European Commission

ISSN 2443-8022 (online)

Circular Economy: Main features and Key Determinants of the EU Secondary Markets for Materials

Lucia Vergano

DISCUSSION PAPER 209 | JULY 2024

EUROPEAN ECONOMY

Economic and Financial Affairs

European Economy Discussion Papers are written by the staff of the European Commission's Directorate-General for Economic and Financial Affairs, or by experts working in association with them, to inform discussion on economic policy and to stimulate debate.

Authorised for publication by Maarten Verwey, Director General for Economic and Financial Affairs.

This paper exists in English only and can be downloaded from
https://economy-finance.ec.europa.eu/ecfin-publications_en.

Luxembourg: Publications Office of the European Union, 2024

PDF ISBN 978-92-68-01827-9 ISSN 2443-8022 doi:10.2765/903804 KC-BD-23-026-EN-N

CREDIT
Cover photography: © iStock.com/g-stockstudio

European Commission

Directorate-General for Economic and Financial Affairs

Circular Economy: State of Play and Key Determinants of the EU Secondary Markets for Materials

Lucia Vergano

Abstract

Social acceptance is growing about the need for moving from a linear to a more circular use of resources. This allows for lowering raw material consumption and waste generation, while reducing the EU resource and energy dependence from abroad, which has become economically and geo-strategically important.

The EU circular economy could further expand by fostering waste prevention and preparing for re-use. Despite recent improvements in waste management capacity, the EU circularity could also benefit from enlarging secondary markets by feeding back more secondary raw materials into the economy. However, materials' specific features and/or economic and technological constraints might limit recycling capacities.

Therefore, understanding the economic drivers of recycling is key for defining effective and efficient policy measures. These range from regulation (e.g. specific technological or performance standards including waste collection/sorting methods and eco-design) to market-based instruments, whether price- (e.g. taxes and charges, subsidies and public facilities) or quantity-based (e.g. cap-and-trade), or both. The optimal policy mix design may nevertheless vary according to a range of economic, social, cultural, political and institutional factors. Specific policy interventions promoting recycling encompass a possible review of the EU waste hierarchy, a broader eco-design and a harmonised waste legislation, data definition and collection.

JEL Classification: Q30, Q53, Q58.

Keywords: circular economy, recycling, waste hierarchy, secondary markets for materials.

Acknowledgements: This brief benefited from valuable comments by Åsa Johannesson Linden, Géraldine Mahieu Peter Voigt, Alessio Terzi and Florian Flachenecker. It also benefited from the inputs received by Arnaud Mercier, Madgalena Spooner, Barbara Bacigalupi, Cristina Corsini, Oscar Gomez Prieto and Joanna Sulik.

Contact: Lucia Vergano, lucia.vergano@ec.europa.eu, European Commission, Directorate-General for Economic and Financial Affairs, B.4 Economics of Resilience and Transition Unit.

CONTENTS

Introduction 3

1. Recycling and the circular economy 3

2. Recycling and the EU waste hierarchy 5

3. Recycling and the EU circular economy: overview 7

4. The economics of recycling 12

 4.1 The economic drivers of recycling 12

 4.2 Main policy instruments to support recycling 14

5. The EU secondary markets for materials/ products 15

 5.1 Main features of selected eu secondary markets for materials/products 15

 5.2 Main barriers to the eu secondary markets for materials/products 18

6. Policy conclusions 23

REFERENCES 25

ANNEX I – Recyling and the EU circular economy: selected secondary markets 28

ANNEX II – EU quantitative targets for the circular economy 40

GRAPHS

BOX 1 RECYCLING AND THE EU WASTE FLOWS……………. 10

BOX 2 CRITICAL RAW MATERIALS (CRMS)… 16

BOX 3 EXAMPLES OF SELECTED EU SECONDARY MARKETS FOR PRODUCTS AND COMPONENTS… 21

INTRODUCTION

In recent years, the concept of circular economy has gained growing attention from policy makers, researchers and businesses. Rising pollution and climate change require limiting anthropogenic pressures on the environment by rethinking production and consumption activities towards a more sustainable economy and society. Reducing the EU resource and energy dependence from abroad has in addition become economically and geo-strategically important.

However, improving the circularity of the EU economy requires changes in both production and consumption patterns. On the one hand, expanding material and product eco-design is essential to allow to reuse, refurbish/remanufacture and recycle products and components. On the other hand, individuals should as much as possible shift their consumption towards sustainable products, i.e. reusable, recycled or recyclable products.

In this context, the policy framework plays a relevant role by providing regulatory and economic incentives to foster the transition from a linear to a circular economy. To be effective, policy measures must nevertheless be targeted and reflect the features of both existing and potential secondary raw materials markets. Therefore, knowing the main factors driving or hindering the development of secondary raw materials markets is key for policy making.

This note discusses the state of play and key determinants of EU secondary markets for materials and products/components. The aim is to understand whether the economic potential of secondary markets is currently fully exploited, or whether these markets could be further developed to increase the circularity in the EU economy.

Section 1 briefly explains the role recycling plays in the circular economy. Section 2 illustrates the role recycling plays in the EU waste hierarchy, on which the EU waste policy builds. Section 3 highlights the recent trends in recycling and the dimension of the EU circular economy based on the available empirical evidence. Section 4 reviews the main economic drivers of recycling and the main policy instruments to promote recycling. Section 5 briefly depicts the characteristics of the main EU secondary markets (glass, paper and cardboards, rubber, plastic, wood, textiles, batteries, vegetable waste, ferrous and non-ferrous metallic waste and waste electrical and electronic equipment (WEEE)) and identifies the main barriers for their functioning. Section 6 draws some policy conclusions, by identifying the main areas for intervention and possible solutions. Annex I provides additional data on the selected EU secondary markets analysed in Section 5. Annex II lists current quantitative EU policies' targets for the circular economy.

1. RECYCLING AND THE CIRCULAR ECONOMY

A circular economy is commonly identified as a restorative or regenerative system promoting a responsible and cyclical use of resources to reduce the environmental burden. Although a broadly accepted and precise definition is still lacking (Mayer et al., 2019), a *circular model*[1] is rooted into a *life-cycle approach*, in which the entire life cycle of a product/service is considered, from raw materials extraction and product manufacturing through use and maintenance to end-of-service-life treatment (Vezzoli, 2014). Therefore, circularity implies extending the value and utility of products and materials, by minimising waste production and using waste as secondary resource (Moraga et al., 2019). In this respect, the circular model is opposed to the *linear 'take-make-dispose' model*, in which

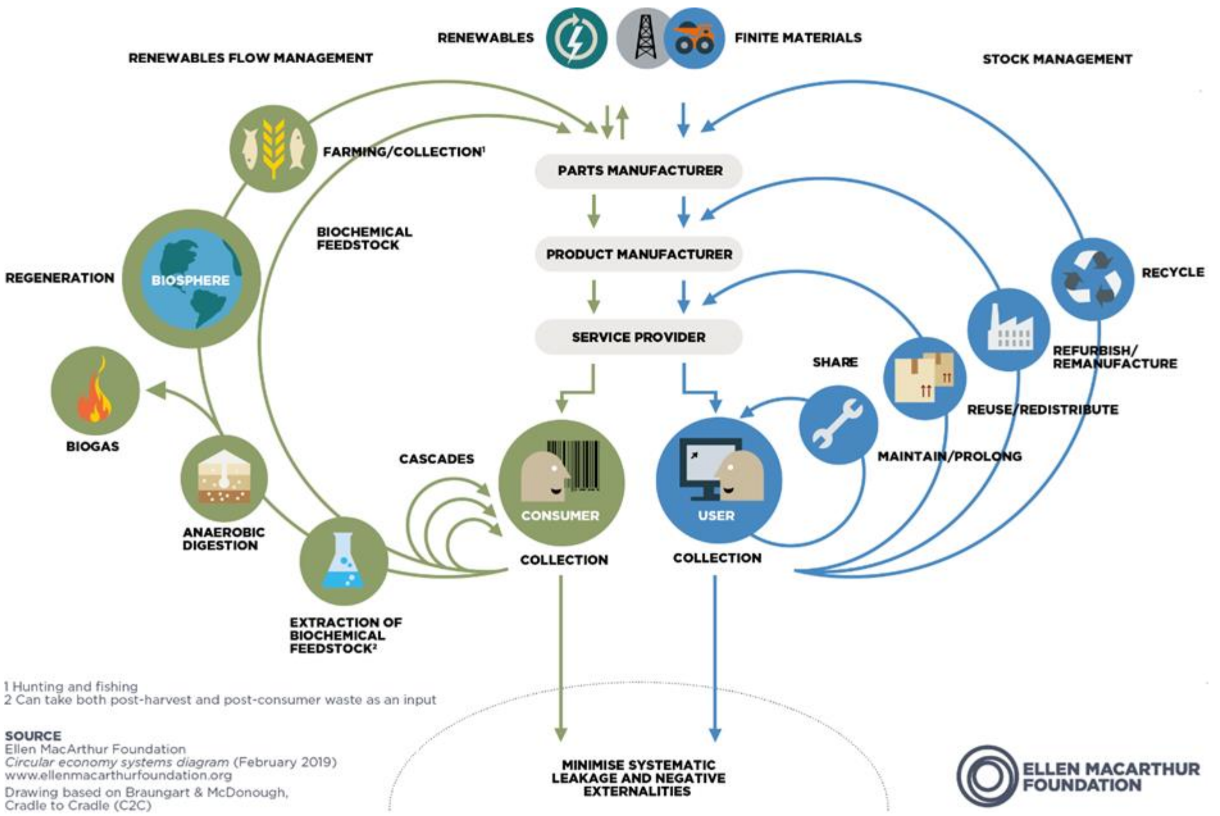
[1] The concept builds on the spaceship theory (Boulding, 1966), according to which the earth is a circular system with no exchanges of matter with the outside environment.

companies harvest and extract materials, use them to manufacture a product and sell the product to consumers who then discard it when it no longer serves their purposes.

Recycling is one of the activities contributing to the circularity of the economy, by reducing the overall resources depletion and waste generation. *Recycling* means transforming discarded materials, i.e. waste, so as to use them as input for new products (Kopsidas and Giakoumatos, 2021). It is possible to distinguish between different types of recycling, depending on the quality of the recycled material and its possible use. *Functional recycling* is the process of recovering materials for the original purpose or for other purposes, excluding energy recovery. *Up/Downcycling* is usually defining the process of converting materials into new materials of higher/lesser quality and increased/reduced functionality. All these processes[2] ensure a reduction of raw materials consumption and pollution, and ultimately contribute to optimising waste management. Replacing natural resources with secondary raw materials as inputs to production allows for reducing the pressure on the environment through a lower extraction of natural resources, lower emissions into the environment and a lower overall amount of waste for recovery and disposal, thereby avoiding incineration and landfilling.

However, from a circular economy approach recycling is not always the best option. Although often less than other options for waste handling, also recycling impacts on the environment by collecting, sorting and processing materials. In addition, it is less effective in limiting raw materials consumption and reducing waste creation than other material/product uses after end-of-life.

Figure 1: **Ellen MacArthur's circular economy butterfly diagram**



[2] Composting is also a form of recycling, through which biological nutrients naturally return to the soil. For a biological process, microorganisms (e.g., bacteria and fungi), insects, snails and earthworms break down organic materials (such as leaves, grass clippings, garden debris, and certain food wastes) into a soil-like material called compost.

In addition to recycling, other options provide valuable, and sometimes even preferable, alternatives to still use materials and components and/or extract energy from them after their end-of-life, depending on the quality of waste. As Figure 1 shows, when products or components after use are still in good quality for the same purpose for which they were originally conceived, in their original form or with little enhancement or change, they can be used again (*reusing*). When the original quality is instead damaged, it is not possible to directly use again the original product or component. However, product quality can be restored by replacing or repairing its major components (*refurbishment*), but its performance may be less than as new. In addition, functioning, reusable components can be taken out of a used product and rebuilt into a new one (*remanufacturing*), after possible enhancements or changes to ensure quality if needed. Non-recyclable waste can in some cases[3] be converted into useable heat, electricity or fuel through a variety of so-called waste-to-energy processes, including combustion, gasification, pyrolysis, anaerobic digestion and landfill gas recover (*energy recovery*).

Reusing is more effective than refurbishment, remanufacturing and recycling in reducing waste creation. Moreover, it is also more energy efficient, as it does not require modifying the physical properties of materials.

2. RECYCLING AND THE EU WASTE HIERARCHY

Together with other forms of waste handling, recycling plays a relevant role in the waste hierarchy approach. The waste hierarchy is a conceptual framework establishing an order of priority in waste handling. Its guiding principle is to reduce waste generation and opt for forms of waste treatment, including recycling, reducing adverse environmental impacts and improving resources efficiency. Therefore, it is a useful tool to understand when recycling is the best option for waste handling.

Figure 2: **The EU waste hierarchy**

Source: European Commission (2023).

The *EU waste hierarchy* is a powerful tool to support circularity and is at the heart of the EU waste policy. The EU Waste Framework Directive (European Union, 2008) introduced the EU waste hierarchy establishing a five-stage order of priority in waste handling from the most preferred option of

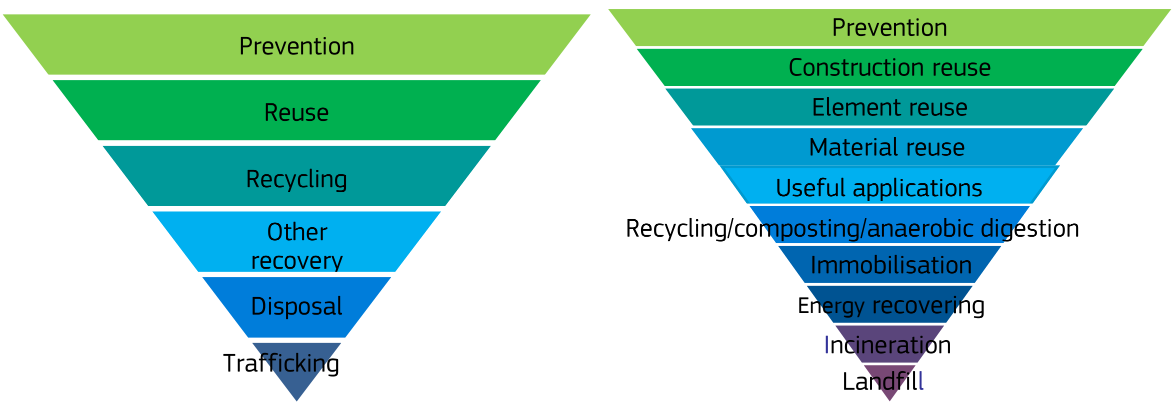
[3] To be aligned with a circular approach, energy recovery should be an option only for truly non-recyclable waste.

"prevention" to the least preferred option of "disposal"[4] (Fig. 2). Recycling[5] is not the overall preferred option, but it becomes so when prevention and preparing for re-use are not suitable. Waste disposal is the least preferred option, when all the others are not feasible. In this respect, the EU waste hierarchy promotes the circular use of natural resources.

However, amendments to the EU waste hierarchy have been proposed to optimise waste handling and the use of natural resources. Despite the already existing flexibility in applying the EU waste hierarchy[6], a first proposal adds waste trafficking at the bottom of the hierarchy to consider also illegal waste trade (Figure 3.a). Illegal dumping and stockpiling are still common practices especially in some, often developing, countries, leading to risks to human health and environmental hazards (Zhang et al, 2022). Another proposal replaces the waste hierarchy with a hierarchy of resource use, to ensure that the resource value is better preserved, by better refining the concept of recovering, including reprocessing (figure 3.e). Figure 3.f shows instead how the EU waste hierarchy might be modified to move from waste management to resource management.

Additional amendments have been proposed also to tackle the features of specific types of waste and to consider technological development in waste treatment. Conceived for any type of waste, the EU waste hierarchy has limits in reflecting the specific features of some types of waste. For instance, anaerobic digestion is environmentally more suitable for food than composting and other recovery options; dry anaerobic digestion followed by composting is environmentally more suitable than composting alone for garden waste and for mixtures of food waste, and energy recovery options are more suitable than recycling for lower grade wood[7] (Defra, 2011). Figure 3.c shows how the waste hierarchy could be adjusted to reflect the specific features of this type of waste. Amendments have been conceived also for other waste categories, e.g. construction and demolition waste, and WEEE (Figure 3.b and 3.d). For WEEE, sustainable design is particularly relevant for reducing waste.

Figure 3: **Proposed amendments to the EU waste hierarchy**



a) All waste

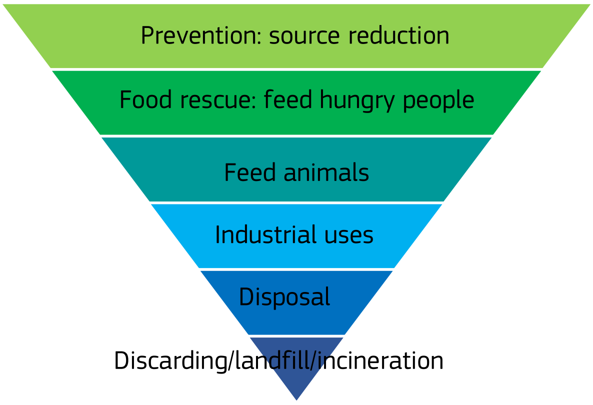
b) Construction and demolition waste

[4] This approach builds on the 1975 Council Directive on Waste (European Union, 1975), distinguishing the methods for waste management between "reduction in quantities of waste" and "disposal via recycling and re-use, via recovery and via storage and underground"; the order of preference the Dutch politician Ad Lansink proposed in 1979 for waste management and resource conservation options from "reduce" at the top to "landfill" at the bottom ("Ladder of Lansink") and the 1991 Council introducing the concepts of "disposal" and "recovery", together with "prevention or reduction" and "recovery" as optional priorities Directive (European Union, 1991).

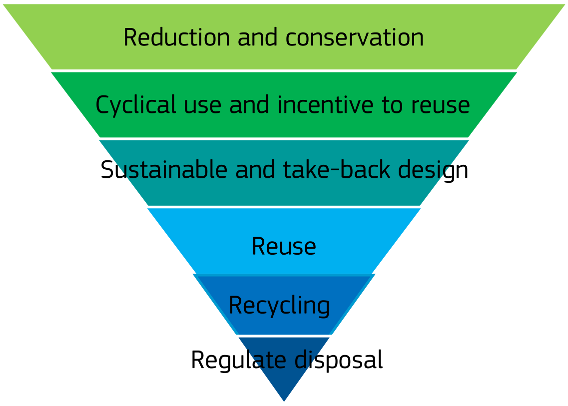
[5] As Art. 4 of the Waste Framework Directive specifies, "recovery" refers to other forms of waste recovery, being recycling one of them.

[6] Art 4(2) of the Waste Framework Directive already gives to Member States some flexibility in allowing to opt for the options delivering the best overall environmental outcome based on a life-cycle approach, even if this may imply a departure from the hierarchy.

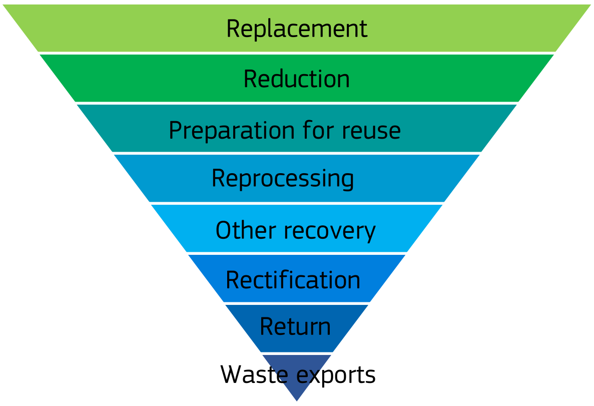
[7] Wood is classified according to some quality criteria in different grades.



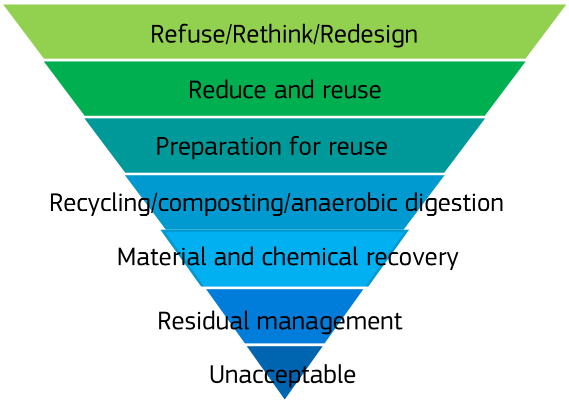
c) Food waste



d) WEEE



e) All waste



f) All waste

Source: Zhang et al (2022).

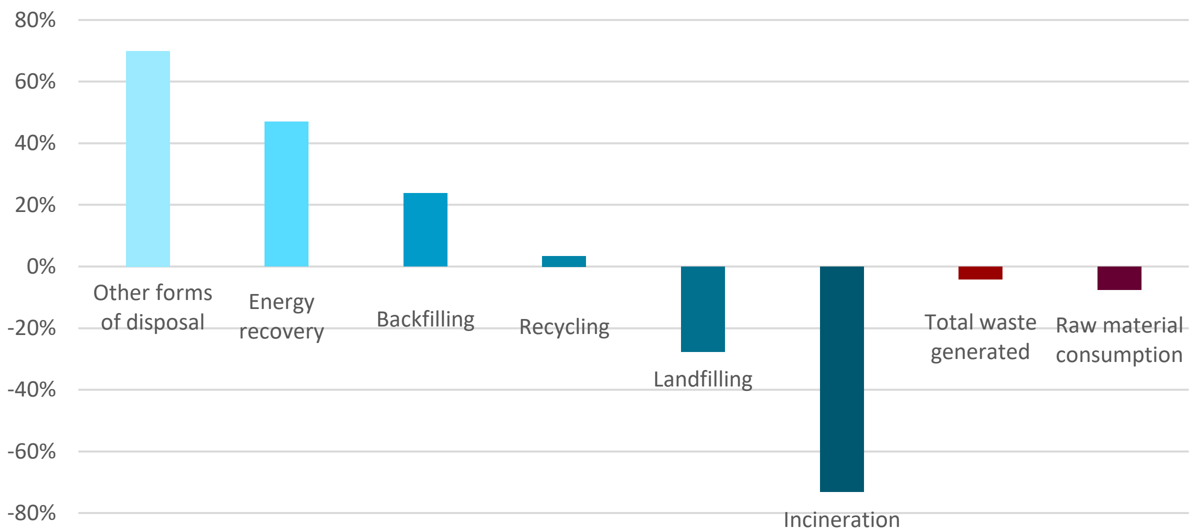
3. RECYCLING AND THE EU CIRCULAR ECONOMY: OVERVIEW

In the last decade, behavioural changes and technological development has made recycling more profitable. From the one side, individuals, public institutions and businesses are getting used to separate the waste they produce. From the other side, businesses are using more and more recycled input in their activities and are designing their products so that it is easier to recycle them. Technological developments are driving this process and the quality of secondary materials is improving. Furthermore, technological developments and adapted product design allow businesses also to expand products and components' recycling.

In addition, the EUs' internal market for secondary raw materials registered positive developments, showing that EU businesses are further reaping the benefits from circularity. Between 2010 and 2023, the intra-EU trade of recyclable raw materials expanded by almost 19%, mainly driven by wood, copper, aluminium, nickel, and ferrous metals. However, it represented only a limited, although slightly increasing, share of GDP (from 0,26% in 2020 to 0,46% in 2023).

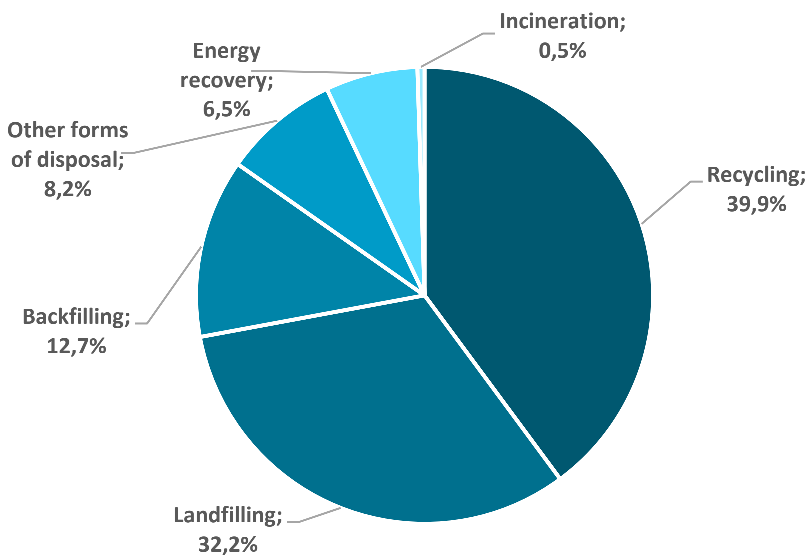
However, the contribution of recycling to the EU circular economy did not significantly improve. Between 2010 and 2020, the total *waste recycled per capita* only slightly increased (3,4%, Graph 1), reaching almost 40% of the waste treated[8] (Graph 2). As already highlighted, an increase in recycling is not necessarily positive per se, as in a perfectly circular economy repairing and reusing should limit as much as possible raw material consumption and the need to recycle. At the same time, the *raw material consumption per capita* and the volume of *waste generated per capita* only slightly slowed down (-7,5% and about -4%, respectively, Graph 1). In addition, *the end-of-life recycling input rates*, which measures, for a given raw material, how much of its input into the production system comes from recycling of end-of-life products, was limited, especially for rare-earth elements like lithium, gallium and neodymium (around 1% in 2022), but for raw materials used in batteries as well (16% for nickel and 22% for cobalt in the same year).

Graph 1: **Waste trends (2010-2020), variation in kg/per capita**



Source: author's elaboration based on Eurostat data (2024).

Graph 2: **Waste recovery and disposal as share of waste treated (2020)**

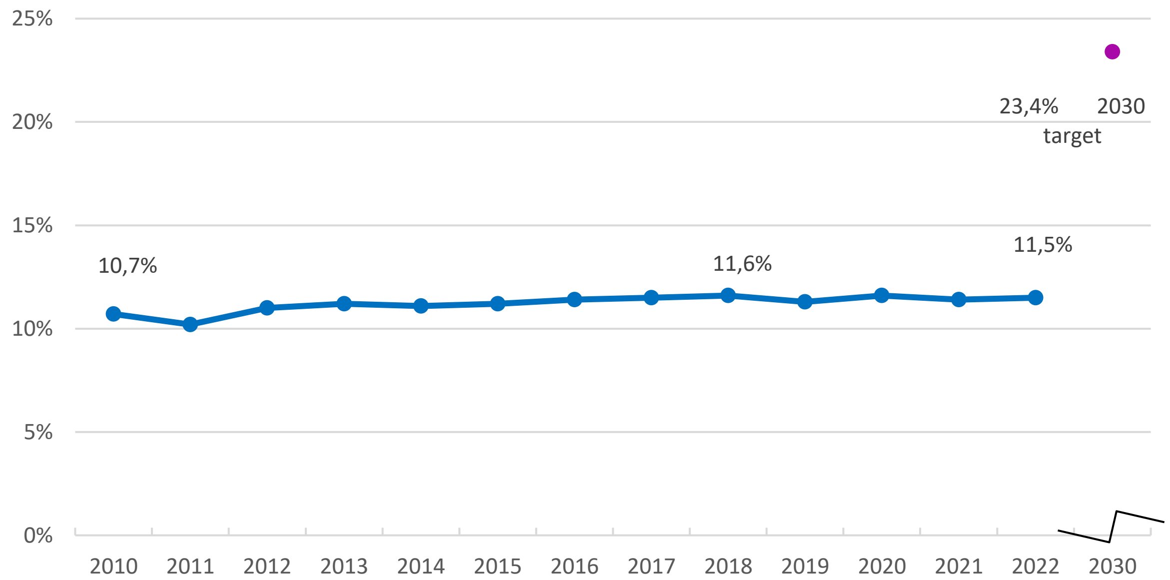


Source: author's elaboration based on Eurostat data (2024).

[8] Total waste recycled is expressed as share of total waste treated as data for waste collected are not available.

Therefore, in the next few years stronger progress is needed to meet the EU 2030 target for circularity. The total share of material recycled and fed back into the EU economy, i.e. the circular use of materials[9] in overall material use, known as the *circular material use rate* or the *circularity rate* (Graph 3), should more than double to reach the 23.4% 2030 target (DG ESTAT, 2024). The limited circular use of materials is explained also because some materials, especially minerals, are used in long-life goods like buildings and infrastructure and therefore they are not easily available for recycling and reuse. Furthermore, a large share of materials, especially fossil fuels, is burnt for energy generation and therefore not recyclable.

Graph 3: **Circular material use rate (%)**



Source: author's elaboration based on Eurostat data (2024).

Increasing the volume of *waste treated* could further expand recycling and thus improve the circularity of the EU economy, while reducing the EU's dependence on material imports and hindering illegal waste. Between 2010 and 2020, the volume of waste treated (Box I) as share of waste generated was stable at already high levels (around 91,5%). Further expanding it by increasing the treated share of waste collected could at least partially strengthen the EU's capacity to meet its demand for recycling, especially for some materials, thus boosting the EU's resilience and competitiveness (see Box 2). Despite significant decline (almost 35%), the EU was still a net importer of recyclable raw materials from extra-EU countries (around 8,5 Kg/per capita in 2021). This implies that the EU was not able to internally meet the demand for recyclable raw materials to satisfy its domestic demand for secondary raw materials. Either the EU recycling capacity was able to absorb more than the waste recyclable raw materials domestically produced or the imported recyclable raw materials were cheaper than those domestically available. Further increasing the volume of treated waste could also reduce the amount of illegal waste (Box 1), which was stable at around 8.5% over the considered period. This represents not only an economic loss, but possibly also a threat for human health and the environment in case of hazardous waste.

Improving the circularity of the EU economy also requires a decrease in alternative treatments for waste recovery and disposal. Between 2010 and 2020, *total waste backfilled* considerably expanded (almost 24%, Graph 1), reaching in 2020 about 13% of total waste treated per capita (Graph 2). In the same period, *total waste used for energy recovery* registered a higher increase

[9] The circular use of materials is approximated by the amount of waste recycled in domestic recovery plants minus imported waste destined for recovery plus exported waste destined for recovery abroad.

(almost 47%, Graph 1)[10], while representing in 2020 a limited share of the waste treated per capita (6,5%, Graph 2). After a drastic drop (around 73%, Graph 1), in 2020 the share of *total waste used for incineration* was negligeable (0,5%, Graph 2). This is a positive achievement, as incineration, including for energy recovery, can result in the emission of dioxins and other atmospheric pollutants, thus contributing to global warming. Despite a considerable decrease during the previous ten years[11] (almost 28%, Graph 1), in 2020 the *total waste landfilled* as share of total waste treated per capita was instead overall still high (32,2%, Graph 2). Once waste generation is minimised, a circular approach would instead require reducing as much as possible the share of landfilled waste, which is the waste management option with the highest adverse environmental impacts.

As a matter of fact, the *EU circular economy* is still limited and its economic potential is not fully exploited. In 2021, the EU circular economy represented only around 2% of total EU GDP, 2% of total employment and attracted investment in tangible goods corresponding to 0.8% of GDP. However, these figures only partially capture the dimension of the real circularity of the EU economy, as they do not consider the physical flows of materials, recycled materials, repaired goods, waste reductions and other variables separately captured by other specific indicators.

BOX 1 **– RECYCLING AND THE EU WASTE FLOWS**

According to the EU waste statistics, recycling is one of the available operations for waste treatment. Therefore, it comes at the end of waste life. Figure B.1 shows the place of recycling within the overall waste flows, from waste generation to waste recovery/disposal.

The waste resulting from households' consumption and production activities together with the by-product of waste treatment, also known as secondary waste, is referred to as waste generated. The amount of waste generated which is collected (waste collected) can either be exported (waste exported) or treated together with the waste imported. The waste treated can be either recovered or disposed. Waste recovery includes energy recovery, recycling and backfilling[1], while waste disposal covers incineration, landfilling and other forms of disposal[2]. Energy recovery differs from simple waste incineration because the energy generated while incinerating waste in power stations and industrial facilities is used to produce heat or electricity[3].

However, the waste resulting from households' consumption and production activities can also become illegal waste. This, if not exported (waste illegally exported), together with waste illegally imported can be illegally treated (waste illegally treated). This implies an economic loss proportional to the market value of the waste taken away from the formal economy. In addition, it might also imply serious threats for the environment and human health in case of hazardous waste.

Both waste exported and waste imported include also recyclable raw materials. These are waste raw materials and by-products for selected categories1 that given their quality and the available technologies can be recycled. As any other type of recyclable waste, once recycled they are re-injected into the economy and they are usually referred to as secondary raw materials. Exporting recyclable raw materials may result from a limited recycling capacity and/or a too expensive and therefore not economically profitable available recycling technology in the EU. Importing recyclable raw materials may instead be necessary when the recycling technologies available in the EU are economically efficient, but the EU recycling capacity can absorb more than the domestic supply of recyclable raw materials to meet the domestic demand. A low domestic supply can be driven by a limited amount of waste collected, resulting from a limited amount of recyclable raw materials generated and/or an inefficient waste collection system, possibly due also to households and businesses being incompliant with the existing obligations of waste sorting.

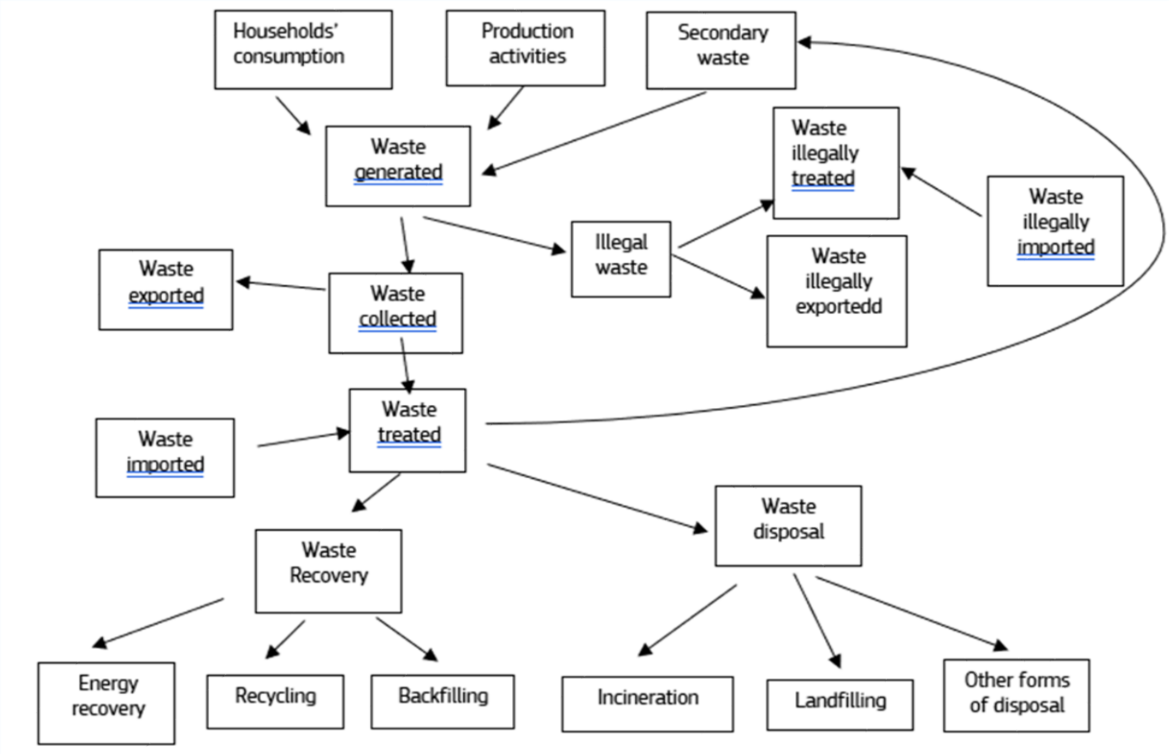
[10] This increase also reflected legal changes on definitions.

[11] Since the EU landfill Directive (European Union, 2006), no rubber waste has been landfilled.

BOX 1 – continuation

Recycled materials, including secondary raw materials, can both be imported and exported, but they are not shown in Figure B.1 as they are not classified as waste.

Figure B.1: **Waste flows**



Source: author's elaboration based on DG ESTAT (2024, forthcoming).

[1] The recovery operation where suitable waste is used for reclamation purposes in excavated areas or for engineering purposes in landscaping and where the waste is a substitute for non-waste materials (European Commission, 2011).

[2] These include land treatment (e.g. biodegradation of liquid or sludgy discards in soils, etc.), deep injection (e.g. injection of pumpable discards into wells, salt domes or naturally occurring repositories, etc.), surface impoundment (e.g. placement of liquid or sludgy discards into pits, ponds or lagoons, etc.), release into a water body except seas/oceans, release into seas/oceans including sea-bed insertion.

[3] To be classified as energy recovery, the incineration of waste must also meet some specific criteria, as specified by the EJC's rulings in the cases C-228/00 and C-458/000.

4. THE ECONOMICS OF RECYCLING

4.1 THE ECONOMIC DRIVERS OF RECYCLING

Recycling rates mainly depends on the relative price of secondary raw materials with respect to virgin raw materials, resulting from a number of economic drivers. Understanding such drivers is key to allow secondary markets for materials/products to reach their optimal size and thus contribute to the functioning of the EU internal market.

A first driver is the *scarcity of raw materials/new products* as reflected in their market prices. A limited raw material/new product availability is usually reflected in higher prices, thus making waste recycling more desirable (e.g. metallic waste and especially CRMs, WEEE, batteries), if technologically feasible at competitive prices. However, this is not always the case, as sometimes prices do not correctly reflect natural resources' scarcity (*market failures*), leading to a suboptimal resources' depletion rate (over depletion) and consequently to a suboptimal recycling rate (under recycling). This typically happens when depletion choices are made without considering either the needs of future generations or the environmental impact of resources' extraction (*negative externality*).

A second driver is the *volume of available waste material/product*, which impacts on the economic profitability of recycling. Unit costs of recycling typically decrease when the supply of waste material increases (*economies of scale*). This is for instance the case of recycling rates for metals, for which nevertheless also other factors matter, i.e. product eco-design[12]. Unit costs of recycling instead increase when the number of different recyclable materials and applications increases (*diseconomies of scope*). This is for instance the case of some rare materials used in small quantities in complex products like batteries and mobile phones.

Another driver of recycling rates is the *availability of recycling technologies* ensuring an efficient and environmentally friendly process providing good quality secondary material/recycled product. Plastics, batteries[13], textiles, metallic waste and WEEE recycling would benefit from further technological improvements for recycling. In addition, progress in manufacturing and artificial intelligence are promising also for extending material/product life/use, by e.g. repairing and/or replacing worn parts of products with 3D printed ones (EIB, 2020).

***Recycling capacity*, i.e. suitable industrial facilities for fully/further exploiting the available recyclable waste, also drives recycling rates by allowing for economies of scale**. In some cases, the EU instead lacks such facilities, leading to under recycling (see Section 5.2).

Recycling rates, as well as the circular material user rate, depend also on the *demand for recycled materials/products*, which reflects their market prices. Producers and consumers more likely opt for recycled materials/products if their prices are competitive with respect to the ones of raw materials/virgin products. Such prices reflect both the availability of cost-effective recycling technologies and a scaled recycling capacity. However, the lack of data on both the EU demand for recycled materials/products and their market prices prevent from any further analysis.

The *environmental footprint* of recycling is another driver of recycling rates. Depending on the efficiency of the disposal and storage facilities, recycling is usually less energy and emissions intensive than natural resources' extraction and consumption goods' production (van Beukering et al., 2014).

[12] Recycling rates are usually higher when materials are used in large quantities in easily recoverable applications like lead in batteries or when they have a higher value (van Beukering et al., 2014).

[13] For instance, a recent innovative recycling process combining the benefits of hydrometallurgical and direct recycling technologies (Ma et al., 2021) preserves the quality of lithium-ion batteries made with recycled cathode materials.

Based on available data, *energy savings* range from 47% for paper to 99% for textiles, while *CO2 emissions savings* range from 18% for paper to 98% for textiles (Table 1).

***International trade* is another factor impacting on recycling rates**. As recycling costs and benefits differ across countries, international trade contributes to an efficient allocation of recyclable waste, while bridging domestic gaps between demand and supply of recyclable materials (van Beukering et al., 2014). For net exporters, either the domestic demand for recyclable raw materials to produce secondary raw materials cannot fully absorb the domestic supply of recyclable waste, or it is economically more profitable to export as international prices of recyclable raw materials are higher than domestic ones. For net importers, either the domestic supply of recyclable raw materials does not satisfy the domestic demand to produce secondary raw materials, or imported recyclable raw materials are cheaper than domestic ones. However, international trade often entails a flow of low quality recyclable raw materials from industrialised countries, richer in capital and recyclable resources, to developing countries, richer in labour and natural resources, but with lower income and therefore with higher demand for low quality, cheap materials for domestic manufacturing. Unfortunately, international trade is sometimes also driven by waste dumping in countries with laxer environmental regulations, more likely developing countries (waste haven effect)[14].

Additional drivers for recycling are *policy measures*, which aim at either promoting more circular production/consumption behaviours or discouraging less circular production/consumption behaviours, while raising public awareness about health and environmental impacts of waste disposal. Policy intervention is typically needed to correct for market failures leading to sub-optimal recycling.

Table 1**: Energy and CO2 emissions savings from materials' recycling with respect to primary production**

Materials		CO_2 emissions savings	Energy savings
Metals	Aluminium	92%	95%
	Steel	98%	72%
	Copper	65%	85%
Paper		18%	47%
Glass		87%	82%
Plastics	HDPE[1]	89%	89%
	PET	70%	83%
Textiles		98%	99%
Tyres		88%	85%

Note: [1] HDPE stands for High-Density Polyethylene and PET for Polyethylene Terephthalate.

Source: EuRIC (2019).

[14] The recently revised Regulation on waste shipments aims at ensuring that the EU takes greater responsibility for its waste and does not export its environmental challenges to third countries (European Union, 2024).

4.2 MAIN POLICY INSTRUMENTS TO SUPPORT RECYCLING

Policy measures to support waste recycling can mainly take the form of either regulation or market-based instruments, or both. The EU policy also apply *targets* to induce policy action at Member State level, e.g. minimum recycling rates for packaging waste, batteries and electronic equipment (Annex II). Additional measures in place to promote circular production and consumption patterns are e.g. *Extended Producer Responsibility* (EPR) schemes, making producers responsible for the environmental impacts of their products throughout the whole product chain, the *EU taxonomy* for sustainable finance and *Green Public Procurement* (GPP).

Under *regulation*, firms or individuals must comply with specific technological or performance standards. However, for this type of regulation to be effective some conditions must be satisfied, namely the regulator has full information and the government is able to enforce the policy. This is typically the situation for which the appropriate instrument is a *ban* (Cameron, 2006), e.g. the one introduced in the EU on landfilling of rubber waste. Other examples are specific requirements for *waste collection and sorting methods*, which in the EU currently not always satisfy the specific needs of each material/product (see Section 5.2), and *product eco-design*, which is relevant for all types of waste and heavily impacts on collection/sorting methods (see Section 5.2).

***Market-based instruments* make recycling economically more attractive for economic agents**. They can do it through *price-based instruments*, either imposing additional costs on non-recycling behaviours (taxes and charges) or reducing recycling costs and increasing disposal and storage costs (subsidies and public facilities), which vary across material/product and across countries. In addition, they can also be *quantity-based*, i.e. cap-and-trade. Opting for market-based instruments is preferable in case of heterogeneous firms or when the regulator has uncomplete or asymmetric information about firm costs, as in these cases regulatory measures would imply higher enforcement costs (Terzi, 2022).

Both *taxes* and *charges* put a burden on those producing waste ("*polluter pays*" *principle*). *Taxes* at the end of the chain make waste disposal options like landfilling and incineration more expensive than recycling. Taxes on specific products, like for instance plastic bags, provide an incentive to use them less or for a longer time. Taxes applied at the beginning of the chain, e.g. on natural resources, are less effective in promoting recycling (van Beukering et al., 2014). *Charges* for waste collection and processing can be either fixed or variable depending on the amount of waste ("*pay as you throw*"). Lower rates can be applied to specific type of waste, like glass or paper, to promote recycling. However, the ability to properly enforce taxation and charges is important to prevent an increase in illegal waste treatment.

***Subsidies* on recycling are usually applied in case of market imperfections or high risk of illegal waste disposal practices**. In the case for instance of waste from ships, subsidies can make port facilities more attractive than dumping in the sea.

In practice, *mixed instruments* are also common, like tradable landfill permits, differentiated tax rates and deposit-refund systems. *Deposit-refund-schemes* charge users an extra fee when they buy a product, which is refunded if the product packaging is returned for recycling or reuse, as does for instance the German PFAND system for beverages' bottles. Although effective, they however entail considerable handling and administrative costs. The optimal policy design, including the mix of instruments, depends not only on the recycling supply/demand elasticity, but also on other specific social, cultural, political and institutional factors.

5. THE EU SECONDARY MARKETS FOR MATERIALS/ PRODUCTS

5.1 MAIN FEATURES OF SELECTED EU SECONDARY MARKETS FOR MATERIALS/PRODUCTS

The lack of harmonised data across Member States unfortunately currently limits the analysis of the EU secondary markets. Not only waste collection may be differently organised on national basis, but also data collection may reflect different national definitions of waste management operations[15]. In addition, data on the circularity rate are not provided by type of material/product, which limits quite substantially any assessment and analysis.

However, available reliable data show that between 2010 and 2020 the EU secondary markets for materials differed quite significantly in their size, reflecting specific features of each market. As displayed in Table 2, in 2020 the largest secondary markets were those for *vegetable waste* and for *paper and cardboards* (98 and about 69 kg/per capita, respectively), which also registered very high recycling rates (94 and 98% respectively). The EU *glass* and *batteries* waste were fully recycled, but they were not so relevant in terms of volume, especially batteries waste (3 Kg/per capita). *Wood* waste had the lowest recycling rate (46%), but the volume of recycled wood was not negligeable with respect to other secondary markets (41 Kg/per capita).

Table 2**: Size and features of selected EU secondary markets (2020)[1]**

Material/product	Recycled volume (kg/per capita)	Recycling rate (% treated waste)	Intra-EU trade of waste recyclable raw materials (kg/per capita)	Balance of extra-EU trade of waste recyclable raw materials (kg/per capita)
Vegetal waste	98	94%	46	44
Paper and cardboards	68	98%	26	-12
Wood	41	46%	6	1
Glass	35	100%	6	1
Plastics	18	72%	6	-1
Rubber	4	67%	0	0
Batteries	3	100%	n.a.	n.a,
Textiles	2	73%	2	-2
Metals - ferrous	n.a.	-	59	-33
Metals – non ferrous precious	n.a.	-	1	0
Metals – non ferrous (Cu, Al, Ni)	n.a.	-	11	-1
WEEE	n.a.	-	n.a.	n.a.

Note: Data in columns fourth and fifth refer to 2023.

Source: author's elaboration based on Eurostat data (2024).

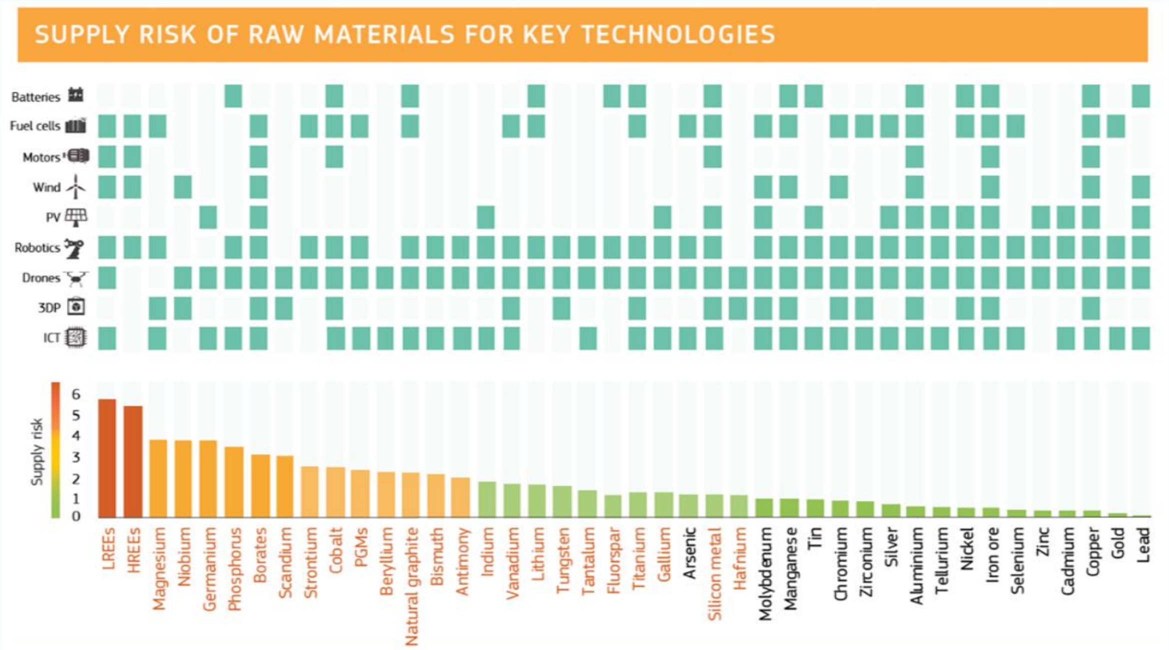
[15] A recent study (Habib et al., 2022) estimated that in 2018 only half (51%) of the WEEE produced in Europe was reported. In addition, it 12% of unreported WEEE was recycled under non-compliant conditions as part of mixed-metal scrap, 7% was scavenged for valuable components with an estimated monetary value of Euro 150 million (EERA, 2022), 6% was disposed in household waste and 3% was legally exported. The remaining 21% might also have been illegally exported.

BOX 2 **– CRITICAL RAW MATERIALS (CRMs)**

CRMs are essential to produce a broad range of common goods[1] **and therefore crucial for the EU industry.** They are used as input also for high tech products[2] and emerging innovations, including clean technologies like solar panels, wind turbines, electric vehicles and energy-efficient lighting. Among CRMs, sixteen raw materials are considered as *strategic* (SRMs)[3], having the highest supply challenges and a strategic relevance for the green transition and the digital transformation as well as for their defence and space applications.

Most of these primary raw materials are produced and supplied from non-European countries. This is due either to the absence of those materials in the European ground or to socio- economic factors negatively affecting the exploration (for deposit discovery and characterisation, estimation of resources and reserves) or the extraction (closure of existing mines, reluctance to open new mines, etc.) (European Commission, 2018). In addition, the supply of many CRMs is highly concentrated. For example, China satisfies 98% of the EU's demand of rare earth elements (REE); Turkey satisfies 98% of the EU's demand of borate, Brazil satisfies 85% of the EU's demand for Niobium and South Africa satisfies 71% of the EU's demand for platinum and an even higher share of the platinum group metals iridium, rhodium and ruthenium. The EU is instead self-sufficient for hafnium (84% from France[4]) and strontium (100% from Spain). Consequently, for some materials the supply risk is quite high (Figure B.2).

Figure B.2: **Supply risk of raw materials for key green and digital technologies**



Source: European Commission's Raw Materials Information System.

[1] A smartphone might for instance contain up to 50 different kinds of metals (European Commission, 2018).

[2] Battery manufacturing notably needs cobalt, lithium, nickel and manganese, which have significantly impact on the environment and society and for which the EU is largely dependent from imports.

[3] The European Commission's 2023 list of strategic raw materials includes: Bismuth, Boron – metallurgy grade, Cobalt, Copper, Gallium, Germanium, Lithium – battery grade, Magnesium metal, Manganese - battery grade, natural Graphite – battery grade, Nickel – battery grade, Platinum Group Metals, Rare Earth Elements for magnets (Nd, Pr, Tb, Dy, Gd, Sm, and Ce), Silicon metal, Titanium metal, Tungsten.

[4] Hafnium is the only CRM for which an EU Member State (France) is the global main producer (European Commission, 2018).

Some recyclable metals showed a high trade dynamism. In 2023, recyclable ferrous metals waste, i.e. iron and steel waste, registered the largest intra-EU trade (almost 59 Kg/per capita). At the same time, the EU was also a net exporter of recyclable waste of these metals to extra-EU countries. This is not surprising, as iron and steel are widely used in the construction, transport and commercial sectors and the EU is the second largest producer of steel in the world after China. For recyclable non-ferrous metals waste, the lower domestic supply of raw materials reflected in a much more limited intra-EU trade and a negligeable extra-EU trade flow.

Further expanding the availability of recycled metals would ensure security of supply and reduce the current EU's dependency on extra-EU imported materials, especially for those needed for the green transition and the digital transformation. The EU produces only about 3% of the primary raw materials necessary to meet a growing demand for metals (EuRIC, 2020). This is especially relevant for *critical raw materials* (CRMs) (European Commission, 2023)[16], a limited number of metals - not covered by Table 2 - together with some minerals with high economic relevance and high risk of supply disruption (Figure B.2 in Box 2). Despite the high recycling potential of several CRMs and the growing demand for CRMs in various sectors, e.g. batteries and solar panels production, the share of secondary CRMs in raw material EU supply is generally low. This might reflect the limited availability of many CRMs that are locked up in long-life assets and some complexities in separating/removing them from products (Gislev *et al*., 2018).

5.2 MAIN BARRIERS TO THE EU SECONDARY MARKETS FOR MATERIALS/PRODUCTS

Based on available information, it is possible to identify some factors limiting the functioning of existing EU secondary markets. Removing any possible barrier to recycling is key to fully reap the benefits from circularity, while reducing environmental impacts and thus boosting the sustainability of the EU economy.

Among these factors, the *availability of raw materials* does not encourage recycling of some materials. As much as raw materials are available, the lower their market price and likely also the lower the demand for secondary raw materials. For instance, it is likely that the abundance of ferrous metals in the EU reduces the demand for secondary materials and thus for recycling. However, a detailed analysis of raw materials market prices in the EU goes beyond the purposes of this note.

***Inappropriate product design* makes collection and sorting processes more complex and more expensive for all types of waste, thus reducing waste materials/products availability**. Product design not allowing to easily separate and remove the different materials embedded in products reduces the amount of available recyclable waste, ultimately making recycling more expensive. *Metals* can for instance all be indefinitely recycled via mechanical treatment without losing their intrinsic properties, quality and functionality. However, they are often present in very small quantities and/or mixed with other materials in products like *batteries* and *WEEE*[17], thus making harder the recovery of materials and reducing the overall product lifetime. Similarly, for *glass*[18], *textiles*[19], *wood*[20], *vegetal waste*[21], *plastics*[22]

[16] The European Commission's 2023 list of critical raw materials includes: Antimony, Arsenic, Baryte, Bauxite, Beryllium, Bismuth, Boron, Cobalt, Coking Coal, Copper, Feldspar, Fluorspar, Gallium, Germanium, Hafnium, Heavy Rare Earth Elements, Light Rare Earth Elements, Lithium, Magnesium, Manganese, Natural Graphite, Nickel – battery grade, Niobium, Phosphate rock, Phosphorus, Platinum Group Metals, Scandium, Silicon metal, Strontium, Tantalum, Titanium metal, Tungsten, Vanadium.

[17] In most cases, portable consumer electronics in the EU, including light electric vehicles, currently incorporate rechargeable lithium-ion batteries, which are complex to remove. The use of adhesives and solder also makes batteries removal more complex, as it requires specialized tools and knowledge (IIIEE and EEB, 2021).

[18] Glass is entirely and endlessly recyclable without loss in quality or purity, but the presence of ceramics, stones and porcelain, heat-resistant materials, metal, plastics and organic materials limit its recyclability if not removed.

[19] The presence of fibre blends, zippers and buttons limits the recyclability of textiles if not removed.

and *rubber* from end-of-life tyres[23] quality standards for recyclability require that other materials, including hazardous contaminants, be removed. By considering the environmental impact at each stage of product development and life starting from the design phase, *product eco-design* instead facilitates materials recovery and removal, thus increasing the amount of available recyclable waste and reducing recycling costs. The benefits from eco-design can be strengthened through *eco-labelling*, which provides consumers with relevant information about the environmental performance of goods based on certified standard criteria[24].

The *lack of harmonised quality standards for waste collection/sorting* also makes collection and sorting processes more complex and more expensive for some types of waste, thus reducing waste materials/products availability. Without harmonised requirements for waste collection and sorting methods reflecting specific features of each material, waste quality could deteriorate, thus reducing the amount of available recyclable waste. Waste collection must instead ensure separate streams for pure and clean discarded materials, requiring suitable sorting methods, for instance differentiated by colour (colour/polymer) for glass (plastics) and reflecting waste classification for wood[25] (Bioreg 2018a and 2018b). For this to be more effective, products should be eco-designed and eco-labelled.

Furthermore, *inappropriate waste sorting capacity* limits waste collection, ultimately also reducing waste materials/products availability. As sorting is often a pre-requisite for recycling, inappropriate capacity for waste sorting which reflects specific features of each material inevitably reduces the amount of available recyclable waste, thus limiting recycling potential.

The *lack of suitable recycling technologies* at competitive costs is also relevant for different materials. Expensive recycling technologies impact on the price of secondary raw materials, making them less attractive for producers. Therefore, further research is needed to develop cheaper solutions to cope with specific features of each material. For instance, due to their composition, batteries and WEEE may need different recycling processes for each of the different metals and compounds, often present in very small quantities and therefore more costly to recycle. In addition, current methods of recovering some metals from electronic waste often use large amounts of energy, but ongoing technological developments are promising[26]. However, the considerable increase (above 40%) of WEEE treated from 2010 to 2020 (Table A.12 in Annex I) is encouraging. Technological constraints exist also for plastics. Only some conventional fossil-based plastics[27] can currently be recycled[28] into several different products, but only PET can be recycled into bottles and food containers, if it meets purity standards and

---

[20] Only clean wood can be recycled or converted into energy. Contaminated wood can only sometimes be used for energy recovery otherwise must be landfilled, while hazardous waste can only be landfilled.

[21] The presence of mixed materials for packaging limits the recyclability of vegetal waste.

[22] Hazardous contaminants limit the recyclability of plastics if not removed.

[23] Tyres are made at 75% by rubber, 15% steel and 10% textile fibres (EuRIC, 2021). Steel extracted from tyres is very clean and thus very well suited for producing new high-quality products (EuRIC, 2021)

[24] The Commission proposal for a Digital product passport (2022) enables all products regulated under the Eco-design for Sustainable Products Regulation, to be tagged, identified and linked to data relevant to their circularity and sustainability.

[25] "Clean" recycled wood (Grade A) produced from pallets and secondary manufacture is suitable for animal bedding and mulches. Grade A wood and construction/demolition waste are suitable for panel board (Industrial fuel grade - Grade B). Grade A, Grade B, municipal collections and civil amenity sites can be used for biomass fuel (Fuel grade – Grade C). All types of hazardous waste, including treated material like fencing and trackwork, require special facilities for disposal (Grade D).

[26] Birloaga and Vegliό (2022) have proposed a new chemical-processing system that can be carried out at room temperature and pressure.

[27] Only Polyethylene Terephthalate (PET), High-Density Polyethylene (HDPE) and Polypropylene (PP) are commonly recycled. Low-Density Polyethylene (LDPE) is only sometimes recycled, while Polyvinyl Chloride (PVC), Polystyrene (PS) and other types of conventional plastics, e.g. poly- carbonate (PC), polylactide (PLA), polyurethane (PU) and acrylonitrile butadiene styrene (ABS), are almost never recycled.

[28] Conventional plastics can be recycled together with their bio-based counterparts, given that a recycling stream for a specific plastic type is established, e.g. PE together with Bio-PE or PET together with Bio-PET.

does not contain hazardous contaminants (Bio-Plastics Europe, 2022). For other types of plastics[29], there is no recycling stream established yet. For textiles, recycling technologies vary depending on the fibre. Some technologies, like mechanical recycling of pure cotton, are already well established. Research on other technologies, like chemical recycling of polyester, have instead been ongoing and reaching results. Fibre-to-fibre recycling, turning textile waste into new fibres used to create new clothes or other textile products, nowadays only absorbs less than 1% of textile waste, probably due to often strict required standards for fibre composition and purity (McKinsey & Company 2022). Moreover, some tissues like elastane and fibre blends are difficult to be treated, as advanced, accurate and automated fibre sorting and pre-processing are not yet developed. These technological constraints might at least partially explain why in 2020 almost 11% of textiles waste treated was landfilled (Table A.6 in Annex I). For wood, the recycling costs depend on the type of wood and the employed technologies.

Moreover, *insufficient recycling capacity* limits the expansion of EU secondary markets for some materials. As already stressed, unsuitable recycling facilities for fully/further exploiting the available recyclable waste do not allow for economies of scale, ultimately making recyclable raw materials less economically profitable for production purposes. This is for instance the case of vegetal waste. Although the already high volume of recycled vegetal waste, the EU would benefit from additional anaerobic digestion and composting facilities for the industrial transformation[30] of vegetal waste into compost, i.e. an organic fertiliser highly rich in humus, microbic flora and microelements and has different agronomic uses, from floriculture to agriculture[31] (European Compost Network, 2022). The difference between the volume of waste generated and that treated (around 20 kg/per capita in 2020, Table A.2 in Annex I) might imply that limits exist also for paper and cardboards, as the volume of waste treated was almost entirely recycled (Table A.2 in Annex I). To a lesser extent, this might also apply to plastics (Table A.4 in Annex I), but the recent increase in the installed recycling capacity for plastics is encouraging (Plastics Recyclers Europe, 2021). Wood also registered a high difference between the waste generated and the way treated (around 16 kg/per capita in 2020, Table A.5 in Annex I), but this might at least partially depend on being wood and wood-based products often used at the end of their lifespan as furniture and/or building materials.

In addition, the *international demand* for recyclable raw materials might shrink the EU secondary markets for some materials. Exporting recyclable waste of raw materials outside the EU reduces the availability of waste for recycling. Between 2010 and 2020, the EU was a net exporter of recyclable waste of ferrous metals (Table A.9 in Annex I) with an increasing trend. To a much lesser extent, this was also the case for recyclable textiles waste (Table A.6 in Annex I), plastics waste (Table A.4 in Annex I) and paper and cardboards waste (Table A.2 in Annex I), but with a decreasing trend for the latter. For recyclable rubber waste, the surplus in the trade balance was instead negligeable (Table A.3 in Annex I).

Based on a review, *policy measures* can play a relevant role in removing the barriers to EU secondary markets. Without claiming to be complete, the above discussion of the main bottlenecks to EU secondary markets reveals that policy measures can play a relevant role in fostering recycling and ultimately in making the EU economy more circular. For instance, all waste materials could benefit from stricter standards on waste collection/sorting methods and on product eco-design. In addition, benefits for several materials could arise from policy measures promoting technological development for more efficient and less environmentally impactful recycling processes, as well as from policy measures like subsidies (charges) making secondary raw materials (virgin materials) economically more (less) profitable. However, the review does not cover any relevant specific national factor impacting on secondary markets for materials, which a more detailed and complete analysis going beyond the purposes of this note should also consider.

[29] For instance, Polylactic acid (PLA).

[30] The decomposition process of vegetal waste through microorganisms reproduces a natural process at a quicker pace under controlled aerobic conditions.

31 In addition, organic material such as trees, plants, agricultural and urban waste can be used to produce biomass, which through specific processes can be transformed in either biofuels or bio-based plastics.

BOX 3 – **EXAMPLES OF SELECTED EU SECONDARY MARKETS FOR PRODUCTS AND COMPONENTS**

Cars

The automotive manufacturing sector is reorganising itself to promote sustainable mobility.

***Stellantis* is for instance investing in its "Circular economy business" unit** to extend as long as possible the life of vehicles and their components and to return material (e.g. metals, including lithium, and plastics) and end-of-life vehicles to the manufacturing loop for new vehicles and products. For example, the new Citroën 'oli' [all-ë] is a conceptual multi-activity family vehicle using lightweight and recycled material and produced through sustainable production processes. The business unit is also launching its new *SUSTAINera label* for parts and accessories, allowing for savings of up to 80% materials and 50% energy as compared to their equivalent new parts. By the end of the year, Aramis, a European leader in the online multi-brand purchase and sale of used cars Stellantis acquired in 2016, will have seven in-house refurbishing centres, placed over Western and Central Europe. In addition, a leading *Circular Economy Hub* will be launched in 2023 at Stellantis' Mirafiori Complex in Turin (Italy).

The *Renault Group* is rolling out in Flins (France) the first European refactory dedicated to mobility, which should be fully functional by 2024. This industrial and commercial site open to start-ups and partnerships aims at encouraging initiatives and fostering innovation to achieve carbon neutrality in 2040. By 2023, more than 45.000 second-hand vehicles will be reconditioned each year. In addition, at the end of 2023 a new body repair activity for heavily damaged vehicles, the Bodywork Factory, will be launched for fleets and insurance companies. This will repair 3,000 vehicles in 2023 to reach up to 25,000 vehicles in 2025. The *Retrofit unit* of the refactory refurbishes the robots no longer in use in the group's plants before they return to production lines. In the first half of 2022, the unit has revamped 40 robots.

The *Volkswagen* group's sustainability strategy to reduce the CO2 emissions over the entire vehicle life cycle includes the use of both renewable raw materials like e.g. flax, hemp, cellulose, cotton and kenaf[1], and secondary raw materials like recycled plastics[2]. Approximately one third of the gross weight of many Volkswagen's vehicles is already accounted for by recycled metals and oil-based materials. *Porsche*, which is part of the Volkswagen group, has developed with the Swedish company "Box of Energy" a stationary energy storage system using decommissioned batteries from electric cars. This allows to prolong the service life of those high-voltage batteries that after many years of service have partially lost their performance capability as source of home power or to charge a hybrid or electric car. At the end of their life cycle, they are then recycled to extract the raw materials for new batteries. *Audi*, which is also part of the Volkswagen's group, recently rolled out the "Aluminium Closed Loop pilot project" to set up a closed-loop recycling system. Audi returns offcuts from the used sheet aluminium to its suppliers, who recycle them. The resulting secondary raw material is then used in Audi's production process. In addition, all the aluminium cuttings produced in the Volkswagen plant in Kassel satisfying some quality standards[3] are melt directly on site to produce secondary raw material.

Printers

***Xerox,* world leader in printers, has been committed to responsible and environmental business practices since long time**. With its Green World Alliance recycling programme, Xerox leads the industry in alternatives for used printer supplies, including print cartridge reprocessing, waste toner reuse, plastics and metals recovery and turning waste into energy.

Its products, packaging and supplies design ensures an efficient use of resources while minimising waste, reusing material where feasible and recycling what cannot be reused. Returned products are sorted and items suitable for remanufacturing are cleaned, inspected and then remanufactured with the same performance as new products. Remanufactured products contain an average of 90% reused/recycled components. Items not suitable for remanufacturing are recycled or recovered through energy from waste. Recycled waste toner and toner reclaimed from manufacturing that qualifies for reuse may account for 25% of the weight of new toner, without compromising toner functionality.

BOX 3 – continuation

Solar panels

The Catania based (Italy) Enel Green Power's 3Sun photovoltaic panels factory promoted the development of TANGO (iTaliAN pv Giga factOry), an industrial-scale production facility for the manufacturing of innovative, sustainable and high-performance bifacial photovoltaic (PV) modules. The intention is to foster high efficiency solar technology by investing around 600 million Euro, 118 of which from the EU's Innovation Fund, to increase the factory's production capacity from the current 200 MW/year to 3GW/year by 2024. The combination of bifacial heterojunction (B-HJT) PV cells capturing sunlight on both front and rear surfaces and the "Tandem" structure with two stacked cells capturing more light compared to single-cell structures should lead to significant energy efficiency improvement (30%) and ultimately to a higher average energy production. The expected enlarged production capacity could generate up to about 5.5 TWh of renewable electricity/year, replacing up to almost 1.2 billion cubic meters of gas/year while saving almost 25 million tons of CO2 over ten years.

The Gigafactory is being designed and constructed following sustainable and circular principles by increasing the use of environmentally friendly and recycled materials to reduce energy and resources' consumption. In cooperation with international research centres and leading companies in the sector, research is ongoing to: i) develop new recycling processes for end-of-life PV modules, ii) recover and reuse materials like plastics, silver, glass, resins and indium in the production process and iii) use highly automated procedures including artificial intelligence algorithms to improve the control of manufacturing processes and reduce final scrap.

Batteries

Norway is leading the sustainable, circular production of batteries. **In 2019, the *EYDE Cluster*, the Norwegian Centre of Expertise (NCE) for Sustainable Process Industry, launched the *BATMAN project*** (Lithium ion BATteries - Norwegian opportunities within sustainable end-of-life MANagement, reuse and new material streams). This involves regional suppliers, multinational companies, research organisations and educational institutions mainly located in Southern Norway in finding new opportunities for recycling and reusing Lithium-ion batteries.

In 2020, *Norsk Hydro* and the *Swedish NorthVolt* created *Hydro Volt*, a joint venture for battery recycling and urban mining. The new company built Europe's largest electric vehicle battery recycling plant, which started its operations in 2022. This has the capacity to process approximately 12.000 tons of battery per year (around 25,000 EV batteries), sufficient to recycle all the Norwegian end-of-life batteries. The fully automated recycling process can recover around 95% of battery materials, including plastics, copper, aluminium and black mass, i.e. a compound containing nickel, manganese, cobalt and lithium. Hydrovolt is exploring an expansion of recycling capacity within Europe, with a long-term target to recycle approximately 70,000 tons of battery packs by 2025 (approximately 150,000 EV batteries) and 300,000 tons of battery packs by 2030 (approximately 300,000 EV batteries).

Wind turbine blades

Many wind turbines currently in use are approaching their end of life, being the life cycle of their blades about 20 years. As these are made by composite materials which can hardly be recycled[4], environmental concerns arise about the estimated 185 to 570 kT of blade waste that will be generated in the EU by 2030 (Lichtenegger et al., 2020; Sommer et al., 2020).

However, the recent considerable increase in electricity production from wind has fostered technological developments to produce recyclable wind turbine blades. In September 2020, the French *IRT Jules Verne research centre* launched the *ZEBRA (Zero waste Blade Research) project* involving a consortium of manufacturers developing a new technological solution to produce sustainable wind blades. They intend to replace hard to recycle thermosetting composites with thermoplastic composites, which are also resistant and light, but can be remelted after use to make new materials. After a year of material development and testing, in March 2022 *LM Wind Power*, one of the consortium partners, designed and built at its Ponferrada plant in Spain the first prototype of fully recyclable wind turbine thermoplastic blade. A chemical recycling process allows to depolymerise the thermoplastic resin, separate the fibre from the resin and recover a new virgin resin ready to be reused.

BOX 3 – continuation

Full-scale structural lifetime testing of such prototype is ongoing. Waste dismantling and recycling, followed by the analysis test results, should be completed by 2023.

In addition, research is ongoing to identify the best technological solution for waste blade management to optimise material recovery. According to a recent study (Diez-Cañamero and Mendoza, 2023), recycling through solvolysis, i.e. chemical recycling, is the most circular and low- carbon solution if compared to repurposing, grinding, pyrolysis (i.e. thermal recycling), co-processing in cement kilns, incineration with energy recovery and landfilling. Despite being highly energy consuming, solvolysis allows 90% to 100% material recovery.

Waste electrical and electronic equipment

The composition of electrical and electronic equipments make complex waste recovery and recycling. Waste from electrical and electronic equipments (WEEEs) includes a large range of devices such as computers, fridges and mobile phones and their components (e.g. batteries, toner cartridges, cathode ray tubes, gas discharge lamps, liquid crystal displayers, external electric cables,) at the end of their life[5]. These devices contain a complex mixture of materials, some of which are rare and expensive (CRMs[6]) or hazardous (e.g ozone-depleting substances and fluorinated greenhouse gases, mercury, asbestos, radioactive substances). If not properly managed, discarded devices can therefore cause major environmental and health problems.

Among the WEEEs, iPhones' recycling is expanding. Founded in 2016, the Finnish business *Swappie* purchases used iPhones to either repair them in-house or recycle all their reusable parts to produce and sell refurbished iPhones after an extensive quality testing. The objective is to reuse all functional parts by 2024.

[1] Kenaf is a tropical plant from which fine fibres are extracted to produce for instance the door trim of the current Golf. Other applications of renewable raw materials include armrests, floor insulation, trunk linings, door and side panel trim and hood insulation.

[2] Recycled plastics are for instance used in spare wheel compartment covers, floor coverings or wheel arch inserts.

[3] Those produced from alloy Al 226 with a residual moisture level below two percent.

[4] The main technology for recycling composite waste is through cement co-processing.

[5] 'Waste electrical and electronic equipment' or 'WEEE' means electrical or electronic equipment which is waste within the meaning of Article 3(1) of Directive 2008/98/EC, including all components, sub-assemblies and consumables which are part of the product at the time of discarding (European Union, 2012).

[6] Battery manufacturing notably needs cobalt, lithium, nickel and manganese, which have significantly impact on the environment and society and for which the EU is largely dependent from imports.

6. POLICY CONCLUSIONS

Recycling possibilities differ quite significantly across types of materials and waste. This certainly reflects specific materials' features including technological constraints, making either the recycling process expensive or secondary raw materials not qualitatively comparable with virgin materials, therefore ultimately making recycled materials not competitive and preventing EU secondary markets to expand.

However, some policy interventions can be identified to remove common factors that limit recycling across different types of materials and products. Seven points are worth highlighting.

First, reviewing and, if necessary, updating the *EU waste hierarchy*, to improve waste and resource management. At least for some materials, adjustments might be required based on the most recent developments in recycling and waste collection/treatment technologies to improve the efficiency of waste handling. These adjustments would better clarify the potential of recycling with respect to the other available options for waste handling, especially repairing and reusing, according to the specific features of each material. In addition, an overall shift from waste management to resource management would further strengthen the coherence between the EU hierarchy and a circular use of resources, by reducing the anthropogenic pressures on the environment and thus preserving as much as possible natural resources for future generations.

Second, *further promoting product eco-design* also at national level to increase recycling potential of materials and products as well as energy efficiency in both production and recycling. Clear and easily understandable *eco-labelling* harmonised across EU MSs would guide both producers in choosing virgin and secondary raw materials to be used as inputs in their production process and consumers in purchasing more durable, reusable, easy to repair and recyclable products. At the same time, it would also make *green public procurement* easier by promoting circular products made from recycled materials, while also making materials easier to re-use and recycle at end of their life.

Third, *fostering a harmonised waste legislation* across MSs to ensure common waste classification and materials' quality standards, including for tracking substances of concern like chemicals or re-processed waste used to produce goods. This would foster separate collection of waste streams and ultimately improve waste collection efficiency, by expanding the amount of collected, treated and recycled waste available as input for new products and preventing cross-contamination of recyclables.

Fourth, *fostering a harmonised waste data definition* and *waste collection* across MSs to ensure reliable and comparable data for all types of waste. Moreover, data availability on raw material consumption, circular material use rate, employment in the circular economy, circular economy value added and public/private investments in the circular economy by material/product would allow to have a clearer overview of the circularity of the EU economy and monitoring its development through time.

Fifth, *further promoting circular production patterns* at national level by combining different measures to support waste prevention and the use of recycled materials and products. The *Extended Producer Responsibility* schemes, which make producers responsible for the environmental impacts of their products throughout the product chain, from design to the post-consumer phase, might for instance be combined with fees to discourage non-circular products.

Sixth, *further promoting circular consumption patterns* at national level through financial incentives (e.g. deposit-refund schemes) and possibly targeted, temporary subsidies or reduced charges to support desired activities (e.g. repair, second-hand markets)).

Seventh, *further supporting also at national level both private and public investment* in technological innovation to increase recycling efficiency and reduce the environmental footprint of recycling. Technological progress can not only improve infrastructure and enlarge recycling capacity, but also reduce energy consumption and CO2 emissions during the recycling process. In addition, ensuring access to finance would also strengthen competition among recyclers by lowering the costs for new entrants, together with faster permitting processes.

Finally, *ensuring fair and legal trade of secondary raw materials* within the EU and with extra-EU partners. To ensure that the EU takes greater responsibility for its waste and prevent illegal shipment both within the EU and to non-EU countries with less stringent regulations and inadequate recycling infrastructure, by monitoring the compliance with the recently revised Regulation on waste shipments (European Union, 2024), which promotes easier, faster and traceable waste shipment procedures, and enforcing the EU legislation on chemicals also at the EU borders.

REFERENCES

Basel Convention (1992), Basel Convention > The Convention > Overview > Text of the Convention

Bio-Plastics Europe (2022), Handbook on the impacts of bio-based and biodegradable plastics on existing waste management frameworks, BIO-PLASTICS EUROPE | "On the impacts of bio-based and biodegradable plastics (and additives) on existing waste management frameworks" (bioplasticseurope.eu).

Bioreg (2018a), Absorbing the Potential of Wood Waste in EU Regions and Industrial Bio-based Ecosystems — BioReg. D.2.3: Lessons and recommendations document for regional authorities and policy makers, BIOREG D2.3 Lessons and Recommendations document to Regional Authorities and Policy makers.pdf

Bioreg (2018b), Absorbing the Potential of Wood Waste in EU Regions and Industrial Bio-based Ecosystems — BioReg. D.2.4: Recommendations For Industry Stakeholders, BIOREG D2.4_recommendations to industry stakeholders.pdf

Birloaga I. and Vegliò F. (2022), "An innovative hybrid hydrometallurgical approach for precious metals recovery from secondary resources", Journal of Environmental Management, 307: 114567, An innovative hybrid hydrometallurgical approach for precious metals recovery from secondary resources | Elsevier Enhanced Reader.

Boulding (1966), "The economics of the coming spaceship earth" in Daly H., Freeman W.H. (eds.), Economics, Ecology, Ethics: Essays towards a Steady State Economy (1980), San Francisco.

Cameron H. (2006), "Regulation by prices, quantities or both: a review of instrument choice", Oxford Review of Economic Policy, 22 (2), Hepburn.pmd (silverchair.com)

Defra (2011), Guidance on applying the Waste Hierarchy, Waste hierarchy guidance (publishing.service.gov.uk)

Diez-Cañamero B. and Mendoza J.M.F. (2023), "Circular economy performance and carbon footprint of wind turbine blade waste management alternatives", Waste management, 164: 94-105, Circular economy performance and carbon footprint of wind turbine blade waste management alternatives (sciencedirectassets.com)

DG ESTAT (2024, forthcoming), Manual for the Implementation of Regulation (EC) No 2150/2002 on Waste Statistics

DG ESTAT (2024), Sustainable development in the European Union. Monitoring report on progress towards the SDGs in an EU context, 2024 edition, Sustainable development in the European Union — Monitoring report on progress towards the SDGs in an EU context (2024 edition) (europa.eu)

EERA (2022), EERA Report - Towards EU Regulations: the position of the European Electronics Recyclers Association, EERA+-+Towards+EU+WEEE+Regulations+-+Published+January+2022.pdf (squarespace.com)

EIB (2020), The EIB Circular Economy Guide. Supporting the circular transition, The EIB Circular Economy Guide – Supporting the circular transition

Ellen MacArthur Foundation (2013), Towards the circular economy. Economic and business rationale for an accelerated transition, Towards the Circular Economy Vol. 1: an economic and business rationale for an accelerated transition | Shared by Business (thirdlight.com).

EuRIC (2019), Sound management of waste and chemicals. Requirements by the recycling industry, EuRIC - EuRIC Brochures (euric-aisbl.eu)

EuRIC (2020), Metal Recycling Factsheet, EuRIC - EuRIC Brochures (euric-aisbl.eu).

EuRIC (2021), Mechanical Tyre Recycling Factsheet, EuRIC - EuRIC Brochures (euric-aisbl.eu).

European Commission, Raw Materials Information System, Raw Materials Information System (europa.eu)

European Commission (2011), Commission Decision of 18 November 2011 establishing rules and calculation methods for verifying compliance with the targets set in Article 11(2) of Directive 2008/98/EC of the European Parliament and of the Council, Commission Decision of 18 November 2011 establishing rules and calculation methods for verifying compliance with the targets set in Article 11(2) of Directive 2008/98/EC of the European Parliament and of the Council (notified under document C(2011) 8165) (europa.eu)

European Commission (2023), Annexes to the Proposal for a Regulation of the European Parliament and of the Council establishing a framework for ensuring a secure and sustainable supply of critical raw materials and amending Regulations (EU) 168/2013, (EU) 2018/858, 2018/1724 and (EU) 2019/1020, resource.html (europa.eu)

European Compost Network (2020), ECN report data 2022, https://www.compostnetwork.info/wordpress/wp-content/uploads/ECN-rapport-2022.pdf

European Union (1975), Council Directive of 18 July 1975 on waste (75/442/EEC), https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:31975L0442&from=EN

European Union (1991), Council Directive of 18 March 1991 amending Directive 75/442/EEC on waste (91/156/EEC), https://eur-lex.europa.eu/legal

European Union (2006), Directive 2006/12/EC of the European Parliament and of the Council of 5 April 2006 on waste, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32006L0012&from=EN

European Union (2012), Directive 20012/19/EU of the European Parliament and of the Council of 4 July 2012 on Waste electrical and electronic equipment (WEEE), Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE)Text with EEA relevance (europa.eu)

European Union (2024), Regulation (EU) 2024/1157 of the European Parliament and of the Council of Regulation (EU) 2024/1157 of the European Parliament and of the Council of 11 April 2024 on shipments of waste, amending Regulations (EU) No 1257/2013 and (EU) 2020/1056 and repealing Regulation (EC) No 1013/2006 Text with EEA relevance, Regulation (EU) 2024/1157 of the European Parliament and of the Council of 11 April 2024 on shipments of waste, amending Regulations (EU) No 1257/2013 and (EU) 2020/1056 and repealing Regulation (EC) No 1013/2006Text with EEA relevance. (europa.eu)

Kopsidas O. N. and Giakoumatos S. D. V. (2021), Economics of Recycling and Recovery, Natural Resources, 12: 73-90, Economics of Recycling and Recovery (scirp.org).

Habib H., Wagner M., Baldé C.P., Herreras Martinez L., Huisman J. and Dewulf J. (2022) What gets measured gets managed – does it? Uncovering the waste electrical and electronic equipment flows in the European Union, Resources, Conservation and Recycling, 181, What gets measured gets managed – does it? Uncovering the waste electrical and electronic equipment flows in the European Union - ScienceDirect

IIIEE and EEB (2021), Removable, replaceable and repairable batteries, Removable, replaceable and repairable batteries (eeb.org)

Lichtenegger, G., Rentizelas A.A., Trivyza N. and Siegl S., (2020), Offshore and onshore wind turbine blade waste material forecast at a regional level in Europe until 2050, Waste Management, 106: 120–131, https://doi.org/10.1016/j.wasman.2020.03.018

Ma X., Chen M., Zheng Z., Bullen D., Wang J., Harrison C., Gratz E., Lin Y., Yang Z., Zhang Y., Wang F., Robertson D., Son S.-B., Wen J., Ge M., Xiao X., Lee W.-K., Tang M., Wang Q., Wang Y. (2021), Recycled cathode materials enabled superior performance for lithium-ion batteries**,** Recycled cathode materials enabled superior performance for lithium-ion batteries - ScienceDirect

Gislev M., Grohol M., Mathieux, F., Ardente, F., Bobba, S., Nuss, P., Blengini, G., Alves Dias, P., Blagoeva, D., Torres De Matos, C., Wittmer, D., Pavel, C., Hamor, T., Saveyn, H., Gawlik, B., Orveillon, G., Huygens, D., Garbarino, E., Tzimas, E., Bouraoui, F. and Solar, S. (2018), Report on Critical Raw Materials and the Circular Economy, Report on critical raw materials and the circular economy - Publications Office of the EU (europa.eu).

Mayer A., Haas W., Wiedenhofer D., Krausmann F., Nuss P. and Blengini G. A. (2019), Measuring Progress towards a Circular Economy. A Monitoring Framework for Economy-wide Material Loop Closing in the EU28, Journal of Industrial Ecology, 23(1): 62-76, available at: Measuring Progress towards a Circular Economy: A Monitoring Framework for Economy-wide Material Loop Closing in the EU28 (wiley.com)

McKinsey & Company (2022), Scaling textile recycling in Europe – turning waste into value, Circular fashion in Europe: Turning waste into value | McKinsey

Moraga G., Huysveld S., Mathieux F, Blengini G.A., Alaerts L., Van Acker K., de Meester S and Dewulf J. (2019), "Circular economy indicators: what do they measure?", Resource, Conservation and Recycling, 149: 452-461, Circular economy indicators: What do they measure? - ScienceDirect

Plastics Recyclers Europe (2021), Plastics Recycling Industry in Europe. Mapping of installed plastics recycling capacities 2020, plastics-recycling-industry-in-europe.pdf (plasticsrecyclers.eu)

Sommer, V., Stockschlader J. and Walther G. (2020), Estimation of glass and carbon fibre reinforced plastic waste from end-of-life rotor blades of wind power plants within the European Union, Waste Management, 115: 83–94, https://doi.org/10.1016/j. wasman.2020.06.043

Terzi A. (2002), Growth for Good: Reshaping Capitalism to Save Humanity from Climate Catastrophe", Harvard University Press, Growth for Good — Harvard University Press

Van Beukering P., Kuik O. and Oosterhuis F. (2014), "The Economics of Recycling", in Handbook of Recycling, Elsevier, The Economics of Recycling - ScienceDirect

Vezzoli C. (2014), The 'Material' Side of Design for Sustainability, in Materials Experience. Fundamentals of Materials and Design, 105-121, Chapter 8 - The “Material” Side of Design for Sustainability | Elsevier Enhanced Reader

Zhang C., Hu M., Di Maio F., Sprecher B., Yang X. and Tukker A. (2022), An overview of the waste hierarchy framework for analyzing the circularity in construction and demolition waste management in Europe, in Science for the Total Environment, 803, An overview of the waste hierarchy framework for analyzing the circularity in construction and demolition waste management in Europe (sciencedirectassets.com).

ANNEX I – RECYLING AND THE EU CIRCULAR ECONOMY: SELECTED SECONDARY MARKETS

Table A.1 – Glass waste

	2010	**2020**	**Δ**
EU domestic waste			
Total waste generated (kg/per capita)	32.0	40.0	25.0%
Total waste treated (kg/per capita)	29.0	35.0	20.7%
Total waste treated (% total waste generated)	90.6%	87.5%	-3.1 p.p.
Total waste used for energy recovery (kg/per capita)	0.0	0.0	0,0%
Total waste used for energy recovery (% total waste treated)	0.0%	0.0%	0 p.p.
Total waste recycled (kg/per capita)	27.0	35.0	29.6%
Total waste recycled (% total waste treated)	93.1%	100.0%	6.9 p.p.
Total waste backfilled (kg/per capita)	0.0	0.0	0,0%
Total waste backfilled (% total waste treated)	0.0%	0.0%	0 p.p.
Total waste used for incineration (kg/per capita)	0.0	0.0	0,0%
Total waste used for incineration (% total waste treated)	0.0	0.0	0 p.p.
Total waste landfilled (kg/per capita)	2.0	0.0	-100.0%
Total waste landfilled (% total waste treated)	6.9%	0.0%	-6.9 p.p.
Total waste treated with other forms of disposal (kg/per capita)	0.0	0.0	0,0%
Total waste treated with other forms of disposal (% total waste treated)	0.0%	0.0%	0 p.p.
EU waste trade			
Intra-EU trade[1]	4.3	5.7	31.8%
Balance of extra-EU trade of recyclable raw materials (Kg/per capita)[1]	0.3	1.4	414.4%

Source: author's elaboration based on Eurostat data (2024).

Note: [1] Data in column C refer to 2023.

Table A.2 – Paper and cardboards waste

	2010	2020	Δ
EU domestic waste			
Total waste generated (kg/per capita)	97.0	97.0	0.0%
Total waste treated (kg/per capita)	73.0	69.6	-4.7%
Total waste treated (% total waste generated)	75.3%	71.7%	-3.6 p.p.
Total waste used for energy recovery (kg/per capita)	1.0	1.1	5.9%
Total waste used for energy recovery (% total waste treated)	1.4%	1.5%	0.1 p.p.
Total waste recycled (kg/per capita)	70.0	68.4	-2.3%
Total waste recycled (% total waste treated)	95.9%	98.3%	2.4p.p.
Total waste backfilled (kg/per capita)	0.0	0.0	0.0%
Total waste backfilled (% total waste treated)	0.0%	0.0%	0 p.p.
Total waste used for incineration (kg/per capita)	0.0	0.0	0.0%
Total waste used for incineration (% total waste treated)	0.0%	0.0%	0 p.p.
Total waste landfilled (kg/per capita)	1.0	0.1	-88.6%
Total waste landfilled (% total waste treated)	1.4%	0.2%	-1.2 p.p.
Total waste treated with other forms of disposal (kg/per capita)	0.0	0.0	0.0%
Total waste treated with other forms of disposal (% total waste treated)	0.0%	0.0%	0 p.p.
EU waste trade			
Intra-EU trade[1]	28.2	31.1	10.2%
Balance of extra-EU trade of recyclable raw materials (Kg/per capita)[1]	-10.3	-11.8	-14.7%

Source: author's elaboration based on Eurostat data (2024).

Note: [1] Data in column C refer to 2023.

Table A.3 – Rubber waste

	2010	2020	Δ
EU domestic waste			
Total waste generated (kg/per capita)	5.0	7.0	40.0%
Total waste treated (kg/per capita)	5.0	6.0	20.0%
Total waste treated (% total waste generated)	100.0%	85.7%	-14.3 p.p.
Total waste used for energy recovery (kg/per capita)	2.0	2.0	0.0%
Total waste used for energy recovery (% total waste treated)	40.0%	33.3%	-6.7 p.p.
Total waste recycled (kg/per capita)	3.0	4.0	33.3%
Total waste recycled (% total waste treated)	60.0%	66.7%	6.7 p.p.
Total waste backfilled (kg/per capita)	0.0	0.0	0,0%
Total waste backfilled (% total waste treated)	0.0%	0.0%	0 p.p.
Total waste used for incineration (kg/per capita)	0.0	0.0	0,0%
Total waste used for incineration (% total waste treated)	0.0%	0.0%	0 p.p.
Total waste landfilled (kg/per capita)	0.0	0.0	0,0%
Total waste landfilled (% total waste treated)	0.0%	0.0%	0 p.p.
Total waste treated with other forms of disposal (kg/per capita)	0.0	0.0	0,0%
Total waste treated with other forms of disposal (% total waste treated)	0.0%	0.0%	0 p.p.
EU waste trade			
Intra-EU trade[1]	0.3	0.0	-100.0%
Balance of extra-EU trade of recyclable raw materials (Kg/per capita)[1]	-0.2	-0.3	42.8%

Source: author's elaboration based on Eurostat data (2024).

Note: [1] Data in column C refer to 2023.

Table A.4 – Plastics waste

	2010	2020	Δ
EU domestic waste			
Total waste generated (kg/per capita)	28.0	43.0	53.6%
Total waste treated (kg/per capita)	20.0	25.0	25.0%
Total waste treated (% total waste generated)	71.4%	58.1%	-13.3 p.p.
Total waste used for energy recovery (kg/per capita)	3.0	6.0	100.0%
Total waste used for energy recovery (% total waste treated)	15.0%	24.0%	9 p.p.
Total waste recycled (kg/per capita)	14.0	18.0	28.6%
Total waste recycled (% total waste treated)	70.0%	72.0%	2 p.p.
Total waste backfilled (kg/per capita)	0.0	0.0	0,0%
Total waste backfilled (% total waste treated)	0.0%	0.0%	0 p.p.
Total waste used for incineration (kg/per capita)	0.0	0.0	0,0%
Total waste used for incineration (% total waste treated)	0.0%	0.0%	0 p.p.
Total waste landfilled (kg/per capita)	2.0	1.0	-50.0%
Total waste landfilled (% total waste treated)	10.0%	4.0%	-6 p.p.
Total waste treated with other forms of disposal (kg/per capita)	0.0	0.0	0,0%
Total waste treated with other forms of disposal (% total waste treated)	0.0%	0.0%	0 p.p.
EU waste trade			
Intra-EU trade[1]	4.0	6.5	63.2%
Balance of extra-EU trade of recyclable raw materials (Kg/per capita)[1]	-4.9	-1.3	-73.9%

Source: author's elaboration based on Eurostat data (2024).

Note: [1] Data in column C refer to 2023.

Table A.5 – Wood waste

	2010	2020	Δ
EU domestic waste			
Total waste generated (kg/per capita)	127.0	108.0	-15.0%
Total waste treated (kg/per capita)	113.0	89.9	-20.5%
Total waste treated (% total waste generated)	89.0%	83.2%	-5.8 p.p.
Total waste used for energy recovery (kg/per capita)	57.0	48.0	-15.9%
Total waste used for energy recovery (% total waste treated)	50.4%	53.4%	3 p.p.
Total waste recycled (kg/per capita)	52.0	41.4	-20.5%
Total waste recycled (% total waste treated)	46.0%	46.0%	0 p.p.
Total waste backfilled (kg/per capita)	0.0	0.0	0,0%
Total waste backfilled (% total waste treated)	0.0%	0.0%	0 p.p.
Total waste used for incineration (kg/per capita)	2.0	0.2	-87.7%
Total waste used for incineration (% total waste treated)	1.8%	0.3%	-1.5 p.p.
Total waste landfilled (kg/per capita)	2.0	0.3	-85.5%
Total waste landfilled (% total waste treated)	1.8%	0.3%	-1.5 p.p.
Total waste treated with other forms of disposal (kg/per capita)	0.0	0.0	0,0%
Total waste treated with other forms of disposal (% total waste treated)	0.0%	0.0%	0 p.p.
EU waste trade			
Intra-EU trade[1]	0.1	7.8	9660.6%
Balance of extra-EU trade of recyclable raw materials (Kg/per capita)[1]	0.0	1.0	71640%

Source: author's elaboration based on Eurostat data (2024).

Note: [1] Data in column C refer to 2023.

Table A.6 – Textiles waste

	2010	2020	Δ
EU domestic waste			
Total waste generated (kg/per capita)	4.0	4.0	0.0%
Total waste treated (kg/per capita)	2.0	3.1	57.0%
Total waste treated (% total waste generated)	50.0%	78.5%	28.5 p.p.
Total waste used for energy recovery (kg/per capita)	0.0	0.5	0.0%
Total waste used for energy recovery (% total waste treated)	0.0%	15.3%	15.3 p.p.
Total waste recycled (kg/per capita)	2.0	2.3	14.2%
Total waste recycled (% total waste treated)	100.0%	72.7%	-27.3 p.p.
Total waste backfilled (kg/per capita)	0.0	0.0	-
Total waste backfilled (% total waste treated)	0.0%	0.2%	0.2 p.p.
Total waste used for incineration (kg/per capita)	0.0	0.0	-
Total waste used for incineration (% total waste treated)	0.0%	0.9%	0.9 p.p.
Total waste landfilled (kg/per capita)	0.0	0.3	-
Total waste landfilled (% total waste treated)	0.0%	10.9%	10.9 p.p.
Total waste treated with other forms of disposal (kg/per capita)	0.0	0.0	0.0%
Total waste treated with other forms of disposal (% total waste treated)	0.0%	0.0%	0.p.p.
EU waste trade			
Intra-EU trade[1]	2.1	2.3	10.7%
Balance of extra-EU trade of recyclable raw materials (Kg/per capita)[1]	-1.4	-2.2	59.6%

Source: author's elaboration based on Eurostat data (2024).

Note: [1] Data in column C refer to 2023.

Table A.7 – Batteries waste

	2010	2020	Δ
EU domestic waste			
Total waste generated (kg/per capita)	3.0	4.0	33.3%
Total waste treated (kg/per capita)	3.0	3.0	0.0%
Total waste treated (% total waste generated)	100.0%	75.0%	-25 p.p.
Total waste used for energy recovery (kg/per capita)	0.0	0.0	0.0%
Total waste used for energy recovery (% total waste treated)	0.0%	0.0%	0 p.p.
Total waste recycled (kg/per capita)	3.0	3.0	0.0%
Total waste recycled (% total waste treated)	100.0%	100.0%	0 p.p.
Total waste backfilled (kg/per capita)	0.0	0.0	0,0%
Total waste backfilled (% total waste treated)	0.0%	0.0%	0 p.p.
Total waste used for incineration (kg/per capita)	0.0	0.0	0,0%
Total waste used for incineration (% total waste treated)	0.0%	0.0%	0 p.p.
Total waste landfilled (kg/per capita)	0.0	0.0	0.0%
Total waste landfilled (% total waste treated)	0.0%	0.0%	0.p.p.
Total waste treated with other forms of disposal (kg/per capita)	0.0	0.0	0.0%
Total waste treated with other forms of disposal (% total waste treated)	0.0%	0.0%	0.p.p.
EU waste trade			
Intra-EU trade[1]	n.a.	n.a.	-
Balance of extra-EU trade of recyclable raw materials (Kg/per capita)[1]	n.a.	n.a.	-

Source: author's elaboration based on Eurostat data (2024).

Note: [1] Data in column C refer to 2023.

Table A.8 – Vegetal waste

	2010	2020	Δ
EU domestic waste			
Total waste generated (kg/per capita)	101.0	120.0	18.8%
Total waste treated (kg/per capita)	65.0	104.0	60.0%
Total waste treated (% total waste generated)	64.4%	86.7%	22.3 p.p.
Total waste used for energy recovery (kg/per capita)	4.0	4.0	0.0%
Total waste used for energy recovery (% total waste treated)	6.2%	3.8%	-2.4 p.p.
Total waste recycled (kg/per capita)	58.0	98.0	69.0%
Total waste recycled (% total waste treated)	89.2%	94.2%	5 p.p.
Total waste backfilled (kg/per capita)	0.0	0.0	0,0%
Total waste backfilled (% total waste treated)	0.0%	0.0%	0 p.p.
Total waste used for incineration (kg/per capita)	0.0	0.0	0,0%
Total waste used for incineration (% total waste treated)	0.0%	0.0%	0 p.p.
Total waste landfilled (kg/per capita)	3.0	2.0	-33.3%
Total waste landfilled (% total waste treated)	4.6%	1.9%	-2.7 p.p.
Total waste treated with other forms of disposal (kg/per capita)	0.0	0.0	0,0%
Total waste treated with other forms of disposal (% total waste treated)	0.0%	0.0%	0 p.p.
EU waste trade			
Intra-EU trade[1]	41.9	44.9	7.1%
Balance of extra-EU trade of recyclable raw materials (Kg/per capita)[1]	53.9	44.4	-17.6%

Source: author's elaboration based on Eurostat data (2024).

Note: [1] Data in column C refer to 2023.

Table A.9 – Ferrous metals waste

	2010	2020	Δ
EU domestic waste			
Total waste generated (kg/per capita)	n.a.	n.a.	-
Total waste treated (kg/per capita)	n.a.	n.a.	-
Total waste treated (% total waste generated)	-	-	-
Total waste used for energy recovery (kg/per capita)	n.a.	n.a.	-
Total waste used for energy recovery (% total waste treated)	-	-	-
Total waste recycled (kg/per capita)	n.a.	n.a.	-
Total waste recycled (% total waste treated)	-	-	-
Total waste backfilled (kg/per capita)	n.a.	n.a.	-
Total waste backfilled (% total waste treated)	-	-	-
Total waste used for incineration (kg/per capita)	n.a.	n.a.	-
Total waste used for incineration (% total waste treated)	-	-	-
Total waste landfilled (kg/per capita)	n.a.	n.a.	-
Total waste landfilled (% total waste treated)	-	-	-
Total waste treated with other forms of disposal (kg/per capita)	n.a.	n.a.	-
Total waste treated with other forms of disposal (% total waste treated)	-	-	-
EU waste trade			
Intra-EU trade[1]	64.6	70.7	9.4%
Balance of extra-EU trade of recyclable raw materials (Kg/per capita)[1]	-19.5	-33.3	70.7%

Source: author's elaboration based on Eurostat data (2024).

Note: [1] Data in column C refer to 2023.

Table A.10 – Non ferrous precious metals waste

	2010	2020	Δ
EU domestic waste			
Total waste generated (kg/per capita)	n.a.	n.a.	-
Total waste treated (kg/per capita)	n.a.	n.a.	-
Total waste treated (% total waste generated)	-	-	-
Total waste used for energy recovery (kg/per capita)	n.a.	n.a.	-
Total waste used for energy recovery (% total waste treated)	-	-	-
Total waste recycled (kg/per capita)	n.a.	n.a.	-
Total waste recycled (% total waste treated)	-	-	-
Total waste backfilled (kg/per capita)	n.a.	n.a.	-
Total waste backfilled (% total waste treated)	-	-	-
Total waste used for incineration (kg/per capita)	n.a.	n.a.	-
Total waste used for incineration (% total waste treated)	-	-	-
Total waste landfilled (kg/per capita)	n.a.	n.a.	-
Total waste landfilled (% total waste treated)	-	-	-
Total waste treated with other forms of disposal (kg/per capita)	n.a.	n.a.	-
Total waste treated with other forms of disposal (% total waste treated)	-	-	-
EU waste trade			
Intra-EU trade[1]	0.1	0.4	479.0%
Balance of extra-EU trade of recyclable raw materials (Kg/per capita)[1]	0.0	0.1	367.7%

Source: author's elaboration based on Eurostat data (2024).

Note: [1] Data in column C refer to 2023.

Table A.11 – Non ferrous metals waste (Cu, Al, Ni)

	2010	2020	Δ
EU domestic waste			
Total waste generated (kg/per capita)	n.a.	n.a.	-
Total waste treated (kg/per capita)	n.a.	n.a.	-
Total waste treated (% total waste generated)	-	-	-
Total waste used for energy recovery (kg/per capita)	n.a.	n.a.	-
Total waste used for energy recovery (% total waste treated)	-	-	-
Total waste recycled (kg/per capita)	n.a.	n.a.	-
Total waste recycled (% total waste treated)	-	-	-
Total waste backfilled (kg/per capita)	n.a.	n.a.	-
Total waste backfilled (% total waste treated)	-	-	-
Total waste used for incineration (kg/per capita)	n.a.	n.a.	-
Total waste used for incineration (% total waste treated)	-	-	-
Total waste landfilled (kg/per capita)	n.a.	n.a.	-
Total waste landfilled (% total waste treated)	-	-	-
Total waste treated with other forms of disposal (kg/per capita)	n.a.	n.a.	-
Total waste treated with other forms of disposal (% total waste treated)	-	-	-
EU waste trade			
Intra-EU trade[1]	7.6	12.1	57.9%
Balance of extra-EU trade of recyclable raw materials (Kg/per capita)[1]	-2.1	-1.4	-33.5%

Source: author's elaboration based on Eurostat data (2024).

Note: [1] Data in column C refer to 2023.

Table A.12 – WEEE

	2010	2020	Δ
EU domestic waste			
Total waste generated (kg/per capita)	n.a.	n.a.	-
Total waste treated (kg/per capita)	7.4	10.4	41.0%
Total waste treated (% total waste generated)	-	-	-
Total waste used for energy recovery (kg/per capita)	n.a.	n.a.	-
Total waste used for energy recovery (% total waste treated)	-	-	-
Total waste recycled (kg/per capita)	n.a.	n.a.	-
Total waste recycled (% total waste treated)	-	-	-
Total waste backfilled (kg/per capita)	n.a.	n.a.	-
Total waste backfilled (% total waste treated)	-	-	-
Total waste used for incineration (kg/per capita)	n.a.	n.a.	-
Total waste used for incineration (% total waste treated)	-	-	-
Total waste landfilled (kg/per capita)	n.a.	n.a.	-
Total waste landfilled (% total waste treated)	-	-	-
Total waste treated with other forms of disposal (kg/per capita)	n.a.	n.a.	-
Total waste treated with other forms of disposal (% total waste treated)	-	-	-
EU waste trade			
Intra-EU trade[1]	n.a.	n.a.	-
Balance of extra-EU trade of recyclable raw materials (Kg/per capita)[1]	n.a.	n.a.	-

Source: author's elaboration based on Eurostat data (2024).

Note: [1] Data in column C refer to 2023.

ANNEX II – EU QUANTITATIVE TARGETS FOR THE CIRCULAR ECONOMY

Policy area	Target	Time horizon	Legislative source
Circular material use rate	23.4%	By 2030	Communication (2023) 168 final
Extraction of EU geological resources of SRMs as percentage of the EU annual consumption	≥10%	By 2030	Proposal for a Regulation COM (2023) 160 final
EU production of SRMs as percentage of the EU annual consumption	≥40%	By 2030	Proposal for a Regulation COM (2023) 160 final
Recycling of SRMs as percentage of the EU annual consumption	≥15%	By 2030	Proposal for a Regulation COM (2023) 160 final
Supply dependence of any SRM from a single third country	≤ 65%	By 2030	Proposal for a Regulation COM (2023) 160 final
Lead-acid batteries recycling rate	75%	By 2025	Regulation (EU) 2023/1542
Lead-acid batteries recycling rate	80%	By 2030	Regulation (EU) 2023/1542
Lithium-based batteries recycling rate	65%	By 2025	Regulation (EU) 2023/1542
Lithium-based batteries recycling rate	70%	By 2030	Regulation (EU) 2023/1542
Other waste batteries recycling rate	50%	By 2025	Regulation (EU) 2023/1542
Cobalt recovery from batteries	90% 95%	By 31.12.27 By 31.12.31	Regulation (EU) 2023/1542
Copper recovery from batteries	90% 95%	By 31.12.27 By 31.12.31	Regulation (EU) 2023/1542
Lead recovery from batteries	90% 95%	By 31.12.27 By 31.12.31	Regulation (EU) 2023/1542
Lithium recovery from batteries	90% 95%	By 31.12.27 By 31.12.31	Regulation (EU) 2023/1542
Nickel recovery from batteries	90% 95%	By 31.12.27 By	Regulation (EU) 2023/1542

		31.12.31	
Cobalt recovered to be reused in new batteries	16% 26%	From 18.08.31 From 18.08.36	Regulation (EU) 2023/1542
Lead recovered to be reused in new batteries	85% 85%	From 18.08.31 From 18.08.36	Regulation (EU) 2023/1542
Lithium recovered to be reused in new batteries	6% 12%	From 18.08.31 From 18.08.36	Regulation (EU) 2023/1542
Nickel recovered to be reused in new batteries	6% 15%	From 18.08.31 From 18.08.36	Regulation (EU) 2023/1542
Light means of transport batteries collection rate	51% 61%	By 2028 By 2031	Regulation (EU) 2023/1542
Portable batteries collection rate	45% 63% 73%	By 2023 By 2027 By 2030	Regulation (EU) 2023/1542
Construction and demolition waste preparing for re-use and recycling rate	70%	By 2020[1]	Directive 2008/98/EC
End-of-life vehicles re-use and recovery rate	≥ 95%	≥ 2015	Directive 2000/53/EC
End-of-life vehicles re-use and recycling rate	≥ 85%	≥ 2015	Directive 2000/53/EC
Landfilled municipal waste recycling rate	≤10%	by 2030 (by 2040)[2]	Council Directive 1999/31/EC
Municipal waste preparing for re-use and recycling rate	55% 60% 65%	By 2025 By 2030 By 2035	Directive (EU) 2018/851
All packaging recycling rate	55% 65% 70%	Current By 2025 By 2030	Directive 94/62/EC
Aluminium packaging recycling rate	- 50% 605	Current By 2025 By 2030	Directive 94/62/EC
Ferrous metals packaging recycling rate	50% (incl. Al) 70% (incl. Al) 80% (incl. Al)	Current By 2025 By 2030	Directive 94/62/EC
Glass packaging recycling rate	60% 70% 75%	Current By 2025 By 2030	Directive 94/62/EC
Paper and cardboard packaging recycling rate	60% 75% 85%	Current By 2025 By 2030	Directive 94/62/EC

Plastic packaging recycling rate	25% 50% 55%	Current By 2025 By 2030	Directive 94/62/EC
Wood packaging recycling rate	15% 25% 30%	Current By 2025 By 2030	Directive 94/62/EC
Lightweight plastic carrier bags consumption	40 per person/year	By 2025	Directive (EU) 2015/720
Microplastics released into the environment	-30%	By 2031	Communication COM (2021) 400 final
Plastic litter at sea	-50%	By 2030	Communication COM (2021) 400 final
Plastic waste shipment from the EU to non-OECD countries	0[3]	≥ 2021	Regulation (EU) 2020/2174
Share of recycled plastic in PET beverage bottles	25% 30%	≥ 2025 ≥ 2030	Directive (EU) 2019/904
Single use plastic products waste separate collection rate	77% 90%	By 2025 By 2029	Directive (EU) 2019/904
Waste electrical and electronic equipment recovery rate	75% ≥ x ≤ 85%	≥ 2019	Directive 2012/19/EU
Waste electrical and electronic equipment preparing for re-use and recycling rate	55% ≥ x ≤ 80%	≥ 2019	Directive 2012/19/EU
Minimum requirements for water reuse for agricultural irrigation	Several quality targets by water quality class	-	Regulation (EU) 2020/741
Primary energy consumption	≤ 992.5 Mtoe	By 2030	Directive (EU) 2023/1791
Final energy consumption	≤ 763 Mtoe	By 2030	Directive (EU) 2023/1791
Share of renewable energy	≥ 42.5%	By 2030	Directive (EU) 2023/2413
Biomethane production	35 bcm/year	By 2030	REPowerEU (SWD (2022) 230)
Renewable hydrogen production	10 Mt	By 2030	REPowerEU (SWD (2022) 230)
Renewable hydrogen import	10 Mt	By 2030	REPowerEU (SWD (2022) 230)
GHG emissions	-55% wrt 1990	By 2030	Regulation (EU) 2021/1119

Source: Commission's services (2024).

Notes: [1] By 31 December 2024, the Commission shall consider the setting of preparing for re-use and recycling targets for construction and demolition waste and its material-specific fractions, textile waste, commercial waste, non-hazardous industrial waste and other waste streams, as well as preparing for re-use targets for municipal waste and recycling targets for municipal bio-waste.

[2] Member States with a landfill rate >60 % in 2013 have been granted a derogation up to 2040. However, in this case landfill rate does not have to exceed 25 % in 2035.

[3] Except for clean plastic waste sent for recycling.

EUROPEAN ECONOMY DISCUSSION PAPERS

European Economy Discussion Papers can be accessed and downloaded free of charge from the following address: Publications (europa.eu).

Titles published before July 2015 under the Economic Papers series can be accessed and downloaded free of charge from:
http://ec.europa.eu/economy_finance/publications/economic_paper/index_en.htm.

GETTING IN TOUCH WITH THE EU

In person

All over the European Union there are hundreds of Europe Direct Information Centres. You can find the address of the centre nearest you at: http://europa.eu/contact.

On the phone or by e-mail

Europe Direct is a service that answers your questions about the European Union. You can contact this service:

- by freephone: 00 800 6 7 8 9 10 11 (certain operators may charge for these calls),
- at the following standard number: +32 22999696 or
- by electronic mail via: http://europa.eu/contact.

FINDING INFORMATION ABOUT THE EU

Online

Information about the European Union in all the official languages of the EU is available on the Europa website at: http://europa.eu.

EU Publications

You can download or order free and priced EU publications from EU Bookshop at: http://publications.europa.eu/bookshop. Multiple copies of free publications may be obtained by contacting Europe Direct or your local information centre (see http://europa.eu/contact).

EU law and related documents

For access to legal information from the EU, including all EU law since 1951 in all the official language versions, go to EUR-Lex at: http://eur-lex.europa.eu.

Open data from the EU

The EU Open Data Portal (http://data.europa.eu/euodp/en/data) provides access to datasets from the EU. Data can be downloaded and reused for free, both for commercial and non-commercial purposes.

Publications Office
of the European Union