

The **CIRCULARITY GAP** **REPORT** Nations

Methodology Document

Circle Economy
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Table of Contents

Table of Contents	2
List of abbreviations and acronyms	2
Glossary	3
Introduction	9
1. Research aims	9
2. Research approach	9
3. Scope of circularity	12
3.1 Material perspective	12
3.2 Socio-economic perspective	13
3.3 Circular strategies	14
4. Analyses	16
4.1 Circularity Indicator Set	16
4.2 Circular Jobs Analysis	24
Annex A: Industrial ecology toolkit	26
Economy-Wide Material Flow Accounting	26
Traditional approach	29
Extended approach	31
Circle Economy's approach	35
Environmentally Extended Multi-Regional Input-Output Analysis - Weavebase model	39

List of abbreviations and acronyms

CE: Circular economy

CGR: *Circularity Gap Report*

CM: Circularity Metric

EE-MRIOA: Environmentally-Extended Multi-Regional Input-Output Analysis

EW: Economy-wide

GDP: Gross domestic product

HSUT: Hybrid supply and use tables

IE: Industrial ecology

LCA: Life cycle assessment

EW-MFA: Economy-Wide Material Flow Accounting

NSI: National Statistical Institute

PSUT: Physical supply and use tables

RME: Raw material equivalents

SEM: Socioeconomic metabolism

SEEA: System of Environmental-Economic Accounting

SNA: System of National Accounts

SNAC: System of national account consistent

Glossary

By-products: A product that is produced simultaneously with another product, but which can be regarded as secondary to that product, for example, gas produced by blast furnaces. In the context of measuring a circular economy, this refers to substances or objects resulting from a production process, the primary aim of which is not the production of that item. In this case, a substance or object may be regarded as being a by-product only if it is produced as an integral part of a production process, its further use is certain and lawful, and it can be used directly without any further processing other than normal industrial practice. By-products are not waste (source: SNA).

Circular economy: A circular economy is an economy where the value of materials in the economy is maximised and maintained for as long as possible; the input of materials and their consumption is minimised; and the generation of waste is prevented and negative environmental impacts reduced throughout the life-cycle of materials (source: OECD expert group and UNECE Task Force)

Consumption: The usage or consumption of products and services meeting (domestic) demand. In environmental assessments, *consumption* refers to 'using up' products or services, while *use* refers to the act of employing a product or service. *Intermediate consumption* is an economic concept that refers to the monetary value of goods and services consumed or 'used up' as inputs in production by enterprises, including raw materials, services, and various other operating expenses. *Final consumption* is the expenditure by resident institutional units—including households and enterprises whose main economic centre of interest is in that economic territory—on goods or services that are used for the direct satisfaction of individual needs or wants or the collective needs of members of the community. *Absolute consumption* refers to the total volume of either physical or monetary consumption of an entity. *Relative consumption* refers to the volume consumed by an entity in relation to the unit of another variable, for instance, population (*per-capita consumption*) or Gross Domestic Product (*consumption intensity*). Expressing consumption in 'per unit of another variable'—that is, in relative terms—enables cross-entity comparisons due to the introduction of a common scale (normalisation).

Domestic Material Consumption (DMC): An environmental indicator that covers the flows of products and raw materials alike by accounting for their mass. It can take an 'apparent consumption' perspective—the mathematical sum of domestic production and imports minus exports—without considering changes in stocks. It can also take a 'direct consumption' perspective, in that products for import and export do not account for the inputs—be they raw materials or other products—used in their production (source Sala et al. 2019)¹

Ecological cycle: Also referred to as biological cycle, is the processes - such as composting and anaerobic digestion - that together help to regenerate natural capital. The only materials suitable for these processes are materials of biological origin or bio-based materials, excluding materials embedded in geological formations and/or fossilised (source: Ellen Mac Arthur Foundation Glossary)

Greenhouse gases (GHG) refers to a group of gases contributing to global warming and climate breakdown. The term covers seven greenhouse gases divided into two categories. Converting them to carbon dioxide equivalents (CO₂e) through the application of characterisation factors makes it possible to compare them and to determine their individual and total contributions to Global Warming Potential (see below).²

¹ Sala, S., Benini, L., Beylot, A., Castellani, V., Cerutti, A., Corrado, S., Crenna, E., Diaconu, E., Sanyé-Mengual, E., Secchi, M., Sinkko, T., & Pant, R. (2019) *Consumption and consumer footprint: methodology and results. Indicators and assessment of the environmental impact of EU consumption*. Luxembourg: Publications Office of the European Union, ISBN 978-92-79-97256-0, doi:10.2760/98570, JRC 113607

² Eurostat (2016). Glossary: Greenhouse gas, Eurostat: Statistics explained. Retrieved from: [Eurostat website](https://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&language=en&code=1600000)

Global warming potential (GWP) The heat absorbed by any greenhouse gas in the atmosphere as a multiple of the heat that would be absorbed by the same mass of carbon dioxide (CO₂). The GWP of CO₂ is 1. For other gases, the GWP depends on the gas and the time frame considered (source: IPCC).³

Goods: Physical objects for which a demand exists, over which ownership rights can be established and whose ownership can be transferred from one institutional unit to another by engaging in transactions on markets; they are in demand because they may be used to satisfy the needs or wants of households or the community or used to produce other goods or services (source: SNA).

Material: Substances or compounds are used as inputs to production or manufacturing because of their properties. A material can be defined at different stages of its life cycle: unprocessed (or raw) materials, intermediate materials and finished materials. For example, iron ore is mined and processed into crude iron, which in turn is refined and processed into steel. Each of these can be referred to as materials (source EU Commission).⁴

Material footprint: The attribution of global material extraction to a country's final domestic demand. In this sense, the material footprint represents the virtual total volume of materials (in Raw Material Equivalents) required across the whole supply chain to meet final demand. The material footprint, as referred to in this report, is the sum of the material footprints for biomass, fossil fuels, metal ores and non-metallic minerals (source: UNSD).⁵

Material flows: The amounts of materials in physical weight that are available to an economy. These material flows comprise the extraction of materials within the economy as well as the physical imports and exports (*id est*, the mass of goods imported or exported). Air and water are generally excluded (source: Eurostat).⁶

Natural resources: include land, water, air and materials. They are seen as parts of the natural world that can be used for economic activities that produce goods and services. Material resources are biomass (like crops for food, energy and bio-based materials, as well as wood for energy and industrial uses), fossil fuels (in particular coal, gas and oil for energy), metals (such as iron, aluminium and copper used in construction and electronics manufacturing) and non-metallic minerals (used for construction, notably sand, gravel and limestone) (source: UNEP).⁷

Primary raw materials: Also known as virgin materials, are basic natural materials that are extracted from the ground or harvested and processed into new materials or products. For example, bauxite is the raw material that is processed into aluminium, petroleum for plastics manufacture, iron ore for steel manufacture and wood pulp for paper manufacture. Conversely, non-virgin materials, also referred to as "secondary materials" would include materials in products that have been reused, refurbished or repaired; components that have been remanufactured; materials that have been recycled (source: SEEA-CF).

Products: Goods and services exchanged and used for various purposes, as inputs in the production of other goods and services, as final consumption, or for investment. *Semi-finished products* are products that have undergone some processing but require further processing before they are ready for use. They may be sold to other manufacturers or transferred to sub-contractors for further

³ Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S. L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M. I., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J. B. R., Maycock, T. K., Waterfield, T., Yelekçi, O., Yu, R., & Zhou, B. (eds.). (2021) *Climate change 2021: The physical science basis. Contribution of working group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press (In Press), Retrieved from: [IPCC website](#)

⁴ European Commission. (n.d.). EU Science Hub, Raw Materials Information System (RMIS). Retrieved from: [RMIS website](#)

⁵ United Nations Statistics Division. (2022). SDG Indicator Metadata. Retrieved from: [UN statistics website](#)

⁶ Eurostat, Statistics explained. (2017) Glossary: Material flow indicators. Retrieved from: [Eurostat website](#)

⁷ UN Environment Programme. (n.d.). Glossary. Retrieved from: [Resource Panel Glossary](#)

processing. Typical examples would include rough metal castings sold or transferred for finishing elsewhere (NACE Rev. 2). *Finished products or goods* consist of goods produced as outputs that their producer does not intend to process further before supplying them to other institutional units. A good is finished when its producer has completed their intended production process, even though it may subsequently be used as an intermediate input into other processes of production.

Raw materials: Natural resources which are converted into useful primary materials. Examples are ores (for metals), minerals (e.g. chalk, gravel, sand, stones), air and water, but also oil, natural gas, coal and biomass if they are used as matter (e.g. construction materials, lubricants). A distinction can be made between ‘primary raw materials’ and ‘secondary raw materials (source: OECD MFA Guide)

Raw Material Equivalent (RME) A virtual unit that measures how much of a material was extracted from the environment, domestically or abroad, to produce the product for final use. Imports and exports in RME are usually much higher than their corresponding physical weight, especially for finished and semi-finished products. For example, traded goods are converted into their RME to obtain a more comprehensive picture of the ‘material footprints’; the amounts of raw materials required to provide the respective traded goods (source: Eurostat).⁸

Raw Material Consumption (RMC) The final domestic use of products in terms of RME. RMC, referred to in this report as the ‘material footprint’, captures the total amount of raw materials required to produce the goods used by the economy. In other words, the material extraction necessary to enable the final use of products (source: Eurostat).⁹

Recovery: Any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy. It’s a subcategory of “waste management” (source: EU Waste Framework Directive).

Recycling: Any activity by which materials are recovered from a waste stream for the purpose of providing material inputs for use in another production process (other than processes designed for energy recovery, the reprocessing into fuels or material for backfilling) (source: EU Waste Framework Directive).

Residuals: Flows of solid, liquid and gaseous materials, and energy that are discarded, discharged or emitted by establishments and households through processes of production, consumption or accumulation. The term “waste” can be understood as referring to any kind of residuals (source: SEEA-CF).

Reuse: Any operation by which products or components that are not waste are used again for the same purpose for which they were conceived. Reusable products are used and end-of-life goods (including second-hand goods) diverted from the waste stream for re-use, remanufacturing, repair or trade (e.g. electrical and electronic equipment or its components that can be used for the same purpose for which they were conceived). Reusable products can be diverted from the waste stream after waste collection (thus ceasing to be waste), or before the products become waste (source: EU Waste Framework Directive).

Secondary materials: Materials that have been previously used and have been recovered or prepared for reuse. This includes materials in products that have been reused, refurbished, or repaired; components that have been remanufactured; and materials that have been recycled. Synonym of “non-virgin materials” (source: Based on Ellen MacArthur Foundation and IRP).

⁸ Eurostat, Statistics explained. (2017) Glossary: Material flow indicators. Retrieved from: [Eurostat website](#)

⁹ Eurostat. (2022) Handbook for estimating raw material equivalents. Retrieved from: [Handbook-country-RME-tool \(europa.eu\)](#)

Secondary raw materials: Materials recovered from recycling. This is a subcategory of “secondary material”¹⁰. The EU Extractive Waste Directive (2006/21/EC) and the legal definitions of waste and waste management hierarchy regulated by the EU Waste Framework Directive (2008/98/EC) do not distinguish between “secondary material” and “secondary raw materials” (source: CES Waste Statistics Framework).

Sector: Any collective of economic actors involved in creating, delivering and capturing value for consumers, tied to their respective economic activity. We apply different levels of aggregation aligned with the classifications used in Exiobase V3. These relate closely to the European sector classification framework NACE Rev. 2.

Socio-economic metabolism (SEM): The self-reproduction and evolution of the biophysical structures of human society. It comprises the biophysical transformation processes, distribution processes and flows, that are controlled by humans for their purposes. Together, the biophysical structures of society ('in use stocks') and Socio-economic metabolism form the biophysical basis of society (source Pauliuk et al 2015).¹⁰

Stressor: In Input-Output Analysis, is defined as the environmental impact occurring within the region that is the subject of the analysis. There is, therefore, an overlap between the stressor and the footprint, as they both include the share of impact occurring within the region as a result of domestic consumption. Conversely, while the rest of the stressor is made of impacts occurring within the region as a result of consumption abroad (embodied in exports), the footprint includes impacts occurring abroad as a result of domestic consumption (embodied in imports).

Technical cycle: The processes that products and materials flow through in order to maintain their highest possible value at all times. Materials suitable for these processes are those that are not consumed during use - such as metals, plastics and wood (source: Ellen MacArthur Foundation Glossary). Material belonging to the technical cycle (technical materials) are non-bio-based materials stemming from non-renewable natural assets (see ecological cycle). In a circular economy their value is maintained by re-using (and repair of) products made from technical materials or material recycling.

Waste: Any material which the holder discards or intends or is required to discard. The term waste is understood to encompass all types of residuals (source: CES Waste Statistics Framework).

Waste collection: The gathering of waste, including the preliminary sorting and preliminary storage of waste for the purposes of transport (source: EU Waste Framework Directive and CES Waste Statistics Framework)

Waste disposal: Any operation which main purpose is not the recovery of materials or energy even if the operation has as a secondary consequence the reclamation of substances or energy. It includes incineration without energy recovery, deposit into or onto land (e.g. landfilling), deep injection, surface impoundment, release into water bodies and permanent storage (source: CES Waste Statistics Framework).

Waste management: Set of lawful activities carried out by economic units of the formal sector, both public and private for the purpose of the collection, transportation, and treatment of waste, including final disposal and after-care of disposal sites. It refers to legal activities carried out by economic units of the formal sector (source: CES Waste Statistics Framework).

¹⁰ Pauliuk, S., & Hertwich, E. G. (2015). *Socio-economic metabolism as paradigm for studying the biophysical basis of human societies*. Ecological Economics, 119, 83-93. doi:10.1016/j.ecolecon.2015.08.012

Waste prevention: Measures taken before a substance, material or product has become waste, that reduce (a) the quantity of waste, including through the re-use of products or the extension of the life span of products; (b) the adverse impacts of the generated waste on the environment and human health; or (c) the content of harmful substances in materials and products. To be understood as prevention of any kind of residuals, also including emissions to air and to water (source: EU Waste Framework Directive and CES Waste Statistics Framework).

Waste treatment: Recovery or disposal operations, including preparation prior to recovery or disposal. It's a subcategory of «waste management» (source: EU Waste Framework Directive).

Introduction

This document outlines the general methodology used in national *Circularity Gap Reports*, accompanied by Technical Annexes that offer additional insights into the research process. For a comprehensive understanding, this document should be read in conjunction with the Project Annexes.

To clarify terminology and abbreviations used in this methodology pack, please consult the Glossary and List of acronyms and abbreviations.

1. Research aims

Circularity Gap Reports aim to:

1. Identify how materials flow through and accumulate in the economy, providing an understanding of the Socioeconomic metabolism (SEM) of an economy and identifying hotspots to advance the circular economy;
2. Provide a snapshot of how circular a country is by implementing the Circularity Indicator Set (CIS), a systemic approach of indicators to monitor progress towards the circular economy, including the level of Circular Jobs;
3. Spotlight possible interventions within significant sectors and value chains that can drive the transition to circularity and reduce their material and carbon footprints;
4. Provide evidence-based recommendations and spotlight avenues for decision-makers within government and business to drive the circular economy transition and revamp production and consumption patterns.

2. Research approach

Circularity Gap Reports use a mixed research approach and integrate quantitative and qualitative research methods drawing from the *industrial ecology toolkit* to establish baseline circularity and model the effects of a set of circular strategies on the baseline circularity and carbon footprint.

We use two main methods to map how material resources are extracted, transformed and consumed: 1) Economy-Wide Material Flow Accounting (EW-MFA) and 2) Environmentally Extended Multi-Regional Input-Output Analysis (EE-MRIOA). These two tools help understand how material resources are extracted, used, and disposed of within an economy, as well as the GHG emissions, among other environmental impacts, associated with these processes. They are the foundations for the establishment of the Circularity Indicator Set (CIS).

Figure one presents a schematic depiction of the relationships between these methods and their outputs. A brief description of each is provided below in Box 1.1 and Box 1.2, respectively. See Annex A for more information on these approaches.

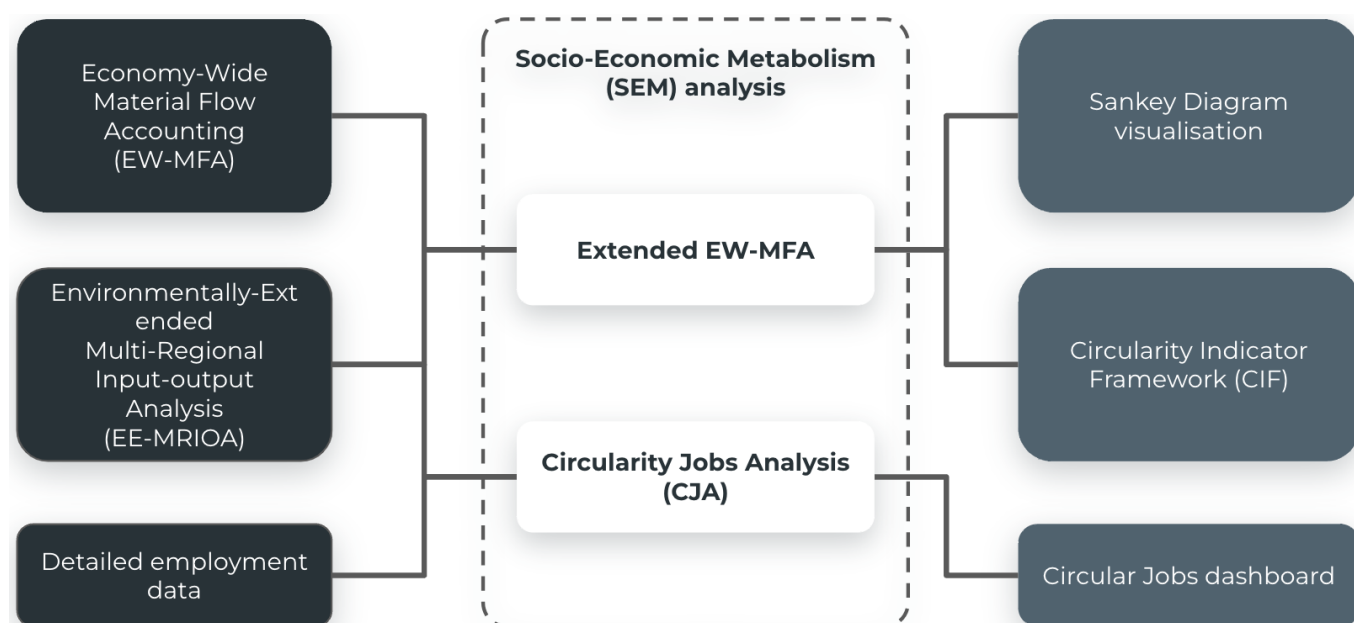


Figure one. Relationship between methods used and their outputs.

Data for this study was gathered through a combination of desktop research collaboration with project partners and consultation with coalition members. For a list of project-specific data sources, see the Project Annex. General data sources underlying Circle Economy's models are referenced throughout this document and its Annexes.

To ensure the robustness and comprehensiveness of the research findings, expert interviews, surveys and workshops were conducted with relevant stakeholder groups. These methods served to validate the data, refine the quantitative findings, and address any knowledge gaps identified during the research process. A summary of the stakeholders consulted can be found in the Project Annex.

Box one: Economy-wide material flow analysis (EW-MFA)

EW-MFA is a tool that quantifies physical material and energy flows and stocks in a system defined in a specific space and time.¹¹ In its traditional and highly standardised form, EW-MFA represents a robust framework for the compilation of direct material flow data sets that focus on primary material extraction, physical trade (that is, imports and exports), waste and emissions. The direct accounts treat the national economy as a black box and exclude upstream and downstream material flows associated with trade (that is, indirect flows) as well as recycling or reuse flows within the economy and mobilisation of materials that do not enter the economic process. EW-MFA results are also commonly presented as a set of six headline indicators, such as Domestic Material Consumption (DMC) and Domestic Material Input (DMI), that measure the resource burden for the economy (see Annex A of the Technical Annex document).

EW-MFA indicators can be compared to other ones related to the economy, as well as to each other. For example, resource productivity is a measure of the total amount of materials an economy uses in relation to Gross Domestic Product (GDP). Trends in resource productivity can be shown once EW-MFA indicators have been established. If material consumption reduces compared to GDP, this is known as decoupling. Decoupling may indicate the possibility

¹¹ These material flows exclude bulk water and air. The scale of water use is so significant that including its mass in MFAs obscures other resource use. For this reason, standard MFA practice only includes water mass contained in products e.g. agricultural produce and imported beverages. Water for other consumptive uses (cleaning or irrigation) and in situ uses (such as hydroelectric power), sometimes known as bulk water in MFAs, will be excluded from these accounts. It is important to highlight that while MFA typically emphasises material resources over water, it can also be effectively employed to analyse water resources.

Box two: Environmentally-Extended Multi-Regional Input-Output Analysis (EE-MRIOA)

Environmental Indicators

There are generally three types of methods used to calculate footprint indicators, including the RMC or material footprint :¹² (1) top-down approaches that start from the macroeconomic level and focus on national or regional economic structures and material extraction, (2) bottom-up approaches that use specific coefficients that represent the material input required per unit of product, and (3) hybrid approaches combining both top-down and bottom-up approaches.

Top-down approaches build on input-output analysis (IOA), which focuses on the economic structure of a country in the form of matrices that depict inter-industry flows, final consumption categories and factor inputs, known as Input-Output Tables (IOTs). Each column of an IOT can be interpreted as an inventory of production inputs. The environmental data on material use linked as environmental extensions (EE) to an IO table can be considered an inventory of environmental inputs such as raw materials, GHG emissions or employment.

¹² Lutter, S., Giljum, S., & Bruckner, M. (2016). A review and comparative assessment of existing approaches to calculate material footprints. *Ecological Economics*, 127, 1-10.

In general, two main types are distinguished: single-region and multi-regional input-output (MRIO) models. Single-region IO models assume that imported products are produced with the same technology as domestic products. In MRIO models, country IOTs are linked via bilateral trade data, which means they consider different technologies applied in each country. MRIO analysis allows product value chains and related environmental flows to be tracked along the various life cycle stages of all products and services, from material extraction to final demand, considering specific material intensities across countries.

As such, EE-MRIOA represents a macroeconomic tool with a number of advantages for the calculations of indirect flows: (1) it allows for the calculation of a broad range of footprints (such as material, emissions, employment) for all products and industries, including those with very complex global supply chains and (2) by following a top-down approach, MRIOA avoids double counting, and as a result, the global system is always consistent. Key disadvantages are: (1) the limited number of commodities and regions distinguished, which is determined by the sectoral or industrial and regional disaggregation of an IO model and (2) the assumption of homogenous environmental characteristics of all products within a product group.

An MRIO approach complements traditional territorial and production-based perspectives by looking at direct environmental flows (or direct material flows) with a consumption-based and life-cycle perspective. This enables practitioners to understand these activities in terms of impacts along and across global supply chains, including indirect environmental flows (that is, the RME of material flows).

For their headline indicators, *Circularity Gap Reports* employ a consumption-based and life-cycle approach, which ensures that environmental impacts are allocated to economies that drive production through consumption. In other words, it considers the environmental impact caused by the demand for products and services in a particular area, regardless of where those goods are produced and including indirect flows associated with them (See Annex A of the Technical Annex document for more information on the *CGR EE-MRIO model*).

Employment Indicators

Labour is also considered an input into the economy. As such, we can use labour satellite accounts in the input-output system to determine employment intensity factors (employment or economic output) per sector.

The level of sector granularity in the IO tables may not be sufficient to expose circular sectors. We utilise granular employment data to split out the national tables, and employment intensity factors are computed. In the Circular Jobs Analysis, estimates are made for the proportion of final demand, and consequent circular economic output is determined. This is used to determine the new circular employment intensities, which are applied back to total employment.

For more information on how sectors' circular activities are mapped, refer to Mapping Table five of the Project Annex. For more information on how circular activities and final demand are determined, see Section 4.2 of this methodology document.

3. Scope of circularity

3.1 Material perspective

To measure material circularity, we look at how economies use resources, focusing on the flow of materials through an economy—versus how they are used long-term—as a starting point. This approach, known as an extended Economy-Wide Material Flow Analysis (EW-MFA), studies the flows and stocks of materials and

energy through a society's economic system. This method builds on and is inspired by the work of leading academics in the field.^{13,14}

Our research takes a broad perspective on material circularity. Instead of focusing on a single metric (such as recycling), we have developed a monitoring system— CIS — that provides an overview of all inputs and outputs within an economy. The CIS broadly categorises these into circular inputs, linear inputs, and stock build-up.

To complement this overview of circularity, we summarise other aspects of SEM through the compilation of sectoral material and carbon footprint breakdowns, visualised by a Sankey diagram. This diagram illustrates the flow of embodied materials through the economy, tracing their journey from the source (national or imported) to provisioning systems and ultimately to their end-of-life handling or export (see Annex D in the Technical Annex document)

This material-focused perspective, together with the Circular Strategies (see Section 3.3), aligns with the 'Material life-cycle and values chain' building block of the UNECE/OECD conceptual framework¹⁵. This component reflects key features and major outcomes of the circular economy, considering the material basis and productivity of the economy, the efficiency of materials and waste management, the circularity of material flows, and the interactions with trade and globalisation (for more information on the relationship between the Circularity Gap Report and other circularity frameworks see Annex B of the Technical Annex document).

3.2 Socio-economic perspective

The transition to circularity will be driven by work and workers and must be just. While global material extraction and consumption can spur development, the benefits have yet to be distributed equally, leading to the exploitation of land, people and communities worldwide. The circular economy can offer a solution by fulfilling society's needs with less whilst reducing planetary impacts.

Our study considers circular jobs—that is, the share of the current workforce contributing to the circular economy—as an entry point to a broader socio-economic perspective. By first establishing the current sectors and workers that are employed in the circular economy, we can identify opportunities to boost circularity by creating more circular jobs in key sectors. We can begin to analyse and understand the quality and conditions of circular work versus work in the linear economy to ensure decent work in the circular economy.

This socioeconomic perspective, along with the Circular Strategies (see Section 3.3), aligns with the 'Socio-economic opportunities and Economic efficiency and social equity' building blocks of the UNECE/OECD conceptual framework.¹⁶ This framework focuses on creating socio-economic opportunities for

¹³ Pauliuk, S., & Hertwich, E. G. (2015). Socio-economic metabolism as paradigm for studying the biophysical basis of human societies. *Ecological economics*, 119, 83-93.

¹⁴ Haas, W., Krausmann, F., Wiedenhofer, D. & Heinz, M. (2015). How circular is the global economy? An assessment of material flows, waste production, and recycling in the European Union and the world in 2005. *Journal of Industrial Ecology*, 19(5), 765–777. doi:10.1111/jiec.12244

¹⁵ Guidelines for Measuring Circular Economy - Part A: Conceptual Framework, Indicators and Measurement Framework, ECE/CES/STAT/2023/5, UNECE/OECD

¹⁶ Guidelines for Measuring Circular Economy - Part A: Conceptual Framework, Indicators and Measurement Framework, ECE/CES/STAT/2023/5, UNECE/OECD

a just transition and structures CE indicators around four themes: (i) market developments and new business models; (ii) trade developments; (iii) skills, awareness and behaviour; and (iv) inclusiveness of the transition. Specifically, the Circular Jobs Analysis aligns with (i) market developments and new business models—measured by jobs in CE sectors and the gross value added (GVA) of CE sectors—as well as with (iv) inclusiveness of the transition, which address the distributional aspects of CE policies.

3.3 Circular strategies

There are several conceptual frameworks which aim to classify the circular economy based on its core activities, such as lowering resource use, extending the lifespan of resources, and recycling materials. These frameworks include the 10R framework,¹⁷ the Key Elements Framework,¹⁸ the Bocken et al. (2016) model,¹⁹ and the approaches developed by Ellen MacArthur²⁰ and Aguilar-Hernandez et al. (2018).²¹

Table one. *Strategies compared across selected circular economy frameworks.*

10R framework	Key Elements Framework (Core Elements)	Bocken et al. (2016)	Ellen MacArthur Foundation	Aguilar-Hernandez et al. (2018)
	Prioritise regenerative resources	Regenerate flows	Regenerate ecosystems	
Refuse		Narrow flows	Design out waste	Resource Efficiency (RE)
Reduce				
Rethink				
Reuse	Stretch the lifetime	Close flows (use phase) Slow flows (design phase)	Keep products in use for longer	Closing Supply Chains (CSC) Product Lifetime Extension (PLE)
Repair (and maintenance)				
Refurbish				
Remanufacture				
Repurpose				
Recycle	Use waste as a resource		Design out waste	Residual Waste Management (RWM)
Recover				

We base our circular strategy framework on the work of Bocken et al. (2016) and Aguilar-Hernandez et al. (2018). For communication purposes, the more immediate and accessible terminology created by Bocken and colleagues is used, whereas for modelling purposes, the more technical terminology adopted by

¹⁷ Potting, J., Hekkert, M. P., Worrell, E., & Hanemaaijer, A. (2017). Circular economy: measuring innovation in the product chain (No. 2544). PBL Publishers. Retrieved from: PBL website

¹⁸ Circle Economy. (2021). The key elements of the circular economy. Retrieved from: [Circle Economy website](https://www.circleeconomy.com/en/what-is-circular-economy/)

¹⁹ Bocken, N., de Pauw, I., Bakker, C. & van der Grinten, B. (2016). Product design and business model strategies for a circular economy. *Journal of Industrial and Production Engineering* 33(5), 308-320. doi:10.1080/21681015.2016.1172124

²⁰ Ellen MacArthur Foundation. (n.d.). What is a circular economy? Retrieved from: [Ellen MacArthur Foundation website](https://www.ellenmacarthurfoundation.org/what-is-a-circular-economy/)

²¹ Aguilar-Hernandez, G.A., Sigüenza-Sanchez, C.P., Donati, F. Rodrigues, J. & Tukker, A. (2018). Assessing circularity interventions: a review of EEIOA-based studies. *Economic Structures*, 7. 14. doi.org/10.1186/s40008-018-0113-3

Aguilar-Hernandez et al. (2018) is employed. As shown in the table above, the two frameworks are largely overlapping (see Section 4.3):

- **Narrow flows—Use less:** The amount of materials (including fossil fuels) used in the making of a product or in the delivery of a service are decreased. This is done through circular design, greater *resource efficiency (RE)* or increasing the usage rates of materials and products. In practice: Sharing and rental models, material lightweighting (mass reduction), multifunctional products or buildings, energy efficiency, digitisation.
- **Slow flows—Use longer:** Resource use is optimised as the *functional lifetime of products is extended (PLE)*. Durable design, materials and service loops that extend life, such as repair and remanufacturing, both contribute to slowing rates of extraction and use. In practice: Design for longevity, modular design and design for disassembly, design for recyclability (both technical and biological).
- **Regenerate flows—Make clean:** Fossil fuels, pollutants and toxic materials are replaced with regenerative alternatives, thereby increasing and maintaining value in natural ecosystems. In practice: Regenerative and non-toxic material use, renewable energy, regenerative agriculture and aquaculture.
- **Cycle flows—Use again:** The reuse of materials and products at end-of-life is optimised, facilitating *closed-loop supply chains (CLS)*. This is enhanced by the optimal cascading of resources, development of reverse logistics and take-back schemes, as well as improved *residual waste management (RWM)*. In practice: Reuse, repair, remanufacturing, refurbishing, renovation and remodelling over building new structures, recycling.

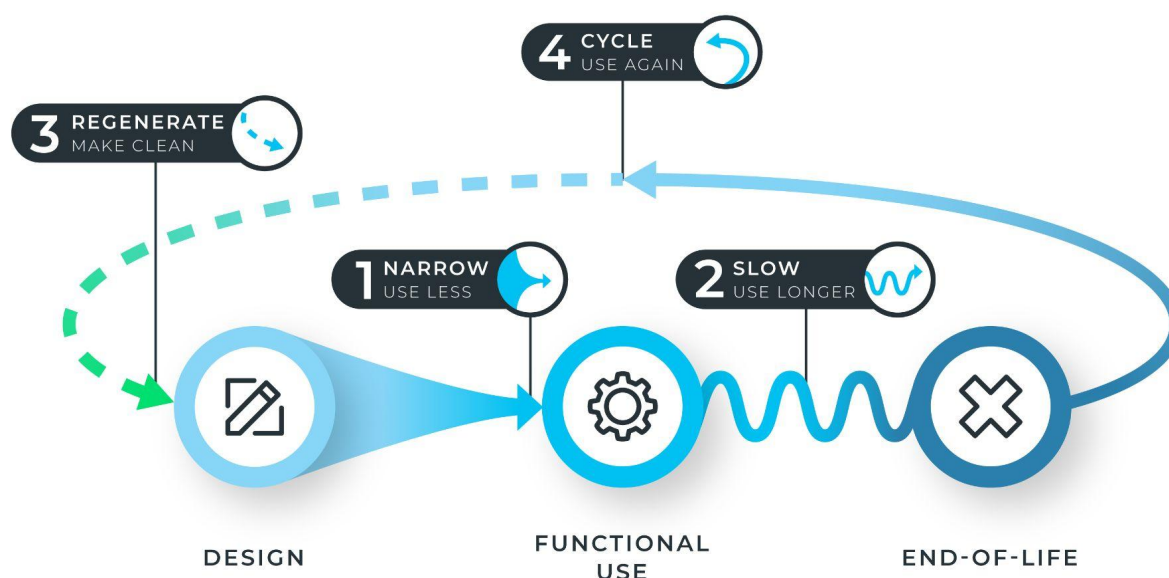


Figure two. Four strategies to achieve circular objectives: narrow, slow, regenerate and cycle.

4. Analyses

4.1 Circularity Indicator Set

The CIS is based on extended EW-MFA principles taken from the work of Mayer et al. (2018)²², Haas et al. (2020)²³ and previous research.^{24 25 26} The underlying measurement framework fully integrates waste flows, recycling and downcycled materials with traditional EW-MFA statistics. In Circle Economy's model, the approach is further extended to include indirect flows (see Annex A of the Technical Annex document for more details).

The Circularity Indicator Set can be compared to and complemented with other indicators from monitoring frameworks on the circular economy such the one developed by ISO/DIS 59020 and UNECE/OECD. For more information on how the Circularity Indicator Set relates to these frameworks, see Annex B.

Due to different statistical definitions and system boundaries between the EW-MFA and waste statistics, coherence and compatibility is lacking, and *harmonisation* is needed when they are to be employed in the same analysis. Moreover, while the extended and traditional EW-MFA frameworks aim to quantify the same headline indicators using largely the same data, they do so using slightly different approaches. This often results in differing results, which require *reconciliation*. The processes of harmonising input data and reconciling output results are, therefore, critical in the development of integrated and comprehensive datasets that are also accurate and robust. For more information about the harmonisation and reconciliation efforts in this study, see Section 1.2 in the Project Annex.

The CIS distinguishes between scale indicators, which provide measures for the overall size of the SEM, and metabolic rates, which measure technical and ecological cycling relative to input and output flows. Providing independent measures for flows on both the input and output sides is necessary and insightful due to the delaying effect that in-use stocks of materials have on output flows. Inputs²⁷ expressed in absolute terms are used to measure the **scale** of circular and non-circular flows and can be distinguished as follows:

- Circular inputs:
 - **Secondary Material Inputs (SMIc):** Accounts for all materials that were formerly waste but are cycled back into use, including recycled materials from both the technical cycle (such as recycled cement and metals) and recycled biological inputs (such as paper and wood). In its metabolic form, it refers to the share of secondary materials out of the total material consumption of an economy.
 - **Renewable Biomass Inputs (RBIc):** Accounts for primary biomass (such as timber, food products or agricultural residues) that is *carbon-neutral*. Because it is carbon neutral, this biomass has the *potential* to be circular—and indeed, part of it is, and therefore *could* be

²² Mayer, A., Haas, W., Wiedenhofer, D., Krausmann, F., Nuss, P., & Blengini, G. A. (2018). Measuring progress towards a circular economy: A monitoring framework for economy-wide material loop closing in the EU28. *Journal of Industrial Ecology*, 23(1), 62–76. doi:10.1111/jiec.12809

²³ Haas, W., Krausmann, F., Wiedenhofer, D., Lauk, C., & Mayer, A. (2020). Spaceship earth's odyssey to a circular economy—a century long perspective. *Resources, Conservation and Recycling*, 163, 105076.

²⁴ Haas, W., Krausmann, F., Wiedenhofer, D., & Heinz, M. (2015). How circular is the global economy?: An assessment of material flows, waste production, and recycling in the European Union and the World in 2005. *Journal of Industrial Ecology*, 19(5), 765–777. doi:10.1111/jiec.12244

²⁵ Kovanda, J. (2014). Incorporation of recycling flows into economy-wide material flow accounting and analysis: A case study for the Czech Republic. *Resources, Conservation and Recycling*, 92, 78–84. doi:10.1016/j.resconrec.2014.08.006

²⁶ Nuss, P., G.A. Blengini, W. Haas, A. Mayer, V. Nita, and D. Pennington. (2017). *Development of a Sankey diagram of material flows in the EU economy based on Eurostat data*. JRC technical reports, EUR 28811 EN. Luxembourg: Publications Office of the European Union.

²⁷ Note: These are to be intended as inputs to final consumption (i.e. excluding exports)

considered under SMIc. However, due to data limitations, it is difficult to guarantee full nutrient cycling—the second criterion for biomass to be considered circular and renewable—allowing ecosystem biocapacity to remain the same.

- Linear inputs:
 - **Non-Renewable Biomass Inputs (NRBIc):** Accounts for primary biomass that is *not carbon neutral* as a minimum—yet not sufficient—criteria for renewability and circularity.
 - **Fossil Fuel Inputs (FFIc):** This category centres on fossil-based energy carriers, such as fuel oil, gasoline, diesel and natural gas, among others. These fuels are burned mainly for energy and, to a lesser extent, to produce chemicals and plastics. As they burn, they release GHG emissions into the atmosphere. These inputs cannot be cycled and are *inherently non-circular*. Here, the circular transition will naturally prevent emissions through actions that aim to directly reduce fossil fuel consumption.
 - **Recyclable Inputs (RIc):** Accounts for materials like metals, plastics, paper and glass found in everyday products. Contrary to SMIc, this category represents *materials that can potentially be cycled but are currently not*, whether within the country or abroad.
- Stock build-up:
 - **Net Additions to Stocks (NAS):** Accounts for the material in products with a lifespan longer than one accounting year that are added to long-term in-use stocks in the form of buildings, infrastructure, machinery, equipment, inventories and so on.

On the other hand, absolute total material use can be measured in the following ways:

- On the input side, **Domestic Material Consumption (DMC)**, also referred to as ‘apparent consumption’, measures all materials directly used in a national production system and is regarded as a proxy for the aggregated pressure the economy exerts on the environment. On the output side, **Domestic Processed Output (DPO)** measures the total amount of solid waste and emissions from a national economy;
- To capture the full amount of materials used in the production of finished products, a life-cycle indicator was included in the form of **Raw Material Consumption (RMC)** or material footprint;²⁸ a measure of global raw material use associated with domestic final consumption. No corresponding indicator on the output side is available at the moment of writing;
- To account for the use of secondary materials (which are usually not included in conventional EW-MFA indicators), the **Processed Materials (PM)** or **Processed Raw Materials (PRM)** are the sum total of DMC (or RMC) and SMIc. Similarly, on the output side, **Interim Outputs (IntOut)** measure End-of-Life (EoL) wastes and emissions before materials for recycling and downcycling are diverted. Even in industrial countries, stocks are growing. IntOut in a given year are thus much smaller than the amount of PM in that year, which inhibits loop closing at present. This produces a delaying effect on the potential recycling of these materials after their lifetime has ended in the future.

Bringing together scale indicators for circular and linear flows with total materials use measured at the input- and output-side, five pairs of metabolic **rate indicators** can be calculated, which measure material flows relative to interim inflows (PM) and outflows (IntOut):

²⁸ Wiedmann, T. O., Schandl, H., Lenzen, M., Moran, D., Suh, S., West, J., & Kanemoto, K. (2013). The material footprint of Nations. *Proceedings of the National Academy of Sciences*, 112(20), 6271–6276. doi:10.1073/pnas.1220362110

1. The Technical Cycling rates measure the contribution of SMIc to PM and PRM (**Input Technical Cycling rate [ITCr]**) and the share of IntOut that is diverted to be used as secondary materials (**Output Technical Cycling rate [OTCr]**). Recycled waste from material processing and manufacturing (such as recycled steel scrap from autobody manufacturing) is considered an industry internal flow and is not accounted for as a secondary material. In this model of the physical economy, secondary materials originate from discarded material stocks only. The outflows from the dissipative use of materials and combusted materials (energy use) can, by definition, not be recycled. This assumption may lead to a minor underestimation of downcycled materials when solid wastes from the combustion of fossil materials are used in construction. Energy recovery (electricity, district heat) from the incineration of fossil or biomass waste is not considered recycling since it does not generate secondary materials.
2. For biomass, derived circularity indicators are more intricate. Due to the absence of a clear definition and recognised criteria for renewable biomass, as well as a lack of related data, we use the share of RBlc (that is., renewable biomass in DMC/RMC) in PM/PRM for the **Input Ecological Cycling rate potential (IECrp)** and the share of RBO (that is, renewable biomass in DPO) in IntOut for the **Output Ecological Cycling rate potential (OECrp)**. Because ecological cycling is a crucial part of CE strategies, data and adequate indicators must be developed so that technical and ecological cycling rates indicate the overall circularity of an economy. So far, neither robust criteria nor comprehensive indicators are available to identify the fraction of biomass production which qualifies for sustainable ecological cycling. As a first approximation for renewable biomass, we only consider carbon-neutral biomass. We interpret this as a minimum requirement, while more comprehensive assessments should be developed. It can, therefore, be stated that the IECrp relates to the circularity of terrestrial carbon stocks. Conversely, the **Input Non-Renewable Biomass (INRBr)** and **Output Non-Renewable Biomass rate (ONRBr)** measure the share of NRBlc in PM/PRM and IntOut, respectively.
3. The **Input Non-Circular rate (INCr)** and **Output Non-Circular rate (ONCr)** measure the share of FFlc (that is, the energy use of fossil energy carriers) in PM/PRM and IntOut, respectively, thus quantifying the share of material flows that do not qualify for technical and ecological loop closing. Due to unreliable information on dissipation rates of fertilisers or salt for de-icing roads, for example, we did not allocate these materials to non-circularity flows.
4. The **Net Stocking rate (NSr)** measures the (NAS) that are not available for cycling during the current accounting period as a share of PM/PMR. It is only used as an input-side indicator.
5. The difference between 100% and the sum total of the four metabolic rates serves as a measure of the unexploited potential for technical cycling and represents the input and output of non-renewable materials available for cycling, namely the **Input Non-Renewable rate (INRr)** and **Output Non-Renewable rate (ONRr)**.
6. Finally, any difference between RMC and DMC is referred to as net extraction abroad (NEA), and it is considered a bridging item rather than an actual indicator (see Annex A for more detail on the meaning and purpose of net extraction abroad).

Table two. Overview of the system of indicators for monitoring economy-wide loop closing.

	Dimension	Input-side Indicator	Output-side Indicator
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		Direct	Life-cycle	Direct	Life-cycle
Scale indicators (t)	In- and output flows	Domestic material consumption (DMC)	Raw material consumption (RMC)	Domestic Processed Output (DPO)	n.a.
	Interim flows	Processed Materials (PM) = DMC + SMIc	Processed Raw Materials (PRM) = RMC + SMIc	Interim Outputs (IntOut) = EoL waste + DPO emissions	n.a.
Metabolic rates (%)	Technical Cycling (TC)	Input Technical Cycling rate (ITCr) = Share of SMIc in PM	Input Technical Cycling rate (ITCr) = Share of SMIc in PRM	Output Technical cycling rate (OTCr) = Share of SMIc in IntOut	n.a.
	Ecological cycling potential (ECp)	Input Ecological Cycling rate potential (IECrp) = Share of DMC of primary renewable biomass in PM	Input Ecological Cycling rate potential (OECrp) = Share of DMC of primary renewable biomass in PRM	Output ecological cycling rate potential (OECrp) = Share of DPO renewable biomass in IntOut	n.a.
	Non-Renewable Biomass (NRB)	Input Non-Renewable Biomass rate (INRBr) = Share of DMC of primary non-renewable biomass in PM	Input Non-Renewable Biomass rate (INRBr) = Share of DMC of primary non-renewable biomass in PRM	Output Non-Renewable Biomass rate (ONRBr) = Share of DPO non-renewable biomass in IntOut	n.a.
	Non-Circularity (NC)	Input non-circularity rate (INCr) = Share of eUse of fossil energy carriers in PM	Input non-circularity rate (INCr) = Share of eUse of fossil energy carriers in PRM	Output non-circularity rate (ONCr) = Share of eUse of fossil energy carriers in IntOut	n.a.
	Net additions to stocks (NAS)	Net stocking rate (NSr) = Share of NAS in PM	Net stocking rate (NSr) = Share of NAS in PRM	n.a.	n.a.
	Net Extraction Abroad (NEA)	n.a.	Net extraction abroad rate (NEAr) = share of NEA in PRM (where NEA = RMC - DMC)	n.a.	Outputs from Net extraction abroad rate (NEAr) = share of NEA in PRM (where NEA = RMC - DMC)
	Non-renewability (NR)	Input Non-Renewable rate (INRr) = 100 - (ITCr + IECrp + INRBr + INCr + NSr)	Input Non-Renewable rate (INRr) = 100 - (ITCr + IECrp + INRBr + INCr + NSr + NEAr)	Output Non-Renewable rate (ONRr) = 100 - (OTCr + OECrp + ONRBr + ONCr)	Output Non-Renewable rate (ONRr) = 100 - (OTCr + OECrp + ONRBr + ONCr + NEAr)

*Mass-based circular economy indicators include two types of measurements: scale indicators, which measure the absolute size of input and output flows in tonnes, and metabolic rates, which measure the cycling and linearity of these flows as a percentage relative to input and output. (n.a. = not applicable). For more information on the variables used to

calculate these indicators, refer to Annex A. Note that not all indicators listed in the table may be included in the final report.

It should be noted that for simplicity, so far, we have considered the net trade balance of secondary materials as part of SMIC despite these flows being explicitly quantified and treated in Circle Economy's EW-MFA model. The estimation of imported and exported secondary materials is based on the methodology developed by Eurostat and used in calculating the CMUr (see Boxes three and four).²⁹

Box three: Computations behind Input Technical Cycling rate (ITCr)

Let's consider *ITCr* — the share of secondary materials in PRM — and re-write it in mathematical terms:

$$ITCr = SMIC/PRM$$

Where:

$$PRM = RMC + SMIC$$

$$SMIC = RCV_R_B_{cons} + BP_{cons} + RP_{cons}$$

A higher ITCr rate value means that more secondary materials substitute for primary raw materials thus reducing the environmental impacts of extracting primary material. The numerator and denominator of the equation above can be measured in different ways depending on considerations of analysis and data sources.

In principle, this indicator can measure either 1) a country's capacity to produce and consume secondary raw materials and 2) its effort to collect waste for recovery. In a closed economy, with no imports or exports, both are one and the same. However, in reality, countries are open economies with flows of imports and exports of waste collected in one country but treated and used in another. **In that case, the production and consumption (of secondary raw materials) and collection effort (of waste for recycling) in one country may not be one and the same. Therefore the ITCr rate must focus on one or the other.** This is a design choice. The ITCr rate indicator may come with a different specification, depending on the approach sought.

In this respect, it was decided that the ITCr rate measures a country's effort to deploy secondary materials. This perspective credits the country's effort to produce and consume secondary material from recycled waste instead of gathering waste bound for recovery. Producing and consuming secondary materials more directly contributes to the worldwide supply of secondary materials and hence avoids primary material extractions.

Aligned with the definition adopted by the UNECE and OECD³⁰, **secondary materials** are defined as "*Materials that have been previously used and have been recovered or prepared for reuse. This includes materials in products that have been reused, refurbished, or repaired; components that have been remanufactured; by-products; and materials that have been recycled (also referred to as secondary raw materials)*".

The ITCr rate indicator is based as much as possible on official statistics. In the EU context, these are compiled by Member States and reported to Eurostat under legal obligations:

- **Waste statistics:** Regulation (EC) No2150/2002 on waste statistics (WStatR) is a framework for harmonised Community statistics in this domain. The WStatR requires EU Member States to provide data on the

²⁹ Eurostat. (2018). *Circular material use rate: calculation method*. Eurostat manuals and guidelines. Luxembourg: Publications Office of the European Union, 2018. Retrieved from: [Eurostat website](https://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&language=en&code=sdg12.2.1)

³⁰ Conference of European Statisticians Guidelines for Measuring Circular Economy- Part A: Conceptual Framework, Indicators and Measurement Framework ECE/CES/STAT/2023/5, UNECE/OECD, 2023

generation, recovery and disposal of waste every second year. Data set on waste treatment (env_wastrt) are used (or compiled based on such regulation) for the calculation of ITCr rate;

- **Economy-wide material flow accounts:** As already mentioned, EW-MFA describes the interaction of the domestic economy with the natural environment and the rest of the world economy in terms of flows of materials (excluding water and air). EW-MFA is a statistical framework conceptually embedded in environmental-economic accounts and fully compatible with concepts, principles, and classifications of national accounts — thus enabling a wide range of integrated analyses of environmental, energy and economic issues e.g. through environmental-economic modelling. The collection of EW-MFA data is based on Regulation (EU) 691/2011, and the dataset used (or compiled) is (or is based on) the env_ac_mfa data set;
- **International trade in goods statistics (ITGS)** measures the value and quantity of goods traded between countries. 'Goods' means all movable property, including electricity. ITGS are the official harmonised source of information about the EU's exports, imports and trade balances. Data is extracted from the COMEXT website for European member states, while data is extracted from the BACI database for non-European member states. The main classifications for ITGS are the Combined Nomenclature (CN) and Harmonised System (HS).

The ITCr can then be approximated by three components: the amount of waste recycled in domestic recovery plants, indirectly or directly substituting raw materials (*W_RCV*), by-products (*BP*) and reused products (*RP*). However, all these types of secondary materials can also be corrected by imports and exports. These two aspects are developed below.

Amount of domestic secondary materials

The **first component of ITCr** - *W_RCV* - is measured from waste statistics and includes residual material legally declared as waste which is recovered and, after treatment, fed back to the economy (material flowing through the legally demarcated waste management system). It represents the amount of materials recycled in domestic plants.

While waste statistics measures the input of waste into recovery operations and not the amount of secondary raw materials that result from these operations; an analysis by Eurostat concluded that the input to recovery plants is an acceptable proxy for the output from recovery plants. However, it should be noted that this assumes that the sorting and processing losses during recycling operations are negligible. Based on the treatment operations defined in the Waste Framework Directive 75/442/EEC, a distinction is made in treatment types, namely:

- Recovery – energy recovery (RCV_E). Operation R1 corresponds with the treated amount of waste used principally as fuel or other means to generate energy.
- Recovery – recycling and backfilling (RCV_R_B). RCV_R_B breaks down into RCV_R (Recovery – recycling) and RCV_B (Recovery – backfilling). RCV_R is the waste recycled in domestic recovery plants, and it comprises the recovery operations R2 to R11 – as defined in the Waste Framework Directive 75/442/EEC.

For the ITCr rate indicator, it is concluded that the best option is to include recycling and backfilling (code: RCV_R_B), (i.e., excluding energy recovery). While backfilling often involves low-value recycling applications and can arguably be considered as a circular flow, it should be noted that the exclusion of waste from UDE (most notably W126 Soils and W127 dredging spoils) prevents low-value backfilling from overly weighting on the ITCr as almost the totality of it relates to W121 mineral waste from construction and demolition.

The **second component of ITCr** - *BP* - includes residual material outside the legal waste coverage (outside the waste management system), generated e.g. as an incidental or secondary product during certain production processes and fed back into the economy. This category can further be distinguished into:

- Residual material subject to economic transactions between establishments;

- Intra-establishment flows

As specified by the UNECE and OECD, in the context of measuring a circular economy by-products refer to substances or objects resulting from a production process, the primary aim of which is not the production of that item. In this case, a substance or object may be regarded as being a by-product only if it is produced as an integral part of a production process, its further use is certain and lawful, and it can be used directly without any further processing other than normal industrial practice. By-products are not waste and therefore not covered by conventional waste statistics.

The **third component of ITCr - RP** - includes re-used/re-usable products which are used and end-of-life goods (including second-hand goods) diverted from the waste stream for re-use, remanufacturing, repair or trade (e.g. electrical and electronic equipment or its components that can be used for the same purpose for which they were conceived). Reused/re-usable products are not waste and therefore not covered by conventional waste statistics.

Adjusting circular use of material for trade balance

ITCr focuses on representing a country's effort to produce and consume secondary materials, including waste collected in another country and later imported for domestic deployment. Consequently, the total amount of secondary materials is adjusted as follows:

$$RCV_R_B_{cons} = RCV_R_B_{dom} + RCV_R_B_{imp} - RCV_R_B_{exp}$$

$$BP_{cons} = BP_{dom} + BP_{imp} - BP_{exp}$$

$$RP_{cons} = RP_{dom} + RP_{imp} - RP_{exp}$$

with:

X_{imp} : amount of imported waste bound for recovery, by-products or reused products and

X_{exp} : amount of exported waste bound for recovery, by-products or reused products

$RCV_R_B_{cons}$ equals the amount of waste recycled in domestic recovery plants, plus imported waste destined for recovery, minus exported waste destined for recovery abroad. When adjusting the amounts of recycled waste in treatment operations by imports and exports of secondary material, the country which uses the secondary material (recovered from former waste) gets the 'credit' for contributing to the worldwide saving of primary raw materials. This perspective is closer to the national accounts' logic in which most re-attributions are directed towards final use.

To calculate the amounts of imported waste and by-products ($RCV_R_B_{imp}$, BP_{imp}) and exported waste and by-products ($RCV_R_B_{exp}$, BP_{exp}), Eurostat has identified the CN codes that can be considered such³¹. For application to non-EU countries, CE has developed a mapping table between the CN and HS classification that allows it to replicate the methodology on international trade databases such as BACI.

It is important to note that for EU countries, the main source for $RCV_R_B_{cons}$, the env_wasrt dataset³², measures waste bound for recovery at the recycling plant, thus already including imported waste for recycling and excluding exported waste for recycling. Furthermore, while BP_{imp} and BP_{exp} can be estimated using list of codes and international trade databases, BP_{dom} as well as RP_{cons} are currently lacking reliable systematic estimation approaches and therefore needs to rely on ad-hoc data collection which often missing

³¹ Eurostat. (2022). *List of CN-codes used to approximate imports and exports of waste destined for recycling*. Retrieved from: [Eurostat website](#)

³² Eurostat. (n.d.). Waste generation and treatment (env_wasgt). Metadata. Retrieved from: [Eurostat website](#)

Box four: An overview of economy-wide circularity indicators

With the increasing number of indicators aimed at measuring progress towards the circular economy, it is more important than ever to understand what each is measuring as well as how they differ. Eurostat reports on at least three physical 'ratio' indicators that are relevant to the circular economy.

The **Traditional Recycling Rate** is expressed as the ratio between the volume of waste collected for recycling (RCV_R or RCV_R_B items in the env_wastrt³³ or env_was_oper dataset³⁴) over the total volume of treated waste. Since this indicator measures how much of the total waste that is collected ends up at recycling plants, it is an **output-side indicator**. Its denominator is the total amount of waste treated, which can be seen as an outflow of the production and consumption system. It's important to note that the numerator—the amount of waste collected for domestic recycling—does not represent the actual amount of recycled (secondary) materials produced by the plant, as sorting and processing losses may occur during the recycling process. The difference between the env_wastrt and env_was_oper datasets is that, while the former measures waste destined for recycling within national borders (consequently including imported and excluding exported waste), the latter focuses on national waste treated regardless of the country in which the treatment takes place (consequently including exports and excluding imports of waste).

The **End-of-Life Recycling Input Rate (EOL-RIR)** is expressed as the ratio between the input into the production system that comes from the recycling of 'old scrap' (or 'end-of-life scrap')—for instance, scraps and waste derived from the treatment of products at their end-of-life—and the total input to the production system requires for a particular raw material. Since its denominator is the total amount of inputs into a process of a raw material's supply chain, for instance, processing or manufacturing, this is considered an **input-side indicator**. Contrary to the Traditional Recycling Rate, the EOL-RIR explicitly takes imports of secondary materials into account.

The **Circular Material Use Rate (CMUR)**, reported by Eurostat, is expressed as the ratio between waste destined for recycling and the total raw materials and manufactured products used by an economy expressed as Domestic Material Consumption (DMC). As with the EOL-RIR, since the denominator is the total input into the economy, this is considered an **input-side indicator**. The CMUR adds the amount of exports of waste destined for recycling abroad to the traditional domestic recycling (R_RCV from env_wastrt) while subtracting the amount of imports destined for domestic recycling. The resulting figure thus represents the amount of waste collected for either domestic or foreign recycling. In the CMUR, the input of waste into recovery operations is deemed an acceptable proxy for the amount of secondary materials produced as a result of the same recovery operations.

The difference between input- and output-side indicators is key to understanding why different indicators may vary so much. In fact, material outputs are usually much smaller compared to their counterparts on the input side due to material accumulation in long-term stocks as well as dissipation during use—for example, when fossil fuels are combusted and become emissions. What's more, the distinction between collected waste destined for recycling, by-products and secondary materials, as well as the different perspectives on imports and exports, can play a significant role in the final figures as well as on their interpretation.

The **Input Technical Cycling rate** (also referred to as Circularity Metric), as calculated in *Circularity Gap Reports*, is expressed as the ratio between waste destined for recycling and the total raw material equivalents used by the economy, which is known as Raw Material Consumption (RMC) or the consumption-based Material Footprint (MF). When it comes to trade in waste, the *Circularity Gap Report* methodology distinguishes between waste collected for recycling and by-products and uses this distinction to refine the allocation of trade. **The ITCr is an input-side**

³³ ibid

³⁴ Eurostat. (n.d.). Management of waste excluding major mineral waste, by waste management operations (env_wasoper). Metadata. Retrieved from: [Eurostat website](https://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&language=en&plugin=1)

indicator, like the CMUR, but with some key differences:

- Firstly, the ITCr is a life-cycle indicator based on Raw Material Consumption (RMC), while the CMUR is based on Domestic Material Consumption (DMC). DMC represents the physical weight of material consumption and imports and exports, while RMC represents all the raw materials used for each component of the DMC in terms of Raw Material Equivalents (RMEs). For example, a smartphone may weigh only a couple hundred grams but requires far more resources to produce. The CMUR does not account for this;
- Secondly, while the CMUR credits collection efforts (deducting imports and adding exports), the ITCr credits waste processors/consumers (adding imports and subtracting exports of by-products). This perspective is closer to the national accounts' logic, in which most re-attributions are directed towards final use. It discourages the export of waste abroad (often seen as 'problem shifting') and encourages the development of local waste treatment capacity;
- Thirdly, the ITCr includes backfilling (RCV_R_B) and not just recycling (RCV_R). While backfilling often involves low-value recycling applications and can arguably be considered as a circular flow, it should be noted that the exclusion of waste from UDE (most notably W126 Soils and W127 dredging spoils) prevents low-value backfilling from over weighting on the ITCr as almost the totality of it relates to W121 mineral waste from construction and demolition;
- Finally, the ITCr is part of a wider set of indicators, while the CMUR is a stand-alone metric. The ITCr should be viewed in the context of the other indicators that make up the CIS. While highlighting the share of secondary raw material consumption in the economy is crucial, so is knowing the proportion of materials going into stocks, of carbon-neutral and non-carbon-neutral biomass inputs or of fossil fuel inputs, which are inherently non-recyclable.

4.2 Circular Jobs Analysis

In addition to the material perspective, we estimate the circular jobs in select sectors of the economy as per the Circular Jobs Methodology developed by Circle Economy, International Labour Organization and International Financial Corporation.

To estimate the extent of circular employment within a country, the building block methodology provides a structured approach that classifies economic sectors in International Standard Industrial Classification of All Economic Activities (ISIC) (Revision 4), based on their contribution to the circular economy. This approach distinguishes between fully circular and partially circular sectors, allowing for tailored measurement depending on the nature of economic activities.

- **Fully circular sectors** are those where all employment is assumed to contribute directly to the circular economy by virtue of the occupational functions involved. These include sectors such as repair and maintenance, waste collection and material recovery (excluding landfill and incineration), sewerage, renting and leasing activities, remediation services, the retail sale of second-hand goods, and wholesale of waste and scrap. In addition, a subset of the transport sector—urban and suburban passenger land transport (ISIC H4921)—is also considered fully circular due to its role in shared access and reducing car dependency. Employment in these sectors can be directly counted using national labour force or sectoral employment data.
- **Partially circular sectors** are those where only a portion of employment is considered circular, given the coexistence of linear and circular activities. These include material- and resource-intensive

sectors such as agriculture, mining, manufacturing, and construction. Since employment datasets in ISIC do not distinguish between circular and non-circular activities within these sectors, our estimates rely on modelling.

- For agriculture, biological circularity is proxied by the proportion of cropland under organic agriculture.
- For mining, economic circularity is proxied by the sector's contribution to the recycling sector through domestic sales and exports.
- For manufacturing and construction, circularity is estimated using an average of material circularity (the share of secondary, i.e. non-virgin inputs in the sector's material inputs) and economic circularity (the sector's contribution to the recycling sector through domestic sales and exports).

The methodology also accounts for informal employment, which is critical in many national contexts, particularly in the Global South. When labour statistics are disaggregated by formality status, circular employment in each sector is split into formal and informal categories based on the sector's informal employment share. In cases where such disaggregation is unavailable, the methodology imputes values using country income group-based averages.

In applying this methodology at the national level, the highest level of employment data resolution is used, ideally at ISIC four-digit level. Where such granularity is unavailable, aggregated data is supplemented with imputations drawn from country income group averages. Gender-disaggregated estimates can also be included, either directly from national data or inferred from income group averages.

While the methodology provides a replicable and scalable approach to measuring circular employment, it is important to acknowledge certain limitations. Existing statistical systems and input-output models are often built around linear economic assumptions and do not fully capture informal, small-scale, or non-standard circular activities. In many countries, data on informal employment remains incomplete or inconsistently classified, and the assumptions within input-output databases (such as Eora) may not reflect sectoral diversity or local production structures. As a result, estimates derived from this methodology should be interpreted as indicative rather than exhaustive, with results likely underestimating the true scope of circular employment. Nevertheless, this methodology offers a robust starting point for countries to quantify, analyse, and track their circular employment landscape.

The list of economic sectors along with the indicator used for determining circular employment has been listed in Annex B

Technical Annex

Annex A: Industrial ecology toolkit

Economy-Wide Material Flow Accounting

Table one. Summary of traditional and extended MFA variables with description and formulas (greyed out cells means that the variable is not included in the approach, empty cells means that the variable is input data with no calculation needed)

Label	Code	Description	Traditional	Extended
Domestic extraction	DE	Extraction of raw materials from the domestic environment		
Physical Imports	IMP	Imports of raw materials, semi-finished and finished products		
Raw Material Equivalents of Imports	RME_IMP	Indirect flows or upstream raw material requirements related to imports		
Physical Exports	EXP	Exports of raw materials, semi-manufactured and manufactured products		
Raw Material Equivalents of Exports	RME_EXP	Indirect flows or upstream raw material requirements related to exports		
Domestic Material Input	DMI	Primary material inputs into an economy	$DE + IMP$	$DE + IMP$
Raw Material Input	RMI	Primary inputs into an economy expressed in raw material equivalents	$DE + RME_IMP$	$DE + RME_IMP$
Domestic Material Consumption	DMC	Primary material or apparent consumption of an economy	$DMI - EXP$	$DMI - EXP$
Raw Material Consumption	RMC	Primary consumption into an economy expressed in raw material equivalents	$RMI - RME_EXP$	$RMI - RME_EXP$
Recycled waste for domestic consumption	$RCV_R_B_{cons}$	Domestic (excl. exports) and imported waste recycled in domestic recovery plants. It does not include waste from unused extraction. Recycling includes backfilling.		$RCV_R_B_{dom} + RCV_R_B_{imp} - RCV_R_B_{exp}$
By-products for domestic consumption	BP_{cons}	Domestic (excl. exports) and imported by-products for domestic consumption		$BP_{dom} + BP_{imp} - BP_{exp}$

Reused products for domestic consumption	RP_{cons}	Domestic (excl. exports) and imported reused for domestic consumption		$RP_{dom} + RP_{imp} - RP_{exp}$
Secondary material inputs consumed	$SMIc$	Secondary material consumption of an economy		$RCV_{R-B_{cons}} + BP_{cons} + RP_{cons}$
Processed Materials	PM	Primary and secondary material consumption of an economy		$DMC + SMIc$
Processed Raw Materials	PRM	Primary and secondary material consumption of an economy where primary material consumption only is expressed in raw material equivalents ³⁵		$RMC + SMIc$
Energetic use	$eUse$	Fraction of PM that is used to provide energy. Comprises not only technical energy but also feed for livestock and food for humans		Calculated based on coefficients from material flow database and Mayer et al. (2018) - see table three in Project Annex
Material use	$mUse$	Fraction of PM that is used for material purposes. Comprises all metals and non metallic minerals, fractions of biomass and fossil energy carriers		
Gross additions to stock	GAS	Materials used to build up in-use stocks of materials (life span >1 yr)		
Reported waste from energetic use	W_{eUse}	Solid waste from combustion of fuels and excrements of humans and livestock at the water content of biomass intake (i.e. excluding water uptake by humans and livestock) as reported in official statistics		Calculated from waste statistics and Mayer et al. (2018) - see table five in Project Annex
Reported waste from material use	W_{mUse}	Solid waste from discarded stocks (life span >1 yr), short-lived products (life span <1 yr) and processing and manufacturing waste		
Reported End-of-Life waste	EoL_r	Total end of life waste comprises all solid waste from $eUse$ and $mUse$, including throughput materials reported in waste statistics.		$W_{eUse} + W_{mUse}$
Short-lived material use of crop residues	Crp	Crops residues for feed and deliberative dissipative uses (fertilisers)		Based on Mayer et al. (2018)
Extractive waste	Ext	Waste rock from domestic mining		Calculated based on material flow

³⁵ Methodological issues related to the estimation of secondary materials in raw material equivalents can be found in this [Technical Note](#)

				statistics
Unreported waste from material use	Wu_{mUse}	Waste from material uses not fully reported in waste statistics. This can include country-specific under- or mis-reported waste fraction required for mass balancing (Wu)		$Crp + Ext + Wu$
Unreported waste from energetic use	Wu_{eUse}	Excrements generated from food and feed intake not fully reported in waste statistics		Calculated based on material flow statistics and Mayer et al. (2018)
Unreported End-of-Life waste	EoL_u	Total waste not reported in waste statistics		$Wu_{eUse} + Wu_{mUse}$
Total End-of-Life waste	EoL_t	Total reported and unreported waste from		$EoL_r + EoL_u$
Demolition and Discard	$D\&D$	Solid waste from discarded in-use stocks. Comprises construction and demolition waste but also all other discarded long living products		$W_{mUse} - (mUse - GAS - Wu_{mUse})$
Domestic processed output from energy (emissions)	DPO_e	All gaseous outputs including vapour from combustion and human and animal respiration; oxygen input from air is excluded.		$eUse - W_{eUse} - Wu_{eUse}$
Domestic processed output from materials	DPO_w	All EoL waste excluding materials recovered for re- and downcycling. All liquid and solid outputs including moisture content as included in extracted material but excluding extra added water (e.g during industrial processes or drinking water)		$EoL_t - RCV_{R_B}_{dom}$
Domestic processed output	DPO	Total waste and emissions released to the environment		$DPO_e + DPO_w$
Interim outputs	$IntOut$	Total wastes and emissions after the use phase		$EoL_t + DPO_e$
Balancing items input-side	BI_{in}	Mostly oxygen demand for combustion and respiration processes		All variables are pre-calculated at the net of the balancing items
Balancing items output-side	BI_{out}	Mostly water vapour generated from combustion processes, gases from respiration and evaporated water from biomass products		
Net additions to stock	NAS	Measure of the "physical growth of the economy", i.e. the quantity (weight) of new construction	$DMC + BI_{in} - BI_{out} - DPO$	$GAS - D\&D$

		materials accumulating in buildings, infrastructure and materials incorporated into durable goods (life span >1 yr)		
Land Use and Land Use Change emissions	<i>LULUCF</i>	Technically not part of the EW-MFA framework as this is an environment-to-environment flow. Included in the extended approach for calculations related to the biological cycle		

Traditional approach

EW-MFA is a statistical accounting framework describing the physical interaction of the economy regarding material flows with the natural environment and the rest of the world economy. It represents a useful framework for deriving a high-level overview and understanding of the SEM of the system under analysis³⁶. EW-MFA records the throughput of materials (excluding bulk flows of water and air) at the input and output sides of the national economy based on a conservation of mass principle. The mass balance principle is used to check the consistency of the accounts. It also provides one possibility to estimate the net accumulation of materials also known as stocks. The mass balance principle can be formulated as:

$$\text{Inputs} = \text{outputs} + \text{additions to stocks} - \text{removals from stocks} = \text{outputs} + \text{net stock changes}$$

Material inputs into national economies include:

- Domestic Extraction of material originating from the domestic environment;
- Physical Imports (all goods) originating from other economies;
- Balancing Items on the input side

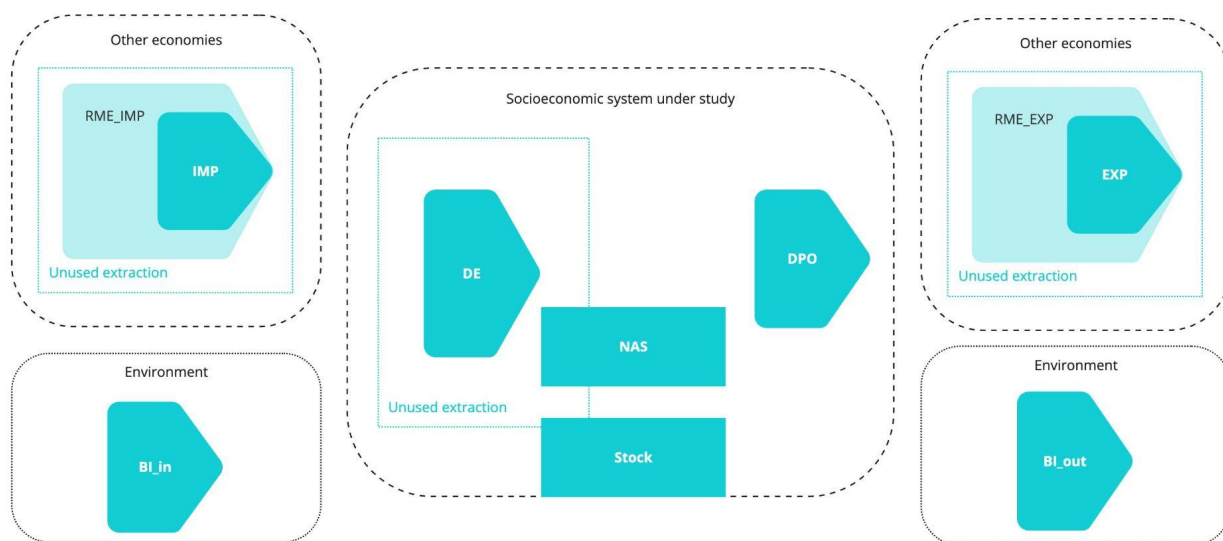
Material outputs from national economies include:

- Domestic Processed Output to the domestic environment;
- Physical Exports (all goods) to other economies;
- Balancing Items on the output side

In most national economies, the amount of physical input exceeds the physical output. The difference between inputs and outputs corresponds to the net accumulation of material in the economy in the form of, e.g. buildings and infrastructures, machinery and durable goods. In EW-MFA, this material accumulation in a single year is called net additions to stock (NAS). **Figure one** depicts a traditional EW-MFA system.

Figure one. Traditional EW-MFA system, also referred to as the “black-box” approach.

³⁶ Nairobi, K. (2021). The use of natural resources in the economy: A Global Manual on Economy Wide Material Flow Accounting.



Domestic Extraction (DE). This includes the annual amount of solid, liquid and gaseous raw materials (except for water and air) extracted from the natural environment to be used as material factor inputs in economic processing. The term “used” refers to acquiring value within the economic system. Domestic extraction is categorised into four groups in most MFAs:

1. Biomass which comprises agriculture harvest, timber, animal grazing, and fishing;
2. Metal ores which include ferrous and non-ferrous metals;
3. Non-metallic minerals, sometimes divided into construction and industrial minerals); and
4. Fossil energy materials/carriers which comprises coal, natural gas and crude oil.

Imports (IMP) and Exports (EXP). This covers all imported or exported commodities in tonnes. Traded commodities comprise goods at all stages of processing from basic commodities to highly processed products.

Domestically Processed Outputs (DPO). Comprises all waste and emission flows that occur in the processing, manufacturing, use, and final disposal stages of the production-consumption chain. Recycled material flows are considered flows within the economy (e.g. of metals, paper, glass) and thus are not considered as outputs (nor inputs, “black-box” approach³⁷). DPO includes:

- Direct emissions to air and water;
- Industrial and household wastes deposited in uncontrolled landfills (whereas wastes deposited in controlled landfills are regarded as an addition to socioeconomic stock);
- Dissipative use of products (where materials are dispersed into the environment through their use) e.g. fertiliser application; and
- Dissipative losses e.g. emissions to air from automobile tyre; and brake wear and road abrasion.

The scale of water use is so significant that including its mass in MFAs obscures other resource use. For this reason, standard MFA practice only includes water mass contained in products e.g. agricultural produce and

³⁷ Krausmann, F., Lauk, C., Haas, W., & Wiedenhofer, D. (2018). From resource extraction to outflows of wastes and emissions: The socioeconomic metabolism of the global economy, 1900–2015. *Global environmental change*, 52, 131–140.

imported beverages. Water for other consumptive uses (cleaning or irrigation) and in situ uses (such as hydroelectric power), sometimes known as bulk water in MFAs, will be excluded from these accounts.

Balancing Items (BIs) and Material Accumulation (NAS). The input and output sides of the MFA are balanced to ensure all materials flowing into an economy in one year are accounted for. Balancing items on the input side mainly include oxygen requirements for combustion processes and respiration, nitrogen for ammonia production, and water requirements for the domestic production of exported beverages. Balancing items on the output side mainly include water vapour generated from combustion processes, gases from respiration and evaporated water from biomass products.

After adding the balancing items to input and output flows, the remaining materials are classified as material accumulation (or Net Additions to Stocks). This includes materials which are retained within the economy in the form of buildings, infrastructure and longer-life products (e.g. furniture, and electronics). Landfilled waste is also considered a stock since the material is permanently stored in a human-controlled environment.

Indirect Flows and Hidden Flows. Indirect flows measure the upstream quantity of materials associated with the imports of semi-finished and finished goods into the economy. They are needed to estimate the raw material requirements (RME) of traded commodities in an MFA. For example, to produce a tonne of imported canned fish, the upstream raw material requirements are the fish, metal cans, and the fossil fuel energy used to produce the canned fish. As these upstream raw material requirements are not exactly known, they are estimated based on input coefficients for different production processes, also known as RME coefficients. These coefficients are averaged factors for various inputs. Similar indirect flows can be defined for exports of semi-finished and finished products.

The domestic extraction of “unused materials” is classified as hidden flows. Examples of hidden flows are unused extraction from mining and quarrying (also known as overburden), discarded material from harvesting (e.g. wood harvesting losses), and soil and rock moved due to construction and dredging. Like indirect flows, these are also estimated using coefficients for biomass and minerals extraction processes.

Neither flow enters the focal socioeconomic system but the first, unused extraction remains within the natural system, and the second, RME remains in foreign economies. Both indirect and hidden flows are acknowledged but rarely quantified in traditional EW-MFA.

Having defined these material flow categories, we now can write a national material balance equation in EW-MFA terms:

$$DE + IMP + BI_{in} = EXP + DPO + BI_{out} + NAS$$

Extended approach

At both the Global and European level, nation-states report on a variety of statistics such as the production and trade of manufactured goods annually (known as ProdCom³⁸, ComExt³⁹ and Comtrade⁴⁰), the production

³⁸ Eurostat. (n.d.). Prodcom - Statistics by products - Overview. Available online at [ProdCom](http://prodcom.ec.europa.eu/)

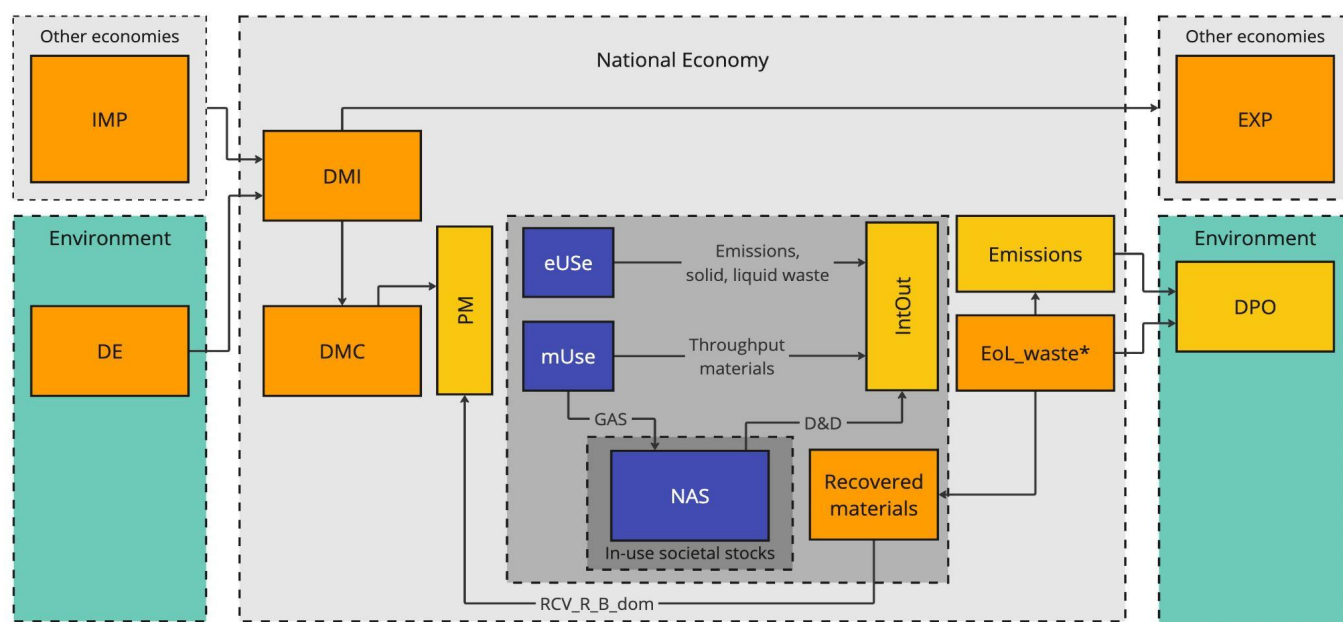
³⁹ Eurostat. (n.d.). Focus on Comext. Available online at [ComExt](http://comext.ec.europa.eu/)

⁴⁰ Statistic Division of the United Nations (n.d.) UN COMTRADE. International Merchandise Trade Statistics. Available online at <http://comtrade.un.org/>

of agricultural products such as crops and livestock (FAOSTAT⁴¹) or the supply and use of energy carriers (UNSD Energy Statistics Database⁴²). These detailed databases give consistency to nation EW-MFAs, allowing great comparability. The Eurostat's and UNEP's MFA Questionnaires^{43,44} are fully functioning templates for conducting traditional EW-MFAs.

While the traditional approach provides a standardised way to quantify key material flows and stocks and related indicators, it sometimes falls short in describing and reconciling the link between all the datasets employed. The extended framework for an economy-wide CE assessment developed by Mayer et al. (2018)⁴⁵ is *"a framework for a comprehensive and economy-wide biophysical assessment of a CE, utilising and systematically linking official statistics on resource extraction and use and waste flows in a mass-balanced approach"*. Built upon traditional EW-MFA, it extends by discerning high-level material uses and by integrating waste flows, recycling and downcycling materials, that is by opening up the "black box" and uncovering flows within the economy (**Figure two**). Based on such a framework, a comprehensive set of indicators that measure the scale and circularity of total material and waste flows and their technical and ecological loop closing is developed.

The rationale for applying this framework to the standard EW-MFA data is to monitor progress towards a CE from an economy-wide perspective at the national or subnational scale. In fact, only at these levels it is possible to also capture system-wide effects such as displacement or rebound effects and to assess whether absolute reductions in resource use and waste flows were achieved. The novelty of the approach is the expansion of the EW-MFA boundaries by including flows of secondary materials and systematically mass-balance material inputs with waste, and secondary materials flows reported in the different statistical sources.



⁴¹ Food and Agriculture Organization of the United Nations (n.d.). FAOSTAT statistical database. Available online at <https://www.fao.org/faostat/en/#home>

⁴² Statistic Division of the United Nations (n.d.). UN ESD. Energy Statistic Database. Available online at <https://unstats.un.org/unsd/energystats/data/>

⁴³ Eurostat. (2024). Questionnaire for economy-wide material flow accounts. Available online at [EW-MFA Questionnaire](#)

⁴⁴ Environmental Programme of the United Nations (n.d.). UNEP. Questionnaire for economy-wide material flow accounts. Available online at [EW-MFA Questionnaire](#)

⁴⁵ Mayer, A., Haas, W., Wiedenhofer, D., Krausmann, F., Nuss, P., & Blengini, G. A. (2018). Measuring progress towards a circular economy: A monitoring framework for economy-wide material loop closing in the EU28. *Journal of Industrial Ecology*, 23(1), 62–76.

doi:10.1111/jiec.12809

Figure two. Simplified extended EW-MFA framework based on Mayer et al. (2018). This framework applies from individual materials (e.g., DE of corn or iron) to aggregated material categories (e.g., PM of biomass, fossil energy carriers) to the total material level (e.g., total DE). Colours indicate data sources used: Orange = reported data (e.g. official statistics), blue = mass-balanced modelling, yellow = mix of statistical and modelling approach. Note that compared to the traditional framework, Balancing Items on both sides are not included as all the flows and indicators are computed already at the net of such items. * EoL waste excludes any flow related to Unused Domestic Extraction

The accounting framework shown in **Figure two** traces materials by main material groups from their extraction to major uses within the socioeconomic system and towards discard and either material recovery or deposition to nature as wastes and emissions. The main physical stages of the flow of materials through the entire system are marked by throughput indicators, represented as boxes. These include the source of material inputs (e.g., domestic extraction, imports), major material transformation processing stages within the system (e.g. processed materials, energetic and material use, in-use stocks of materials, waste treatment, EoL waste) and the destination of outflows (e.g., exports, domestic processed output to the environment). Flows of materials are displayed as arrows between these boxes; the colours of flows indicate the type of data source.

Processed materials (PM) were defined as the sum total of DMC and waste recycled in domestic plants ($RCV_R_B_{dom}$). PMs were allocated to either energetic or material use based on coefficients from material flow database and Mayer et al. (2018) - see table three in Project Annex. Energetic use (*eUse*) comprises materials used to provide technical energy (fuel wood and biofuels) and feed and food, the primary energy sources for livestock and humans. mUse was split into extractive waste, materials used for stock building (i.e., gross additions to in-use stocks of materials [*GAS*]), and throughput materials. Extractive waste refers to waste material that occurs during the early stages of the processing of domestically extracted ores and directly goes from PM to interim output (*IntOut*). Stock building materials comprise all materials that accumulate in buildings, infrastructures, or durable goods with a lifetime of more than one year (e.g., concrete, asphalt, or steel). The share of stock-building materials in mUse was estimated based on information from industry and production statistics, results from material flow studies and assumptions (see table three in Project Annex). Throughput materials comprise materials that do not accumulate in in-use stocks. They can be split into two types of materials: first, materials used deliberately in a dissipative way, such as salt or fertiliser minerals, and losses that occur during material processing (wastage, not reported in waste statistics); and second, short-lived products such as packaging or newspaper, manufacturing wastes, and food waste (reported in waste statistics).

All materials that are neither added to stocks nor recycled are converted into gaseous, solid, or liquid outputs within the year of extraction. Together with demolition and discard (*D&D*) from in-use stocks that have reached the end of their service lifetime, these outflows were denoted as interim outputs (*IntOut*) in figure two. IntOuts were split into emissions, comprising all gaseous emissions (e.g., carbon dioxide [*CO2*], sulphur dioxide [*SO2*], methane [*CH4*]), including water vapour and into EoL waste, including all solid (and liquid) outputs. Emissions cannot be recycled and go straight into domestic processed output (*DPO*). A fraction of total EoL waste, reported as *RCV_R_B* (Recovery - Recycling and backfilling (excluding energy recovery)) is reentering socioeconomic processes as secondary materials. The remaining EoL waste (after subtracting *RCV_R_B*) is returned to the environment as DPO waste and either landfilled, incinerated, or deliberately applied (e.g., manure, fertiliser). DPO emissions and DPO waste together form the total DPO.

To close the material balance between input and output flows, we combine data from statistical reporting with modelling. This was done separately for eUse and for the mUse components in two balancing calculations. The following equations summarise the mass balancing for eUse (equation 1) and mUse (equation 2).

$$DPO\ emissions = eUse - solid\ and\ liquid\ wastes \quad 1)$$

$$Demolition\ and\ discard = EoL\ waste\ from\ mUse - throughput\ materials\ in\ waste \quad 2)$$

Note that these two equations are equivalent to the ones reported in table one. We assumed that all materials used to provide energy were converted into DPO emissions (including water vapour) and solid waste within the year of extraction. We used data for solid waste from combustion reported in waste statistics and estimated the amount of solid waste from human and animal metabolism (excrements) by applying appropriate coefficients reflecting the non-digestible fraction of food and feed intake (Wu_{eUse}). DPO emissions were then calculated as the difference between eUse and the outflow of solid waste (Wu_{eUse} and Wu_{mUse}). Note that so-called balancing items (oxygen uptake from air during combustion and water consumed by humans and livestock) were excluded. This means that all outflows from eUse include only the materials contained in actual inputs as composed in PM (e.g., CO₂ or SO₂ in terms of C or S content; excrements at the average water content of food and feed intake). Closing the mass balance for eUse in this way implies that all inaccuracies in statistical data and assumptions that result in inconsistencies between input and output flows accrued in DPO emissions ($DPOe$). For the combustion of fossil energy carriers we cross-check the calculated DPO emissions with data from emission statistics. If the difference is found to be significant (negative difference or positive difference >10%), either model parameters or input data are modified to reconcile the results (for the cross-check and reconciliation, see table two in the Project Annex).

Due to a lack of knowledge of actual in-use stocks, we used the following approach to close the material balance: In the first step, a consistent split of total EoL waste from mUse Wu_{mUse} into waste flows resulting from discard and demolition ($D\&D$) and throughput materials was required. Total EoL waste from mUse (EoL_r) was derived from waste statistics. While waste statistics report information on construction and demolition waste, this waste flow was not fully consistent with EoL waste from discard and demolition, which also contains waste flows from discarded long-living products such as furniture, cars, or electric appliances. In a second step, we calculated the amount of discard and demolition as the difference between EoL waste from mUse reported in waste statistics and the fraction of throughput materials (i.e., materials with a life span < 1 year) in mUse (e.g., waste from packaging, paper, food waste, etc.). In the third step, NAS were calculated as the difference between additions to stocks and discard and demolition. Closing the mass balance in this way implies that all inaccuracies in statistical data and assumptions that result in inconsistencies between input and output flows for mUse accrue in demolition and discard flows as residual flow category, and consequently in the value for NAS. The fact that NAS are therefore calculated by balancing additions to stock and stock depletion rather than as a statistical balance between inputs and outputs represents one of the key differences between the traditional and extended EW-MFA approaches.

All flows and indicators were calculated for the four main material groups distinguished in EW-MFA. The calculation at the level of material groups on the output side was challenging due to the heterogeneity of solid, liquid and gaseous waste flow. Waste materials reported in one category typically comprise multiple material categories in EW-MFA, which requires conceptually linking them to flows on the input side and allocation to resource groups via composition coefficients. Moreover, waste flows reported in waste statistics

needed adjustments to the system boundaries used in EW-MFA to ensure that input and output flows could be mass balanced (see table five in the Project Annex).

The extended EW-MFA framework by Mayer and colleagues brings considerable improvements to the traditional approach, by systematically linking material flow, waste and emission statistics in a mass-balanced approach. The economy “black box” is opened up and flows that are considered within the economy - such as recycling, fossil fuels used for energy purposes, non renewable and (potentially) renewable material inputs - and that are key for monitoring progress towards circularity are exposed and quantified. However, the extended approach still falls short on a number of elements:

1. Trade flows of secondary materials are not included, preventing a fully consistent consumption-based metric for technical cycling. Secondary materials include recyclable (or recycled) waste ($RCV_R_B_{imp}$ and $RCV_R_B_{exp}$), by-products (BP_{imp} and BP_{exp}) and reused products (RP_{imp} and RP_{exp});
2. Some flows within the economy which are typically not covered by statistics such as generation of by-products for domestic consumption (BP_{dom}) and domestically reused products (RP_{dom}) are not included;
3. Indirect flows or upstream raw material requirements of trade flow (RME_{imp} , RME_{exp} and RMC) are not included.

All three issues are addressed by Circle Economy in its EW-MFA model.

Circle Economy’s approach

Circle Economy’s CGR EW-MFA model is used for calculating the CIS, a comprehensive set of indicators that measure the scale and rate of technical and ecological circularity - as well as the circularity gap - at the national level⁴⁶. Built on top of the extended framework, the CGR EW-MFA model adds four important improvements:

1. Trade flows of waste destined to recycling ($RCV_R_B_{imp}$ and $RCV_R_B_{exp}$) and by-products (BP_{imp} and BP_{exp}) are systematically included using the Eurostat’s CMUR methodology⁴⁷ (see box three of the general methodology document). Trade flows of reused products (RP_{imp} and RP_{exp}) are included, if available from national sources;
2. By-products for domestic consumption (BP_{dom}) and domestically reused products (RP_{dom}) are included, if national sources are available;
3. Indirect flows or upstream raw material requirements of trade flow (RME_{imp} , RME_{exp} and RMC) are included and a set of indicators calculated on both apparent consumption (DMC) and material footprint (RMC). The estimation of indirect flow is based on the EE-MRIOA (see section Environmentally Extended Multi-Regional Input-Output Analysis - The Weavebase model)
4. Results from the traditional and the extended approach are cross-checked and reconciled to ensure the consistency and robustness of the results. Hidden flows are excluded at this time as data, thus far, remains insufficient.

⁴⁶ With some methodological adjustments, the model allows also for sub- and supra-national assessments

⁴⁷ Eurostat. (2018). *Circular material use rate: calculation method*. Eurostat manuals and guidelines. Luxembourg: Publications Office of the European Union, 2018. Retrieved from: [Eurostat website](https://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&language=en&code=sdg12_10_1)

Figure three shows a simplified depiction of the CGR EW-MFA measurement framework and model. In the context of CGRs, there are three instances of model use:

1. *All traditional EW-MFA datasets and headline indicators are already available at the required level of detail.* This is the case for most EU28 nations. Minimal additional data collection is required to deploy the CGR EW-MFA model;
2. *Some traditional EW-MFA datasets and headline indicators are unavailable or available but not at the required level of detail:* This is the case of countries where, for instance, DMC is available but DPO or NAS are not. Here, a *streamlined approach* can be taken whereby DPO and BIs are only estimated using the best available data to derive NAS;
3. *No traditional EW-MFA datasets and headline indicators are available:* This is often the case in assessments at the sub-national level or for data poor countries, where only basic production and trade statistics are available. Here, two approaches can be taken:
 - 3.1. The *integral approach* entails building the accounts from scratch following the international or European handbooks' guidelines and apply the CGR EW-MFA framework integrally⁴⁸;
 - 3.2. The *simplified approach* entails using internationally available data sources and a combination of traditional and extended EW-MFA approaches together with simplified "rules of thumb" and assumption to quantify only variable that are strictly necessary for the calculation of the CIS⁴⁹

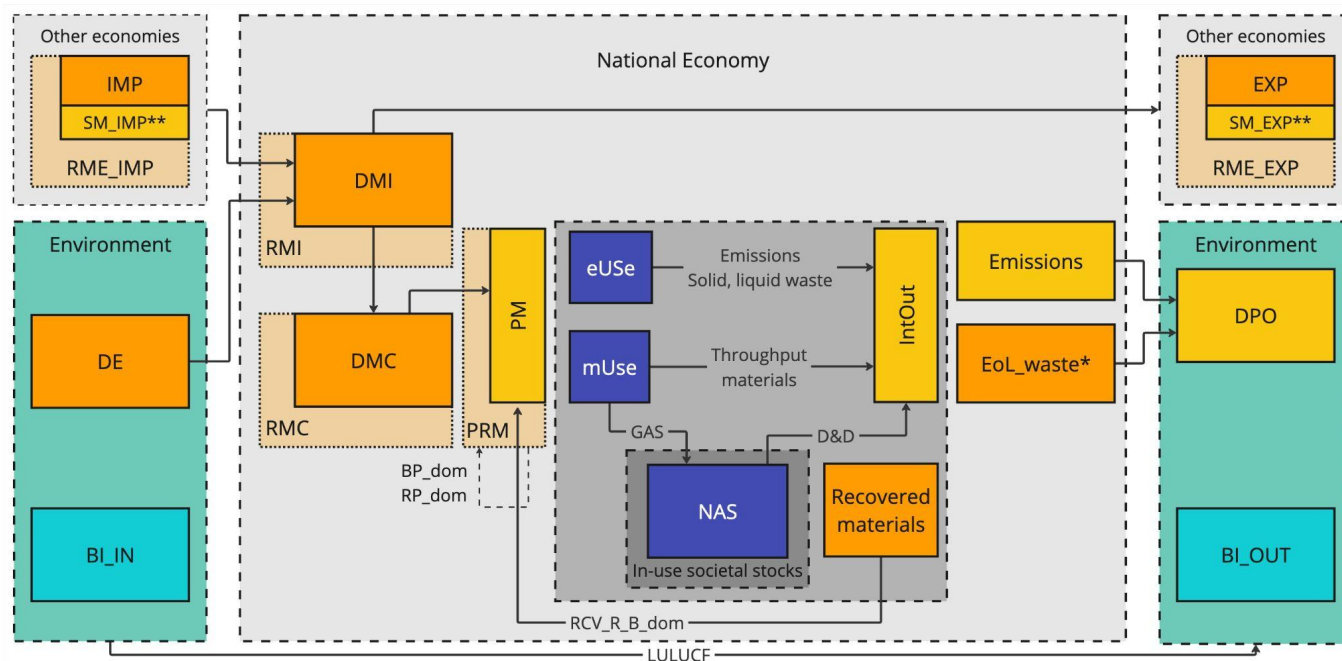


Figure three. Simplified CGR EW-MFA framework. Differences with the extended EW-MFA framework are marked in bold. Blue = official statistics, yellow = mass-balanced modelling, purple = mix of statistical and modelling approach. Note that compared to the traditional framework, Balancing Items on both sides are not included as all the flows and indicators are computed already at the net of such items. * EoL waste excludes any flow related to Unused Domestic Extraction. ** For simplicity, SM_{imp} and SM_{exp} are assumed to include both BP_{imp} and BP_{exp} , $RCV_R_B_{imp}$ and $RCV_R_B_{exp}$

⁴⁸ For more detail on the methodology for sub-national assessment see [document WIP]

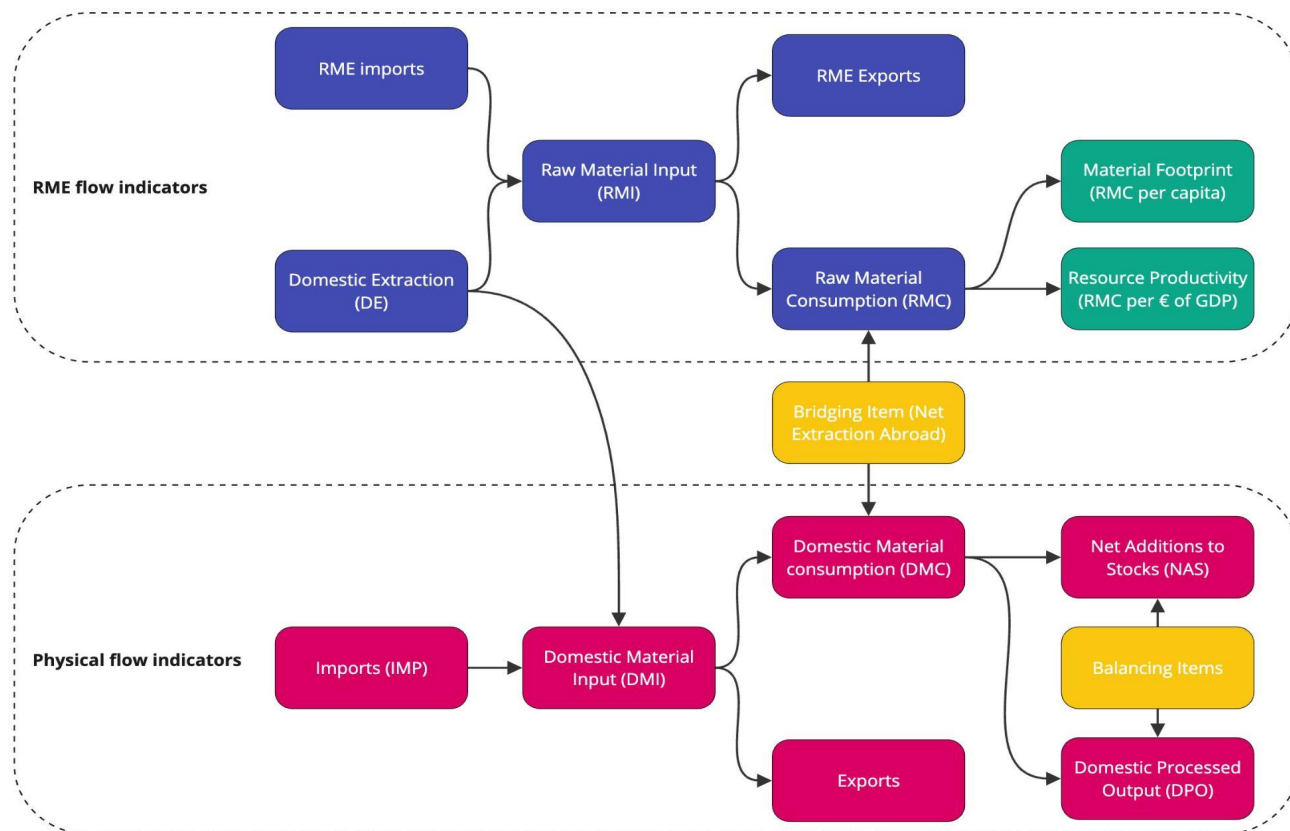
⁴⁹ For more detail on the methodology for supra-national assessment see [CGR IAC methodology](#). Note that terminology and variable names can differ from the current document

The extended MFA approach, particularly the process of harmonisation of systems boundaries across the EW-MFA and waste statistics, often generates headline indicators results that differ from those of the traditional approach. In order to minimise this difference, a manual iterative reconciliation process is performed. The objective is to minimise the difference between the two figures NAS and DPO indicators by changing values of particular coefficients in the extended MFA framework (e.g. share of mUse in DMC and share of stock additions in mUse - for the full list refer to table three of the Project Annex). Whenever the difference between indicators cannot be reconciled to satisfactory levels, an additional estimation of unreported waste is introduced (it should be noted the treatment route of such unreported waste remains unspecified). For more project-specific information on the reconciliation process see section 1.2 of the Project Annex.

The Bridging Item issue

CGRs typically report the CIS indicator based on *PRM* while indicators based on *PM* are calculated but not reported. *PRM*-based indicators have the advantage of taking a life-cycle perspective by reallocating raw material extraction to the point of final consumption; however, this has the disadvantage of introducing an overlap in the system boundary definition which is not straightforward to reconcile. Calculating indicators on *PRM* the same way as on *PM*, would imply extending assumptions that are supposedly valid only within the defined system boundary (the socioeconomic system under study) to outside of it (all the other economies). For example, let's consider the estimation of the non-circular flows: The eUse fraction of fossil fuels in *PM* is made of the actual fuels (e.g. gasoline, diesel, kerosene) that are being burned so the identification of their use is straightforward. However, the eUse fraction of fossil fuels in *PRM* accounts for the raw materials (e.g. petroleum) across all kinds of products and applications, thus not necessarily related eUse. In other words, direct physical flows - *IMP* and *EXP* - and derived indicators *DMC* and *PM* are conceptually different from upstream material requirements expressed in RMEs - *RME_IMP* and *RME_EXP* - and derived indicators *RMC* and *PRM*. The application of the extended approach to the latter requires proper consideration. Therefore, we introduce a bridging item calculated as $RMC - DMC$ and refer to it as net extraction abroad (NEA) as shown in figure four.

Figure four. Position of NEA as bridging item between RME and Physical flow indicators. Blue = Indicators expressing quantities of actual or “virtual” raw materials only. Purple = Indicators expressing quantities of a mix of actual raw materials, semi-finished and finished products. Yellow = special bridging and balancing items. Green = indicators expressing normalised physical quantities.



When the NEA rate is negative, it means that the economy under study extracts more resources to satisfy final demand abroad than those extracted abroad to satisfy domestic final demand and vice versa. In case of *positive NEA*, the difference is arbitrarily added to the NRI indicator due to the difficulty of tracing their fate and thus allocating these flows to the rest of the indicators. This pinpoints another limitation in the use of RMEs rather than physical flows, that is the difficulty to track the fate of raw materials extracted abroad that are either embedded into the traded commodity or transformed into waste and emissions during processing in the foreign country. Conversely, in case of *negative NEA* the difference is subtracted from the NRI thereby, reducing it.

The Renewable Biomass issue

Ecological cycling is commonly assumed, but hardly operationalized in CE assessments. However, using biomass does not automatically imply safe ecological loop closing, as negative environmental impacts from land-use indicate. So far, neither robust criteria nor comprehensive indicators are available which enable identifying the fraction of biomass production which qualifies for sustainable ecological cycling⁵⁰. As a first approximation for renewable biomass we only consider carbon neutral biomass. We interpret this as a minimum requirement, while more comprehensive assessments should be developed, as we elaborate in the discussion section. To estimate the flow of primary biomass which cannot be regarded as carbon neutral, we

⁵⁰ Navare, K., Muys, B., Vrancken, K. C., & Van Acker, K. (2021). Circular economy monitoring—How to make it apt for biological cycles?. *Resources, Conservation and Recycling*, 170, 105563.

deduct the net emissions of carbon from deforestation caused by land use change^{51 52} from socioeconomic biomass flows, consistently re-estimated as tons of carbon content. To calculate the amount of circular and non-circular biomass, the flow of primary biomass through the economy is converted into dry matter using appropriate information on the moisture content of different biomass types and further into C, assuming a carbon content of 50% in dry matter biomass. The share of biomass that does not qualify for ecological cycling in a specific year is then calculated as the ratio of net emissions of C from deforestation to the C content of primary biomass inputs and to the C content of the output of wastes and emissions from biomass use, respectively, in that year. These shares are then applied to split the biomass flow in fresh weight circular and non-circular biomass on the input and output side.

$$BIO_{ren} = DMC_{bio} * BIO_{ren\%}$$

$$BIO_{ren\%} = 1 - ((LUC * 0.27) / (DMC_{bio} * DM_{avg_bio\%} * 0.5))$$

Where DMC_{bio} is the fresh weight of biomass consumed, LUC are the CO₂ emissions from deforestation caused by land use change embodied in trade, 0.27 is the molar ratio of elemental carbon to CO₂, $DM_{avg_bio\%}$ is the average dry matter share of biomass (calculated by subtracting the average water content at harvest from each biomass MF code) and 0.5 is the average elemental C content in dry biomass.

Box five: LULUCF vs deforestation

We have chosen to use deforestation emissions embodied in trade to proxy non-circular biomass. While previous iterations of this methodology used LULUCF, this data is notoriously unreliable to use and as such not included in the emissions databases by default. On a more practical note, LULUCF is also not easily linked to non-circular biomass as its emissions may be negative in the case of huge carbon sink territories (e.g. Brazil). Especially when combined with a CBA approach, this opens up the question on which parts of LULUCF emissions may be exported for the benefit of the importing territory. This approach had the additional side effect of theoretically allowing the import of negative emissions, which is illogical from an environmental perspective.

Instead, we have chosen to use deforestation emissions embodied in trade, developed by Singh & Persson (2024), which attributes deforestation - and related emissions - across the world to the expansion of cropland, pastures and forest plantation, and the commodities produced on this land. This, by definition, attributes the negative changes (deforestation) in land use change to the consumption of commodities, and thus more accurately reflects the non-circular use of biomass, globally.

Environmentally Extended Multi-Regional Input-Output Analysis - Weavebase model

Environmentally-extended input-output analysis (EE-MRIOA) provides a simple and robust method for evaluating the linkages between economic consumption activities and environmental impacts, including the harvest and degradation of natural resources. EEIOA is now widely used to evaluate the upstream,

⁵¹ Pendrill, F., Persson, U. M., Kastner, T. & Wood, R. (2022). Deforestation risk embodied in production and consumption of agricultural and forestry commodities 2005-2018. Chalmers University of Technology, Senckenberg Society for Nature Research & Norwegian University of Science and Technology (NTNU). <https://zenodo.org/records/5886600>

⁵² Singh, C. & Persson, U. M. (2024). Global patterns of commodity-driven deforestation and associated carbon emissions. Earth ArXiv. <https://doi.org/10.31223/X5T69B>

consumption-based drivers of downstream environmental impacts and to evaluate the environmental impacts embodied in goods and services that are traded between nations.

Of the available Multi-Regional EEIO databases (EE-MRIO), EXIOBASE stands out as a database compatible with the SEEA with a high industrial detail matched with multiple social and environmental satellite accounts. EXIOBASE represents the production and consumption of 164 industries and/or 200 economic goods for 43 countries and 5 rest-of-the-world (ROW) regions. Satellite accounts for resources and emissions are available for each sector and country. The original EXIOBASE 3 data series ended in 2011. However, in later releases, nowcasting procedures have been applied based on a range of auxiliary data, but mainly trade and macro-economic data which go up to 2022 when including International Monetary Fund projections.

Another prominent EE-MRIO is Eora26, which boasts highly detailed regional coverage with 189 regions, but only 26 high level sectors. Eora uses the national accounts for each region, and while the full version has the original sector coverage as originally reported, this database is neither symmetric nor easy to harmonise , and we instead opt for the simplified Eora26 database.

Given the requirements of having global regional coverage, whilst supporting detailed sectoral breakdowns, we have developed a robust, authoritative, and highly resolved MRIO database for analysing environmental footprints related to the circular economy. The database utilises the high sectoral disaggregation of EXIOBASE's 163 sectors to augment Eora26 while keeping the high regional resolution of the latter (188 countries after dropping the historic USSR). The high level sector (26) totals adhere to the Eora26 monetary database, and are not too dissimilar to the EXIOBASE linkages where regions are identical (with mostly minor differences due to total industrial output differences between databases). However, in the case of the 5 EXIOBASE ROW regions, the relative shares of the sub sectors are shared among these regions, but applied to their national high level sector totals. This results in a database with Eora26 regions and EXIOBASE sectors, which adheres to the Eora26 monetary totals.

This method is in fact the opposite of the approach implemented by Cabernard et al. (2021)⁵³ in which Exiobase was used as the baseline and regionally expanded using Eora. We argue that it is more beneficial to increase sectoral resolution while preserving original country-specific information for a vast amount of nations than to increase regional resolution while preserving "black box" "Rest of the World" region totals.

For the extensions, we start with using the EXIOBASE satellite and apply the opposite method as described above: we instead retain the EXIOBASE extension, but extended regionally using Eora26 satellites. EXIOBASE is used much more commonly for environmental impact assessment, and we found that retaining its satellite structure was beneficial in this regard.

Given that the satellite is based on EXIOBASE, as of v3.8.2,⁵⁴ the end years of real data points used are: 2015 energy, 2019 all GHG (non-fuel, non-CO2 are nowcasted from 2018), 2013 material, 2011 most others such as land and water. Due to the relatively outdated nature of the material accounts, CE has developed its own version where materials extraction is updated to the latest year available on a country-by-country basis using the high-resolution Global Material Flow Database - 2024 edition compiled using the Common Compilation Categories and provided under request by the International Resource Panel (IRP).⁵⁵ The IRP database is based mostly on reported data until 2019-2020 and modelling estimates for later years⁵⁶. Industry allocations of the

⁵³ Cabernard, L., Pfister, S., & Hellweg, S. (2019). A new method for analyzing sustainability performance of global supply chains and its application to material resources. *Science of the Total Environment*, 684, 164-177.

⁵⁴ Exiobase v3. (2020). Exiobase 3, version 3.8. doi:10.5281/zenodo.4277368

⁵⁵ International Resource Panel. (n.d.). Global material flows database. Retrieved from: [IRP website](#)

⁵⁶ CSIRO. Technical annex for Global Material Flows Database - 2024 edition. Available online at: [IRP website](#)

baseline year 2011 have been applied under the assumption that the structure of the extractive industries has not radically changed in the last decade. This operation allows us to calculate reasonably robust material footprint accounts up until the year 2019-2020, under a defined set of assumptions (e.g. nowcasted monetary data from 2011 or industry allocation shares for material extraction).

Similarly, the emissions data has been updated to the base year using EDGAR v8.0, retaining sectoral emission intensities as originally calculated by Exiobase, but applied to the full regional coverage of our extended database, any leftover regions in EDGAR that we do not cover in the MRIO are redistributed so as to adhere to the global total (this is a minute difference).

In Europe, due to the high quality and granular data available in Eurostat, we additionally update the materials and emissions using “env_ac_mfa” and “env_ac_ainah_r2” respectively.

We update the employment extensions using data from the ILO to the given year, whilst adding additional employment indicators related to types of employment, (in-)formality, and more.

Lastly, to enable environmental impacts assessment (LCIA), we characterise the EXIOBASE stressors using IW+.

All calculations are performed using the open-source tool for analysing global EE-MIOTs, **pymrio**.⁵⁷ Production- and consumption-based accounts are calculated using a standard set of IO formulas as specified below and in **Table 3**.

$$\begin{aligned}
 D_{cba}^i &= D_{pba}^i + D_{imp}^i - D_{exp}^i \\
 D_{pba} &= Fe + Ge \\
 D_{imp} &= MY_t \\
 D_{exp} &= MY_t^{\wedge} e
 \end{aligned}$$

Table 3. Description of main Pymrio variables

Note: the $\wedge$ symbol represents the diagonalised vector, the e symbol represents a summation vector of 1s

Variable name	Symbol	Description
Consumption-based accounts	D_{cba}^i	Footprint of consumption
Production-based accounts	D_{pba}^i	Footprint of production or territorial accounts
Imports accounts	D_{imp}^i	Footprint of imports or factors of production occurring abroad (embodied in imports) to satisfy domestic final demand
Exports accounts	D_{exp}^i	Footprint of exports or factors of production occurring domestically (embodied in exports) to satisfy final demand abroad

⁵⁷ Pymrio. (n.d.). pymrio - Multi regional input output analysis in python. Retrieved from: [pymrio website](https://pymrio.org/)

Factor production	F_e	Factors of production: extension plus value-added block
Final demand factors	G_e	Factors of production: extension of final demand
Multipliers	$M = SL$	–
Leontief inverse	$L = (I - Zx^{\wedge})^{-1}$	Total requirements matrix
Factor production coefficients	$S = Fx^{\wedge-1}$	–
Gross output	$x = Z_e + Y_e$	–
Transaction matrix	Z_e	Matrix of interindustry flows or intermediate transaction matrix
Final demand matrix	Y_e	–
Final demand matrix to satisfy factors of production abroad	$Y_t = Y - Y_{i,j} i = j$	Final demand matrix with domestically satisfied final demand set to zero

Scholars and practitioners have extensively discussed the merits and drawbacks of different input-output database structures, compilation and manipulation techniques.^{58,59,60,61,62} According to Tukker and colleagues and Wiedmann and colleagues^{63,64,65}, there are several approaches to calculate footprints.

When possible, we employ a variation of method six (the SNAC approach⁶⁶), in which flows are not rebalanced after the nesting of national data into the multi-regional system. This is not critical for a national analysis, and updating the global database for the national lens ensures that discrepancies related to global harmonisation are not going to impact the results for a national analysis. The SNAC approach consists of updating the domestic monetary blocks using bottom-up (national) IOTs. However, in order to keep the MRIO

⁵⁸ Schoer, K., Wood, R., Arto, I., & Weinzettel, J. (2013). *Estimating raw material equivalents on a macro-level: comparison of multi-regional input-output analysis and hybrid LCI-IO*. Environmental science & technology, 47(24), 14282-14289. doi:10.1021/es404166f

⁵⁹ Giljum, S., Lutter, S., Wieland, H., Eisenmenger, N., Wiedenhofer, D., Schaffartzik, A., & West, J. (2015). *An empirical assessment comparing input-output based and hybrid methodologies to measure demand-based material flows*. Paris: Organisation for Economic Co-operation and Development.

⁶⁰ Bruckner, M., Fischer, G., Tramberend, & S., Giljum, S. (2015). *Measuring telecouplings in the global land system: A review and comparative evaluation of land footprint accounting methods*. Ecological Economics 114, 11-21. doi:10.1016/j.ecolecon.2015.03.008

⁶¹ Kovanda, J., Weinzettel, J., & Schoer, K. (2018). *What Makes the Difference in Raw Material Equivalents Calculation Through Environmentally Extended Input-Output Analysis?*. Ecological economics, 149, 80-87. doi:10.1016/j.ecolecon.2018.03.004

⁶² Giljum, S., Wieland, H., Lutter, S., Eisenmenger, N., Schandl, H., & Owen, A. (2019). *The impacts of data deviations between MRIO models on material footprints: A comparison of EXIOBASE, Eora, and ICIO*. Journal of industrial ecology, 23(4), 946-958. doi:10.1111/jiec.12833

⁶³ Tukker, A., de Koning, A., Owen, A., Lutter, S., Bruckner, M., Giljum, S., ... & Hoekstra, R. (2018). *Towards robust, authoritative assessments of environmental impacts embodied in trade: Current state and recommendations*. Journal of Industrial Ecology, 22(3), 585-598. doi:10.1111/jiec.12716

⁶⁴ Tukker, A., Giljum, S., & Wood, R. (2018b). *Recent progress in assessment of resource efficiency and environmental impacts embodied in trade: An introduction to this special issue*. Journal of Industrial Ecology, 22(3), 489-501. doi:10.1111/jiec.12736

⁶⁵ Wiedmann, T., Chen, G., Owen, A., Lenzen, M., Doust, M., Barrett, J., & Steele, K. (2021). *Three-scope carbon emission inventories of global cities*. Journal of Industrial Ecology, 25(3), 735-750. doi:10.1111/jiec.12736

⁶⁶ Edens, B., Hoekstra, R., Zult, D., Lemmers, O., Wilting, H., & Wu, R. (2015). *A method to create carbon footprint estimates consistent with national accounts*. Economic Systems Research, 27(4), 440-457

symmetrical, the sectoral classification system is remapped to the EXIOBASE sectors, or vice-versa, aggregating and disaggregating any sectors where needed. Imports and exports in the national IOT are used to correct the linkages with other regions in the MRIO.

However, note that the environmentally-extended (EE) part of the MRIO is not often updated, and still contains emission and material use intensities based on the EXIOBASE sectors. In rare cases, this may cause unintended results. For example, if a sector (e.g. Research and Development) has a low monetary value in EXIOBASE its emission intensity may be relatively high without much impact, but when the national IOT suddenly reports a much bigger monetary value in this sector it will use the high intensity factor from EXIOBASE and thus create a large impact out of “thin air”. These cases cannot be easily predicted and arise from the nature of MRIOs in and of themselves.

Annex B: Supporting information for the Circular Jobs Analysis

Table 1: Overview of sectors of [fully] circular economy activity, identified in ISIC

Sectors of	ISIC	R	Rationale for	Known issues / challenges	Corresponds with
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circular economy activities	(1-4 digit)	strategies	inclusion		CEA
Renting and leasing of motor vehicles; personal and household goods; other machinery, equipment and tangible goods (N)	771 772 773	Rethink Reduce	Shared access, and the shift from product to service can reduce production needs. Can create incentives for extended product lifespans.	Rebound effects ⁶⁷ (e.g. increased affordability of new, luxury goods). Circularity depends on product longevity, usage patterns and business models.	No
Library and archives activities (R)	9101		Shared access improves product utilization. Reduces demand for new goods.	Need to be accessible to avoid idle time. Digital alternatives may be more resource efficient.	No
Urban and suburban passenger land transport (H)	4921	Rethink Reduce	Shared access, and the shift from product to service can reduce production needs. Reduces demand for new extraction and private car usage.	Extent of circular strategies like repair, remanufacturing and recycling within public transport are not captured. Public transport in many countries still largely relies on fossil fuels.	No
Retail sale of second-hand goods (G)	4774	Reuse	Extends product lifespans. Reduces demand for new goods.	Rebound effects (e.g. increased affordability of new, luxury goods that retain resale value). Circularity depends on product longevity and usage patterns.	No
Repair of fabricated metal products, machinery and equipment (C)	331	Repair Refurbish	Extends product lifespans. Reduces the need for new production.	Often requires new manufactured parts rather than refurbished / reused equipment. Some specialized repairs may be energy and resource intensive.	No

⁶⁷ "Circular economy rebound occurs when circular economy activities, which have lower per-unit-production impacts, also cause increased levels of production, reducing their benefit." ([Zink and Geyer, 2017](#)).

Maintenance and repair of motor vehicles (G)	452				No
Repair of computers and personal household goods (S)	95				No
Washing and (dry-) cleaning of textile and fur products (S)	9601		Extends the lifetime of products. Can also carry out repairs and alterations.	It sometimes requires intensive use of chemicals, water and energy.	No
Sewerage (E)	37	Recycle Recover	Wastewater treatment enables recycling and reuse, and the recovery of nutrients.	Wastewater is not always treated. Treated water is often discharged instead of recycled.	Yes
Waste collection (E)	381		Extracts valuable materials from waste streams.	Waste collection does not ensure recycling.	Yes
Materials recovery (E)	383		Enables recycling and materials recovery.	Downcycling limits full recovery potential.	Yes
Remediation activities and other waste management services (E)	39			Losses during recovery, sorting and processing.	Yes
Wholesale of waste and scrap and other products n.e.c. (G)	4669		Extracts value from waste streams. Reduces demand for new extraction.	Should exclude wholesale of industrial chemicals ('other products n.e.c.').	No

Table 2: Overview of sectors of partially-circular economy activity, identified in ISIC

Sector of partially circular economy activities	Sectors of circular economy activities	ISIC 4-digit	Approach to determining circularity
Agriculture	Growing of cereals (except rice), leguminous crops, and oil seeds	0111	Agriculture secondary model
	Growing of rice	0112	Agriculture secondary model
	Growing of vegetables and melons, roots and tubers	0113	Agriculture secondary model
	Growing of sugar cane	0114	Agriculture secondary model
	Growing of tobacco	0115	Agriculture secondary model
	Growing of fibre crops	0116	Agriculture secondary model
	Growing of other non-perennial crops	0119	Agriculture secondary model
	Growing of grapes	0121	Agriculture secondary model
	Growing of tropical and subtropical fruits	0122	Agriculture secondary model
	Growing of citrus fruits	0123	Agriculture secondary model
	Growing of pome fruits and stone fruits	0124	Agriculture secondary model
	Growing of other tree and bush fruits and nuts	0125	Agriculture secondary model
	Growing of oleaginous fruits	0126	Agriculture secondary model
	Growing of beverage crops	0127	Agriculture secondary model
	Growing of spices, aromatic, drug and pharmaceutical crops	0128	Agriculture secondary model
	Growing of other perennial crops	0129	Agriculture secondary model
	Support activities for crop production	0161	Agriculture secondary model
Mining and quarrying	Quarrying of stone, sand and clay	0810	Economic circularity
	Support activities for other mining and quarrying	0990	Economic circularity
Manufacturing	Processing and preserving of meat	1010	Average of economic circularity and material circularity

	Processing and preserving of fish, crustaceans and molluscs	1020	Average of economic circularity and material circularity
	Processing and preserving of fruit and vegetables	1030	Average of economic circularity and material circularity
	Manufacture of vegetable and animal oils and fats	1040	Average of economic circularity and material circularity
	Manufacture of dairy products	1050	Average of economic circularity and material circularity
	Manufacture of grain mill products	1061	Average of economic circularity and material circularity
	Manufacture of starches and starch products	1062	Average of economic circularity and material circularity
	Manufacture of bakery products	1071	Average of economic circularity and material circularity
	Manufacture of sugar	1072	Average of economic circularity and material circularity
	Manufacture of cocoa, chocolate and sugar confectionery	1073	Average of economic circularity and material circularity
	Manufacture of macaroni, noodles, couscous and similar farinaceous products	1074	Average of economic circularity and material circularity
	Manufacture of prepared meals and dishes	1075	Average of economic circularity and material circularity
	Manufacture of other food products n.e.c.	1079	Average of economic circularity and material circularity
	Manufacture of prepared animal feeds	1080	Average of economic circularity and material circularity
	Distilling, rectifying and blending of spirits	1101	Average of economic circularity and material circularity
	Manufacture of wines	1102	Average of economic circularity and material circularity
	Manufacture of malt liquors and malt	1103	Average of economic circularity and material circularity
	Manufacture of soft drinks; production of mineral waters and other bottled waters	1104	Average of economic circularity and material circularity
	Manufacture of tobacco products	1200	Average of economic circularity and material circularity
	Preparation and spinning of textile fibres	1311	Average of economic circularity and

			material circularity
	Weaving of textiles	1312	Average of economic circularity and material circularity
	Finishing of textiles	1313	Average of economic circularity and material circularity
	Manufacture of other textiles	1391	Average of economic circularity and material circularity
	Manufacture of knitted and crocheted fabrics	1392	Average of economic circularity and material circularity
	Manufacture of made-up textile articles, except apparel	1393	Average of economic circularity and material circularity
	Manufacture of carpets and rugs	1394	Average of economic circularity and material circularity
	Manufacture of cordage, rope, twine and netting	1399	Average of economic circularity and material circularity
	Manufacture of wearing apparel, except fur apparel	1410	Average of economic circularity and material circularity
	Manufacture of articles of fur	1420	Average of economic circularity and material circularity
	Manufacture of knitted and crocheted apparel	1430	Average of economic circularity and material circularity
	Tanning and dressing of leather; manufacture of luggage, handbags, saddlery and harness	1511	Average of economic circularity and material circularity
	Manufacture of footwear	1520	Average of economic circularity and material circularity
	Sawmilling and planing of wood	1610	Average of economic circularity and material circularity
	Manufacture of veneer sheets; manufacture of plywood, laminboard, particle board and other panels	1621	Average of economic circularity and material circularity
	Manufacture of builders' carpentry and joinery	1622	Average of economic circularity and material circularity
	Manufacture of wooden containers	1623	Average of economic circularity and material circularity
	Manufacture of other products of wood; manufacture of articles of cork, straw and plaiting materials	1629	Average of economic circularity and material circularity

	Manufacture of pulp, paper and paperboard	1701	Average of economic circularity and material circularity
	Manufacture of corrugated paper and paperboard and of containers of paper and paperboard	1702	Average of economic circularity and material circularity
	Manufacture of other articles of paper and paperboard	1709	Average of economic circularity and material circularity
	Printing	1811	Average of economic circularity and material circularity
	Service activities related to printing	1812	Average of economic circularity and material circularity
	Reproduction of recorded media	1820	Average of economic circularity and material circularity
	Manufacture of coke oven products	1910	Average of economic circularity and material circularity
	Manufacture of refined petroleum products	1920	Average of economic circularity and material circularity
	Manufacture of basic chemicals	2011	Average of economic circularity and material circularity
	Manufacture of fertilizers and nitrogen compounds	2012	Average of economic circularity and material circularity
	Manufacture of plastics and synthetic rubber in primary forms	2013	Average of economic circularity and material circularity
	Manufacture of pesticides and other agrochemical products	2021	Average of economic circularity and material circularity
	Manufacture of paints, varnishes and similar coatings, printing ink and mastics	2022	Average of economic circularity and material circularity
	Manufacture of soap and detergents, cleaning and polishing preparations, perfumes and toilet preparations	2023	Average of economic circularity and material circularity
	Manufacture of other chemical products n.e.c.	2029	Average of economic circularity and material circularity
	Manufacture of man-made fibres	2030	Average of economic circularity and material circularity
	Manufacture of pharmaceuticals, medicinal chemical and botanical products	2100	Average of economic circularity and material circularity
	Manufacture of rubber products	2211	Average of economic circularity and material circularity

	Manufacture of plastics products	2220	Average of economic circularity and material circularity
	Manufacture of glass and glass products	2310	Average of economic circularity and material circularity
	Manufacture of refractory products	2391	Average of economic circularity and material circularity
	Manufacture of clay building materials	2392	Average of economic circularity and material circularity
	Manufacture of other porcelain and ceramic products	2393	Average of economic circularity and material circularity
	Manufacture of cement, lime and plaster	2394	Average of economic circularity and material circularity
	Manufacture of articles of concrete, cement and plaster	2395	Average of economic circularity and material circularity
	Cutting, shaping and finishing of stone	2396	Average of economic circularity and material circularity
	Manufacture of other non-metallic mineral products n.e.c.	2399	Average of economic circularity and material circularity
	Manufacture of basic iron and steel	2410	Average of economic circularity and material circularity
	Manufacture of basic precious and other non-ferrous metals	2420	Average of economic circularity and material circularity
	Casting of metals	2431	Average of economic circularity and material circularity
	Manufacture of structural metal products	2511	Average of economic circularity and material circularity
	Manufacture of tanks, reservoirs and containers of metal	2512	Average of economic circularity and material circularity
	Manufacture of steam generators, except central heating hot water boilers	2513	Average of economic circularity and material circularity
	Manufacture of weapons and ammunition	2520	Average of economic circularity and material circularity
	Manufacture of fabricated metal products, except machinery and equipment n.e.c.	2591	Average of economic circularity and material circularity
	Manufacture of cutlery, hand tools and general hardware	2592	Average of economic circularity and material circularity
	Manufacture of other fabricated metal	2599	Average of economic circularity and material circularity

	products n.e.c.		material circularity
	Manufacture of electronic components and boards	2610	Average of economic circularity and material circularity
	Manufacture of computers and peripheral equipment	2620	Average of economic circularity and material circularity
	Manufacture of communication equipment	2630	Average of economic circularity and material circularity
	Manufacture of consumer electronics	2640	Average of economic circularity and material circularity
	Manufacture of measuring, testing, navigating and control equipment	2651	Average of economic circularity and material circularity
	Manufacture of watches and clocks	2652	Average of economic circularity and material circularity
	Manufacture of irradiation, electromedical and electrotherapeutic equipment	2660	Average of economic circularity and material circularity
	Manufacture of optical instruments and photographic equipment	2670	Average of economic circularity and material circularity
	Manufacture of magnetic and optical media	2680	Average of economic circularity and material circularity
	Manufacture of electric motors, generators, transformers and electricity distribution apparatus	2710	Average of economic circularity and material circularity
	Manufacture of batteries and accumulators	2720	Average of economic circularity and material circularity
	Manufacture of wiring and wiring devices	2731	Average of economic circularity and material circularity
	Manufacture of electric lighting equipment	2740	Average of economic circularity and material circularity
	Manufacture of domestic appliances	2750	Average of economic circularity and material circularity
	Manufacture of other electrical equipment	2790	Average of economic circularity and material circularity
	Manufacture of general-purpose machinery	2811	Average of economic circularity and material circularity
	Manufacture of pumps, compressors, taps and valves	2813	Average of economic circularity and material circularity
	Manufacture of lifting and handling	2816	Average of economic circularity and

	equipment		material circularity
	Manufacture of other general-purpose machinery	2819	Average of economic circularity and material circularity
	Manufacture of special-purpose machinery	2821	Average of economic circularity and material circularity
	Manufacture of metal-forming machinery and machine tools	2822	Average of economic circularity and material circularity
	Manufacture of machinery for metallurgy	2823	Average of economic circularity and material circularity
	Manufacture of machinery for mining, quarrying and construction	2824	Average of economic circularity and material circularity
	Manufacture of other special-purpose machinery	2829	Average of economic circularity and material circularity
	Manufacture of motor vehicles	2910	Average of economic circularity and material circularity
	Manufacture of bodies (coachwork) for motor vehicles; manufacture of trailers and semi-trailers	2920	Average of economic circularity and material circularity
	Manufacture of parts and accessories for motor vehicles	2930	Average of economic circularity and material circularity
	Building of ships and boats	3010	Average of economic circularity and material circularity
	Manufacture of railway locomotives and rolling stock	3020	Average of economic circularity and material circularity
	Manufacture of air and spacecraft and related machinery	3030	Average of economic circularity and material circularity
	Manufacture of military fighting vehicles	3040	Average of economic circularity and material circularity
	Manufacture of transport equipment n.e.c.	3090	Average of economic circularity and material circularity
	Manufacture of furniture	3100	Average of economic circularity and material circularity
	Manufacture of jewelry and related articles	3211	Average of economic circularity and material circularity
	Manufacture of musical instruments	3212	Average of economic circularity and material circularity
	Manufacture of sports goods	3230	Average of economic circularity and

			material circularity
	Manufacture of games and toys	3240	Average of economic circularity and material circularity
	Manufacture of medical and dental instruments and supplies	3250	Average of economic circularity and material circularity
	Manufacture of brooms and brushes	3290	Average of economic circularity and material circularity
	Repair of fabricated metal products, machinery and equipment	3311	Average of economic circularity and material circularity
	Installation of industrial machinery and equipment	3320	Average of economic circularity and material circularity
Construction	Construction of buildings	4100	Average of economic circularity and material circularity
	Construction of roads and railways	4210	Average of economic circularity and material circularity
	Construction of utility projects	4220	Average of economic circularity and material circularity
	Construction of other civil engineering projects	4290	Average of economic circularity and material circularity
	Demolition	4311	Average of economic circularity and material circularity
	Site preparation	4312	Average of economic circularity and material circularity
	Electrical installation	4321	Average of economic circularity and material circularity
	Plumbing, heat and air-conditioning installation	4322	Average of economic circularity and material circularity
	Other construction installation	4329	Average of economic circularity and material circularity
	Building completion and finishing	4330	Average of economic circularity and material circularity
	Other specialized construction activities	4390	Average of economic circularity and material circularity