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Analysis of the circular material use rate and the doubling target

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Contents

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Summary

This report analyses the progress made by the European Union (EU) in the circular material use rate (CMUR), supporting a better understanding of the observed status and trends. In addition, it provides a first simplified assessment of the prospects of the EU to move towards its ambition to double the CMUR within a decade, in the context of the Circular Economy Action Plan (CEAP) and the European Green Deal (EGD). Broadening the scope, the report looks also into unaccounted flows of recycled materials, a key driver of CMUR. It also complements the CMUR assessment by quantifying environmental impacts linked to material consumption, the main current driver of CMUR. This analysis helps to understand and interpret the observed status, trends and possible future developments for the CMUR, both on the total CMUR as well as on the CMUR for the four broad material categories as published by Eurostat. The insights are considered in the context of the CEAP's aim of "*doubling the CMUR in the coming decade*" at the EU level. The integration of the environmental impact from material uses brings in different perspectives into the analysis and interpretation of the CMUR.

1 Introduction

1.1 Policy targets and current status

The Circular Economy Action Plan (CEAP), published in 2020, includes a non-legally binding target of doubling the circular use of materials in the coming decade ([1]). Both the reduction of material use and increasing the demand for recycled material saves the extraction of primary raw materials. This is likely to reduce the environmental impacts associated with the EU's production and consumption.

Data shows that the circular use of materials, expressed through the circular material use rate (CMUR), also referred to as the circularity rate, in the EU stood at 11.7 % ([2;3]) in 2021. In terms of volume, this translates as around 837 million tonnes of recycled materials out of a total of 7,158 million tonnes of material use. Although this value has increased by 0.9 percentage point since 2010, from 10.8 %, and by 3.4 percentage points since 2004, from 8.3 %, the past trends indicate that the EU target of doubling the CMUR will be very challenging to reach.

For the purpose of this report, it is assumed that meeting this non-legally binding target would mean moving from 11.7 %, the 2020 value for the EU, to 23.4 % in 2030, as the CEAP defines neither a reference year nor a target value. Also, the target refers to the EU as a whole with no individual country-level targets set. Therefore, this analysis of the CMUR focuses on the EU as a whole.

1.2 Description of the indicator

The CMUR ([4]) indicator is part of the EU's Circular Economy Monitoring Framework. It is used to monitor progress towards a circular economy on the thematic area of 'secondary raw materials'. This indicator is also one of the EEA's indicators on resource efficiency and waste (EEA, 2023). The CMUR measures the share of material recovered and fed back into the economy in overall material use:

$$\text{circular material use rate (CMUR)} = \frac{\text{circular use of materials}}{\text{overall use of materials}}$$

The circular use of materials (numerator) is approximated by the amount of waste recycled in domestic recovery plants, corrected by imports and exports. The overall use of material (denominator) is measured by domestic material consumption (DMC), and additionally the circular use of materials is included to ensure that the rate ranges between 0 and 1. Domestic material consumption is the total amount of material used directly in an economy as defined in economy-wide material flow accounts ([5]). Instead of DMC, Eurostat prefers using the raw material consumption (RMC) indicator of overall material use. This, however, is currently only available as a modelling estimate per Member State, causing Eurostat to use DMC instead as a proxy indicator. This report sticks to the methodological choices made by Eurostat.

A higher circularity rate value means that more primary raw materials are substituted by secondary ones thus generally reducing the environmental impacts of extracting primary material unless the substitution effect is overcompensated by an increase in the use of virgin materials.

[1] The Circular Economy Action Plan (CEAP) (EC, 2020) states, "[…] *the EU needs to accelerate the transition towards a regenerative growth model that gives back to the planet more than it takes, advance towards keeping its resource consumption within planetary boundaries, and therefore strive to reduce its consumption footprint and double its circular material use rate in the coming decade*".

[2] Source: Eurostat databases Circular material use rate by material type: env_ac_curm (last update: 24/01/2023).

[3] The 2020 data is affected by the economic slowdown due to COVID-19.

[4] Eurostat metadata of the CMUR: env_ac_cur.

[5] Eurostat metadata of material flow accounts of which the DMC is part: env_ac_mfa.

Data sources that define both the numerator and the denominator of the CMUR are identified as the best proxies among official statistics of the European Statistical System. Data are available for the whole EU economy and by material category – biomass ([6]), metal ores ([7]), non-metallic minerals ([8]) and fossil energy carriers/materials ([9]) (Eurostat, 2018).

1.3 Aim and structure of the report

The overall aim of this report is to perform an analysis that helps understand and interpret the observed status, trends and possible future developments of the CMUR, and to analyse the prospects for the EU to move towards its target.

A first aim is to have a better understanding of the CMUR for EU and the past trends (**Chapter 2**). Although the target only applies to the total of materials, the focus is on the total CMUR as well as on the four broad material categories individually, i.e., biomass, metal ores, non-metallic minerals, and fossil energy carriers/materials. The identification of drivers is a key point in analysing this indicator and its sub-components in order to understand which levers policy makers can use to improve the CMUR. **Chapter 2** discusses the understanding of the CMUR indicator, its components and observed trends, and identifies drivers that influence it. A second part of the analysis focuses on secondary material flows which are not directly captured by the CMUR (**Chapter 3**). The recovery of energy from waste and the use of industrial by-products and production waste are examples of such flows, although they do influence the CMUR through their substitution effect on lowering the DMC and, as a result, they have a positive effect on the CMUR. In Chapter 3, a mainly qualitative understanding is provided on the (potential) impact of these flows on the (future) CMUR. Based on insights from the analysis of the CMUR, the prospects for the EU to move towards its target are analysed, with a focus on considerations of possible changes in both material use and recycling, and an assessment made of these changes on the hypothetic future development of the overall CMUR (**Chapter 4**). Additionally, a detailed analysis of the environmental impacts related to material use is performed, to complement the mass based CMUR (**Chapter 5**). **Chapter 5** develops some reflections on the relevance of the different material groups for different environmental impacts. This will facilitate the identification of priority areas for action and further analyses.

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6 Biomass records material flows from the environment to the economy related to the human appropriation of cultivated and non-cultivated biomass. While the latter, for example, wild fish catch, hunting and gathering, logging from natural forests, can be measured straightforwardly at the boundary between environment and economy, the former cannot and by convention the so-called harvest approach is introduced. Amounts harvested from cultivated biological resources are available from agriculture and forestry harvest statistics.

7 Metal ores records material flows from the environment to the economy related to the mining of metallic minerals performed through underground or open-cast extraction, seabed mining, etc.

8 Non-metallic minerals records material flows from the environment to the economy related to mining and quarrying of mineral material other than metals and fossil energy carriers such as stone, sand, clay, salt, etc. It refers not only to the extraction from a mine or quarry, but also the dredging of alluvial deposits, rock crushing and the use of salt marshes.

9 Fossil energy materials/carriers extraction records material flows from the environment to the economy related to extraction of solid, liquid and gaseous fossil mineral fuels through underground or open-cast mining, and the operation of crude oil and natural gas fields. Extraction of oil shale and sands is included.

2 Understanding the circular material use rate and its past trends

Key message 2.1
The trend of the CMUR is mainly driven by DMC, both at total and material flow category levels, and much less by the trend in recycling. Different recycling levels do have an effect on CMUR values for the different material categories: the highest for metal ores, followed by non-metallic minerals, and the lowest for fossil fuels, followed by biomass.

Key message 2.2
The CMUR is a volume-based indicator, dominated by non-metallic minerals which make up 52 % of DMC and 66 % of recycled waste.

Key message 2.3
Improving the CMUR needs different approaches for fossil fuels and biomass on the one hand and metals and non-metallic minerals on the other. The first group is largely converted into emissions as most of these materials are used for energy generation or as food, and recycling options are therefore limited. Therefore, the circular material use rate for these materials can mainly be increased by reducing their use for energy purposes and replacing them with renewable energy technologies, and by reducing food waste. The second group largely goes into the stock build-up and stock maintenance, and becomes available for recycling at some point in time. Approaches for improving the CMUR of metals and non-metallic minerals should be targeted towards both reducing their use in the economy, by, for example, increasing the usable lifetime of materials currently in stock, and increasing the recycling of those materials when they become waste.

Key message 2.4
The EU's primary waste generation is still strongly linked to economic activity. Only if decoupling between waste generation and gross domestic product (GDP) occurs through higher material efficiency, lower material intensity, reduced and sustainable consumption, etc., driven, for example, by ambitious circular economy and recycling policies, a higher growth rate of recycling could be achieved.

2.1 Calculation methodology explained

The CMUR components are DMC, waste recycling, notably recycling, RCV_R ([10]), and international trade in waste bound for recovery (IMP_W ([10]) and EXP_W ([10])). The rate stems from the ratio between circular use of materials (U) and overall material use (DMC + U).

The formula for the CMUR is:

$$\mathrm{CMUR} = \frac{\mathrm{U}}{\mathrm{DMC} + \mathrm{U}} = \frac{(\mathrm{RCV\_R} - \mathrm{IMP_w} + \mathrm{EXP_w})}{\mathrm{DMC} + (\mathrm{RCV\_R} - \mathrm{IMP_w} + \mathrm{EXP_w})}$$

Data sources that define both the numerator and the denominator of the circular material use ratio – circular use of materials (U) over overall material use (DMC + U) – are identified as the best proxies among official statistics of the European Statistical System.

The CMUR is developed making use of different European statistics, all of them provided by Eurostat. The components of the CMUR by material category are based on the following.

[10] RCV_R: the amount of waste recycled in domestic recovery plants. Waste recycled in domestic recovery plants comprises the recovery operations R2 to R11 as defined in the Waste Framework Directive 2008/98/EC.
IMP_w: the amount of imported waste destined for recycling.
EXP_w: the amount of exported waste destined for recycling abroad.

- The **DMC** component is directly available, and provided in the material flow categories, from the economy-wide material flow accounts (Eurostat, 2022b).
- The **U** component, the circular use of materials, is calculated based on the amount of waste recycled in domestic recovery plants, RCV_R, derived from waste statistics ([11]), minus imported waste destined for recovery (IMP_W) and plus exported waste destined for recovery abroad (EXP_W) ([12]).
    - The component for recycling, **RCV_R**, is derived from the Treatment of waste by waste category, hazardousness and waste operations dataset ([13]) (Eurostat, 2023c). The statistic is provided through a waste category classification, requiring a conversion to the material categories to derive the RCV_R at a material category level. The conversion factors from waste categories to material categories are provided by Eurostat ([14]). The data is only available for every even year ([15]).
    - The components **IMP_W** and **EXP_W** are approximated from the international trade in goods statistics (Eurostat, 2023b) ([16]). A list of combined nomenclature (CN) codes used to approximate the imports and exports of waste destined for recycling is provided by Eurostat ([17]), together with their allocation to the four material categories.

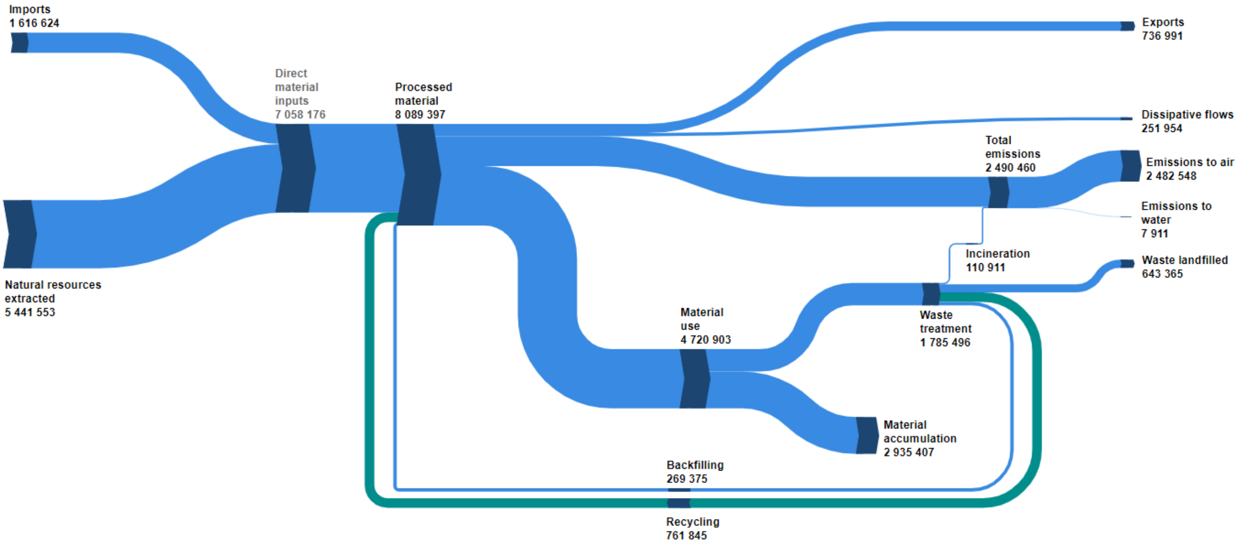
There is a close link between the economy-wide material flow diagram (Figure 1; see also the assessment of the data presented by the 2021 Raw Materials Scoreboard ([18])) and the CMUR. The diagram visualises the material flows captured by the components of the CMUR indicator. A Sankey diagram, in which the width of the arrow is proportional to the size of the flow, presents the (annual) flows of:

(1) resources extracted to make products or be used as a source of energy;
(2) materials and products flowing in and out of society (imports and exports); and
(3) materials and products discarded into the environment as residues, such as landfilled waste or emissions to air, or recovered and fed back into the economy.

This last part closes the loop in the circular economy. Products with a longer life spans and infrastructure such as buildings, roads and machinery are used over a long period during which they mount up in societies, increasing stocks, until they are eventually dismantled or taken out of use.

11 Eurostat metadata on waste generation and treatment: env_wasgt.
12 See the Eurostat manual: Circular material use rate — Calculation method — 2018 edition
13 This statistic is collected on the basis of the Waste Statistics Regulation (EC) No 2150/2002.
14 WStatR in MFA (europa.eu)
15 A gap filling (interpolation) and nowcasting methodology is developed by Eurostat to allow a yearly estimation of the CMUR.
16 Eurostat metadata on international trade in goods
17 cei_srm030_esmsip_CN-codes.pdf (europa.eu)
18 https://rmis.jrc.ec.europa.eu/uploads/scoreboard2021/indicators/ind12.pdf

Figure 1 The material flow diagram for EU, 2021, thousand tonnes.



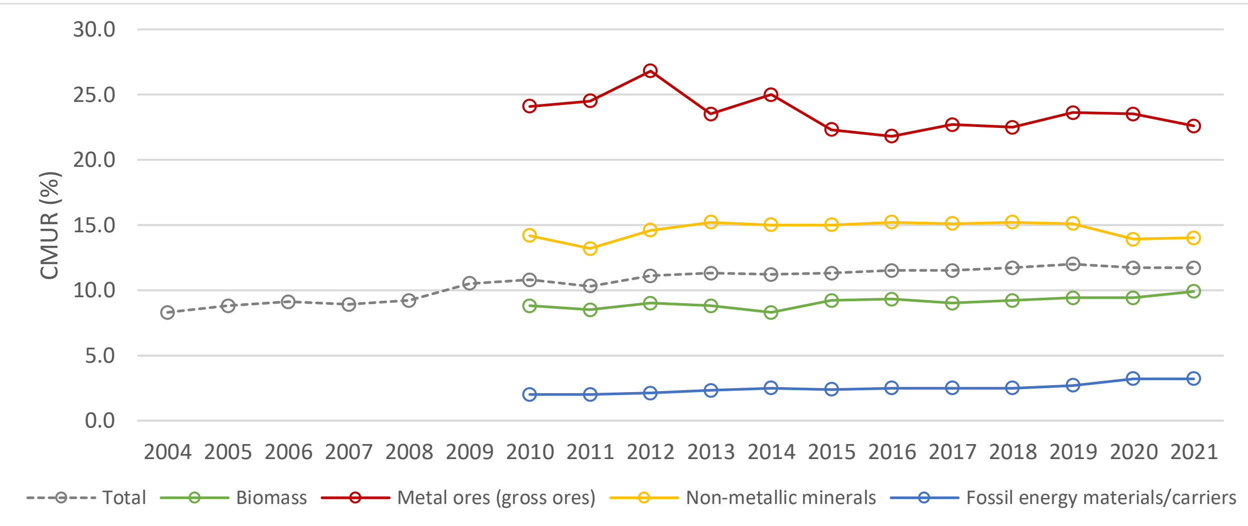
Source: Eurostat (2021) - (env_ac_sd) accessed March 2023.

The CMUR intuitively represents the size of the closing loop relative to the overall amount of materials entering the economy, although definitions, classifications, scope and treatment of imports and exports of waste differ for CMUR and the Sankey (Eurostat, 2023a).

2.2 Past trends in the circular material use rate

In 2021, the overall EU CMUR reached 11.7 %, showing an increase by 3.4 percentage points from 2004 (Figure 2). The levels and trends of the indicator for non-metallic minerals and biomass did not show major differences for the period 2010-2021 compared to the average total. The CMUR of fossil energy materials/carriers showed the same trend as the total CMUR as well, but they stood much below the total average. The trend of the indicator for the metal ores was different, especially with fluctuations between 2010 and 2015. Also, the level of the indicator for metal ores was much higher compared to the other material categories and has the highest variation over time.

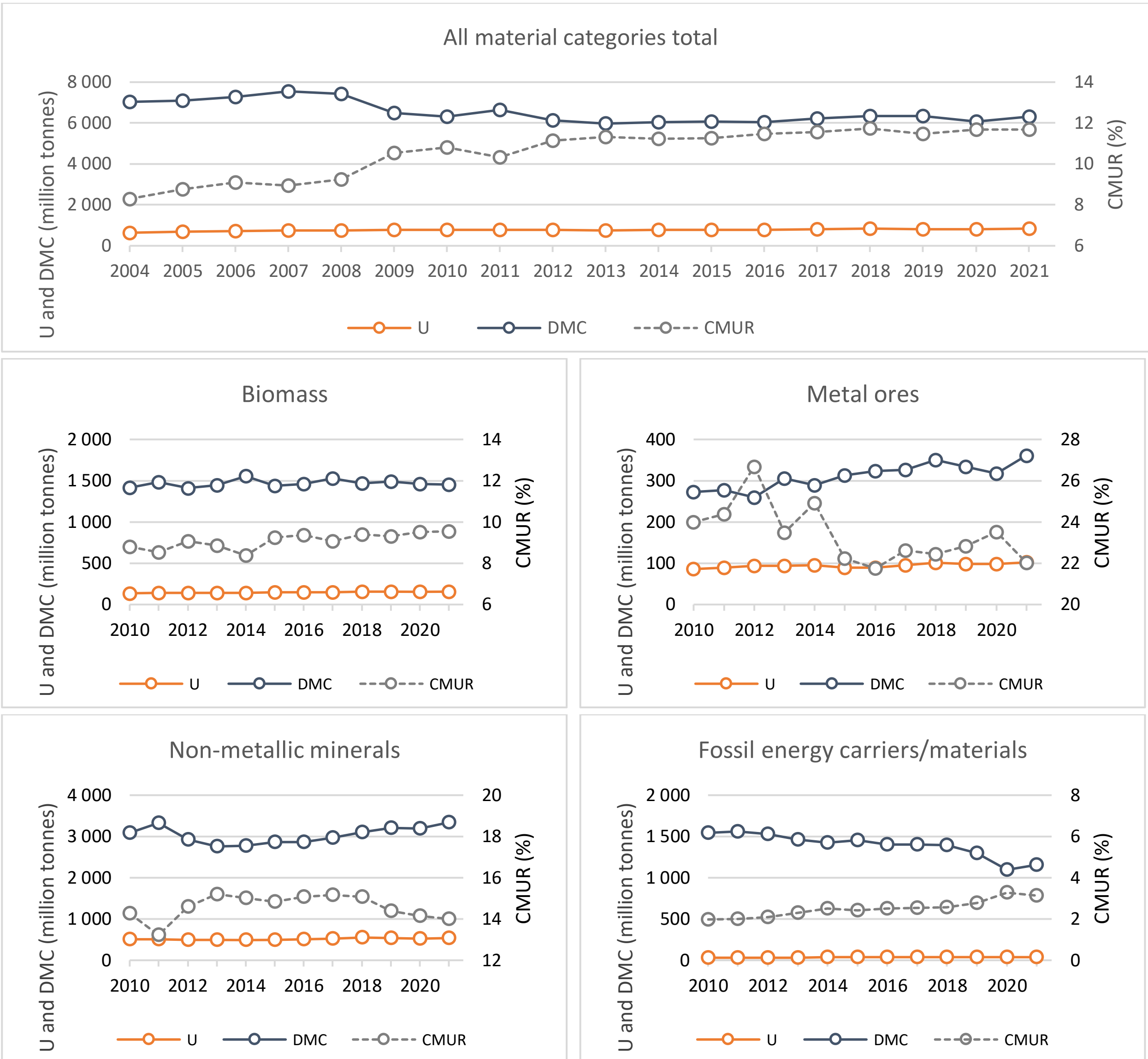
Figure 2 The circular materials use rate, total and by material category, for EU27, 2004–2021, per cent



Source: Eurostat database Circular material use rate by material type: env_ac_curm (last update: 24/01/2023).

Quantitively, the most important components of the CMUR are DMC and recycling. The other components, i.e., the waste flows which are imported and exported, are relatively small in absolute values and they cancel each other out so the net trade is negligible. This is also confirmed when comparing the trend of the CMUR with the trend of the individual components (Figure 3). The CMUR trend is distinctly explained by DMC, both at total and at material flow category levels. Indeed, the trend for the EU27 CMUR reversely reflects DMC's upward and downward developments (Figure 3). As for the level of the EU27 CMUR, this is mainly driven by recycling: the higher the ratio of recycling over DMC, the higher CMUR by material category, such as metal ores and non-metallic minerals. All in all, the interplay between DMC and recycling mathematically determines the rate of CMUR. This is explained more in detail in the next section.

Figure 3 Development of the circular material use rate and its components, circular use of materials and domestic material consumption, totals, 2004-2021, and per material category, 2010-2021, EU27, circular use of materials and domestic material consumption million tonnes, circular material use rate per cent



Note: The breakdown by material categories is not available for 2004-2009. Missing data for odd years from the env_wastrt-database are linearly interpolated.

Note: U and DMC in million tonnes on left vertical axis and CMUR in percentages on right vertical axis.

Source: CMUR: Eurostat databases Circular material use rate by material type: env_ac_curm (last update: 24/01/2023); Source U: ETC-CE own calculations using Eurostat database: treatment of waste (env_wastrt; last update: 13/01/2023) and trade in waste (env_ac_sd; last update: 20/02/2023); Source DMC: domestic material consumption (env_ac_mfa; last update: 01/07/2022).

2.3 Macro determinants of the circular material use rate

A detailed analysis of the macro determinants of the CMUR helps identify drivers of its two major components, DMC and recycling. This analysis is split in two distinct parts due to the different nature of the two indicators. Domestic material consumption is a measure of the total amount of materials directly used by an economy, so stands for the pressure on the environment exerted by the economic system, while recycling provides the response of the same system to solving an environmental issue towards a more sustainable use of resources.

In the next two sections, further insights are provided on the drivers for DMC and recycling, mainly based on observations at the level of the individual material categories. A third section discusses the overall effect of both components on the CMUR indicator and touches upon other potential drivers.

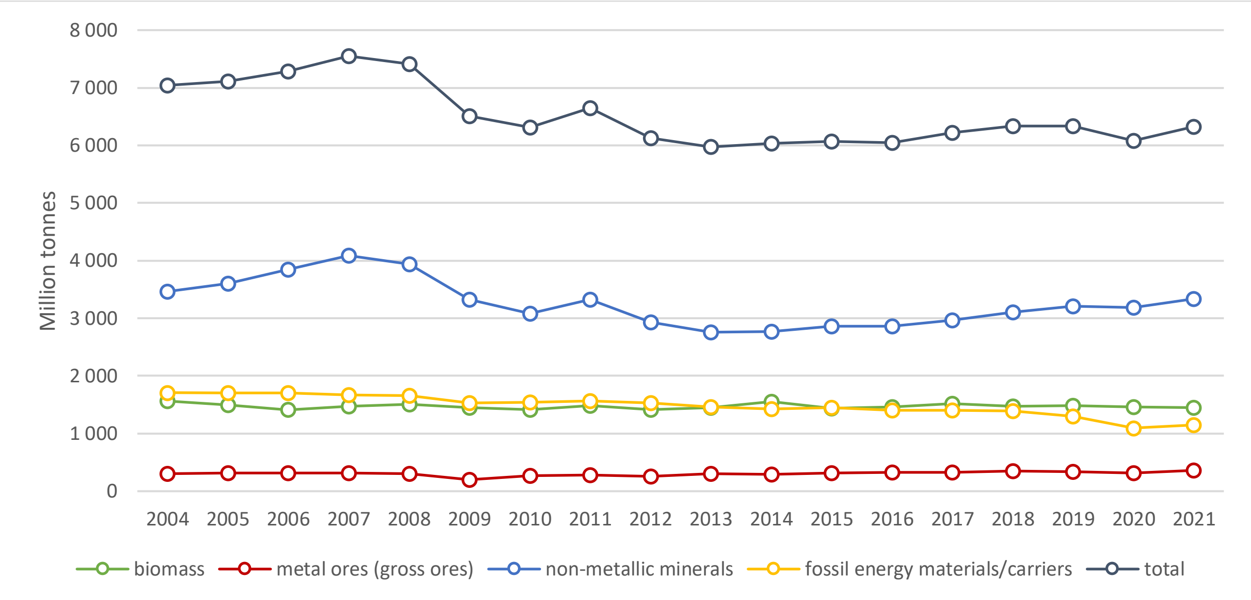
2.3.1 Drivers of the domestic material consumption indicator

Figure 4 presents the trend of the total DMC to 2021, distinguishing the four material categories which allows the identification of the major constituents of this indicator.

From 2004 to 2021, the DMC of the EU27 declined from 7 048 to 6 321 tonnes. During this time, four phases can be identified, with a clear link to the level of the economic activity: first, DMC increased by 7.1 % for 2004–2007; then the economic crisis drove a fall of more than 20 % for 2007–2013, despite the short recovery in 2010–2011; a third phase in 2013–2019 shows the DMC increasing by 6.1 %, coupled to and driven by the economic activity; finally, the pandemic crisis of 2019–2020 brought about a new decline in DMC but recovered in 2021.

Among the four material categories, the DMC of non-metallic minerals accounted for on average about 50 % of the EU27's DMC and was the major driver of the total indicator's development. Two other material categories – biomass and fossil fuels – accounted for slightly more than 22 % each on average. Metal ores' share of the EU27's DMC stood at about 5 %.

Figure 4 The domestic material consumption by material category, EU27, 2004–2021, million tonnes



Source: Eurostat-database env_ac_mfa (last update: 01/07/2022).

As mentioned previously, the up- and downward changes of DMC tend to bring about opposite changes in the CMUR, while the recycled amounts are much more stable over the years. This holds true both at the total and material category levels. It is, therefore, important to identify the key driving forces of DMC. Economic developments are usually the main driving factors.

Box 1 ECONOMIC VARIABLES AS POTENTIAL DRIVERS OF DOMESTIC MATERIAL CONSUMPTION

Resource indicators such as DMC are typically related to the level of economic activity, for example, GDP at constant prices, to show trends in resource efficiency. The physical economy, however, does not always strictly parallel the monetary economy as described in national accounts so that the direct relationship between physical and monetary data requires care.

Moreover, a direct allocation of economic variables to DMC is not straightforward as this indicator represents the volume of domestic extraction and net trade, i.e., physical imports minus physical exports ([19]). To increase the level of detail, possible allocations of domestic extraction and physical trade to specific sectors are explained in the following paragraphs.

The allocation of domestic extraction for industries is quite clear, also because only a limited number of industries is involved. The sectoral attribution is based on the materials' characteristics. For instance, biomass harvest can be simply attributed to the 'agricultural, forestry and fishing industry. In general, the most obvious industries, classified according to NACE Rev. 2, involved in the allocation of domestic extraction, are as follows:

- A Agriculture, forestry and fishing comprises
  - A01 Crop and animal production, hunting and related service activities;
  - A02 Forestry and logging; and
  - A03 Fishing and aquaculture.
- B Mining and quarrying.

In addition, rock and soil excavated for construction purposes are often used within the same or other construction activities. Unless the excavated materials qualify as residuals, i.e., do not have an economic value to the producer, their flows are an input of natural resources from the environment to NACE F Construction.

As for physical trade, one should consider first that import and export flows contain products at different stages of manufacturing and thus, differently from domestic extraction, comprise not only raw materials but also products composed of different materials that have undergone processing steps. And secondly, traded products are used across all industries. Therefore, their allocation is not easy even at a material category level.

All in all, the identification of DMC drivers at a material category level mainly depends on the importance of the two components – domestic extraction and physical trade – in determining DMC for biomass, metal ores, non-metallic minerals and fossil energy materials.

Box 2 IMPACT OF ECONOMIC DOWNTURNS

During 2004–2020 world economies faced two unexpected events: the global economic and financial crisis in 2007–2009 and the COVID-19 pandemic crisis that started in 2020. They had very different impacts on the use of natural resources in the EU27.

The economic crisis resulted in a considerably lower GDP rate of change of +0.6 % in 2008 when the crisis was already apparent, in the 2009 it fell by -4.3 %, and recovered in 2010. This crisis triggered a severe fall in DMC that started in 2008, recovered slightly in 2011 and but fell again until 2013. In the period 2008–2013, DMC decreased by about 20 %, which allowed a CMUR growth by 2.4 percentage points, out of the 3.5 points for 2004–2020.

The COVID-19 crisis arrived after a series of positive rates of change were recorded for 2009–2019. In 2020, the EU27 recorded a considerably larger fall in GDP of almost -6% compared to 2019 than the decrease in economic activity accounted for in 2009. The complete size of the pandemic's economic impact will, however, probably only become apparent in the coming years. On one hand the pandemic has impacted the economy, on the other its

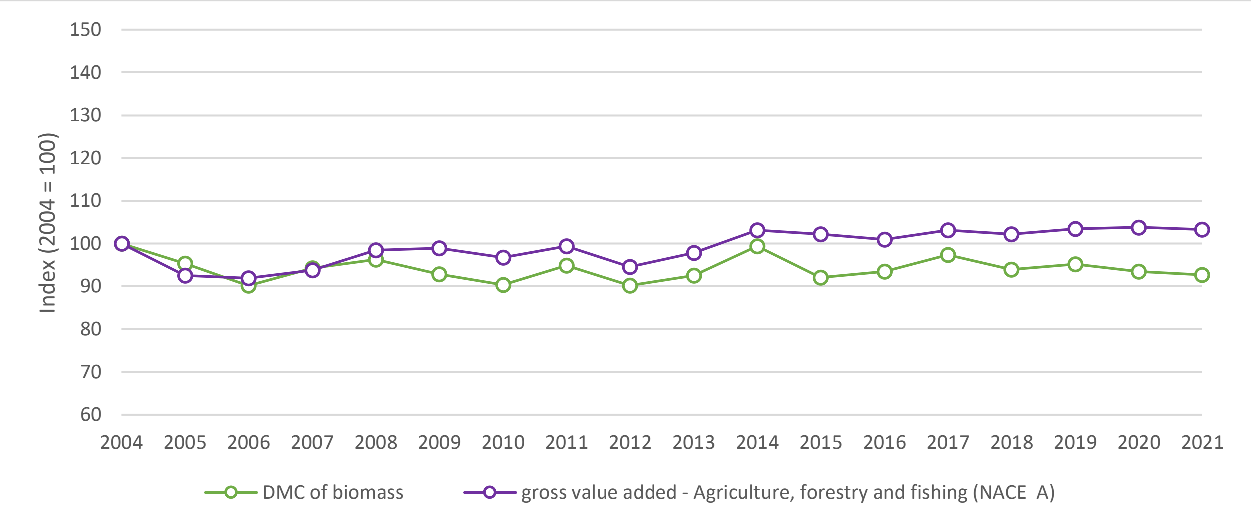
[19] DMC and in general derived economy-wide material flow analysis (EW-MFA) indicators are not fit to identify the material use flows of different specific industries as EW-MFA does not allow the opening of the black box of the economy by reporting flows between industries, which would require the formation of a physical supply and use table of the economy.

effects have differed from one industry to another. In addition, the COVID-19 effects have had a varied impact on different types of expenditure such as consumption and investment. As such, comparisons of data for 2020 with much earlier years combine at least two levels of analysis: structural changes over several years up to 2020 as well as the specific impact of COVID-19 between 2019 and 2020. The pandemic's effect on the use of resources seems to be a less extreme drop compared to the previous crisis. However, DMC data are still provisional for 2020, and an in-depth analysis, which includes the following years, will be needed.

As explained in Box 1, the link between DMC and its determinants at a material category level is more meaningful and direct than at a total material level. All the drivers identified in the following analysis will then affect the total level of the circularity rate.

The physical consumption of **biomass** increased by more than 2 % between 2010 and 2021, albeit with annual fluctuations over the period ([20]) (Figure 5). Domestic extraction dominated the DMC of biomass, as imports offset exports of biomass. The DMC of biomass comprises biomass for human foodstuff and food processing, which accounted for, on average, some 40 % of total biomass between 2004 to 2021; biomass for livestock, less than 40 % over the period; and other biomasses, fibres and wood, about 20 %. These three uses of biomass have their driving force on the supply side of the economy, notably the production in the agricultural sector. In Figure 5 ([21]) the **value added of agriculture, forestry and fishing** is used as proxy for economic production and is compared to the total physical consumption of biomass.

Figure 5 The domestic consumption of biomass and value added as a possible economic driver, EU27, 2004–2021, index (2004 = 100)



Note: gross value added is in chain linked volumes.

Source: DMC: Eurostat database env_ac_mfa (last update: 01/07/2022) and source value added: Eurostat database nama_10_a64 (last update: 02/02/2023).

The DMC of **metal ores** has been more sensitive to economic development than the pandemic crisis, with the caveat that in the following years more data will shed light on the COVID-19 crisis (Figure 6). In the context of the DMC indicator, the 'metal ores' category is defined in a broad sense, i.e., it includes metals

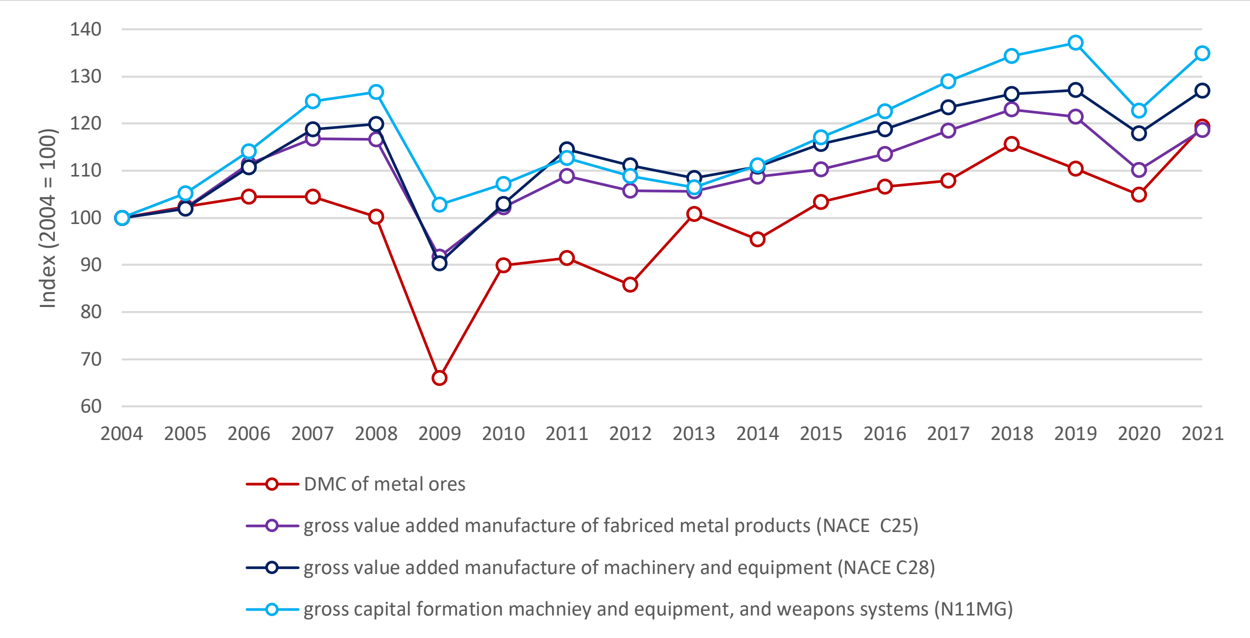
20 Weather conditions are probably the main driver behind the annual fluctuations in this sector. Reduced biomass production can be explained by adverse weather extremes such as extremely cold winters and long heat waves in summer, which affect, among others, cereal growth. Conversely, beneficial weather conditions throughout the growing season result in higher agricultural production (Camia et al., 2018)

21 Both the vertical and horizontal axis of Figure 5 to Figure 8 are kept equal for comparability.

in different forms and not only ore ([22]), for reasons of consistency this terminology is adopted here. The EU27's total supply of metal ores is highly dependent on imports from the rest of the world: in the period 2004–2021 import dependency changed from about 66% of the direct material input (DMI) ([23]) of metal ores at the beginning, to around 52% of DMI at the end of the period. Combining the difference in measurement of domestic extraction (ores) and imports (manufactured product) and the increased share of domestic extraction explains part of the increase in DMC of metals ores. Nevertheless, Figure 6 shows an upward development of consumption of metal ores between the two crises, supported by the increase of ore extraction activities in EU27.

The drivers of the DMC of metal ores presented in Figure 6 are **value added of manufacture of machinery and equipment** and **manufacture of fabricated metal products**, which are triggered by **investment in machinery and equipment and weapons systems**.

Figure 6 The domestic consumption of metal ores, and value added and investment as a possible economic driver, EU27, 2004–2021, index (2004 = 100)



Note: gross value added and investment are in chain linked volumes.

Source: DMC: Eurostat database env_ac_mfa (last update: 01/07/2022); source value added: Eurostat database nama_10_a64 (last update: 02/02/2023); and source gross capital formation: Eurostat database nama_10_an6 (last update: 5/10/2022).

During the economic crisis and the following years up to 2013 the DMC of **non-metallic minerals** declined by about 30 % due to less **investment in construction –** about -20 % both in **dwellings** and in **other buildings and structures**. On the supply side of the economy, the **value added of construction** and **manufacture of other non-metallic mineral products** also fell by a similar amount. The way the

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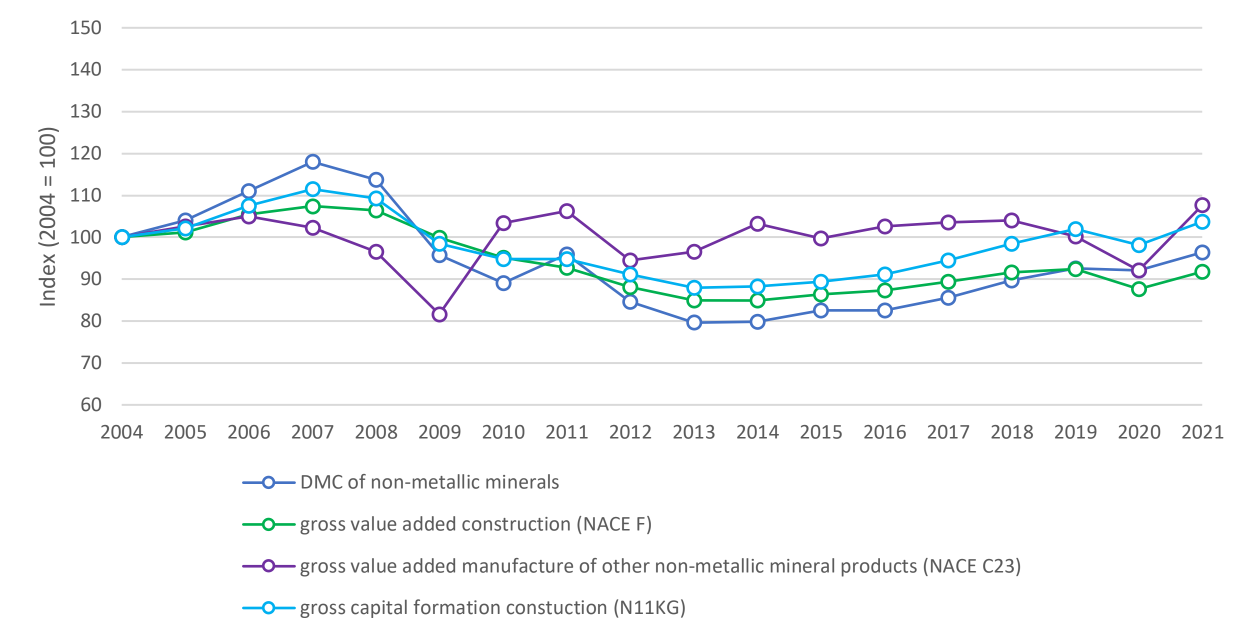
22 Please note that in EW-MFAs the run-of-mine concept applies to domestic extraction of metal ores and other minerals, i.e., only that portion of the excavated rock to be processed to obtain the metal is accounted for, excluding mining overburden. Differently from domestic extraction, it is important to note that EW-MFA trade flows account for the actual weight of traded products at different stages of manufacturing – raw products, semi-finished products and finished products. This results in a much higher weight of metal ores than the actual weight of the traded goods. The waste from the excavated rock processed to obtain the metal is also accounted and, for example, available for recycling.

23 DMI measures all materials, in this case, metal ores, are available for a country's production system. The DMI is calculated as the sum of domestic extraction plus physical imports. Subtracting physical exports, i.e., parts of the production system's output, from DMI, results in DMC, i.e., the total amount of material that is directly used in a national economy.

consumption of non-metallic minerals, which stems nearly completely from the domestic extraction, developed in 2004–2021 and 2010–2021 is a mirror image of both the total CMUR and the non-metallic minerals trends (Figure 7).

Figure 7 The domestic consumption of non-metallic minerals, value added and investments as a possible economic driver, EU27, 2004–2021, index (2004 = 100)



Note: gross value added and investment are in chain linked volumes.

Source: DMC: Eurostat database env_ac_mfa (last update: 01/07/2022); source value added: Eurostat database nama_10_a64 (last update: 02/02/2023); and source gross capital formation: Eurostat database nama_10_an6 (last update: 5/10/2022).

In the EU27, the domestic consumption of **fossil energy materials** showed a decreasing trend between 2004 and 2021 (Figure 8). The most important interface for the interaction between fossil fuels and the economic system is the energy mix used to allow industries and households – notably **energy-intensive industries and value chains, including transport, as well as housing and mobility** – to undertake their intermediate and final consumption activities. Indeed, fossil fuels are mainly used for energy generation by combustion technologies; beside electricity, the main uses of oil and gas are for transport, residential heating and as feedstock for the petrochemicals industry. In the period 2004–2021 the use of **renewable energy sources** has more than doubled ([24]). In 2021, their share of gross final energy consumption reached 21.8 %[25], almost 2 percentage points above the EU27 2020 target ([26]). This positive development has many potential benefits, including the reduction in carbon dioxide (CO_2) emissions, the diversification of energy supplies and a reduced dependency on fossil fuels, particularly oil and gas, from abroad. An indicator that also reflects these positive energy trends is the **efficiency of primary energy consumption** ([27]), also beyond

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24 Renewable sources of energy include wind power; solar power – thermal, photovoltaic and concentrated; hydro power, tidal power, geothermal energy, ambient heat captured by heat pumps, biofuels and the renewable part of waste. B What is meant by this? Does it need some explanation?

25 Source: Eurostat database nrg_ind_ren (last update: 27/01/2023).

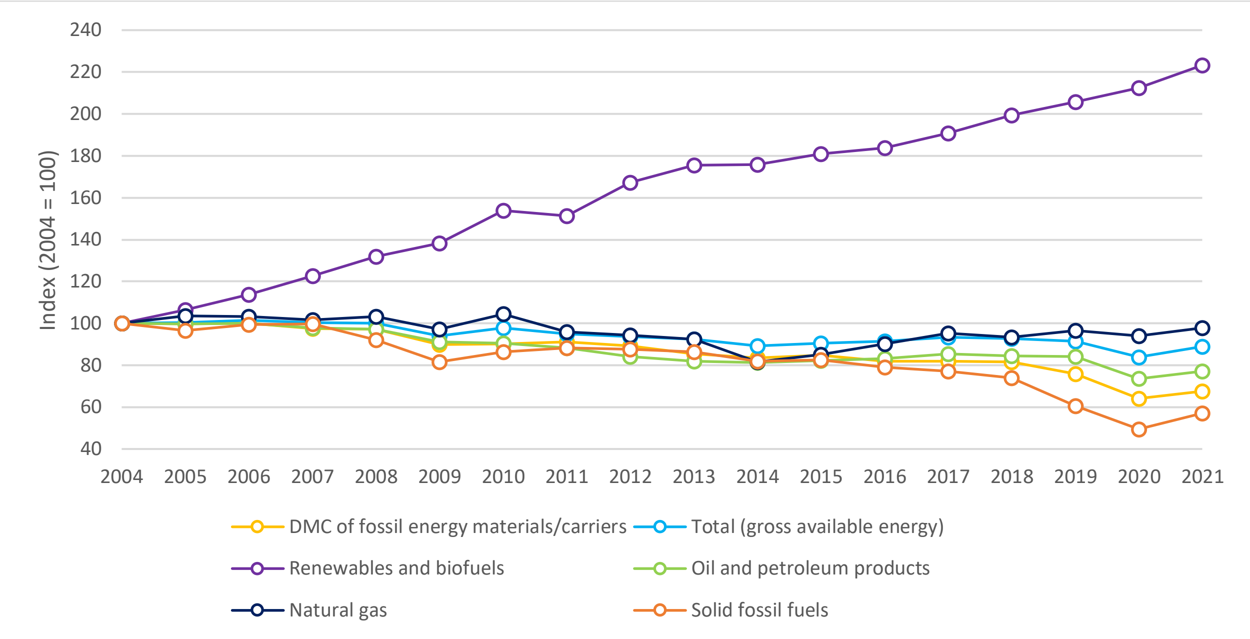
26 The European Council adopted in 2007 energy and climate change objectives for 2020: i) to reduce greenhouse gas emissions by 20 %; ii) to increase the share of energy from renewable sources to 20 %; iii) to improvement energy efficiency by 20 %.

27 The primary energy consumption in the EU27 dropped sharply to 1 236 million tonnes of oil equivalent (Mtoe), which is 5.8 % better than the efficiency target for 2020, thus clearly outperforming it. Yet, this is still 9.6 % away from the 2030 target, implying that efforts to improve efficiency need to be maintained in the years to come.

the EU 2020 target. Indeed, primary energy consumption, and energy needs, are influenced by economic developments, the structural changes in industry and the implementation of energy efficiency measures. The latter include changes in the energy system such as the switch from fossil fuels to renewable sources in electricity generation.

Figure 8 shows the trend of renewables and biofuels in gross available energy ([28]) for the EU27. This increased from 6.9 % in 2004 to 17.3 % in 2021, while in the same period the total gross available energy decreased from 68.8 petajoules (PJ) to 61.1 PJ. This fall in the demand for fossil energy carriers/materials is reflected in a downward trend of the DMC for fossil energy carriers/materials.

Figure 8 The domestic consumption of fossil energy carriers/materials and gross available energy as a possible economic driver, total and selected subcategories, EU27, 2004–2021, index (2004 = 100)



Note: gross available energy is the overall supply of energy for all activities on the territory of the EU27 (primary production + recovered and recycled products + imports – export + stock changes). See footnote 28 for more details.

Selected subcategories are solid fossil fuels (C0000X0350-0370); oil and petroleum products (excluding biofuel portion) (O4000XBIO); natural gas (G3000); and renewables and biofuels (RA000).

Source: DMC: Eurostat database env_ac_mfa (last update: 01/07/2022); source others: Eurostat database nrg_bal_c (last update: 22/01/2023).

2.3.2 Drivers of the recycling indicator

This section analyses the recycling indicator – the amount of waste recycled in domestic recovery plants, RCV_R in the formula of the CMUR – which is the main constituent of the circular use of materials (U). Possible drivers for recycling are identified to better understand and interpret past and future changes in the CMUR.

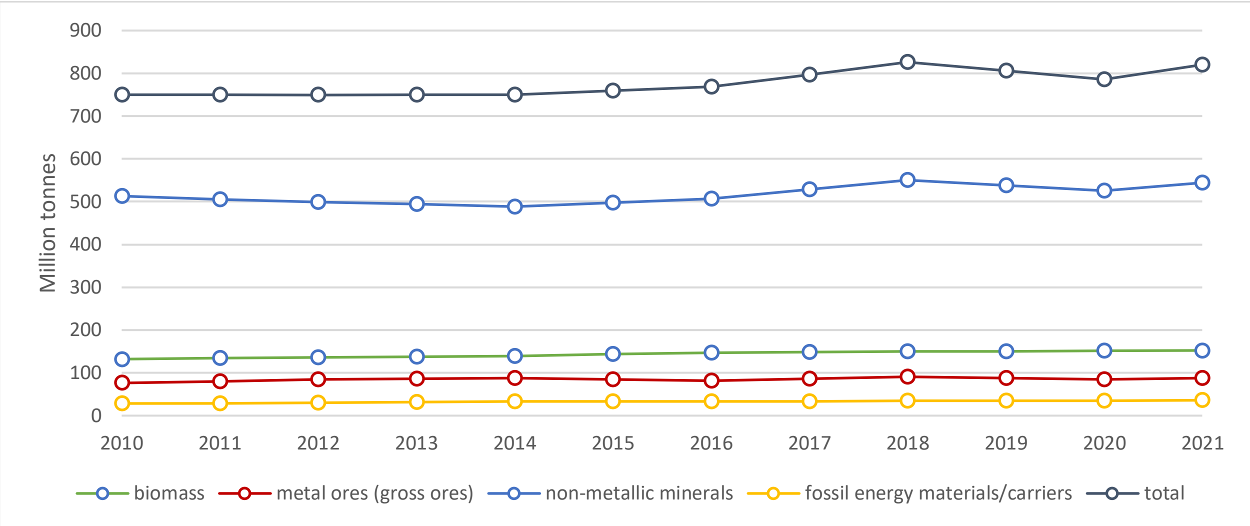
28 Gross available energy means the overall supply of energy for all activities on the territory of a country. It includes energy needs for energy transformation, including generating electricity from combustible fuels; support operations of the energy sector itself; transmission and distribution losses; final energy consumption by industry, transport, households, services, agriculture, etc., and the use of fossil fuel products for non-energy purposes, such as by the chemical industry. It also includes fuel purchased within the country that is used elsewhere, for example, international aviation; international maritime bunkers; and, in the case of road transport. fuel tourism. Gross available energy for the total of all products (fuels) is the most important aggregate in energy balances and represents the quantity of energy necessary to satisfy all energy demands.

Figure 9 presents the trend of the total recycling (RCV_R) to 2021, but now distinguishing the four material categories which allows the identification of the major constituents of this indicator. In terms of waste categories, the material categories encompass the following.

- **Biomass** includes animal and food wastes; paper and cardboard wastes; wood wastes; textile wastes; parts of healthcare and biological wastes; fractions of household and undifferentiated materials; common sludges; and some sorting residues.
- **Metals** include ferrous, non-ferrous and mixed metal wastes; discarded equipment; discarded vehicles; batteries and accumulator wastes; and some chemical wastes.
- **Non-metallic minerals** include acid/alkaline/saline wastes; glass; waste containing polychlorinated biphenyls (PCBs), mineral waste from construction and demolition; other mineral wastes; combustion wastes; and solid or dredging spoils.
- **Fossil energy carriers** include spent solvents; used oils; rubber wastes; plastic wastes; some chemical wastes; fractions of textile wastes; and fractions of mixed and undifferentiated materials.

The total amount of recycled waste that is fed back into the economy depends both on the amount of waste that is generated and the share of this waste that is recycled. Waste policies also play an important role in influencing waste recycling.

Figure 9 Recycling by material category, EU27, 2010–2021, million tonnes



Note: data are only available for even years. The data for odd years is linearly interpolated, and 2021 data is estimated.
Source: RCV_R: ETC-CE own calculations using Eurostat database env_wastrt (last update: 13/01/2023).

In the EU27, recycling in domestic recycling plants grew to 821 million tonnes in 2021, an increase of 9.5 % since 2010. The increased amounts of recycled waste were due to improvements in waste management and growth in waste generated, except for 2020 when the waste generated was lower than in 2010.

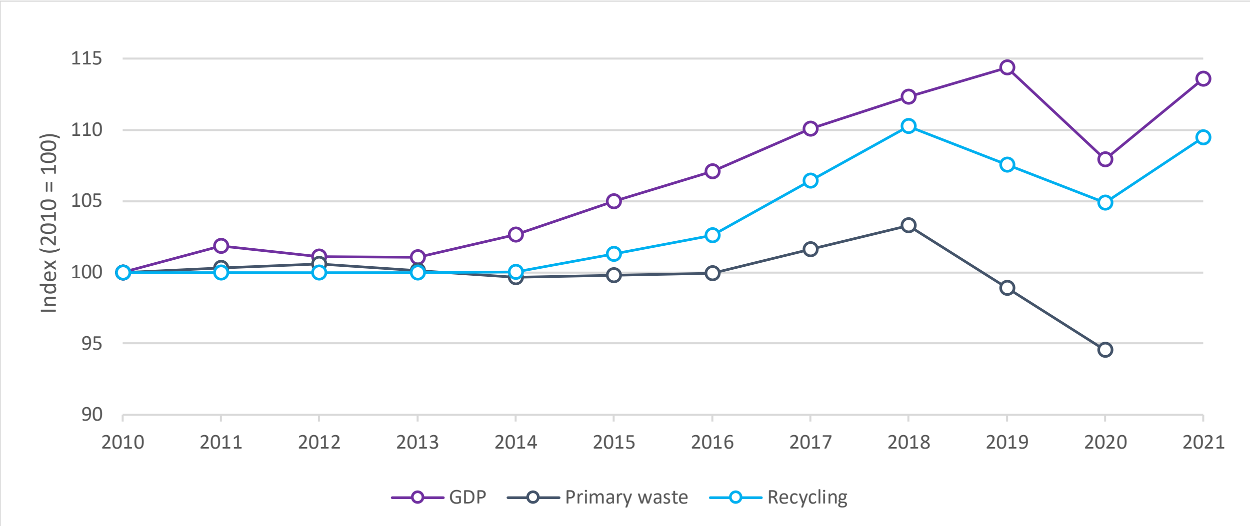
The growth in recycling by the end of the period is modest and only slightly increases the share of circular material use. It should be considered, however, that the period 2010–2021 is quite short and the period is placed in the middle of the two crises the world has faced in the last fifteen years, making it difficult to draw final conclusions.

Figure 10 shows the link between recycling and primary waste generation ([29]), approximated by the difference of total waste and secondary waste, and how waste generation is related to GDP. The two waste indicators increased at the end of the period 2010-2018: primary waste generation rose between 2016

[29] Primary waste is approximated by the difference of total waste and secondary waste. Secondary waste is waste resulting from the treatment of waste, for example, ashes from incineration or sorting residues.

and 2018, while recycling started to increase in 2014. Being a pressure indicator, primary waste generation is, in general, dependent on the level of economic activity. Figure 10 shows a relative decoupling between the two variables, and waste generation intensity slowly decreasing. The fall-back in 2020, mainly due to the restrictions following COVID-19, is worth noting.

Figure 10 Recycling, total primary waste and gross domestic product, EU27, 2010–2021, index (2010=100)



Note: GDP in chain linked volumes.

Both for primary waste and recycling, the data for odd years is linearly interpolated. Data on primary waste generation for 2021 is not available, 2021 data for recycling estimated.

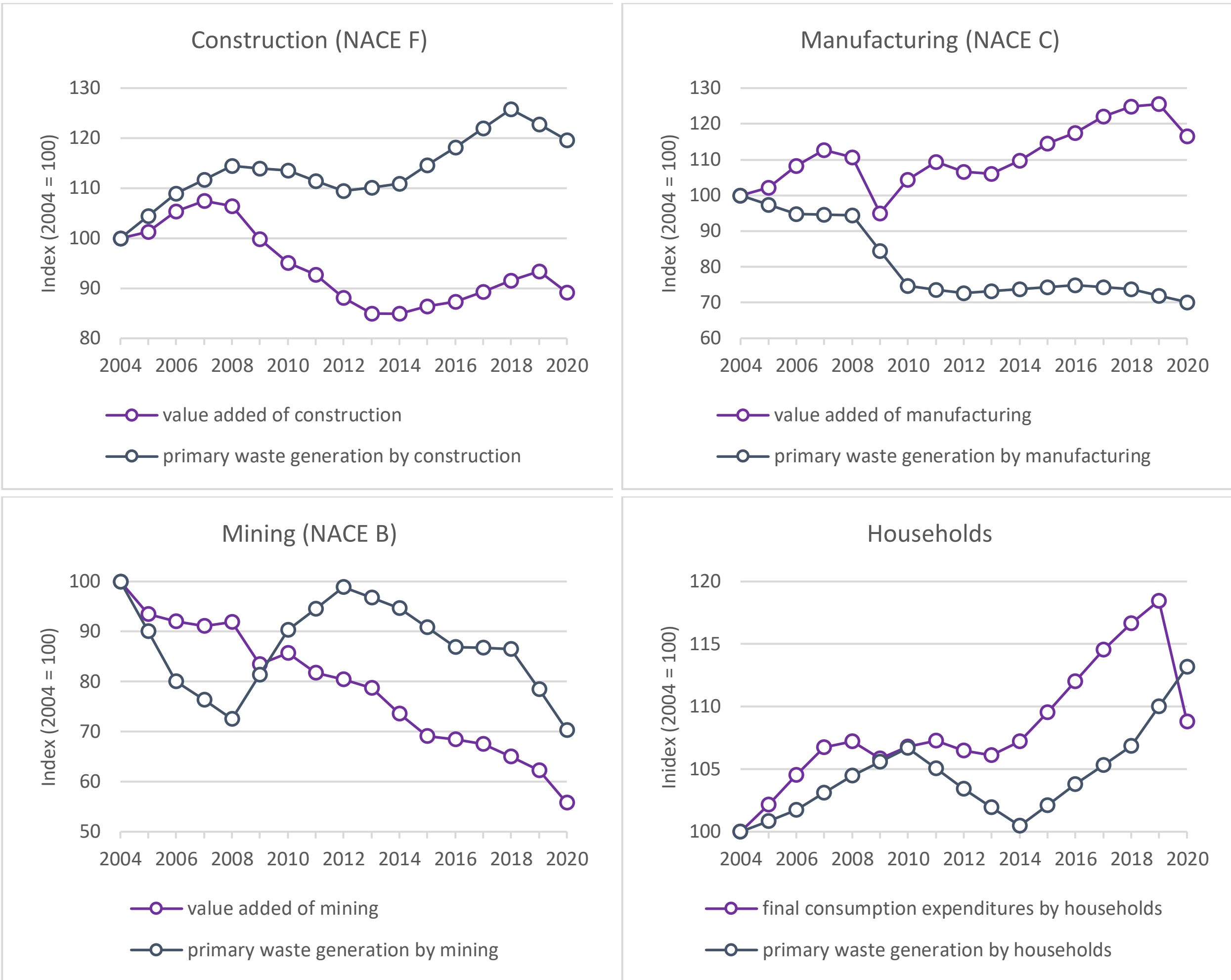
Source: GDP: Eurostat database nama_10_gdp (last update 12/10/2022); source primary waste: Eurostat database env_wasgen (last update 13/09/2022); source RCV_R: ETC-CE own calculations using Eurostat database env_wastrt (last update: 13/01/2023).

On average in the period 2004–2021, about 90 % of primary waste was produced by the following activities and households: construction (NACE F), about 44 %; mining and quarrying (NACE B), about 33 %; manufacturing (NACE C), about 11 %; and households generated the remaining 11 % of primary waste. These activities account for very different shares of the EU27's GDP: the largest is manufacturing which contributes less than 20 % in 2004–2021; construction accounts for some 6 %; and mining around 0.51 %.

The link between waste generation and economic activity is even clearer at the economic sector level. Figure 11 shows that waste intensity only improved for manufacturing activities and households between 2004 and 2020[30]. These results on the link between waste generation and the level of economic activity – according to which higher levels of economic activity tend to increase waste generation – should not be considered as a macro determinant of the stagnating recycling levels in EU27.

[30] 2021-data on primary waste generation are not available.

Figure 11 The value added and primary waste generation of construction, manufacturing and mining and the final demand expenditure by households, EU27, 2004–2020, index (2004 = 100)



Note: data on primary waste generation for odd years is linearly interpolated.

Source: value added: Eurostat database nama_10_a64 (last update: 02/02/2023); source primary waste: Eurostat database env_wasgen (last update 13/09/022); and source final demand expenditures: Eurostat database nama_10_co3_p3 (last update 12/10/2022).

Recycling of **biomass** accounted for about 19 % of total recycled material in 2010–2021 and increased by 15.3 % over the period. It mostly includes vegetal wastes, paper and cardboard wastes, wood wastes, animal and mixed food waste and common sludges. In 2010–2021, the increase of biomass' CMUR from 8.8 % to 9.9 % was due to the higher annual average growth rate of recycling, +1.4 %, than the one of DMC, +0.2 %. Net trade of waste bound for recovery, part of the CMUR ratio, is less important for biomass, accounting for 0.5 % of circular use of materials (U).

The recycling of **metal ores** accounted for about 11 % of total recycled material in 2010–2021 and increased by 14.9 % over the period. Metal ores mainly consists of ferrous and non-ferrous metal wastes and discarded equipment, including discarded vehicles, and waste batteries and accumulators. The simultaneous annual average growth rates of recycling, +1.4 %, and the DMC of metals, +3.0 % from 2010 to 2021 brings about a reduction in metal ores' CMUR, from 24 % to 22.6 %. The net trade of metal waste bound for recovery accounted for about 14 % of U on average over the period.

The recycling of **non-metallic minerals** accounted for about 66 % of total recycled material in 2010–2021 and increased by about 6.2 % over the period. All in all, this material category is the main driver of both EU27 recycling and DMC. This category of waste mainly consists of mineral waste from construction and demolition, soils, mineral wastes from waste treatment and stabilized wastes, combustion wastes, glass wastes, dredging spoils, acid, alkaline or saline wastes and other mineral wastes. The CMUR of non-metallic minerals decreased from 14.3 % to 14.0 % over 2010–2021 due to the lower average annual growth rate of recycling, +0.6 %, than the average annual growth rate of DMC, +0.8 %. Net trade of non-metallic minerals waste bound for recovery is irrelevant to the CMUR for this material category.

The recycling of **fossil energy materials/carriers** accounted for less than 5 % of total recycled material in 2010–2021 and increased by 26.7 % over the period. It mostly includes mixed and undifferentiated materials, plastic wastes, chemical wastes, used oils, rubber wastes, textile wastes and spent solvents. Over the period 2010–2021, the increase of fossil fuels' CMUR from 2.0 % to 3.2 % stems from a negative average annual change of -2.3 % in the DMC of fossil materials, and an average annual growth rate of +2.4 % in the recycling of fossil fuels. The net trade in fossil material waste bound for recovery accounted for about 9 % of U at the beginning of the period to about 4 % in 2021.

It should be noted that there is an upper limit to the volumes of biomass and fossil energy materials/carriers available for recycling. Dominated by their use for energy purposes and food, the volumes available for recycling are largely limited to food waste. If the EU27 is successful in preventing or reducing the use of these materials for energy generation through, for example, the increased use of energy from renewable sources and preventing food waste, the volumes of biomass and fossil energy materials/carriers available for recycling will go down.

Primary waste generation in the EU27 is still strongly linked to economic activity. Only if decoupling between these two variables occurs and policies promoting the circular economy and recycling are improved and fully implemented ([31]), higher growth rates of recycling could be achieved.

BOX 3 CLOSE LINK TO THE END-OF-LIFE RECYCLING INPUT RATE (EOL-RIR)

Next to the CMUR, within the Circular Economy Monitoring Framework, Eurostat reports on the end-of-life recycling input rate (EOL-RIR). This reflects the total material input into the production system that comes from recycling post-consumer scrap into single raw materials (Eurostat, 2022b: Talens et al., 2018). Different from the CMUR, the EOL-RIR focuses on specific materials.

The EOL-RIR is based on detailed material system analyses (MSAs) of individual raw materials, such as cobalt, aluminium and lithium, for the EU27, which are published in the EU Raw Materials Information System (EC, 2022). In contrast, the CMUR is a macro-economic level indicator, based on economy-wide statistics. An overview of EOL-RIR values by material has been periodically reported by the EU Raw Materials Scoreboard (2016, 2018 and 2021 editions), which can be also found within the Raw Materials Information System (RMIS) ([32]). EOL-RIR is an important component in the methodology used to determine the list of critical raw materials (CRMs) for the EU27 – higher values of the indicator are considered to reduce the risk of supply of a material.

2.3.3 Stocks as a driver of the circular material use rate indicator?

From the macro-economic perspective, based on mass flows, there is a difference in use between biomass and fossil energy carriers/materials on the one hand and metals and non-metallic minerals on the other. The first group is largely converted into emissions as most of these materials are used for energy generation or as food, and recycling options are therefore limited. Therefore, the circular material use rate for these materials can mainly be increased by reducing their use for energy purposes and replacing them with renewable energy technologies, and by reducing food waste. The second group actually largely goes into stock, except for the short-lived products and losses, and becomes available for recycling at some point in time (Box 4). Approaches for improving the CMUR of metals and non-metallic minerals should be targeted towards both reducing their input into the economy, for example, through increasing the

31 EU27 policies on circular economy, the first Action Plan for which was released in December 2015, will show their results in the coming years. These results are not currently visible 2010–2020, the period for which waste statistics are available, and 2020 values are affected by the impacts of COVID-19.

32 2021 edition available at https://rmis.jrc.ec.europa.eu/?page=scoreboard2021#/

lifetimes of products and materials currently in use and reduced consumption, and increasing the recycling of these materials when they become waste. Both the transformation of biomass and fossil energy carriers/materials into emissions and the material accumulation make up the huge difference in volumes between DMC and the feedback loop.

BOX 4 DOMESTIC MATERIAL CONSUMPTION AS A HOLISTIC POTENTIAL PRESSURE INDICATOR
Domestic material consumption (DMC) has an important meaning which should be acknowledged, and to which reference should always be made when using it. First, a distinction needs to be drawn between the environmental pressures that the human system exerts on the one hand at the material input side, i.e., those immediately due to resources extraction, and on the other those it exerts at the material output side, i.e., those immediately connected to the form taken by the materials at the end of the annual production and consumption cycles. Looking at the materials' economic cycle from the latter perspective, it can be seen that DMC is equal to the sum of the net addition to stocks, emissions and wastes, products' dissipative uses and dissipative losses. In other words, DMC comprises all the used materials that contribute to a country's environmental pressures on the material output side, regardless of whether the materials were extracted domestically or imported. It is important not to be misled with regards to DMC's meaning by the way it is calculated. The real meaning of DMC is, in fact, connected to the output side even if it is calculated as a sum of inputs. This connection of the two sides is granted by the law of matter conservation (Marra Campanale and Femia, 2013).

Figure 1 actually shows material accumulation which is the net additions to stock. This figure visualises two constraints for improving the circularity of one economy through recycling: i) the large fraction of materials the economic system accumulates as stocks; ii) the large amount of materials used for energy purposes. Both these structural barriers keep the degree of circularity low (Haas et al., 2015).

3 Unaccounted secondary material flows in the calculation of the circular materials use rate

Key Message 3.1
The use of industrial by-products and production residues has a positive effect on the CMUR, through the substitution effect that lowers DMC. The order of magnitude of its effect on the CMUR is, however, lower compared to recycling of materials captured by statistics included in the feedback loop of the CMUR.

Key Message 3.2
In particular, the use of industrial by-products and production and processing residues are not or only to a limited extend captured by the EU waste statistics, on which the calculation of the CMUR is based. This is due to the fact that they are not wastes in legal terms.

Key Message 3.3
Taking all industrial by-products into account in the calculation of the feedback loop of the CMUR would significantly increase the numerator. The substitution effect of all industrial by-products alone is estimated to mathematically increase the amount of secondary material fed back into the economy by around 10 %.

3.1 Unaccounted flows in the circular materials use rate

The waste recovery component (RCV_R) of the CMUR includes only those secondary materials that are registered as wastes in the official EU waste statistics under corresponding waste code numbers. However, beside the waste recovery components there exist other components that substitute primary material. At least two relevant categories of materials, which substitute primary materials and increase the share of secondary materials in the material input of national economies, are not captured for and are not (or only partly) covered by the waste recovery component of the CMUR. These are **industrial by-products**, which arise as by-products from the production of goods and services and are used elsewhere as a material input, and **production residues**, which can often be fed directly back into the production process without ever becoming part of the waste regime and thus do not appear in the waste statistics. Some industrial by-products are included as waste in the waste statistics as part of the combustion waste fraction in the category of generation of waste-by-waste categories (env_wasgen). In addition, **energy recovery** is discussed as it, for example, substitutes for primary energy carriers, but is also not included in the waste recovery part of the CMUR. Energy recovery is excluded from the CMUR indicator by design, not because of data limitations.

This chapter focuses on these unaccounted secondary material flows in the calculation of the CMUR and discusses their (missing) impact on the CMUR. Also, the trends of these flows could have an impact on the future development of the CMUR and affect the potential of reaching the doubling target. The aim of this chapter is to illustrate the effect and impact of such flows on the CMUR and to indicate the impact on future developments of and the outlook for the CMUR. There are no regular EU statistics on the generation of industrial by-products and production residues, therefor the scope of this chapter differs from others as the focus is on specific cases for illustrative purposes, while the other chapters cover EU27 totals.

3.2 Industrial by-products

There are numerous industrial by-products. Some of these are produced in large quantities and can therefore replace significant amounts of primary material. Main industrial by-products include:

- so-called flue-gas desulphurisation (FGD) gypsum, which is produced in the FGD of coal combustion and is almost identical to natural gypsum in terms of its properties;
- fly ash from coal combustion, which is used in part as an aggregate in concrete production;

- iron and steel slags, as well as other slags such as those from waste incineration, which can be processed and are produced in large quantities in countries with high steel production or waste incineration capacities, such as Germany.
- Furthermore, in the processing and production of food, for example, in beer or wine production, large amounts of residual materials, such as pomace, are produced, which can substitute primary animal feed.

Parts of the combustion residues, which are often referred to as industrial by-products, are registered as waste and thus are part of waste statistics and therefore are no longer products in the legal sense. Both the residues of metal production, such as slags, the ashes of coal combustion and desulphurisation sludges in the production of FGD gypsum are registered under the waste category *combustion waste*. In total, 113 million tonnes of combustion waste were registered in the EU27 in 2018, of which 59 % came from the *electricity, gas, steam and air conditioning supply* sector and 25 % from the *Manufacture of basic metals and fabricated metal products, except machinery and equipment* sector. In the same year, 100 million tonnes of combustion waste were sent to treatment plants, of which 34.4 million tonnes were classified as recycling and were thus accounted for in the CMUR.

Unfortunately, however, the statistics do not show which residues are specifically recorded as combustion waste. Are FGD gypsum and granulated blast furnace slag included, or only the residues that remain, for example, after the drying process of desulphurisation sludge and the separation of FGD gypsum? Furthermore, the waste treatment statistics (env_wastrt) unfortunately do not reveal from which economic sectors the 34.4 million tonnes of recycled combustion waste originate and what they are specifically.

For this reason, three examples, FGD gypsum, fly ash from coal combustion and slag from iron and steel production, are used here to illustrate the maximum possible substitution effects, even if some of these residues are already part of official waste statistics and are therefore at least partially taken into account in calculating the CMUR.

Flue-gas desulphurisation gypsum is formed when flue gas is sprayed with liquid milk of lime, thereby binding the sulphur dioxide. Air is then supplied so that gypsum is formed by oxidation. In the following step, the water is separated from the gypsum slurry using the hydrocyclone process, and the moist gypsum slurry is further dewatered and dried. This artificial gypsum is qualitatively comparable to gypsum produced from natural gypsum rock or anhydrite. According to estimates by Haneklaus et al. (2022), around 17 million tonnes of FGD gypsum were produced in Europe by EU manufactures that require a total of 57 million tonnes of gypsum per year.

With the Europe-wide phase-out of coal-fired power generation (EU Renewable Energy Directive, ((EU) 2018/2001)), the production of FGD gypsum will decrease drastically in the next few years. As a result either more gypsum will have to be recycled from plasterboard or the supply gap will have to be covered by natural gypsum. Under its coal exit law, Germany, currently the largest producer of FGD gypsum in Europe, will shut down all its coal power plants by 2038 and, therefore, end FGD gypsum production. For the EU27 plus Norway, Switzerland and the UK, Alwast (2014) estimates a decline in annual FGD gypsum production to 12 million tonnes by 2030.

The substitution potential of 1 000 kilograms (kg) of FGD gypsum is assumed to be 940 kg of natural gypsum (Steger et al., 2020). In relation to the 19.7 million tonnes of FGD gypsum in Europe in 2015, this therefore corresponds to a substitution effect of 18.5 million tonnes of natural gypsum.

Fly ash is produced in large quantities during the combustion of both lignite and hard coal. While lignite fly ash is not used as a substitute construction material due to its heterogeneity, hard-coal fly ash is often used as a cement substitute in concrete production or as a clinker substitute in certain types of cement. The hard-coal fly ash act as a liquefier in fresh concrete, enabling better processing of ready-mix concrete.

Furthermore, fly ash increases the compressive strength of the concrete because the fine fly-ash particles act as a filler to increase the density of the concrete mix and at the same time react hydraulically with the cement paste due to their pozzolanic properties.

No figures are available on the quantities of fly ash produced from coal-fired power generation in Europe. An approximation, using the corresponding coal used for power generation as a proxy indicator, would, however, be possible if, as a simplification, it is assumed that the ash content per tonne of coal used in Germany roughly corresponds to the ratio in Europe. Since hard-coal fly ash is relevant for substitution, it is also intended to focus only on this part of the combustion residues. According to Eck (2020), 32 million tonnes of hard coal was burned in Germany in 2018, resulting in 2.4 million tonnes of fly ash. In its Coal Report (IEA, 2019), the International Energy Authority (IEA) reports a consumption of hard coal for thermal purposes in EU27 of 165 million tonnes. If the ratio of hard coal use and the amount of fly ash produced is transferred, around 12.4 million tonnes of hard-coal fly ash should have been produced in EU27.

Some of the fly ash is used directly in the cement industry as a component of so-called Portland-composite cement. The larger part, however, is used directly in concrete production. In both cases, raw materials and non-required fuels for clinker production are substituted in the ratio of 1 000 kg of fly ash replacing 1 540 kg of raw material and 100 kg of fossil fuels ([31]). With 12.4 million tonnes of hard-coal fly ash, 1.33 million tonnes of fossil fuels and 19.10 million tonnes of raw materials for clinker production are thus substituted.

The war in Ukraine and the resulting change in energy supply – the reduction of the dependence on Russian oil and gas – may slow the phasing out of coal. Therefore, the actual development of the future availability of FGD gypsum and fly ash cannot really be estimated at the moment.

The production of steel can be divided into two different steps. For the first part, iron ore is used to produce pig iron. This step is usually performed in a blast furnace and produces **blast-furnace slag** as a byproduct. The pig iron is afterwards used to produce crude steel. For this step, pig iron can also partially be substituted with scrap metal with steel-mill slag produced as a byproduct. The first step, the production of blast-furnace slag is of particular interest for the circular economy. When blast-furnace slag is cooled immediately, a granulate/sand is produced that can be used as an immediate substitute in the manufacture of cement.

Eurofer (2021) has documented the quantities of blast-furnace and steel-making slags, and their places of use have been documented. Accordingly, a total of 33.2 million tonnes of slag were generated in the iron and steel production sector in EU27. While blast-furnace slag is used almost entirely in the cement industry (ca. 85 %), about 25 % steel-mill slag is recycled internally and around 57 % used in road and pavement construction. Additionally, small proportions are used as fertilisers, about 5 %, as aggregates in the concrete industry, approximately 2 % and in the construction of waterways, around 2 %.

From Steger et al. (2020), the substitution effects for the use of slags are known and can be used for estimating the volumes of EU27 flows. In total, the 33.2 million tonnes of slag (potentially) substitute around 40 million tonnes of virgin materials (

[31] If substitute fuels are not used to a large extent in cement production.

Table 1).

Table 1: Annual substitution quantity of slags by type of application, EU27

Field of Application	Utilised slags ('000 tonnes)	Substitution effect	Substituted material ('000 tonnes)
Cement	17 680	Clinker raw material	27 300
		Fossil fuels	2 109
Road construction/concrete addition/hydraulic engineering	10 308	Aggregates	10 441
Fertilisers	620	Fertilisers:	
		40 % calcium oxide,	Calcium oxide 243
		10 % magnesium oxide, 1 %	Magnesium oxide 61
		phosphorus pentoxide	Phosphorus pentoxide 6.1

Source: Steger et al. (2020) and Eurofer (2021). Note: Data does not cover all EU27 steel production.

The overall substitution effects of the three industrial by-products are roughly estimated as about 80 million tonnes – FGD gypsum, 18 million tonnes; fly ash, 20.4 million tonnes and steel-making slag, about 40 million tonnes – and thus to about 10 % of the waste intended for recycling according to waste statistics. Although these flows are only partially included in the recycling feedback loop, they do impact the DMC. The described substitution effect lowers the demand for (virgin) materials, having a downward effect on the DMC and, in turn, an upward effect on the CMUR.

There is, however, a difference in the magnitude of how this benefit is reflected in the CMUR. The benefit of increased use of industrial by-products is reflected in the CMUR by a lower value for the DMC indicator – the lower value for the denominator increases the CMUR. In contrast, the benefit of increased recycling captured by the official statistics is reflected by both a lower value of the DMC indicator, assuming the input of secondary materials substitutes for other (primary) ones, and an increased value for the feedback loop (RCV_R). This results in both an increased numerator and a decreased denominator. Although the use of industrial by-products effects the CMUR positively, the order of magnitude is lower compared to recycling of materials captured by statistics included in the feedback loop of the CMUR.

3.3 Production residues

In addition to industrial by-products, there are also a number of production residues that are not included in waste statistics, as they are not characterised as waste according to EU waste legislation. The amounts of production residues varies greatly depending on the material category and sector, and generally there are hardly any official statistics on this due, for example, to internal reuse within a facility. The share of production and processing waste can be estimated best for metals, since for these a distinction is usually made between so-called new scrap, i.e., production and processing waste which is not included in EU waste statistics, and end-of-life scrap, and researchers have been working for years on databases of global material cycles and inventory estimates for metals. For metals in particular, the differences in grade purity between new scrap and end-of-life scrap are significant, and thus there is a wider range of recycling options for new scrap.

As seen in Chapter 2, the CMUR for metal ores in the EU varied between 22 % and 27 % in the period 2010-2021. However, for the most important bulk metals, which, to a large extent, determine the metal DMC, the actual percentages of secondary material in the supply of raw materials for metals production are significantly higher.

In a study for the German Federal Environment Agency (Raatz, 2022), the supply and demand as well as the scrap volume for steel, copper, aluminium and zinc were estimated for 2016 and 2030 for Germany, the EU and the world. According to this, the share of all scrap in the supply of all four metals was significantly above the metal CMUR of around 25 %. For steel, the share of scrap 2016 was about 42 % relative to the steel supply in the EU; for aluminium, 58 %; copper, 51 %; and zinc 40 %. The secondary shares in Raatz (2022) are also in line with the orders of magnitude estimated, for example, by Cullen and Allwood (Cullen and Allwood, 2013; 2012) for the global steel and aluminium material systems or the ratios in Glöser-Chahoud (2016) for the global copper cycle. In some cases, the magnitudes of new scrap compared to end-of-life scrap are even higher there.

So, the DMC of metals is not identical to the total supply or demand of metals, since some production residues are recycled but not accounted for in official waste statistics. This recycling substitutes for primary use of metals and has a lowering effect on the DMC. Some new scrap or processing residues in the metals sector, for example, is fed directly back into production in the processing plant itself. This is common practice in iron foundries, for example, where a large part of the material input consists of waste generated at the plant itself. Or there are direct supply relationships, such as between the automotive sector and steel mills. Stamping residues are returned, unmixed, directly to the steel mill, where they can be used again directly for the production of new sheet for vehicle bodies and there is no need to worry about contamination with other alloys.

In the case of plastics, production and processing residues are, to a large extent, not included in waste statistics, since significant quantities of residues generated during the injection moulding of products are ground into small pieces directly on site and fed back into the production process or are bought and sold by wholesalers not as waste but as production residues. In Steger et al.(2020), the shares of production and processing residues compared to the total amount of waste for mechanical recycling vary, for example, from 7.5 % for polyethylene terephthalate (PET) to 44 % for polyvinyl chloride (PVC).

High quantities of production residues are also generated in paper and cardboard production. However, according to Steger et al. (2020), these are mainly used for energy recovery, meaning these flows are part of the waste statistics.

Although these flows are not included in the feedback loop for recycling, they do impact the DMC. The substitution effect described lowers the demand for (virgin) materials and has a downward effect on DMC and, in turn, an upward effect on the CMUR. Although the use of production residues effects the CMUR positively, the order of magnitude is lower than the recycling of materials captured by statistics covering the feedback loop of the CMUR.

3.4 Energy recovery

In many countries, many wastes with a high calorific value are not recycled because the effort required may be too high and the market does not reward this higher sorting and processing effort, or because material recycling is not possible due to additives such as flame retardants in plastics or fungicides applied to wood. Energy recovery is not interpreted as recycling in the CMUR, meaning it is excluded from the feedback loop (RCV_R) which only covers recycling. Nevertheless, the effect of energy recovery is the substitution of energy carriers – energy recovery from waste can substitute fossil fuels or virgin wood. Through this substitution, energy recovery decreases DMC, and thus influences the CMUR positively.

4 Analyse prospects for the EU27 to move towards the circular material use rate target

Key message 4.1
Achieving the doubling target would require the rapid implementation of a combination of different strategies, for example, combining enhanced recycling with reduced material consumption and reducing the consumption of fossil fuels. This would require coordinated efforts by different policy areas such as circular economy and climate policy.

Key message 4.2
Solely, and even drastically, increasing waste recycling will not be sufficient to achieve the EU27 doubling target. Nor would the energy transition and associated climate policies to reduce fossil fuels consumption alone be sufficient to achieve the CMUR doubling target.

Key message 4.3
The CMUR could increase by scaling up the amounts of materials recycled (nominator), by reducing the amount of (raw) materials consumed (denominator), or a combination of both. The EU Green Deal, with its CEAP and other policy packages, directly affects the CMUR through changing economy-wide material and waste flows, and stocks. Varying the underlying parameters of the CMUR gives a first impression of the possible consequences on the indicator and prospects for meeting the associated doubling target.

Key message 4.4
The CMUR could increase to 22 % – just below the 2030 target – if various strategies are combined, such as increasing the recycling of all treated waste to 70 %, reducing material inputs into the economy by 15 % and reducing by 34 % the amount of fossil fuels (following the assumptions in the impact assessment of the EU's Fit for 55 policy package). If the ambition is increased further in a 2050 perspective, to a recycling rate of 90 %, a decrease of material inputs by 45 % and a reduction of fossil fuels consumption by 83 %, the CMUR could reach 39 %.

Key message 4.5
The CMUR is dominated by non-metallic minerals such as construction materials and, hence, changes to the recovery of construction and demolition waste or more intensive use of buildings and infrastructure could alter the CMUR significantly. Important leverage points include, in particular, policies targeting more intensive material/product use, such as through sharing and the modular design of buildings, which reduce physical stock growth and hence material consumption.

4.1 Introduction

The CMUR highlights that currently only 11.7 % of all materials entering the EU27 economy come from recycled materials. However, the 2020 CEAP aims to reduce Europe’s consumption footprint and double the CMUR in the coming decade (EC, 2020). While no baseline and target year are formally mentioned in the CEAP, in this study it is assumed that the base year is 2020, the publication year of the new CEAP, and the target year would then be 2030. For this, policies are being put forward with regard to, for example, a sustainable product legislative initiative, the right to repair, increased circularity in production processes, a strategy for a sustainable built environment, targets on food-waste reduction, updates to waste policy and related targets and sustainable consumption. Furthermore, under the EU Green Deal the European Commission aims to reach climate neutrality by 2050, which will significantly alter the (raw) materials mix of the EU economy by moving away from fossil energy carriers to the use of metals, non-metallic minerals, and biomass for the provisioning of energy from renewable sources and more sustainable products.

Implementing such policies will affect the CMUR indicator. However, it is as yet unclear whether the CMUR 2030 doubling target can be reached through the envisioned policies and how the indicator might develop in the long term. The CMUR can be increased either by increasing the amounts of materials recycled domestically (nominator) or by reducing the amount of materials consumed domestically by the EU economy (denominator), or a combination of both. For example, the CMUR for biomass and fossils would probably gain most from strategies to reduce consumption, while metals and minerals would gain from both strategies reducing consumption and increasing recycling. The magnitude of recycling flows (RCV_R) and DMC are, in turn, dependent on various factors such as the market conditions for secondary materials, technological potentials for recycling, consumption patterns and innovation creating a demand for new material inputs, or dynamics of the anthropogenic material stock, i.e., material requirements due to continuous stock build-up and maintenance, and time delays in the availability of long-lasting products for recycling.

This chapter briefly discusses by how much the CMUR might increase under varying assumptions linked to current policies. Central research questions include the following:

- How could planned EU policies affect the CMUR, both in total and for individual material categories?
- Which overall changes provide the highest leverage points to increase the CMUR?
- What are the limitations to increasing the CMUR?

This section assesses these questions by analysing the influence on the CMUR indicator of varying material and recycling parameters of the CMUR calculation against the background of selected key policies. For example, achieving the EU climate targets requires a reduction of fossil energy carrier inputs to the EU economy, thereby reducing DMC in the CMUR equation. Assuming that all other CMUR parameters remain constant ([32]), this would imply an increase in Europe's rate of circularity. Similarly, recycling flows can be varied, for example, what if most of the waste going to treatment would be recycled, and the implications on the overall CMUR observed.

It should be noted that this exercise is limited as no holistic scenario storylines for the EU are being investigated, such as one in which economy-wide material and waste flows change as a result of coherent scenario narratives over time; instead **the effect of selected (isolated) variations in the underlying parameters on the CMUR indicator is assessed**. This, nevertheless, can provide a first indication of the potentials and possible challenges of achieving the EU's CMUR target.

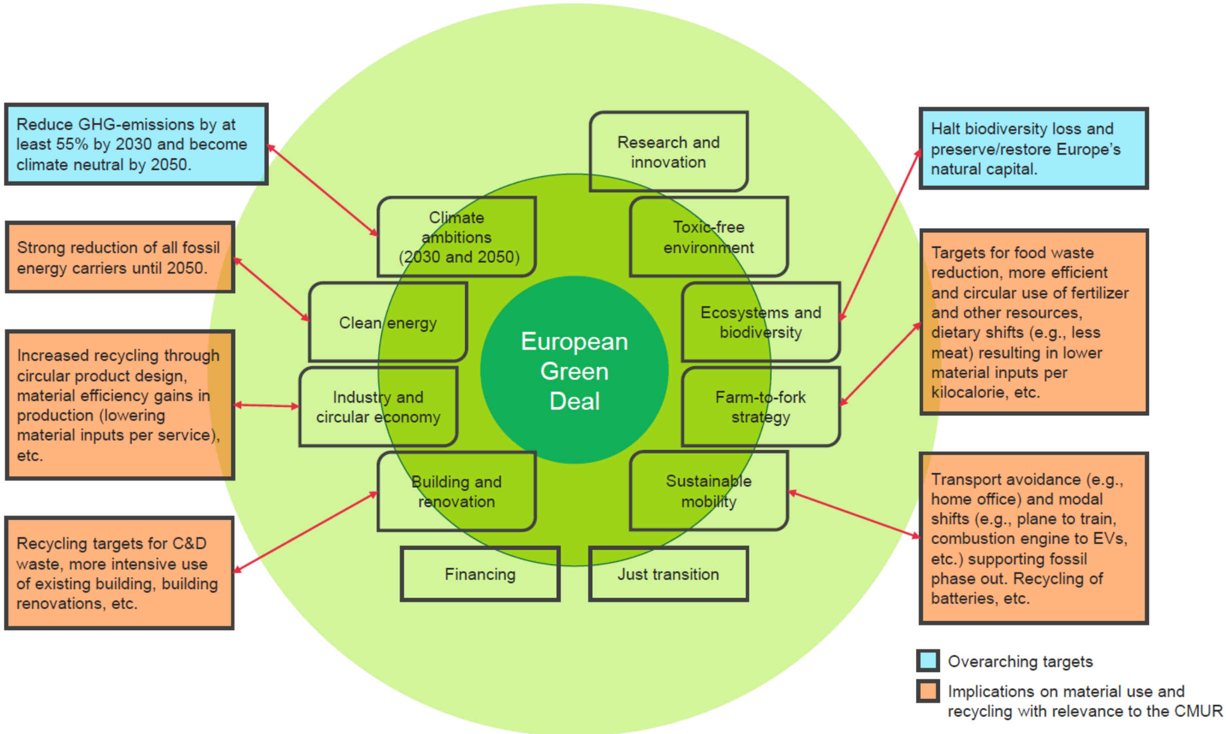
4.2 Policies and strategies affecting the circular material use rate

The CMUR measures the share of materials recovered and fed back into the economy compared to overall material use and is influenced by broader changes to the EU's socio-economic metabolism, such as in regard to materials requirements, recycling efforts and material accumulation/stock build-up (Section 2.3.3).

The European Green Deal (EC, 2019) is the EC's overarching sustainable development strategy of the European Commission to 2030/2050. It aims to transform the EU into a resource-efficient and competitive economy which will be climate neutral by 2050, and in which economic growth is decoupled from natural resource use. Achieving this requires changes to the way in which Europeans produce and consume in the coming decades, with the Green Deal implying alterations in material and recycling flows including a rapid reduction of fossil fuels in view of the 2030/50 climate targets, increasing recycling, material efficiency, and circularity across EU industries, more intensive use of existing buildings and vehicles, and food waste reduction targets (Figure 12).

[32] In reality, such an exercise would also need to account for the increasing demands, for example for metals and construction minerals for renewable energy systems to offset fossil energy carriers or replacing fossil fuel with biofuels. However, in order to get a first impression, this exercise investigated the effects of isolated changes on the CMUR by simply varying some of its underlying parameters.

Figure 12 Elements of the European Green Deal and selected implications on materials and recycling flows with relevance to the circular material use rate



Note: GHG: greenhouse gas, C&D: construction and demolition, EV: electric vehicle.

Source: ETC-CE compilation based on the European Green Deal Communication by the European Commission.

Both, the European Green Deal and the new CEAP include several overarching goals and aims.

- The **Green Deal** aims to enable Europe to become a climate-neutral, resource-efficient and competitive economy by:
  - reducing greenhouse gas emissions by at least 55 % by 2030 (the Fit for 55 package) and by becoming climate neutral by 2050 ([33]) – i.e., to strongly reduce fossil energy carriers by 2050;
  - decoupling economic growth from resource use, especially through policies targeting the energy transition, mobilising industry for a circular economy, introducing sustainable and smart mobility, the farm-to-fork strategy, and encouraging sustainable and energy-efficient buildings, thereby gradually increasing materials efficiency across the whole economy.
- Specifically, under the **CEAP sustainable product policy framework**, "*the* (European) *Commission will consider establishing sustainability principles and other appropriate ways to regulate the following aspects*" (Chapter 2 of the CEAP):
  - improve product durability, reusability, upgradability and reparability; … increase recycled content in products … ; enable remanufacturing and high-quality recycling (i.e., reducing material consumption through longer lasting products and using less material by design, and enhanced end-of-life recycling).
- Under the **CEAP's enhanced waste policy proposal,** the Commission aims to, for example, significantly reduce total waste generation and halve the amount of residual (non-recycled) municipal waste; … put forward waste reduction targets for specific waste streams; … and ensure

33 https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/delivering-european-green-deal_en

high quality recycling through, for example, separate waste collection systems (Chapter 4 of the CEAP) – i.e., enhanced end-of-life recycling and waste prevention ([34]).

In the context of the CMUR indicator, this can be broadly translated into changes with regard to:

(1) enhanced recycling by assuming that a higher share of treated waste is recycled;

(2) using fewer materials by choice and design, i.e., assuming economy-wide materials-efficiency gains over time, and the more intensive use of materials in existing products and more long-lived products, so that fewer materials need to be added to in-use stocks, which reduces consumption; and

(3) achieving EU climate targets by assuming a gradual reduction of the consumption of fossil energy materials and carriers.

Based on that, exploratory scenarios were built for this report, as described in Table 2 and the next section. Table 2 details to which policies the scenarios refer and what assumptions have been made in the calculation of the CMUR for each scenario. For each scenario a 2030 perspective and a 2050 perspective is assumed. A combination of all the scenarios is also explored.

It is acknowledged that looking at these changes to waste and material flows only provides a first back-of-an-envelope estimate of how the CMUR might change, assuming other parameters remain constant, without implementing a full mass-balancing exercise. Other more detailed changes, such as looking at specific waste reduction targets, such as halving the amount of residual municipal waste or reducing the generation of food waste, could not be assessed as they would require a more detailed quantitative material flow model of the EU economy and further separation into material sub-categories.

34 For example, the CEAP 2020 states "*the Commission will propose a target on food waste reduction, as a key action under the forthcoming EU Farm-to-Fork Strategy, which will address comprehensively the food value chain*". Furthermore, the Commission aims to significantly reduce total waste generation and halve the amount of residual (non-recycled) municipal waste by 2030.

Table 2 Overview of policies/strategies and assumed changes explored affecting the circular material use rate

Scenario	Policy/strategy	Current situation *+ past trend* 2020	Assumed changes (scenarios) 2030 perspective	2050 perspective	Implementation in the CMUR calculation
1. **Enhanced recycling:** ensure high-quality recycling and increase recycled content in products (e.g., through technological developments such as better collection, sorting and market incentives for recycling).	**CEAP: sustainable product policy framework and enhanced waste policy**	About 40 % of all waste treated ([34]) is currently recycled. *This share decreased from 36.9 % in 2010 to 35.5 % in 2014 and gradually increased to 39.9 % in 2020.*	70 % of all waste treated is recycled.	90 % of all waste treated is recycled.	70–90 % of all waste going to waste treatment is assumed to be recycled and fed back into the economy (reallocation of output flows while inputs remain constant).
2. **Improving materials efficiency and reducing material consumption:** policy measures such as improved product durability, reusability, upgradability and reparability to increase energy and resource efficiency, i.e., fewer raw materials required for providing the same products/services. Policy measures supporting sustainable consumption/lifestyle changes, e.g., lower per-person floor space or product sharing, lead to a more intensive use of existing products so that fewer materials need to be added to stocks and material inputs are reduced.	**EGD and CEAP**	Material Intensity (MI) looks at the efficiency with which materials are converted into GDP. For the EU27, it equalled 0.49 kg/EUR ([35]) in 2020. *The MI decreased gradually from 0.65 kg/EUR in 2000 to 0.54 kg/EUR in 2010 to 0.49 kg/EUR in 2020.*	15 % reduction in DMC relative to 2020. GDP follows the trend from 1995–2021 ([36]). MI = 0.34 kg/EUR.	45% reduction in DMC relative to 2020. GDP follows the trend from 1995-2021([36]). MI = 0.16/EUR.	Assumed 15% (by 2030) and 45% (by 2050) reductions in DMC from 2020, while keeping U constant. Mass balance is ensured via output reductions in annual material accumulation (lower stock growth) and emissions (e.g., fewer losses during production and use of higher quality products lowering the number of short-lived products).

34 Source: ETC-CE calculations using Eurostat databases env_wastrt (last update: 13/01/2023) calculating the ratio between recovery-recycling and total waste treated.

35 MI = DMC (6 078 123 thousand tonnes)/GDP (EUR 12 531 381.8 trillion) (Eurostat databases env_ac_mfa and nama_10_gdp (GDP in chain linked volumes (2015)).

36 From 1995–2021 GDP increased by around 1.55 % annually and this trend is assumed to continue; GDP expressed in chain linked volumes (2015).

Scenario	Policy/strategy	Current situation + *past trend* 2020	Assumed changes (scenarios) 2030 perspective	2050 perspective	Implementation in the CMUR calculation
3. **Climate change mitigation:** the EGD targets a reduction of net EU GHG emissions to 55 % below 1990 levels by 2030 (the Fit for 55 package) and climate neutrality by 2050. This translates into a gradual phase out of fossil fuels ([37]) over time**.**	**EGD and Climate Policy**	1.10 Gt of fossil energy materials/carriers are consumed in the EU27 (DMC). *The volume gradually decreased from 1.71 Gt in 2004 to 1.10 Gt in 2020.*	Reduction in the consumption of fossil energy materials/carriers by 34 % compared to 2020 ([38]).	Reduction in the consumption of fossil energy materials/carriers by 83 % ([38]) .	Reductions in DMC for fossil energy carriers/materials by 34 % and 83%, respectively (input side). On the output side emissions from fossil fuel use are reduced accordingly.

4.3 Results

4.3.1 Scenario 1: enhanced recycling

According to Eurostat data ([39]), in 2020 a total of 2.0 Gt waste materials were treated in the EU27. Broken down into the four material categories, this waste flow consists of 14 % biomass, 5 % metals, 77 % non-metallic minerals, and 4 % fossil energy carriers. Not all the corresponding waste flows (see Section 2 for the waste flows associated with each material category) can be fully recycled given current technologies and market incentives. According to Eurostat data ([39]), 39.9 % of all wastes treated in 2020 are recycled and (potentially) fed back into the EU economy.

However, better product design for disassembly/reparability, phasing out hazardous substances, technological developments such as enhanced collection and sorting, and putting in place the right market incentives to recycle waste could allow for the recovery of a larger fraction of materials contained in the generated waste flow. For this, this analysis explores how the CMUR changes if:

(1) 70 % of all waste generated were recycled (2030 perspective); and
(2) 90 % of all waste generated were recycled (2050 perspective) (Figure 13).

This scenario assumes the DMC, the trade in waste, and the volume of waste generated remain stable.

The scenario calculation assumes that the recycled materials do not replace an amount of virgin materials, i.e., DMC is unaffected ([40]). Downcycling and losses may limit the potential of recycled materials substituting virgin ones. A higher recycling rate means that more secondary materials potentially substitute primary raw materials, thereby reducing the environmental impacts of extracting primary material (Chapter 5 provides more details on the environmental impact perspective). Caution is required

37 A more sophisticated scenarios approach would consider that, while fossil energy carriers are reduced over time, the demand for other raw materials, e.g., metals for renewable power or wood for construction, might increase over time. In this exercise, however, only the impact of reducing the inputs of fossil energy carriers on CMUR was tested.

38 The EC published several Fit for 55 scenarios highlighting final energy demand by fuel type in 2030 (EC, 2021). These scenarios assume a reduction in fossil fuels by 36-39% in 2030 and 84-85% by 2050 from a 2015 baseline. While these figures cannot directly be translated into the categories for fossil energy carriers in the material flow accounts, it was decided to approximate the reduction in the use of fossil fuels in the scenario analysis for this briefing by re-calculating the reductions to a 2020 baseline and using the assumed reductions in fossil fuel use for the ALLBNK scenario. The increased demand for biomass and materials for building up renewable energy technology/infrastructure is not taken into account as this would require more detailed scenario building.

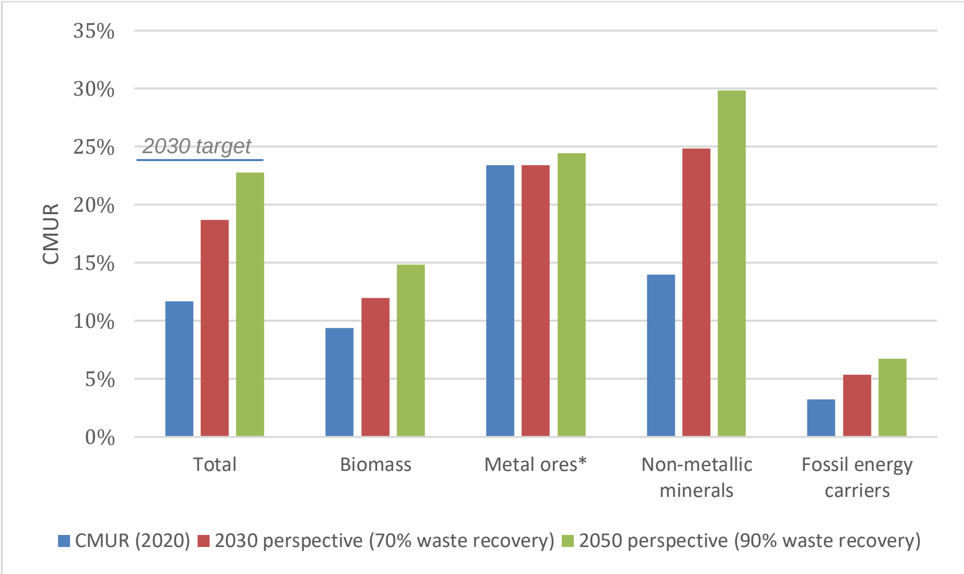
39 ETC CE calculations using Eurostat databases env_wastrt (last update: 13/01/2023).

39 ETC CE calculations using Eurostat databases env_wastrt (last update: 13/01/2023).

40 Lowering the DMC by the amount of additional waste assumed to be recycled would further increase the CMUR by 2–3 percentage points, resulting in the high ambition of scenario 1 the target is met.

with this substitution effect, however. The circular economy rebound effect (Zink and Geyer, 2017) and downcycling are two examples of potential consequences that diminish the full environmental potential of an increased CMUR. For example, the use of construction and demolition waste as a filler material in construction cannot be interpreted as a (full) one-to-one substitute for primary raw materials due to downcycling. The economy-wide view on material use of the CMUR indicator already includes the potential effects of circular economy rebounds.

Figure 13 Potential for increasing the circular material use rate by enhanced waste recycling under different scenarios, EU27, per cent



Note: *Kept at 2020 value for the 2030 scenario as the current ratio of RCV_R/waste treatment for metal ores already equals 84% in 2020 according to Eurostat data ([39]).

Source: ETC CE calculations using Eurostat databases env_wastrt (last update: 13/01/2023) calculating the ratio between recovery-recycling and total waste treated.

The analysis highlights that the CMUR might increase from currently about 11.7 % to 18.7 % in a 2030 perspective scenario (70 % waste recovery) and to 22.8 % in a 2050 perspective scenario (90 % waste recovery). This is still slightly below the EC doubling target of around 23.4 % by 2030 and shows that solely, and even significantly, increasing waste recycling is not sufficient to achieve the doubling target. The effect of this scenario is modelled as an increase in recycling without lowering DMC.

The potential for increasing the CMUR varies by material category and is most pronounced for non-metallic minerals and the least relevant for metal ores, for which recovery is already high according to Eurostat data.

4.3.2 Scenario 2: improving materials efficiency and reducing material consumption

Various activities and policy packages of the EGD and CEAP aim to gradually increase materials efficiency across economic sectors by, for example, making products more durable; improving their reusability, upgradability, and reparability; and making better use of existing products through sharing and overall shifts towards more sustainable lifestyles. Also, policy measures supporting sustainable consumption and lifestyle changes, such as lower per-person floor space or product sharing, could lead to a more intensive use of existing products so that fewer materials would need to be added to stocks and material inputs reduced. This leads to a reduction in DMC, for example, through material accumulation reduction – an approximation of a net addition to stock in the Eurostat circular economy Sankey diagram data sets.

The efficiency with which materials are converted into economic output can be expressed by the *material intensity* (MI), calculated as the ratio of material used and GDP. In 2020, for example, the EU's DMC was around 6.1 Gt while its GDP was around EUR 12.5 trillion, resulting in a MI of 0.49 kg/EUR ([41]).

It is assumed that, starting in 2020, the material efficiency in the EU economy can be increased:
(1) in a 2030 perspective scenario in which DMC is reduced by 15 %; and
(2) in a 2050 perspective scenario in which DMC is lowered by 45 %.
In both scenarios all other CMUR-parameters remain constant (Table 3).

Such demand-side material flow reductions can be achieved by lowering material accumulation through more intensive use and life-style changes – in 2020 2.56 Gt of materials are used to build up and maintain physical stocks in the EU27 which equals 37 % of all materials going into use; decreasing material losses during production and use; and avoiding, whenever possible, material throughputs within one year by, for example, shifting to higher quality and more durable products – lowering overall emissions in the circular economy Sankey diagram. The GDP is assumed to follow the trend from 1995–2021 into the future, i.e., annual GDP growth of around 1.55 %.

Table 3 Improving materials efficiency

Indicator	Current situation	2030 perspective	2050 perspective
	Data for 2020	**15 % reduction in DMC relative to 2020 (**	**45 % reduction in DMC relative to 2020**
Material intensity (kg/EUR)	0.49	0.34	0.22
CMUR (%)	**11.7 %**	**13.5 %**	**19.4 %**

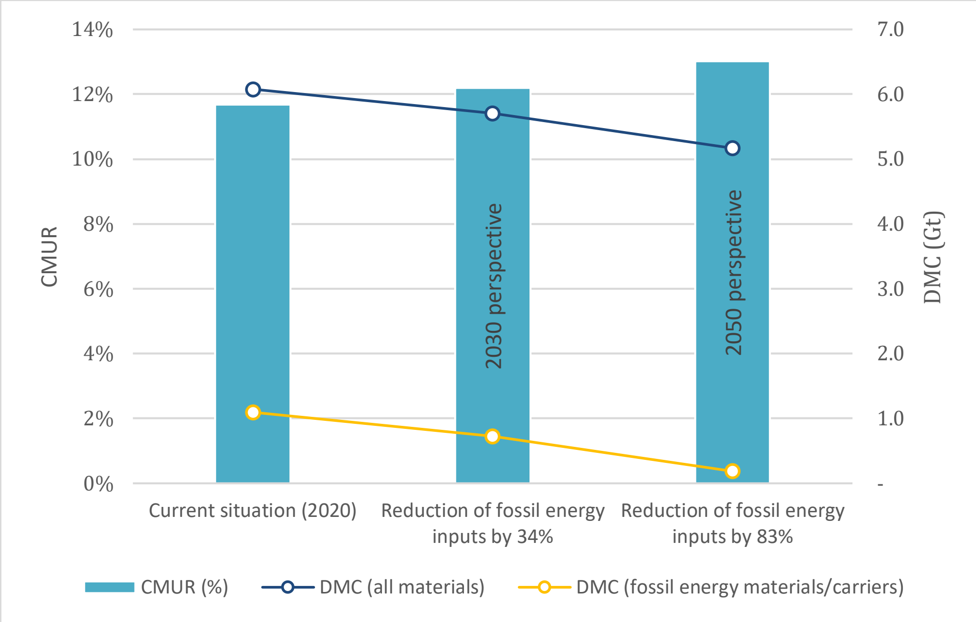
In the 2030 perspective scenario, the CMUR would increase from 11.7 % currently to 13.5 % and in the 2050 perspective scenario up to 19.4 %. Both scenarios result in a CMUR well below the EC doubling target.

4.3.4 Scenario 3: climate change mitigation

The 'Fit for 55' package targets a reduction of net EU greenhouse gas emissions to 55 % below 1990 levels by 2030 and make the EU climate neutral by 2050. This translates into the need for a gradual reduction of fossil energy carrier inputs, i.e., lowering fossil energy carriers/materials in DMC. In this section, it is assumed that fossil energy carrier inputs are reduced by 34 % in the 2030 perspective scenario, and by 83 % in the 2050 perspective scenario (Figure 14). In the 2050 perspective scenario it is assumed that the use of fossil energy materials/carriers as feedstock for fossil-based non-energy use, such as for the production of plastics, would be reduced as well. It should be noted that additional demands for other materials, such as metals in renewable power generation or wood for construction or bioenergy, are not considered in these simple scenarios.

[41] MI = DMC (6 078 123 thousand tonnes)/GDP (12 531 381.8 trillion EUR). Eurostat databases: Eurostat databases env_ac_mfa and nama_10_gdp. GDP expressed in chain linked volumes (2015).

Figure 14 Reduction of fossil energy carriers and implications on the circular material use rate, per cent, and domestic material consumption, gigatonnes, under different scenarios, EU27



In the 2030 perspective scenario, the amount of fossil energy carriers would decrease from around 1.10 Gt currently to 0.72 Gt. The use of fossil energy carriers would furthermore decrease to 0.19 Gt in the 2050 perspective scenario. In turn, the CMUR would increase from 11.7 % currently to 12.2 % in the 2030 perspective scenario and to 13.0 % in the 2050 perspective one. This highlights that the energy transition and associated climate policies to strongly reduce fossil fuels are an important lever to also foster a circular economy but, on their own, are not sufficient to achieve the CMUR doubling target. Also, as the demand for additional materials to facilitate this transition were not considered, the estimates should be interpreted with care.

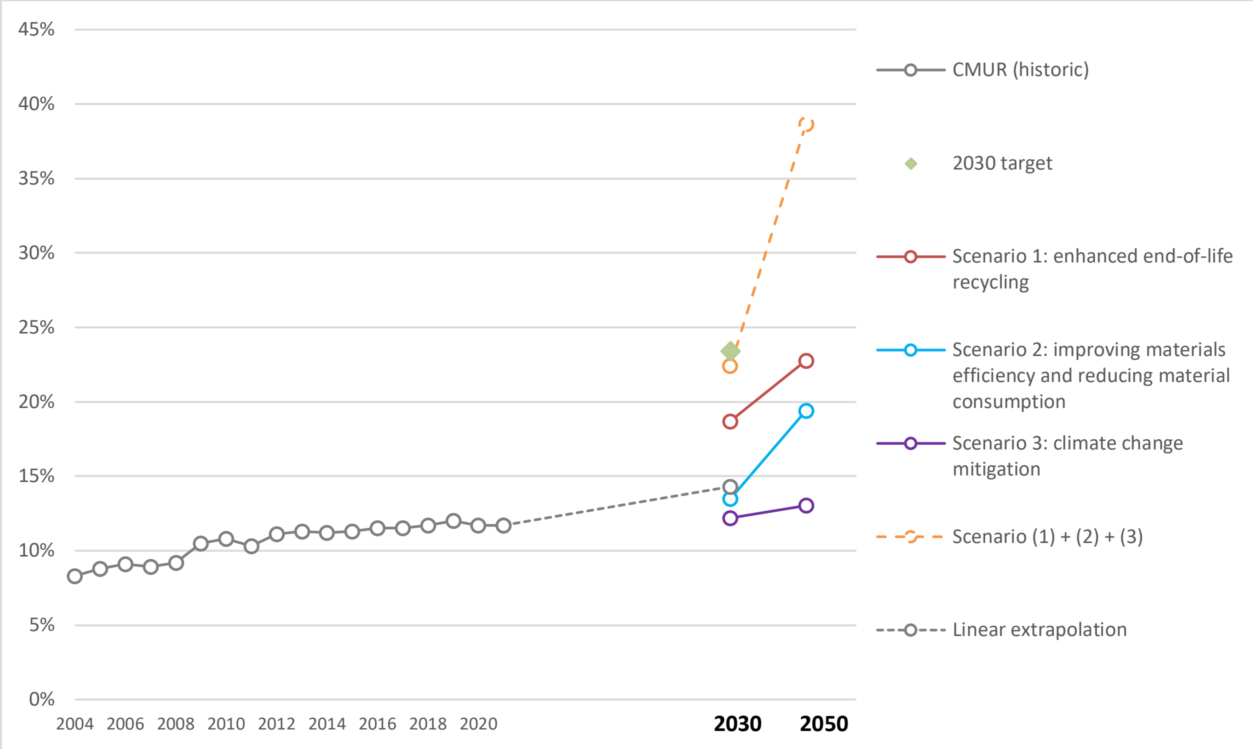
4.3.3 Combined scenarios

This section presents the results of a combination of all the scenarios (Table 2) to get an indication on the potential of combining scenarios to achieve the doubling target. The results of this combination of scenarios is explained below and visualised in Figure 15. The combined scenario assumes that 70 % (2030 perspective scenario) or 90 % (2050 perspective scenario) of waste going to treatment is recycled (Scenario 1); that improved material efficiency and reduced material consumption result in a reduction of 15 % (2030 perspective scenario) and 45 % (2050 perspective scenario) in the 2020 value of DMC (Scenario 2); and that all fossil-fuel consumption is reduced by 34 % compared to 2020 (2030 perspective scenario) or 83 % (2050 perspective scenario) (Scenario 3).

The 2050 perspective scenario with the combination of the three scenarios results in a CMUR of 38.6 %, which by far exceeds the doubling target. Considering all three strategies in the 2030 perspective scenario results in a CMUR of 22.4 %, just below the doubling target.

Figure 15 shows the individual scenarios and the combination of all three for the 2030 and 2050 perspective scenarios. In addition, the figure shows the 2030 target, the historic trend of the CMUR and the result of a linear extrapolation of the CMUR.

Figure 15 Changes in the circular material use rate according to three different scenarios and their combination, EU27, 2004–2030/2050, per cent



Note: the effect of selected (isolated) variations in the underlying parameters of the CMUR indicator is assessed looking at changes to waste and material flows. The results only provide a first back-of-the-envelope estimate of how the CMUR might change (assuming other parameters remain constant), without implementing a full material-flow model.

Table 4 Data accompanying Figure 15

	2030 perspective CMUR change (%)	2050 perspective CMUR change (%)
Scenario 1: enhanced end-of-life recycling	18.7 %	22.8 %
Scenario 2: improving materials efficiency and reducing material consumption	13.5 %	19.4 %
Scenario 3: climate change mitigation	12.2 %	13.0 %
Scenario 1+2+ 3	22.4 %	38.6 %
Linear extrapolation of the historical trend	14.3 %	14.3 %

Figure 15 highlights:

- none of the individual scenarios lead to the doubling target; a very high recycling rate of 90 % of all waste would lead to a CMUR very close to the target;
- the combined scenario achieves the 2030 CMUR doubling target set out in the 2020 CEAP but only exceeds it in the 2050 perspective scenario;
- under the 2030 perspective scenario, only the combination of all scenarios would approach the target;
- focusing on enhanced recycling alone is insufficient for reaching the doubling target; it is, however, an important lever to reach it; and
- under the 2050 perspective scenario, with enhanced waste recycling of 90 % of all treated waste, fossil-fuel reduction by 83 %, and materials efficiency gains (expressed via a 45% reduction in DMC) all assumed, including reduced material consumption, the CMUR is increased to about 39.5 %, i.e., more than tripling the current CMUR.

4.3.4 Comparison with the literature

A limited number of studies exist in which similar estimates of future circularity rates were generated. Using a full material-flow model Haas et al., (2016), for example, estimated that the circularity of the global economy could be increased from a share of 7 % in 2005 to 21–34% through a range of strategies that target the four material categories. The largest loop-closing potential was found for non-metallic minerals through halting stock growth, eco-design and local flow management. This is followed by the energy transition, and the prevention of food waste as well as cascading biomass/wood use. A study for Germany looked specifically at the CMUR and found that enhanced recycling had the largest potential to increase the circularity – an increase in the CMUR from 11.7 % to 21.8 % was estimated if all waste going to treatment would be recovered (Dittrich et al., 2021). The study also highlighted a variety of technical opportunities for increasing recycling of the four material categories. An increase of around 7 percentage points was calculated in scenarios of a greenhouse gas neutral and resource efficient Germany, partly based on the German RESCUE study (Günther et al., 2019), by 2050. The results of these studies are in line with this report's analysis.

4.4 Conclusions

Varying selected parameters of the CMUR calculation highlight that the circularity of the EU27 could increase from 11.7 % in 2020 to about 22.4–38.6 % in the future after Europe has been transformed into a climate neutral economy in which the majority of wastes are recovered and materials efficiencies have constantly increased over time. This 22.4–38.6 % range is the result of combining different scenarios, including the high leverage points in order of their potential to increase the CMUR:

(1) enhanced waste recovery – 70–90 % of all wastes going to treatment;
(2) materials efficiency gains and halting physical material stock growth, thereby lowering DMC by 15 % or 45 %; and
(3) climate mitigation – i.e., a 34-83 % reduction of fossil energy carriers/materials used in the EU economy compared to 2020.

The CEAP's aim of the EU "*doubling the CMUR in the coming decade*" is ambitious. Achieving this target would require the implementation of a combination of different strategies within a short period of time and targeting a high ambition. Increasing recycling alone will not allow the EU to achieve the doubling target.

As the CMUR is dominated by non-metallic minerals, changes to the recovery or more intensive use of buildings and construction and demolition wastes could significantly alter it. Policies such as those on food waste reduction or metal recycling only marginally influence the overall CMUR but have an impact on the CMUR for the individual material categories and can be highly relevant when considering their environmental implications (Chapter 5).

Physical stock growth, such as the expansion of infrastructure or the accumulation of an increasing number of products, is one of the main obstacles to closing material loops. One important leverage point, therefore, is on policies that target reducing stock growth and more intensive material use through, for example, increased sharing and the modular design of buildings. Even if stock growth decreases, however, fully closing material loops will not be possible due to material losses and additional material demands for the energy transition. Virgin materials will, therefore, be required in the long term and EU needs to foster policies targeting the responsible supply of raw materials, while at the same time working toward a more circular, environmentally sound and inclusive economy.

5 Material use from an environmental impact perspective

Key message 5.1: while non-metallic minerals drive the CMUR, the picture changes when the focus shifts to environmental impacts – most of these impacts come from fossil fuels and biomass, the material categories with the lowest CMUR, followed by metals (Figure 22).

Key message 5.2: 76 % of the environmental footprint of EU27 consumption originates from the extraction and processing of materials prior to their use by manufacturing industry. Fossil fuels and derived products, such as plastics and chemicals account for 27 %; biomass accounts for 25 %, metals 19%; and non-metallic minerals only 5 %. The remaining 24 % is impacts linked to downstream activities and to direct impacts of household activities.

Key message 5.3: the materials responsible for the highest environmental impacts, fossil fuels and biomass, are those with the lowest CMUR.

Key message 5.4: in contrast to metals and fossil fuels, for which the environmental footprint is mainly determined by the impact category resource use, the environmental footprint of biomass is determined by a set of environmental impact categories rather than on dominating category.

5.1 Introduction

The CMUR is a macro-level, mass-flow indicator that is very useful for understanding the environmental pressures of material consumption and economy-wide circularity. Information about the environmental impacts linked to resource use is, however, essential to support policy making for the more sustainable use of materials with the objective of achieving a net reduction of impacts (IRP, 2019).

This chapter complements the assessment of the CMUR indicator in the previous chapters and gives an overview of the environmental impacts related to material use. The calculation methodology is a reapplication of that developed by Cabernard et al. (2019) and employs an updated version of the EXIOBASE data model (version 3.8.2) to update results to 2019 (Stadler et al., 2021). EXIOBASE is an environmentally extended multi-region input-output model (EE-MRIO) covering data on production, consumption and associated environmental impacts (Box 6). An input-output analysis allows the analysis of global value chains linked to local consumption. The environmental footprint of consumption can be calculated through different methodologies, depending on the scope and objective of the calculations (Box 5).

Box 5 METHODS TO ASSESS THE ENVIRONMENTAL FOOTPRINT OF CONSUMPTION

There are in general two approaches widely used: the top-down and the bottom-up approach. The top-down approach is based on input/output tables of economic transactions between economic sectors induced by final demand from households, governments and Non-governmental organisations. These transactions are then translated into environmental impacts through the use of the European Commission's Environment Footprint method. The top-down approach is used in this report because it has a comprehensive scope, capturing all economic activities and is good in monitoring macroscopic developments.

The bottom-up method is based on scaling up impacts from specific products, which are calculated through the life cycle assessment methodology, into economic sector-wide impacts based on the economic share of these specific products in the respective sector. This bottom-up methodology is more precise in capturing environmental impacts but less complete in terms of economic activities coverage. For more details on this comparison, please see chapter 3.5 in Sala *et al.* (2019).

The scope of this assessment covers the environmental impacts of material extraction and the processing of materials to the point that they are ready for use by manufacturing industry. Environmental impacts linked to the further processing of ready-for-use materials into final products, i.e., final demand, covering household and government consumption, and investment by households and industry, are grouped into the additional remaining economy category – for example, assembly activities. Impacts that occur during household activities such as emissions from driving a car or heating are grouped under the direct impacts of household activities category. The latter categories allow the reader to see the share of environmental impacts of the ready-for-use materials in the total environmental impact of final demand.

This chapter assesses the overall environmental impacts and impacts of the four material categories – metals, non-metallic minerals, fossil fuels and biomass. Whenever relevant for the interpretation, additional details on specific materials are included by material category. It is important to note that there are differences between the underlying composition of these material categories as compared to the composition of those discussed in previous chapters. In those, the material categories are defined following Eurostat's definition of the main 1-digit material categories from the economy-wide material flow account classification (Eurostat, 2018). In this chapter, however, material categories are defined according to matching economic sectors:

- biomass: agriculture, forestry, fishing, food processing industries, manufacture of wood and pulp production;
- metals: mining of metal ores and basic metal production – aluminium, copper, iron and steel, lead, tin, zinc, other non-ferrous metals and the casting of metals;
- non-metallic minerals: mining of non-metallic minerals, such as sand, clay and gravel, production of fertilisers and the manufacture of mineral products including bricks and tiles;
- fossils: fossil fuel industries, petroleum refineries, chemical industries and production of plastics and rubbers.

This definition of ready-for-use material categories covers a mixture of resources, intermediate products and manufactured products.

The assessment covers the environmental impact categories of the environmental footprint method ([42]). This method, endorsed by the European Commission, includes a wide variety of environmental impacts and provides also guidance to process (normalisation and weighting) impact results into a single aggregated score, expressed in points (Pt).
The assessment covers:

- climate change (kg CO_2-eq.);
- photochemical ozone formation (kg NMVOC-eq.);
- particular matter (disease incidence);
- human toxicity, non-cancer (comparative toxic unit for humans (CTUh));
- human toxicity, cancer (CTUh);
- acidification (mol H+ eq.);
- eutrophication, freshwater (kg P-eq.);
- eutrophication, marine (kg N-eq.);
- eutrophication, terrestrial (mol N-eq.);
- Ecotoxicity, freshwater (comparative toxic unit for ecosystems (CTUe));
- land use (Pt; dimensionless; soil quality index);
- water use (cubic metre (m^3) deprivation);
- resource use, fossils (megajoules (MJ));
- resource use, minerals, and metals (kilogram antimony equivalent (kg Sb-eq.)).

It is important to note that the environmental footprint method defines characterisation factors[33] for more emissions and resources extracted than there are available in EXIOBASE. For some environmental impacts, such as climate change, the coverage of EXIOBASE is quite complete. For other impacts, however, such as

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42 Single Market for Green Products - The Product Environmental Footprint Pilots (https://ec.europa.eu/environment/eussd/smgp/ef_pilots.htm)

33 Characterisation factors allow the conversion of environmental pressure indicators into the environmental impact categories, for example methane emission are converted into CO2-equivalents as part of the climate change impact category.

toxicity, EXIOBASE includes only a limited selection of emissions. No information is available in EXIOBASE to estimate the ozone depletion and ionising radiation impact categories. Therefore, one implication of combining EXIOBASE environmental extensions with the environmental footprint methodology is that not all environmental impacts are captured comprehensively.

BOX 6 METHODOLOGY APPLIED FOR CALCULATING THE ENVIRONMENTAL FOOTPRINT

In this chapter the total environmental impact levels are determined by the use of materials in the upstream production networks of EU27 final demand and the impact per unit of resource. Per year the total environmental impact is allocated to (i) the production of ready-for-use materials, i.e., biomass, metals, non-metallic minerals, fossils; (ii) the remaining economy; and (iii) direct impacts by activities of households. This approach encompasses the same volume of materials as those included in DMC, but while DMC focuses on the mass of materials, in this chapter the environmental impacts related to the production, processing and use of these volumes of materials linked to EU27 final demand is assessed. Due to the strong intertwining of material production networks globally, an accurate quantification of environmental impacts is a challenge (IRP, 2019). An example of their intertwining is the use of fossil fuels for energy to produce metals, and *vice versa*, the use of metals for machinery and equipment to produce fossil fuels. As such, the allocation of environmental impacts to different material groups is quite complex.

To perform this allocation, the macro-economic sustainability assessment method developed by Dente et al. (2019) and Cabernard et al. (2022; 2019) were reviewed, allowing a comprehensive and accurate assessment and avoiding the overlap within production networks. In this chapter the methodology described in Cabernard et al. (2019) is applied. This ensures that each environmental impact is only counted once: the impact is either allocated to a specific category of ready-for-use materials or to the remaining economy. The environmental impacts, which are linked to resource extraction and material processing, are allocated to the ready-for-use materials. These encompass products at different stages of manufacturing. Starting from each ready-for-use material resource group, i.e., biomass, metals, non-metallic minerals, fossils, the environmental impacts caused by all upstream production steps are allocated to this material resource group. Upstream production steps include the supply chains of all inputs to these production steps. The remaining environmental impacts, which occur after the production of the ready-for-use materials, for example, when further processing them into final products, are not linked to any of the ready-for-use material resource groups but are allocated to the remaining economy category. The environmental impacts that occur during household activities, such as driving a car or heating houses, are allocated to the direct impact of household activities category.

Some examples are given to explain and illustrate this allocation.

- Ready-for-use biomass products include raw materials, such as food products from agriculture and wood from forestry; intermediate products, such as pulp; and finished products, including food products from the food processing industries. For pulp, for example, all environmental impacts occurring in the upstream production steps are included. This encompasses, among others, the environmental impact from the extraction and production of the fossil fuels that are required for energy purposes, and the emissions during the burning of the fuels. Out of the scope of ready-for-use biomass products is, for example, the environmental impact of the further processing of pulp into, for example, the final product, paper, which is allocated to the remaining economy category. This impact includes, amongst others, the emissions released during the use of the fossil fuels required for the processing of pulp to paper, but not the impact for the extraction and production of these fuels, as this impact is allocated to the ready-for-use fossils.
- Ready-for-use fossils include the environmental impact related to the extraction and processing of the fossil fuels which are not used in the production chain of the other ready-for-use materials − as these are already allocated to the respective ready-for-use material resource groups. So, it includes the impact of the extraction and processing of fossil fuels used for production of plastics and used as fuel in the remaining economy. The impact generated during the use of the fossils is allocated to the remaining economy category, or to the direct impact of household activities.
- Another example is based on the demand for, and the related environmental impact of, cars. Only the environmental impacts of the car components (intermediate products) are allocated to the ready-for-use material resource groups, such as basic metal production, production of plastic and rubbers, manufacture of mineral products such as glass, fossil fuels providing energy for assembly, etc. Other production steps, including car assembly, retail and marketing, are outside the definition of ready-for-use materials and are allocated to the remaining economy category.

The scope of the ready-for-use material resource groups is defined by the choices made in Cabernard et al. (2019, 2022). Although well-documented, some allocation choices are arbitrary. For example, the industrial activity manufacturing of rubber and plastic products (NACE 22) is allocated as a downstream activity, so it is not part of

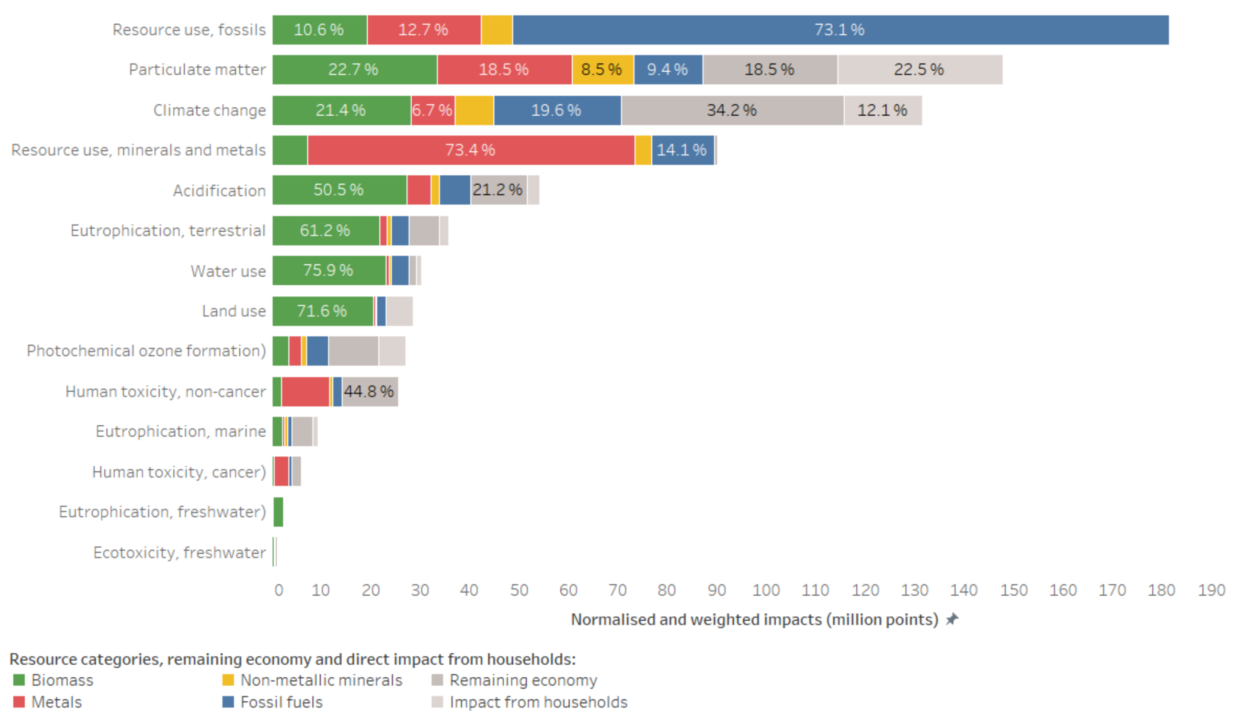
any of the ready-for-use materials categories One could argue it should be allocated to fossil fuels material category.
The authors acknowledge the limited granularity of the EXIOBASE model used, but it is considered to be sufficient for supporting the key messages. A comparison with other approaches is provided in Castellani et al. (2019).

The scope of the analysis covers the extraction and first processing of materials to meet EU27 final demand. The environmental footprint accounts for the impacts regardless where these production activities take place. Intermediate business-to-business demand is included on the condition that it is part of a production network linked to EU27 final demand. If not, the impact linked to this local production is linked to export and considered out of scope. Annex 1 provides more details on the methodology, the data model employed and the environmental footprint method.

5.2 Results: environmental impacts of ready-for-use materials

Figure 16 provides an overview of the environmental impacts linked to the production of ready-for-use materials used for the provision of final products consumed within the EU27. The figure shows results normalised and weighted according to the guidance of the environmental footprint method. The environmental footprint of EU27 final consumption was estimated at 0.8 billion points in 2019 ([43]). This result is the weighted sum of 14 out of the 16 ([44]) individual environmental impact categories considered. Environmental impacts from the use of fossil fuels (resource use, fossils) have the largest contribution, 23 %, followed by particulate matter, 19 % and climate change, 17 %.

Figure 16 Environmental footprint of ready-for-use materials derived from EU27 consumption by impact category, 2019, points. Results for the remaining economy and household activities are also displayed, per cent



Source: ETC CE calculations based on Cabernard et al. (2019) using EXIOBASE v.3.8.2.

43 Europe's consumption footprint (https://www.eea.europa.eu/ims/europe2019s-consumption-footprint)
44 No information is available in EXIOBASE to estimate the impact categories ozone depletion and ionising radiation.

Another perspective is provided by looking at Figure 16 from the different material categories.

- The contribution of **non-metallic minerals** is much smaller than the other material categories, with shares of 1–9 %. The highest share is for particulate matter impacts, 9 %. Other significant contributions are for climate change, 6 %, and eutrophication, 5 %.
- **Biomass,** particularly agricultural activities, dominates several impact categories: acidification, 50 %; eutrophication, both freshwater, 88 %, and terrestrial, 61 %; land use, 72 %; water use, 76 %; and ecotoxicity, 46 %. For the other impact categories the share of biomass is also significant, varying from 7 % to 22 %.
- **Metals** have the largest contribution to human toxicity, both non-cancer, 39 %, and cancer, 47 %; and resource use impacts, minerals and metals, 73 %. The contribution to the other impact categories is smaller, with shares of 1 % to 18 %.
- **Fossil fuels** dominate photochemical zone formation impacts, 16 %, and resource use impacts, fossils, 73 %. The contribution to the other impact categories varies between 7 % and 20 %.

Adding up all impacts across all impact categories show that 27 % of the total environmental impact can be attributed to fossil fuels and derived products, i.e., plastics and chemicals; 25 % to biomass; 19 % to metals; and 5 % to non-metallic minerals. The remainder, 24 %, are impacts linked to the remaining economy, 16 % of which come from downstream activities and 9 % linked to direct impacts by household activities.

The individual results by environmental impact, visualised in Figure 16, show a wide variety of impact hotspots: the environmental impacts disaggregated by resource group – ready-for-use materials and fuels – show differences in contributions by resource group and different patterns by environmental impact.

Whereas the environmental footprint shows a large contribution from three resource groups – fossil energy carriers/materials, biomass and metal ores, the individual environmental impact categories show a more varied pattern of contributions from these resource categories. For example, acidification is mainly determined by biomass, while human toxicity is mainly determined by metals. Fifty-four per cent of the impact on climate change is directly related to the ready-for-use materials, leaving 46 % related to the downstream impact, i.e., the use of these materials and burning of fuels. These downstream impacts for climate change are, to a large extent, related to the use of fossil fuels and to a minor one related to the decomposition of biomass. So, the potential impact on climate change of a shift away from the use of fossil fuels should be interpreted to be larger than the 19.6 % shown in Figure 16.

The resource-use impacts, both fossils, and minerals and metals, derives only from ready-for-use materials, i.e., there are no downstream impacts as all impacts are allocated to the extraction. Related to resource use impacts, impact categories inform about resource scarcity. Seventy-three per cent of the impact by resource use fossils is linked to fossils, 13 % to metals, 11 % to biomass, and 3% to non-metallic minerals. The impact from non-fossils originates from their extraction and use making the use of fossil fuels possible, for example, the need for machinery and equipment. The environmental impact of resource use minerals and metals is mainly determined by metals, 73 %; followed by fossils, 14 %; and biomass, 8 %. The remaining 4% is from non-metallic minerals.

59 % of health impacts linked to particulate matter derive from ready-for-use materials. The impact from biomass is the highest at 23 %, followed by metals, 19 %. Fossils and non-metallic minerals contribute around 9 % each.

5.3 Results: environmental impacts of ready-for-use within resource groups

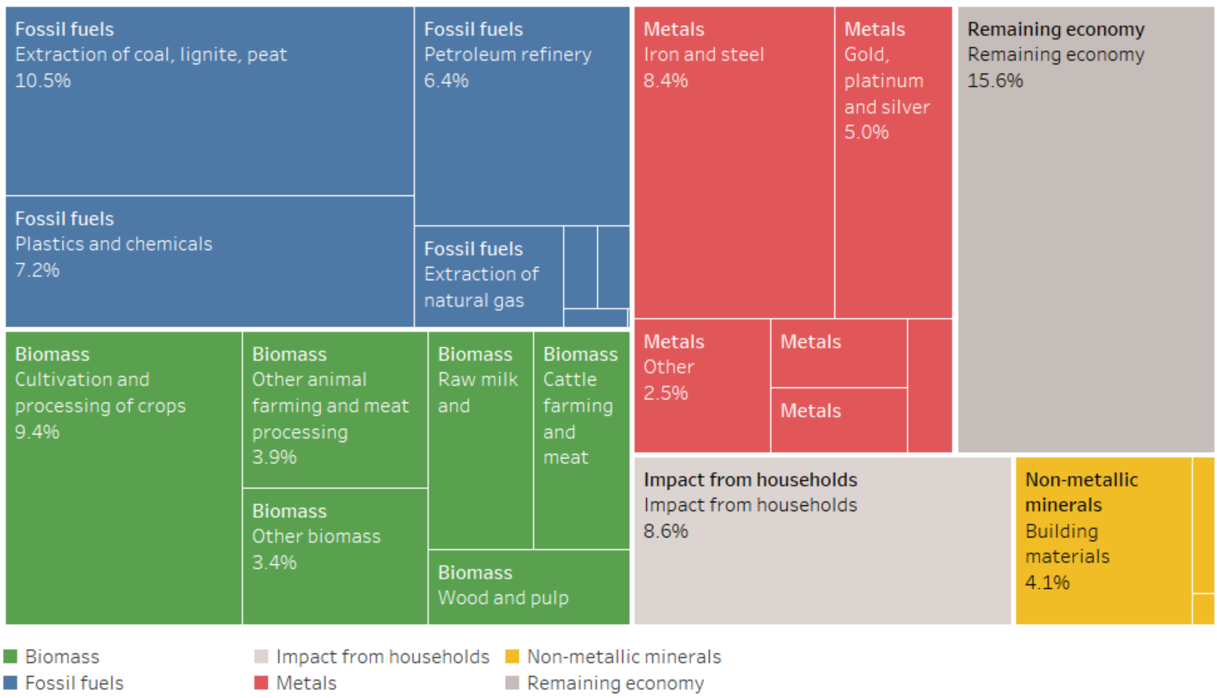
This section provides a further disaggregation of impact results by material category, again displaying impacts from ready-for-use materials, the remaining economy and direct impact of households (Figure 17). Each material category is further broken down into more detailed resource groups. The largest contribution originates from extraction of coal, lignite and peat (fossils, 10.4 %), followed by crops cultivation and processing (biomass, 9.4%), and iron and steel manufacturing (metals, 8.3 %).

Looking in detail at the resource groups not only reveals more details on the subcategories underlying these groups, but also reveals a difference in the contribution of the environmental categories that make up the environmental footprint.

- The impacts from the use of **biomass** are linked to crops (40 %) and animal meat and products (38 %). The remainder is linked to wood, pulp and other biomass products.
- The impacts from the use of **fossil fuels** can be attributed to energy (73 %) and plastics and chemicals (27 %). The impact is mainly determined by resource use impacts from fossils.
- The impacts from the use of **metals** are mainly determined by iron and steel (44%) and the precious metals (26%). The environmental impact categories of resource use minerals and metals, particulate matter and resource use fossils, together determine most of the environmental footprint.
- The impacts from the use of **non-metallic minerals** are largely determined by construction materials (88%).

Figure 18 provides more details by material category.

Figure 17 Summary of the contribution of resource groups, the remaining economy and direct impacts by households to the environmental footprint, EU27, 2019, per cent



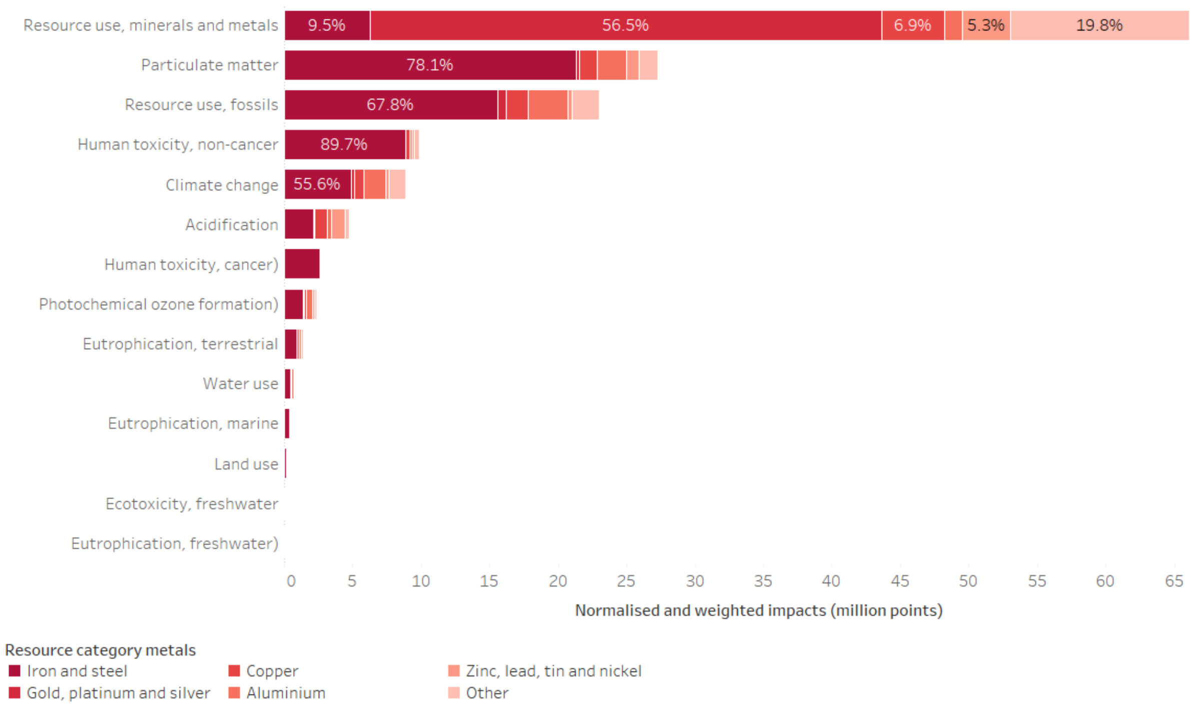
Note: The sum of the percentage points may not sum to 100% due to rounding.
Source: ETC CE calculations based on Cabernard et al. (2019) using EXIOBASE v.3.8.2.

Figure 18 shows the relative contribution of the metal subcategories by environmental impact category. This part is the equivalent of the metals' series in Figure 16.

The environmental impact of metals is mainly determined by iron and steel, 44 %, and precious metals, 26 %. The significant environmental impact of producing iron and steel is mostly related to huge demand, whereas the impacts of precious metals – gold, platinum and silver – are more related to their high impact per unit of production. The categories of resource use for minerals and metals, 45 %; particulate matter, 18 %; and fossils, 16 % together dominate environmental impacts.

The use of copper has a considerable impact (20%) on the acidification category and an impact of 11 % on freshwater eutrophication and land use impacts, although its weighted score only shows an impact of 7 % within the metals' resource group. The same applies to aluminium, which has a score of 6 %, but a share of 18 % for climate change.

Figure 18 Environmental footprint of ready-for-use metals derived from EU27 consumption by impact category, 2019, points. Results for the remaining economy and household activities are also displayed, per cent

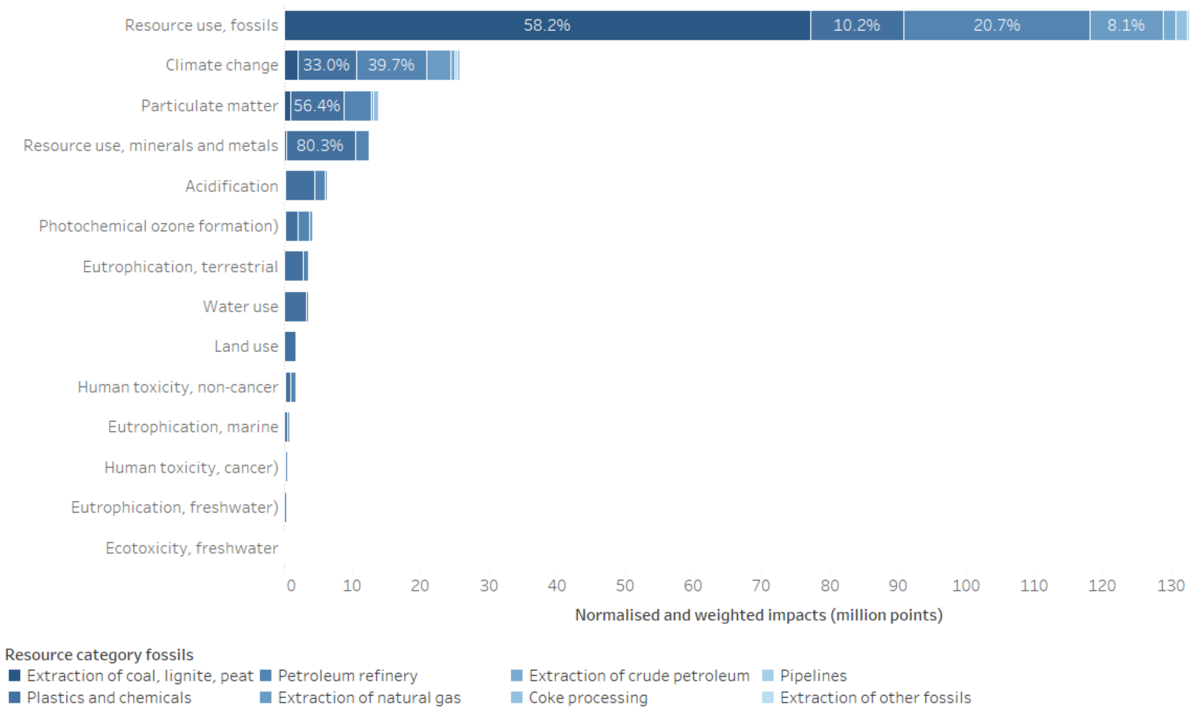


Source: ETC CE calculations based on Cabernard et al. (2019) using EXIOBASE v.3.8.2.

The environmental impact of ready-for-use fossil fuels and derived products is mainly attributed to the extraction of coal, lignite and peat, 38 %; plastics and chemicals, 27 %; refining of petroleum, 23 %; and the extraction of natural gas, 8 % (Figure 19). The four other categories together represent 4% of the environmental impact. The environmental impact category contributing most to the environmental footprint is, by far, resource use of fossils, 64 %; followed by climate change, 12 %; particulate matter, 7 %; and resource use of minerals and metals, 6 %.

The extraction of coal, lignite and peat has the largest contribution to the resource use impact category of fossils, 58 %; followed by the refining of petroleum, 21 %; and plastics and chemicals, 10 %. All other environmental impact categories are mainly determined by plastic and chemicals, followed by the refining of petroleum.

Figure 19 Environmental footprint of ready-for-use fossils derived from EU27 consumption by impact category, 2019, points. Results for the remaining economy and household activities are also displayed, per cent

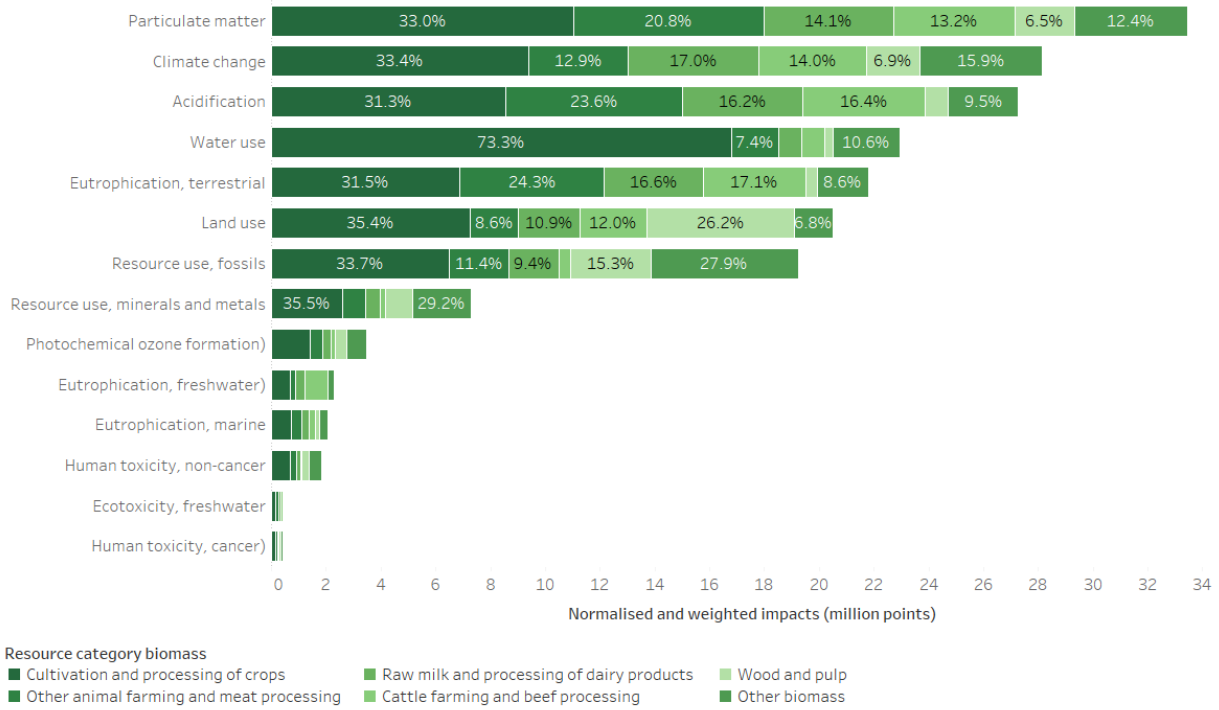


Source: ETC CE calculations based on Cabernard et al. (2019) using EXIOBASE v.3.8.2.

The environmental impact of ready-for-use biomass is mainly from the cultivation and processing of crops, 38 %; animal farming and meat processing, 27 %; raw milk and processing of dairy products, 13 %; and wood and paper, 8 %. In Figure 20 a distinction is made between cattle farming and meat processing and other animal farming and meat processing. The other biomass category includes fish products, textiles, and beverages.

In contrast to metals and fossils, the environmental footprint of biomass is not dominated by an individual category, but rather seven each contribute 11–17 %: particulate matter, climate change, acidification, water use, terrestrial eutrophication, land use, and the use of fossils. The largest contribution stems from the cultivation and processing of crops. This category is not further disaggregated, while animal farming and meat processing are disaggregated into three groups: cattle, other meat, and milk and dairy products.

Figure 20 Environmental footprint of ready-for-use biomass derived from EU27 consumption by impact category, 2019, points. Results for the remaining economy and household activities are also displayed, per cent

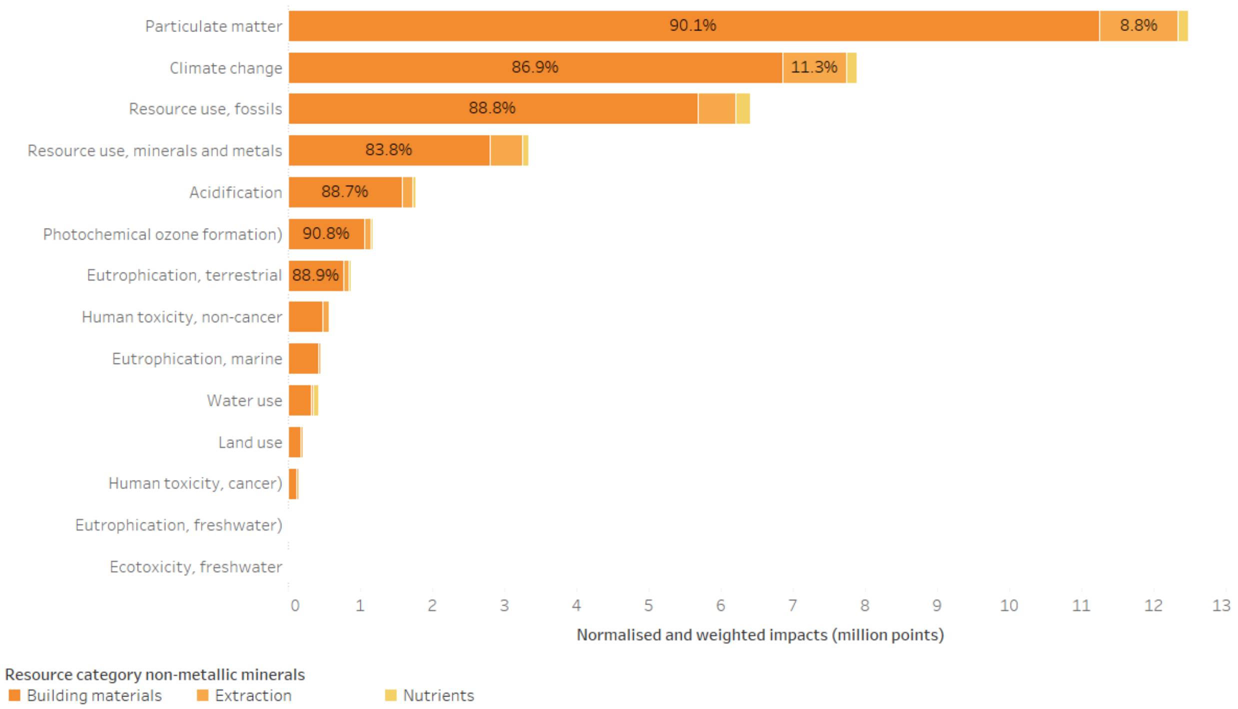


Source: ETC CE calculations based on Cabernard et al. (2019) using EXIOBASE v.3.8.2.

The environmental impact of ready-for-use non-metallic minerals (Figure 21) is almost completely linked, 88 %, to building materials such as construction sand, bricks and tiles. Two per cent of the remainder comes from nutrients such as phosphorus and 10 % from the extraction of non-metallic minerals or other purposes such as the production of. ceramic or glass crockery. The database does not allow further disaggregation of building materials.

The environmental impact categories mainly responsible the environmental footprint of non-metallic minerals are particulate matter, 35 %; climate change, 22 %; the use fossils, 18 %; and the use non-metallic minerals, 9 %.

Figure 21 Environmental footprint of ready-for-use non-metallic minerals derived from EU27 consumption by impact category, 2019, points. Results for the remaining economy and household activities are also displayed, per cent



Source: ETC CE calculations based on Cabernard et al. (2019) using EXIOBASE v.3.8.2.

While non-metallic minerals drive the CMUR, the picture changes when the focus shifts to environmental impacts – most of these impacts come from fossil fuels, biomass, the material categories with the lowest CMUR, followed by metals (Figure 22).

6 Conclusions (and outlook)

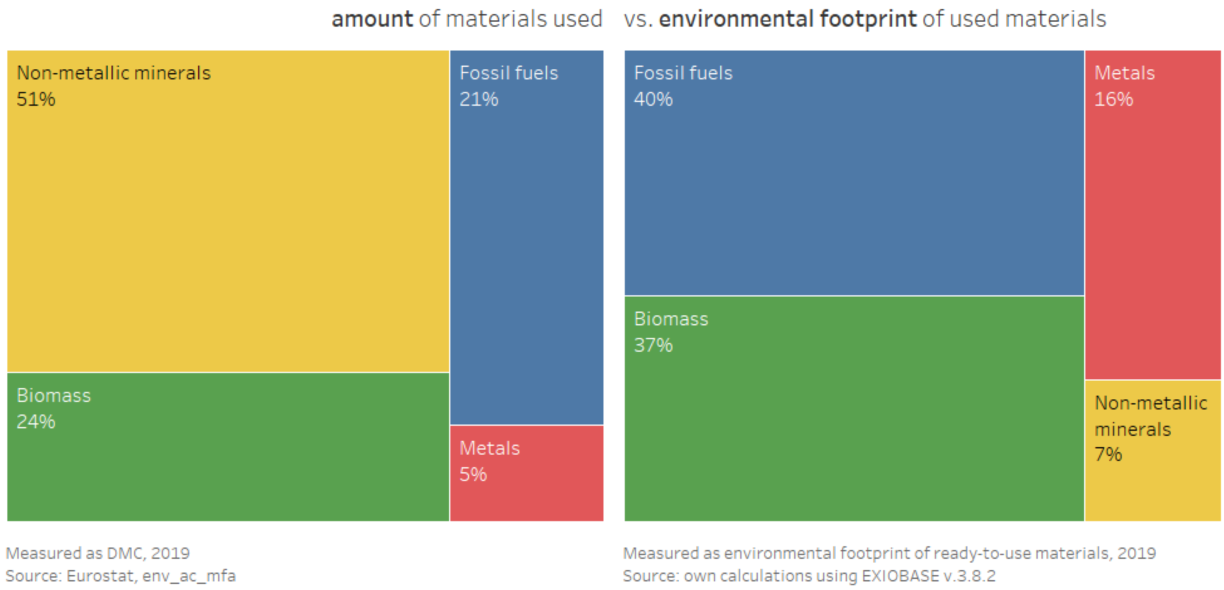
The CEAP, published in 2020, includes a non-legally binding target of doubling the circular use of materials in the coming decade ([45]). Data shows that in 2020 the circular use of materials, expressed by the CMUR indicator or circularity rate, in the EU stood at 11.7 % (Eurostat, 2023a) of 6.9 billion tonnes of material use. Although this value has increased by 3.4 percentage points since 2004 and 0.9 percentage point since 2010, past trends suggest that reaching the target will be very challenging.

Currently, at both total and material flow category levels, the trend of the CMUR is mainly driven by the trend in material consumption and much less by trends in recycling. Yet, the different recycling levels do have an effect on the level of the CMUR for different material categories: the higher the ratio of recycling over material consumption, the higher the CMUR by material category, with metal ores and non-metallic minerals having the highest material-specific CMURs.

As a volume-based indicator, the CMUR is dominated by the non-metallic minerals which make up 52 % of material consumption and 66 % of recycled waste. Thus, the main leverage point for increasing the CMUR are measures to increase the CMUR of non-metallic minerals.

From an environmental perspective, the significance of the material categories is different: around 75 % of the total environmental footprint of the EU27's final demand can be allocated to ready-for-use materials and fuels. Fossil fuels contribute 40 % to the environmental footprint of ready-for-use materials, biomass 37 %, metals 16 %, and non-metallic minerals only 7%. From an environmental perspective, the focus should therefore be first on fossil energy materials/carriers and biomass products. From this perspective it is remarkable that these categories currently have the lowest CMURs.

Figure 22 Comparing the composition of material categories in the amounts used and their environmental footprints, EU27, 2019, per cent



The CMUR can increase by scaling up the amount of materials recycled (nominator), by reducing the amount of (raw) materials consumed (denominator), or a combination of both. The EU Green Deal with

45 The CEAP (EC, 2020) states "[…] *the EU needs to accelerate the transition towards a regenerative growth model that gives back to the planet more than it takes, advance towards keeping its resource consumption within planetary boundaries, and therefore strive to reduce its consumption footprint and double its circular material use rate in the coming decade*".

its CEAP and other policy packages affect the CMUR through changing economy-wide material/waste flows and stocks. Varying the underlying parameters of the CMUR can give a first impression of the possible consequences on the indicator and the prospects towards meeting the doubling target.

The CMUR could increase to 22.4 % – just below the 2030 target – in 2030 if different strategies are combined, for example increasing the recycling of all treated waste to 70 %, decreasing material inputs into the economy by 15 % and reducing the amount of fossil fuels used by 34 %. In a 2050 perspective scenario, realising a recycling rate of 90 %, a reduction of material inputs by 45 % and reducing the amount of fossil fuels used by 83 %, the CMUR could reach 38.6 %.

The European Commission, with its 2030 doubling target, has set an ambitious timeline for increasing Europe's rate of circularity by 2030. Achieving this would require the rapid implementation of a combination of enhanced recycling with material efficiency gains and a massive reduction in fossil fuel use. This requires a coordinated effort from such areas as circular economy and climate policy. Enhanced waste recycling alone will not allow Europe to achieve the doubling target.

The use of industrial by-products and production residues have a positive effect on the CMUR. Their use potentially lowers the demand for new materials, resulting in a lower level of the DMC. The order of magnitude of its effect on the CMUR, however, is lower compared to the use of recycled materials captured by official waste statistics included in the feedback loop of the CMUR. The use of the recycled materials part of official statistics not only results in a lower level of DMC through its substitution effect, but also increases the magnitude of the feedback loop. Caution is, however, required with this substitution effect. Currently available data do not give information about what the recycled amounts actually substitute in the economy. With an overall goal of reducing the net environmental impacts, the additional environmental impact of producing the secondary materials, i.e., the impact of collecting the waste and recycling it, should not outweigh the decrease in impacts from the substituted primary raw materials. In parallel, the trend in the overall use of materials and associated environmental impacts should be (absolutely) decoupled from economic growth and improved wellbeing – double decoupling or absolute sufficient decoupling – as a larger cycle requires more materials and energy to maintain it (IRP, 2019).

Improving the CMUR needs different approaches, on one hand, for fossil fuels and biomass, and metals and non-metallic minerals on the other. As the first group is largely converted into emissions because of their use for energy purposes and food, their circular material use rate can mainly be increased by reducing their use for energy purposes and replacing them with renewable energy technologies, and by reducing food waste. The second group largely goes into the stock build up and stock maintenance, and becomes available for recycling at some point in time. Approaches for improving the CMUR of metals and non-metallic minerals should be targeted towards both reducing their input to the economy and increasing the recycling of these materials when they become available.

Reflecting on the differences in messages from purely the volume based CMUR indicator and the insights from the environmental impacts of material use leads to the following suggestion. Future development of the CMUR could focus on the inclusion of its environmental impacts. Therefore, the exploration of the construction of an environmentally-weighted CMUR is suggested.

Finally, two comments that potentially impact the results of this report should be noted.

- The data used in developing this report runs until 2021, and thus does not reflect the current effect of the Ukraine war and all the policy changes it is driving, with consequences for the sourcing and use of materials.
- Currently the CMUR is calculated using DMC as the denominator. Results could be different when using a material footprint, such as RMC, as indicator for EU consumption.

List of abbreviations

Abbreviation	Name	Reference
Bq	becquerel	
C&D	construction and demolition	
CEAP	Circular Economy Action Plan	
CH_4	methane	
CMUR	circular material use rate	
CN	combined nomenclature	
CO_2	carbon dioxide	
CO_2-eq.	carbon dioxide equivalent	
CRM	critical raw material	
CTUe	comparative toxic unit for ecosystems	
CTUh	comparative toxic unit for humans	
CU	circular use (of materials)	
DMC	domestic material consumption	
DMI	direct material input	
EC	European Commission	
EEA	European Environment Agency	eea.europa.eu
EE-MRIO	environmentally extended multi-region input-output model	
EF	environmental footprint	
e.g.	*exempli gratia* (for example)	
EGD	European Green Deal	
EOL-RIR	end-of-life recycling input rate	
ETC-CE	ETC Circular economy and resource use	eionet.europa.eu/etcs/etc-ce
EU-27	European Union (2020-composition)	
EUR	euro	
EV	electric vehicles	
EW-MFA	economy-wide material flow analysis	
EXPw	exported waste destined for recycling	
FGD	flue-gas desulfurization	
GDP	gross domestic product	
GHG	greenhouse gas	
Gt	gigatonne (10^9 tonnes)	
i.e.	*id est* (that is)	
IEA	International Energy Authority	
IMPw	imported waste destined for recycling	
kBq	thousand becequerals	
kg	kilogram	
m^3	cubic metre	
ME	material efficiency	
MF4	fossil energy carriers/materials	
MI	material intensity	
MJ	megajoule (10^6 joules)	
mol	mole (SI unit)	
mol H+ eq.	unit of mole of H+ equivalents	
mol N-eq.	unit of mole of N equivalents	
MSA	material system analysis	
Mtoe	million tonnes of oil equivalent	
N	nitrogen	
NACE	Statistical classification of economic activities	

	in the European Community
NMVOC	non-methane volatile organic compound
NMVOC-eq.	non-methane volatile organic compound equivalent
P	phosphorous
PCB	printed circuit board or polychlorinated biphenyl (see page 19)
PET	polyethylene terephthalate
PJ	petajoule (10^{15} joules)
Pt	point
PtX	power-to-X (heat, fuels, chemicals)
PVC	polyvinyl chloride
RCV_R	recovery – recycling
RIMS	Raw Materials Information System
RMC	raw material consumption
Sb	antimony
Sb-eq.	antimony equivalent
SI	International System of Units
U	= RCV_R-IMP_w+EXP_w
U-235	uranium 235

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Annex 1: Calculation methodology for Chapter 5

The model EXIOBASE (description from the EXIOBASE-website)

EXIOBASE 3 provides a time series of environmentally extended multi-regional input-output (EE MRIO) tables ranging from 1995 to a recent year (currently 2022) for 44 countries (28 EU Member States plus 16 major economies) and five rest of the world regions. EXIOBASE 3 builds upon the previous versions of EXIOBASE by using rectangular supply-use tables (SUT) in a 163 industry by 200 products classification as the main building blocks. The tables are provided in current, basic prices (million EUR).

EXIOBASE 3 is the culmination of work in the FP7 DESIRE project and builds upon earlier work on EXIOBASE 2 in the FP7 CREEA project and EXIOBASE 1 of the FP6 EXIOPOL project. These databases are available at the official EXIOBASE website.

A special issue of Journal of Industrial Ecology (Volume 22, Issue 3) describes the build process and some use cases of EXIOBASE 3. This includes the article by Stadler et. al 2018 describing the compilation of EXIOBASE 3. Further information (data quality, updates, etc.) can be found in the blog post describing a previous release at the Environmental Footprints webpage.

The original EXIOBASE 3 data series ends in 2011. Additional years are estimated based on a range of auxiliary data, but mainly trade and macro-economic data which (currently) go up to 2022 when including IMF expectations. So, care must be taken in use of the data.

The calculation methodology

The global distribution of pressures and effects related to final the consumption of households have been calculated using an extended multiregional input model based on a modified version of EXIOBASE v.3.8.2 data (Stadler et al., 2021). For this purpose, environmentally extended product-byproduct tables were used. The calculation started from the following identities:

$$\mathrm{x} = \mathrm{A} \cdot \mathrm{x} + \mathrm{y} \qquad (1)$$

where '*x*' is the total output vector, '*A*' the matrix of direct input coefficients (or matrix of technological coefficients), and '*y*' is the final demand vector. Solving the model for output gives:

$$\mathrm{x} = (\mathrm{I} - \mathrm{A})^{-1} \cdot \mathrm{y} = \mathrm{L} \cdot \mathrm{y} \qquad (2)$$

with identity matrix '*I*', and matrix '*L*' the Leontief inverse also known as the multiplier matrix or matrix of direct and indirect output requirements per unit produced for final demand. The Leontief model implies the following assumptions: prices are fixed in the short term, input coefficients are constant regardless of output or final demand level changes, structure of the economy is taken to be constant, at least in the reported period.

The direct environmental effects of national production are the result of the sum of the direct effects associated with each unit produced in each industry:

$$e^T = \sum_1^n e_i = \sum_1^n e_i^{int} \cdot x_n = < e^{int} > \cdot\, x \qquad (3)$$

By multiplying the environmental pressure per output unit (measured in physical units per euro worth of output) by the total output of each industry (measured in Euro), defined by equation (2), an environmentally extended input-output model is created:

$$\mathrm{e^T} = < \mathrm{e^{int}} > \cdot\, \mathrm{x} = < \mathrm{e^{int}} > \cdot\, (\mathrm{I} - \mathrm{A})^{-1} \cdot \mathrm{y} \qquad (4)$$

where 'e^T' is the vector of total environmental pressures associated with the corresponding amounts of the products groups finally used (vector *y*) and 'e^{int}' the environmental pressure intensity vector. Each element of 'e^{int}' represents the amount of the environmental pressure directly caused by the production of a product group. Each element of 'e^{int}' in EXIOBASE is allocated to a sector-region combination, which, for example, allows to derive the EU-27 shares in the total footprint.

To develop a time-series dataset of environmental impacts, an adjustment to the EXIOBASE dataset was applied. The material extraction data are overwritten to match at country level with the UNEP Global Material Flows Database ([46]). The extensions on domestic extraction used in EXIOBASE are modified to match with the total domestic extraction per material flow type, per year and per country from the UNEP-database. The inner country sectoral distribution available from EXIOBASE remains unchanged.

The end years of the extension tables vary. It means that the extension tables are based on real data till a certain year and then the extension coefficients (i.e., the environmental impact by monetary unit of sectoral output) are kept constant. This means that, after the data series based on real data end, the footprint calculations only capture changes in environmental impacts due to changes in output volumes. Changes in environmental efficiency per unit of output are not captured. The end years of the extension tables are: 2015 for energy, 2019 all GHG (nonfuel, non-CO_2 are nowcasted from 2018), 2013 for material use (but is overwritten using the UNEP database), and 2011 for most others, land and water.

The methodology from Cabernard et al. (2019)

In essence, this methodology allows to disaggregate the total environmental footprint from EU27 final demand into a share allocated to ready-for-use materials and fuels, the remaining economy, and direct impact from households. All environmental impacts of production networks up to the point of the defined ready-for-use materials and fuels are allocated to one of the resource groups. The other environmental impacts are allocated to a remaining economy group. The impact from households (direct impacts, e.g., emissions from natural gas for heating at home) are allocated to the household category.

The method is applied to the “target perspective”. In this perspective the impacts are attributed to the “target”, which in this case are the (self-defined) ready-for-use materials and fuels aggregated into the four material categories, including the upstream supply network (Cabernard et al., 2019). The environmental impacts downstream the supply networks are not allocated to the material categories. These downstream emissions are critical mainly for fossil resources as their combustion causes the vast majority of global emissions (a minor part is allocated to biomass through decomposition) (Cabernard et al., 2019).

The material categories are approximated by the resource groups according to a matching sectoral output.

- Biomass is defined by the output of the sectors: agriculture, forestry, fishing, food processing industries, manufacture of wood and pulp production;
    - EXIOBASE sector numbers: 1–19, 35–45, 47, 50–53.
- Metals are defined by the output of the sectors: mining of metal ores, and the basic metal production (i.e., the production of iron and steel, aluminium, lead, zinc, tin, copper, other non-ferrous metals and the casting of metals);
    - EXIOBASE sector numbers: 24-31, 58, 72–84.
- Non-metallic minerals comprise the output of the sectors: mining of non-metallic minerals, the production of fertilisers and the manufacture of mineral products; and
    - EXIOBASE sector numbers: 32–34, 61–62, 65–71.
- Fossils include the output of the extraction of fossils industries, the petroleum refineries, chemical industries and the production of plastics and rubbers;
    - EXIOBASE sector numbers: 20–23, 56–57, 59–60, 63, 122.

The assessment and discussion focus on the contribution of four material resource groups (metals, non-metallic minerals, fossils, and biomass) to the environmental impacts. If relevant, addition details per material category are included.

Application of the environmental footprint

[46] Global Material Flows Database | Resource Panel (https://www.resourcepanel.org/global-material-flows-database)

Applying the methodology as described above gives individual results for each environmental extension available from the EXIOBASE dataset.

In a next step, these extensions are translated into environmental impact categories according to the Environmental Footprint (EF) method v3.1[34]. Translating the 1 113 available (not all of them are eventually used) extension lines into the 16 impact categories of the EF-method requires a conversion through characterization factors. The characterisation factors can be found in the Excel-table. For example, the impact category climate change (expressed in kg CO_2-eq.) requires the conversion of different relevant extension lines: Extension line 24 'CO_2 - combustion - air' is multiplied with characterisation factor 1 as this one is already in kg CO_2-eq. Extension line 25 'methane (CH_4) - combustion - air' is multiplied with 36.8 to convert the kg of CH_4-emissions into kg of CO_2-eq. This characterisation factor is available from the environmental footprint method. A total of 40 extension lines are used to determine the impact category climate change. An important remark here is that the environmental footprint method defines characterization factors for more emissions and resources extracted than available in EXIOBASE. For some environmental impacts, like climate change, the coverage of EXIOBASE is quite complete. For other impacts, however, such as toxicity, EXIOBASE includes only a very limited selection of emissions. No information, and thus no extension lines, is available in EXIOBASE to estimate the impact categories ozone depletion and ionising radiation.

The next step normalises and weighs the different environmental impact categories. To calculate the environmental footprint (expressed in points) in one aggregated score. The normalisation factors and weighting factors are copied from the environmental footprint method and presented in Table 5. The normalisation and weighting allow to express all environmental impacts into a single score. The following table shows the normalisation and weighting factors.

Table 5: The normalisation and weighting factors of the environmental footprint per environmental impact category.

Environmental impact category	Unit	Normalization factor	Weighting factor (Pt)
Climate change	kg CO2 eq	7 553.083	0.2106
Ozone depletion	kg CFC11 eq	0.052348	0.0631
Ionising radiation	kBq U-235-eq	4 220.163	0.0501
Photochemical ozone formation	kg NMVOC-eq	40.8592	0.0478
Particulate matter	disease incidence	0.000595	0.0896
Human toxicity, non-cancer	CTUh	0.000129	0.0184
Human toxicity, cancer	CTUh	1.73E-05	0.0213
Acidification	mol H+ eq	55.56954	0.0620
Eutrophication, freshwater	kg P-eq	1.606852	0.0280
Eutrophication, marine	kg N-eq	19.54518	0.0296
Eutrophication, terrestrial	mol N-eq	176.755	0.0371
Ecotoxicity, freshwater	CTUe	56 716.59	0.0192
Land use	Pt	819 498.2	0.0794
Water use	m^3 deprivation	11 468.71	0.0851
Resource use, fossils	MJ	65 004.26	0.0832
Resource use, minerals and metals	kg Sb-eq	0.063623	0.0755

34 EC Recommendations 2279/2021 & JRC (2023).

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