net loss, or burdens, in some environmental categories (Zink and Geyer, 2017).

In conclusion, SRM has to be used as substitute for a primary equivalent to have a positive environmental effect. Unfortunately, such 'realised substitution potential' is difficult to measure, and the development of an indicator is still ongoing. As a rule of thumb, the more blending with primary raw materials is required to secure compliance with quality standards and product specifications, the lower the achieved environmental benefit associated with the production and use of SRMs.

The energy and greenhouse gas emissions savings from the circular economy can be seen at different levels, as proposed by Bocken et al. (2016); see also OECD (2017) and Zoboli et al. (2019). The level of interest here is the (increasing) 'closure of the use loops' of resources (waste and materials) through the (increasing) degree of material recycling and energy recovery from waste, and the increase in the reuse of materials and products — including after 're-manufacturing' complex products or their parts (e.g. in the automotive sector).

There is robust evidence that closing the material loop, particularly through recycling, can save resources, energy and emissions with respect to production from primary resources. In a report by BIR (2016), based on careful methodologies and industrial information, the energy and greenhouse gas savings are measured for aluminium, copper, ferrous metals and paper production. In the case of aluminium, the energy and carbon footprint savings achieved by recycling compared with primary production would be, for 100,000 tonnes, 4,434TJ of energy and 627ktCO_2e (CO_2 equivalent) of CO_2 emissions. In the case of copper, for 100,000 tonnes, estimated savings are 1,033TJ of energy and 146ktCO_2e of CO_2 emissions,. In the case of ferrous metal production, for 100,000 tonnes, savings are 206TJ of energy and 29ktCO_2e of CO_2 emissions. Lastly, in the case of paper, for 100,000 tonnes, savings are estimated at 1,979TJ of energy and 280ktCO_2e of CO_2 emissions (Figure A1.1). Scaling these unit savings to the worldwide secondary production of the three metals gives a total savings of 572 million tonnes of CO_2 (Table A1.1).

Figure A1.1 Energy savings from secondary production compared with primary production of aluminium, copper, ferrous metals and paper



Source: BIR (2016).

Table A1.1 Energy and CO_2 emission savings from the secondary production of aluminium, copper and ferrous metals

Material	Energy savings (achieved by industry against primary benchmark) (TJ/100,000t)	Annual worldwide secondary production*	Estimated savings in annual CO^2, emissions (Mt)
Aluminium	4,434	18	63.3
Copper	1,033	6	4.8
Ferrous	206	580	503.9
Total Estimated Savings in Annual CO_2 Emissions for the Production of the Secondary Metal Studied (Current Study)			**572.0**

Note: * Annual worldwide secondary production (Mt) as quoted in 2014 for Aluminium and 2013 for Copper and Ferrous.

Source: BIR (2016).

Although these materials already have high recycling rates, there are additional potential energy and CO_2 emissions savings from further developing recycling chains. For example, in the case of aluminium, large quantities are currently in stock and will be available for recycling in the future. Globally, the increase in new capacity of primary aluminium is low, but the demand for secondary aluminium processing is expected to grow. At present, around 20% of the worldwide demand for aluminium is covered by scrap. Major sources of scrap aluminium are construction and demolition, transport and automotive machinery, mechanical engineering, electrical appliances and packaging. According to Material Economics (2018), 'a more circular economy can make deep cuts to emissions from heavy industry: in an ambitious scenario, as much as 296 million tonnes CO_2 per year in the EU by 2050, out of 530 in total — and some 3.6 billion tonnes per year globally'. This potential can be achieved mainly by material recirculation opportunities (recycling) and by material efficiency, especially in the use sectors.

Waste management, and in particular recycling, can be a relevant source of energy savings compared to other resource-efficient solutions. According to the European Commission (EC, 2016), at the EU level 'enhanced recycling efforts as part of waste management suggest the largest identified CED (cumulative energy demand) reduction potentials, as high as 3,500PJ annually. Reducing food waste offers strong potential for energy savings, too, calculated here with up to 2,000PJ per year. Savings from the food sector might be even higher if a broader set of measures were envisaged, including, for example, reduced meat consumption. By reducing CED by nearly as much, technical and behavioural changes in the water sector could account for up to 1,700PJ per year and annually 73,000Mm^3 of saved water. On the other end of the spectrum, though still contributing to an overall potential CED reduction, minimal CED reductions are offered through improvements in WEEE [waste electrical and electronic equipment] recycling in the ICT sector (up to 1.4PJ per year) and through integrated aquaculture (0.5PJ per year).' (See Table A1.2).

Table A1.2 **Summary of main quantitative results for savings in cumulative energy demand, cumulative raw material demand and water in specific sectors, goods and industrial symbioses**

Case study	CED reduction (PJ/yr)	CRD reduction (1000t/yr)	Water (Mm^3/yr)
Waste management: additional recycling	2,900-3,500		
Domestic water sector: irrigation and industry sectors including behavioural changes	1,060-1,700		73,000
Domestic water sector: irrigation and industry sectors excluding behavioural changes	360-685		64,300
Road construction - reclaimed asphalt	254	56,000	0.1
Buildings - clinker optimisation in building concrete	104	11,000	0
Building - increased wood construction	484	439,000	0.5
Building - increased building rehabilitation and lifetime	619	495,000	0.9
Modal shift in urban transport	60	48,000	0.7
ICT: Thin/ zero clients	510	7,800	19
ICT: Recycling plastics from WEEE	8	4,092	n.a.
Food waste	1,4	23	n.a.
Integrated aquaculture	1,000-2,000		4.7
Ferrous sector	0.5		
Industrial symbiosis for by-products and reused components for computer manufacturing	21		
Industrial symbiosis for fermentation residues from biogas plants as raw material for the woodworking industry	1		

Note: CED = Cumulative energy demand; CRD = Cumulative raw-material demand.

Source: EC (2016).

Annex 2. Examples of quality standards, end-of-waste criteria and user specifications

Fraction	Container glass waste	Paper & cardboard waste	Plastic packaging waste	Steel & aluminium packaging waste	WEEE
Sorting output	• Brown container glass cullet • Green container glass cullet • Clear container glass cullet • Mixed container glass cullet	• Mixed paper and cardboard • Corrugated and kraft • Newspapers & magazines • Other and special grades	• Mono-colour or mixed colour bales or big 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 • Baled steel drums and cans • Baled drinking cartons	• Depolluted appliances • Parts from dismantling (cables, compressors, casings, coils & motors, circuit boards, drives, batteries, etc.)
Sorting output criteria	**BSI/WRAP PAS 101 Untreated cullet** a. Whole or broken containers, colour separated b. Whole or broken containers, colour separated but to a lesser standard c. Whole or broken containers, mixed d. Compacted glass • Contamination limits per grade for ferrous metals, non-ferrous metals and organic material • Inorganic contamination (ceramics, porcelain and stones) subject to negotiation between suppliers and re-processor	**CEPI Classes I to IV** • Mixed grades • Corrugated and kraft • Newspapers & magazines • Other grades	**US Institute of Scrap Recycling Industries (ISRI) baled recycled plastic commercial guidelines (P-2018)** **Plastics Recyclers Europe Bales Characterisation Guidelines** • HDPE Bales • PET Coloured Bales • PP Film Bales • PET Clear-blue Bales • PET Light blue Bales • PE Film Bales • PET Clear Bales	**EN 13920-10:2003 for baled aluminium beverage cans** • Maximum moisture and volatile substance levels • Limited concentrations of silicon and a series of metallic impurities • Metal yield >88% • Free from burnt or oxidised cans and aluminium foil **EN 139205-14:2003 and EN 139205-15:2003 for used aluminium packaging** • <5% of steel packaging • Free from plastic, paper and blister packs • <60% of volatile components	**EN 50574 on WEEE containing volatile fluorocarbons or volatile hydrocarbons collection** **TS 50574-2: Specification for WEEE containing volatile fluorocarbons or volatile hydrocarbons — Part 2: specification for de-pollution** **EN 50625-1: WEEE general treatment requirements** **TS 50625-3-2: WEEE specification for de-pollution — lamps** **EN 50625-2-2: Treatment requirements for WEEE containing CRTs and flat panel displays**

Fraction	Container glass waste	Paper & cardboard waste	Plastic packaging waste	Steel & aluminium packaging waste	WEEE
Sorting output criteria	**CEN/TC 261/SC 4/ WG 3 Material recovery** • All contaminants <5% • Ceramics, porcelain and stones <10mm <0.01% • Total ceramics, porcelain and stones 0.25% **US Institute of Scrap Recycling Industries (ISRI) container glass cullet specification (GC-208)**	**EN 643 European List of Standard Grades of Paper and Board for Recycling** • 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	**Specifications Deutsche Gesellschaft für Kreislaufwirtschaft und Rohstoffe (DKR)** • PET (DKR 328-1) • PE (DKR 329) • PP (DKR 324) • Film (DKR 310) • EPS (DKR 340) • Mixed plastics (DKR 350)	**Council Regulation (EU) No 333/2011 EoW aluminium scrap** • Maximum levels of combustible non-metallic materials • Free from polyvinyl chloride (PVC) in form of coatings, paints, plastics **EoW iron and steel scrap: technical proposal on tin-coated packaging scrap** • Excessive moisture, metallic copper, tin devices (and alloys) and lead (and alloys) • Minimum concentrations of free iron or alloy, or of metallic packaging **European Steel Scrap Specifications** **Standard classifications of national industry associations** **US Institute of Scrap Recycling Industries (ISRI) non-ferrous scrap guidelines (NF-2018)** **US Institute of Scrap Recycling Industries (ISRI) ferrous scrap** guidelines (FS-2018) **ASTM E 1134: 1986 Specification for source-separated steel cans**	**TS 50625-3-3: Specification for de-pollution — WEEE containing CRTs and flat panel displays** **EN 50625-2-3: Treatment requirements for temperature exchange equipment** **TS 50625-3-4: Specification for de-pollution — temperature exchange equipment** **EN 50625-2-4: Treatment requirements** for photovoltaic panels **TS 50625-3-5: Specification for de-pollution — photovoltaic panels** **TS 50625-4: Specification for the collection and logistics associated with WEEE** **TS 50625-5: Specification for the end-processing of WEEE fractions — copper and precious metals**

Fraction	Container glass waste	Paper & cardboard waste	Plastic packaging waste	Steel & aluminium packaging waste	WEEE
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 • Aluminium foam • Low-carbon steel • Fibres	• Aluminium scrap, ferrous scrap, copper scrap, circuit boards • PP, PE, PS, ABS and mixes thereof • Glass and mineral fractions
Recycling output criteria	**BSI PAS 102 Specifications for processed glass for selected secondary end markets** • Total contaminant (organic, inorganic, ferrous/non-ferrous metals) • Particle size distribution • Colour requirements • Other requirements		**EN 15342 Characterisation of polystyrene (PS) recyclates** **EN 15345 Characterisation of polypropylene (PP) recyclates** **EN 15346 Characterisation of poly(vinyl chloride) (PVC) recyclates** **EN 15347 Characterisation of plastics wastes** **EN 15348 Characterisation of polyethylene terephthalate (PET) recyclates** **EN 15344 Characterisation of polyethylene (PE) recyclates**	**American National Standard Alloy and Temper Designation Systems for Aluminum 2017 ANSI H35 standards** **Aluminium 3004 Specifications** • ASTM B209 • ASTM B221 • ASTM B313 • ASTM B547 • ASTM B548 • SAE J454 • UNS A93004	**US Institute of Scrap Recycling Industries (ISRI) electronics scrap guidelines (ES-2018)** • EM1: Eddy-Current (EC) Aluminum • EM2: Eddy-Current (EC) Scrap • EM3: Circuitboards and Shredded Circuitboards from the Processing of End-of-Life Electronics • Electronics Scrap Glass and CRT Cullet Specifications • Electronics Scrap Plastics Baled Specs • Electronics Scrap Plastics Shredded Specs

Note: ABS, acrylonitrile butadiene styrene; ASTM, ASTM International; CRT, cathode ray tube; EoW, end-of-waste; EPS, expanded polystyrene; HDPE, high-density polyethylene; LDPE, low-density polyethylene; PE, polyethylene; PET, polyethylene terephthalate; PP, polypropylene; PS, polystyrene; r, recycled (e.g. rPET); WEEE, waste electrical and electronic equipment.

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