Material flows in the circular economy

Content

This document presents additional figures that were elaborated during the data analysis for the monitoring of materials flows in the EU economy (indicator 15) in the 2018 Raw Materials Scoreboard, particularly the material flows diagram (so-called Sankey diagram). The final version of the Scoreboard indicator elaborates on option 1.

This document provides more details about the methodological changes in the indicator as compared to the 2016 version of the Scoreboard and about the alternative data options that were assessed and considered.

Novelties from the 2016 version of the Scoreboard

- An update of Figure 32 in the 2016 Raw Materials Scoreboard, which depicted materials flows in the EU economy using a so-called Sankey diagram. For that, two complementary approaches have been developed by JRC. Firstly, Eurostat statistics to visualize non-food and non-energy raw material flows (option 1). Secondly, a combination of Eurostat statistics with additional data collection/research by the Institute of Social Ecology in Vienna (Alpen Adria University) to visualize total material flows (i.e., including also biomass and fossil fuels for energy purposes) (option 2).

Key points

- A large part of the EU's material use consists of construction minerals, which are used to extend or maintain in-use stocks (e.g., buildings and infrastructure) with long life-times. These stocks often provide value to the EU economy for decades and will only become available for recycling when they reach their end-of-life.
- As long as the demand for raw materials used for in-use stocks with long life-times (e.g., buildings and infrastructure) exceeds the amount of materials that can be supplied from recycled materials, primary extraction will remain necessary.
- With focus on non-food and non-energy materials uses, recycling and backfilling equalled about 20% of overall material inputs to the EU economy in 2014 (Option 1). However, considering also fossil fuels and biomass for energy uses (Option 2), recycling and backfilling flows equalled about 8% of overall material inputs to the EU economy in 2014.
- The magnitude of recycling (compared to overall materials cycling) varies by material category and is highest for metals and lowest for fossil fuels.
- The circular use of raw materials in the EU economy could be improved by extending the life-time of products, e.g., through eco-design, repair and reuse, or by increasing end-of-life recycling rates for materials.

- The EU's import reliance is high for metals (and fossil fuels). While promoting a higher circularity can help to decrease import dependency for metals, the energetic use of raw materials (fossil fuels and biomass) currently limits their circular uses and reduces the overall level of materials circularity of the EU.

Facts and figures

Option 1: Sankey visualization of Eurostat data

- Figure 1a shows that of the 7.3 Gt[1] of materials that are used in the EU economy in 2014, 48% consist of fossil fuels and biomass mostly used for energy purposes[2]. The energetic use of non-renewable raw materials (i.e., fossil fuels) limits the overall level of materials circularity of the EU.
- The remaining 52% of material inputs consist of metals, construction minerals, biomass, and industrial minerals used for material purposes (non-food and non-energy material flows further examined in Figure 1b).

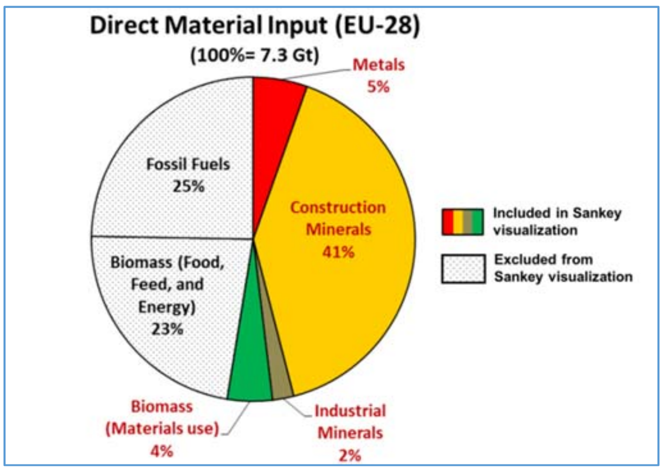


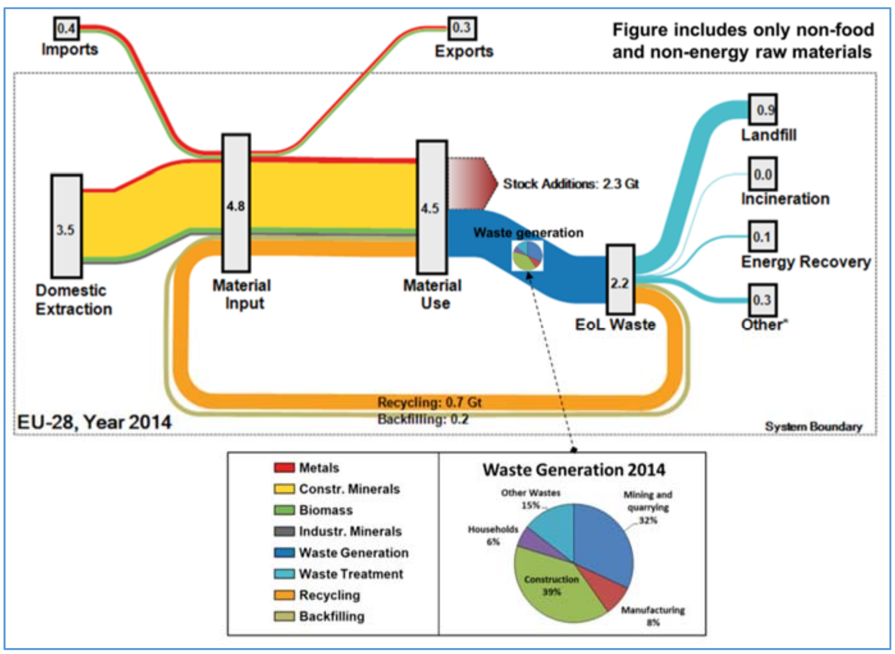
Figure 1a: Direct material input to the EU-28 economy by material type[3].

- Figure 1b depicts non-food and non-energy material flows[4] in the EU-28 economy in 2014. This figure solely relies on existing Eurostat data on material flows (inputs) and waste (outputs). By doing so, it can provide regular[5] insights into the order of magnitude of materials

[1] Gt = Gigatons = billion metric tons.
[2] Biomass for food and feed is considered as energetic use.
[3] Source: JRC elaboration based on Eurostat material flow accounts (http://ec.europa.eu/eurostat/web/environment/material-flows-and-resource-productivity/database)
[4] This focus is in line with the European innovation Partnership (EIP) on Raw Materials.
[5] Updates are possible every two years as new ESTAT material flow and waste statistics become available. Sankey diagrams can be provided from 2004 onwards (currently 2004, 2006, 2010, 2012, and 2014).

used in the EU economy, i.e., the domestic extraction, imports and exports, net stock additions, recycling, and waste treatment options.

- Of the 4.8 Gt of materials that are processed for material uses in the EU economy, 72% (3.5 Gt) originate from domestic extraction (mostly construction minerals), 8% (0.4 Gt) from imports, 15% (0.7 Gt) from recycling, and 5% (0.2 Gt) from backfilling. The EU is highly dependent on metal imports (0.21 Gt or 52% of all metals inputs).
- About 51% (2.3/4.5 Gt) of all non-energy and non-food materials used within the EU were added to stocks in 2014. Stock accumulation limits materials recovery because material stocks are not immediately available for recycling (but will become available in the future when products reach their end-of-life).
- Recycling provides circular use of materials within EU borders. Waste generated within the EU-28 amounted to 2.2 Gt. Of this, 39% (0.9 Gt) was landfilled, 6% (0.13 Gt) was incinerated (4% with energy recovery and 2% without energy recovery), 33% (0.7 Gt) recycled, 10% (0.2 Gt) backfilled (e.g., using materials as roadbed aggregates), and 12% sent to other treatments.



*Balancing flow in the Sankey diagram (e.g., due to unaccounted waste imports/exports).

Figure 1b: Material flows (non-energy and non-food) in the EU-28 economy (2014)[6].

[6] Source: Nuss P., Blengini G.A., Haas W., Mayer A., Nita. V., and Pennington D.P. (2017): Development of a Sankey Diagram of Material Flows in the EU Economy based on Eurostat Data, EUR 28811 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-79-73901-9, ISSN 1831-9424, doi:10.2760/362116.

Option 2: Update of the Sankey diagram of the 2016 version of the Scoreboard (Figure 32)

- Figure 2a depicts material flows in the EU-28 economy in 2014. This figure combines Eurostat data on material flows (inputs) and waste (outputs) with additional data and modelling assumption. By doing so, it provides up to date insights into the order of magnitude of materials used in the EU economy, e.g., the amounts of materials extracted, imported, recycled or disposed, as well as related emissions.
- Figure 2a shows that more than 72% (5.8 Gt[7]) of raw materials used in the EU originate from domestic extraction, 19% (1.5 Gt) from imports and 8% (0.7 Gt) from recycling and backfilling (0.06 Gt from backfilling) in 2014. The EU is highly import-dependent for metals and fossil fuels.
- Of the 8 Gt of materials that are processed in the EU economy, 39% (3.1 Gt) are used for energetic purposes, 53% (4.3 Gt) are used as materials, and 8% (0.6 Gt) are exported. The energetic use of non-renewable raw materials (i.e., fossil fuels) limits the overall level of materials circularity of the EU.
- Short-lived material products that have a life-span shorter than one year as well as manufacturing losses account for 0.8 Gt of all material use. The remaining 86% (3.5 Gt), mostly consisting of construction minerals, are used to build up and maintain societal in-use stocks (e.g., buildings, infrastructure and other goods with long life-times). These goods will only become available for recycling once they have reached their end-of-life.
- Stocks at end-of-life (demolition & discards) account for 0.9 Gt. Together with wastes from other material and energetic uses, total end-of-life (EoL) waste generated equals 2.2 Gt, of which 0.6 Gt remain in the EU economy through recycling and 0.06 Gt through backfilling (together about 0.7 Gt). Together this recycling stream equals 30% of all material waste flows. On the other hand, 2.6 Gt of materials leave the economy, e.g., as emissions to air and waste disposal.
- Option 2 provides complementary information to Option 1 as it also includes fossil fuels and biomass for energy purposes. It builds on Eurostat data, but requires additional data collection and might not be updated without significant research efforts.

[7] Gt = Gigatons = billion metric tons.

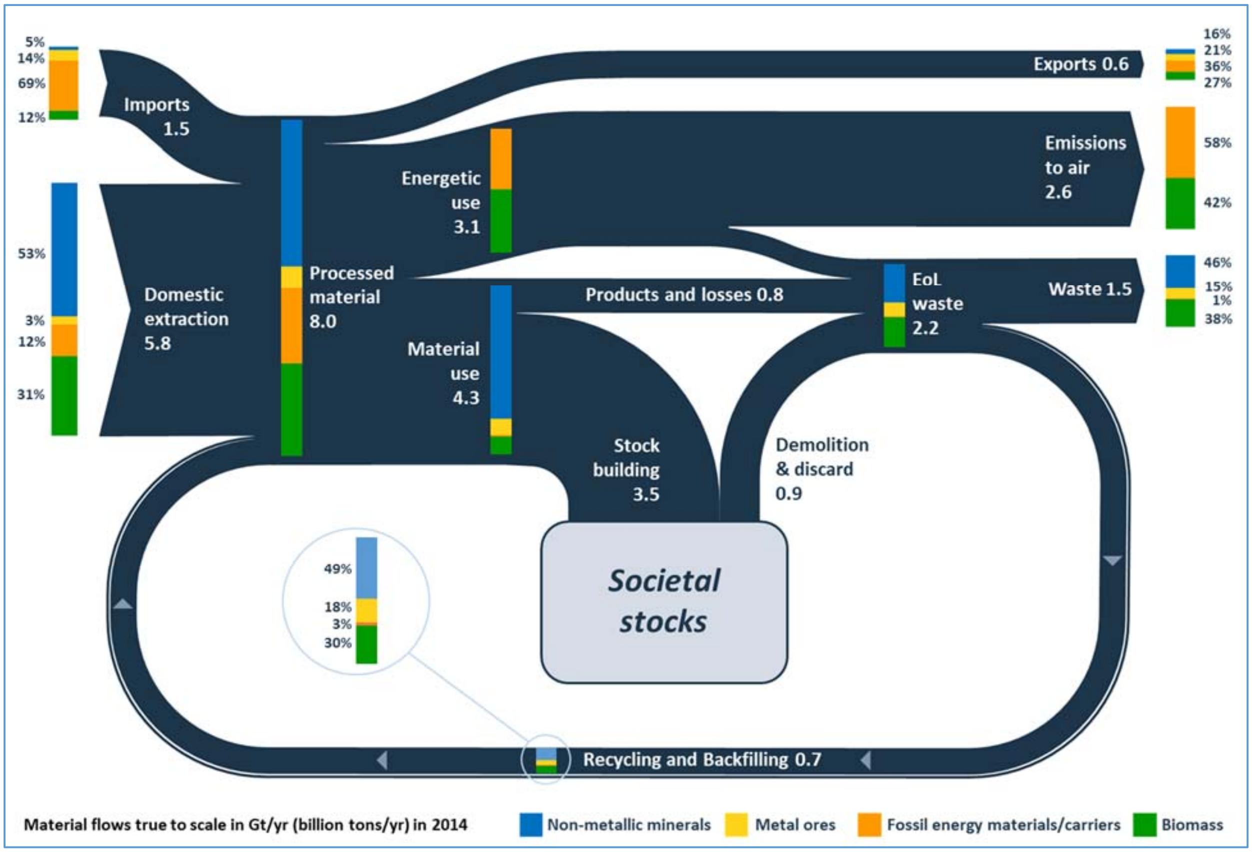


Figure 2a: Material flows in the EU-28 economy (2014)[8].

- Figure 2b shows material flows in the EU-28 in 2014 by individual material categories.
- Non-metallic minerals (top left) (including construction minerals and industrial minerals) represent nearly half of the EU-28's material use (3.1 Gt[9]) which is a considerable reduction in comparison to previous years and mainly a consequence of the financial and economic crisis around 2008. Around 3.1 Gt were added to societal in-use stocks and around 0.7 Gt were discarded, leading to an overall growth of societal in-use stocks in the EU. About 0.35 Gt of all non-metallic minerals were recovered (0.3Gt recycling and 0.05 Gt backfilling), equalling 10% of all inputs.
- As for metal ores (top right), while being of high economic and strategic importance, they only represent a minor proportion of the EU-28's material consumption in terms of mass. A large fraction of metals is from imports: 59% or 0.22 Gt. Of the 0.35 Gt of metals that were processed in 2014 (excluding extractive waste[10]), 34% (0.12 Gt) originate from domestic

[8] Source: Mayer A., Haas W., Wiedenhofer D., Krausmann F., Nuss P., Blengini G.A., 'Measuring progress towards a Circular Economy - a monitoring framework for economy-wide material loop closing in the EU28". Accepted for publication by Journal of Industrial Ecology. doi: 10.1111/jiec.12809.
[9] Gigaton (Gt) = billion metric tons.
[10] Extractive waste refers to the mineral waste remaining after extracting pure metals from the metal ores.

recycling in the EU. More than half of the processed metals were integrated into societal in-use stocks. The domestic extraction of metals (gross ores) splits into pure metal flows and extractive waste flows (0.17 Gt) which become end-of-life waste.

- Nearly a fifth of processed biomass (bottom left), mostly wood from domestic extraction, is used for material uses. About 9% (0.2 Gt) of the processed biomass is secondary biomass from recycling. Approximately 18% (0.4 Gt) of the processed biomass is used for material purposes such as pulp and paper production, for construction purposes, and manufacturing of other wood products (e.g., furniture). About 9% (0.2 Gt) of the processed biomass is added to societal in-use stocks. A major fraction of biomass (1.1 Gt) is used for energetic purposes like food, feed and agro fuels.
- The majority of fossil fuels (bottom right) are used for their energetic value. Less than 3% of the processed fossil energy carriers are used as plastic, oils, tyres, or for chemical purposes – uses from which the carbon could be recovered at end-of-life. 54% of these materials were recovered. The use of fossil resources for energy production limits the circular use of raw materials in the EU.

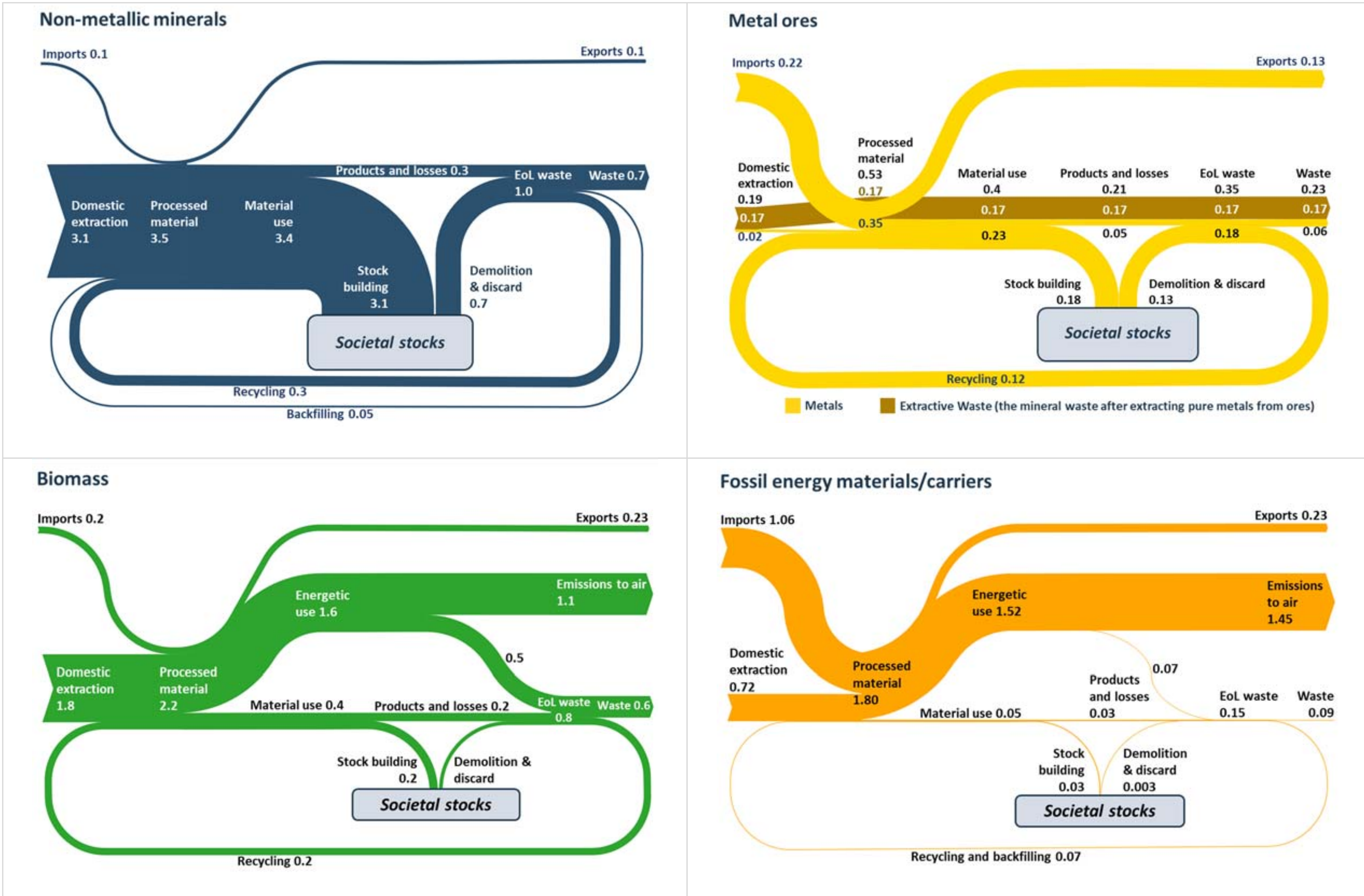


Figure 2b: Material flows for single material categories in the EU-28 economy (2014)[11].

[11] Source: Mayer A., Haas W., Wiedenhofer D., Krausmann F., Nuss P., Blengini G.A., 'Measuring progress towards a Circular Economy - a monitoring framework for economy-wide material loop closing in the EU28". Accepted for publication by Journal of Industrial Ecology. doi: 10.1111/jiec.12809.

Strengths and weaknesses of the options for the material flows figure

Both options presented provide insights into material flows in the EU economy and support, to a large extent, the same key points and message. Strengths and weaknesses are summarised in the following table.

Option	Strengths	Weaknesses
1 Sankey visualization of Eurostat data	Relies only on Eurostat statistics (RACER-compliant) EW-MFA data are annually updated. Waste statistics are updated biannually Sankeys for the period 2004 – 2014 can be generated and trends observed Sankey diagrams for individual EU-28 MS can be generated Focused on EIP scope in terms of raw materials coverage	Due to data availability individual material categories cannot be easily traced throughout the whole life cycle Waste generation and treatment statistics are not directly comparable. For this a "unbalanced / phantom flow" is introduced into the cycle
2 Update of the Sankey diagram of the 2016 Scoreboard	Encompasses also fossil fuels and biomass (for energy uses) and provides, therefore, a more holistic picture of raw material flows in one single Sankey diagram Can initiate a discussion on data required beyond current EU statistics to develop a circular economy Sankey diagram encompassing all major materials Materials can be tracked throughout the whole Sankey diagram (assumptions needed)	Requires additional research and assumptions (beyond existing statistical data) which might hinder future updates and RACER compliancy. Resulting flow magnitudes might not always align with official Eurostat statistics. Time trends not available

Methodological notes

Option 1

- **Name of indicator:** Material flows (Sankey visualization) in the EU economy based on Eurostat data.
- **Organization (data provider) and description of data:** The Sankey diagram elaborated in this option relies on Eurostat statistics provided on an annual / biennial basis. The extraction of raw materials and their imports and exports are captured using **Economy-Wide Material Flow Analysis (EW-MFA)**[12] available for the following material categories: metals, construction minerals, industrial minerals, wood, fossil fuels, and biomass (for energy and food/feed purposes). Because of the focus of the Scoreboard on non-energy and non-food raw materials (EIP-RM), this option follows metals, construction minerals, industrial minerals and timber.

  The material flow from material use to the end-of-lie (EoL) waste stage is quantified using the **ESTAT waste generation statistics (env_wasgen)**[13]. For this, the total waste except W09 (Animal and vegetal wastes), W11 (Common Sludges), and W124 (Combustions Wastes) is used. The biotic fraction of W101 (Houseld and similar wastes) and W102 (Mixed and undifferentiated materials) is excluded assuming an average composition of 31% vegetable matter[14]. Waste generation is broken down into waste flows originating from (1) Mining and Quarrying, (2) Manufacturing, (3) Construction, (4) Households, and (5) Other. The difference between the total material quantities of material use (i.e., domestic materials consumption (DMC) + recycling + backfilling) and waste generation is considered as net additions to stocks in a single year.

  The split from waste management into different waste treatment options is captured using the **ESTAT waste treatment statistics (env_wastrt)**[15]. These provide a split of waste materials into the fractions going to landfills, incineration without energy recovery, incineration with energy recovery (Energy-to-Waste), materials backfilled[16], and recycling[17]. We note that waste treatment includes wastes imported into the EU and the reported amounts are therefore not directly comparable with the waste generation statistics. Because of the difficulty of determining waste imports and exports, we close the balance by using a phantom flow in the Sankey diagram termed "other" waste treatment.
- **Update frequency:** The Sankey diagram elaborated in this option relies on Eurostat statistics provided on an annual / biennial basis.
- **Geographic and time coverage:**

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[12] http://ec.europa.eu/eurostat/web/environment/material-flows-and-resource-productivity/database
[13] http://ec.europa.eu/eurostat/web/environment/waste/database
[14] Fraunhofer, 2014. Waste2Go: Waste Profiling. FhG-IBP (Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V.).
[15] http://ec.europa.eu/eurostat/web/environment/waste/database
[16] Backfilling is the use of waste in excavated areas for the purpose of slope reclamation or safety or for engineering purposes in landscaping.
[17] Recycling" is defined by ESTAT as: "any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations." The common idea behind recycling is that a waste material is processed in order to alter its physicochemical properties allowing it to be used again for the original or for other purposes and thus of closing the economic material circle.

- EW-MFA: EU-28 and each member state from 1990 – 2016 (published annually)
- Eurostat waste generation: EU-28 and each member states for years 2004, 2006, 2008, 2010, 2012, 2014 (published every two years).
- Eurostat waste treatment: EU-28 and each member states for years 2004, 2006, 2008, 2010, 2012, 2014 (published every two years).

- **JRC processing methodology for the indicator:** see JRC Technical report[18].

Option 2

- **Name of indicator:** Material flows in the EU-28 economy.
- **Organization (data provider) and description of data:** The JRC together with the Institute of Social Ecology in Vienna (Alpen Adria University) carried out a study to update the Sankey diagram on material flows in the EU-28 that was included in the 2016 Scoreboard. This updated Sankey diagram combines Eurostat economy-wide material flow accounts (EW-MFA) and waste statistics for 2014 with additional data collection and research[19]. The Sankey diagram systematically uses the latest available Eurostat data from EW-MFA[20] for raw materials inputs from domestic extraction and imports, and to capture exports to non-EU countries. The allocation of material flows into the different material categories and the split between energetic and material use are based on recent scientific publications[21]. Conversion factors to calculate the amount of metal vs. extractive waste are based on Eurostat[22]. Additional research and literature studies were undertaken, e.g., to determine the fraction of crude oil and natural gas used for material purposes (e.g., plastics, lubricants, tyres), or to determine the share of materials used in short-lived vs. long-lived products.
- **Update frequency:** The Sankey diagram elaborated in this option is not regularly updated.
- **Geographic and time coverage:**
  - EW-MFA: EU-28 and each member state from 1990 – 2016 (published annually)
  - Eurostat waste generation: EU-28 and each member states for years 2004, 2006, 2008, 2010, 2012, 2014 (published every two years).
  - Eurostat waste treatment: EU-28 and each member states for years 2004, 2006, 2008, 2010, 2012, 2014 (published every two years).

[18] Nuss P., Blengini G.A., Haas W., Mayer A., Nita. V., and Pennington D.P. (2017): Development of a Sankey Diagram of Material Flows in the EU Economy based on Eurostat Data, EUR 28811 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-79-73901-9, ISSN 1831-9424, doi:10.2760/362116.
[19] Mayer A., Haas W., Wiedenhofer D., Krausmann F., Nuss P., Blengini G.A., 'Measuring progress towards a Circular Economy - a monitoring framework for economy-wide material loop closing in the EU28". Accepted for publication by Journal of Industrial Ecology. doi: 10.1111/jiec.12809.
[20] http://ec.europa.eu/eurostat/web/environment/material-flows-and-resource-productivity/database
[21] Haas W. et al., 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) (pp. 765-777).
[22] Eurostat 2013. *'Economy-wide material flow accounts (EW-MFA) Compilation Guide 2013'*.

- **JRC processing methodology for the indicator:** see JRC/Vienna University scientific publication[23] for full details that complements those provided here. Eurostat waste treatment statistics[24] are used and, where necessary, are complemented to model the amounts of waste at end-of-life (EoL), recycling and backfilling flows, and waste crossing into nature. Because the waste flows are reported using different classifications than the EW-MFA, waste flows were reallocated to match the material flow accounts (material categories) using a mix of information, e.g., from the scientific literature and expert judgements. A further distinction between wastes originating from material or energetic uses is made. Selected modifications are made, e.g., to adjust the water contents in flows of sludge and effluents.

  The Sankey model is based on the law of conservation of mass. It combines reported input and output data from the Eurostat statistics, and models flows which are not reported in official statistics to balance differences in reported input and output flows. Estimates of the annual material stock additions and the fraction of demolition and discard flows from societal stocks to EoL waste management are based on stocking rates reported in the scientific literature[25] [26].

  Figure 15.3 presents an overview of the different data points for material flows through the EU-28 indicating some of the data sources used and an assessment of the degree of uncertainty of the diagram's different components. Grey and blue boxes indicate flows that are based on Eurostat statistics, while green boxes represent estimates based on the MFA model developed. The numbers included in the small circles further present an assessment of the degree of data uncertainty (i.e., the best estimate ± uncertainty range) and the lack of completeness of data sources. These uncertainties in material flow data were classified using expert judgements and the scientific literature[27] [28] and range from ±10% (lower uncertainty), ±20% (medium uncertainty), to ±30% (higher uncertainty).

[23] Nuss P., Blengini G.A., Haas W., Mayer A., Nita. V., and Pennington D.P. (2017): Development of a Sankey Diagram of Material Flows in the EU Economy based on Eurostat Data, EUR 28811 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-79-73901-9, ISSN 1831-9424, doi:10.2760/362116.

[24] http://ec.europa.eu/eurostat/web/environment/waste/database

[25] Haas W. et al., 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) (pp. 765-777).

[26] Krausmann, F. et al. 2017. *'Global socioeconomic material stocks rise 23-fold over the 20th century and require half of annual resource use'*. Proceedings of the National Academy of Sciences 114(8) (pp. 1880–1885).

[27] Fischer-Kowalski, M., Krausmann, F., Giljum, S., Lutter, S., Mayer, A., Bringezu, S., Moriguchi, Y., Schütz, H., Schandl, H., Weisz, H., 2011. *'Methodology and Indicators of Economy-wide Material Flow Accounting'*. Journal of Industrial Ecology 15, 855–876. doi:10.1111/j.1530-9290.2011.00366.x

[28] Monier, V., M. Hestin, M. Trarieux, S. Mimid, L. Domrose, M. van Acoleyen, P. Hjerp, and S. Mugdal. 2011. '*Study on the management of construction and demolition waste in the EU*'. Contract 07.0307/2009/540863/SER/G2. Final report for the European Commission DG Environment. Paris: Bio Intelligence Service S.A.S

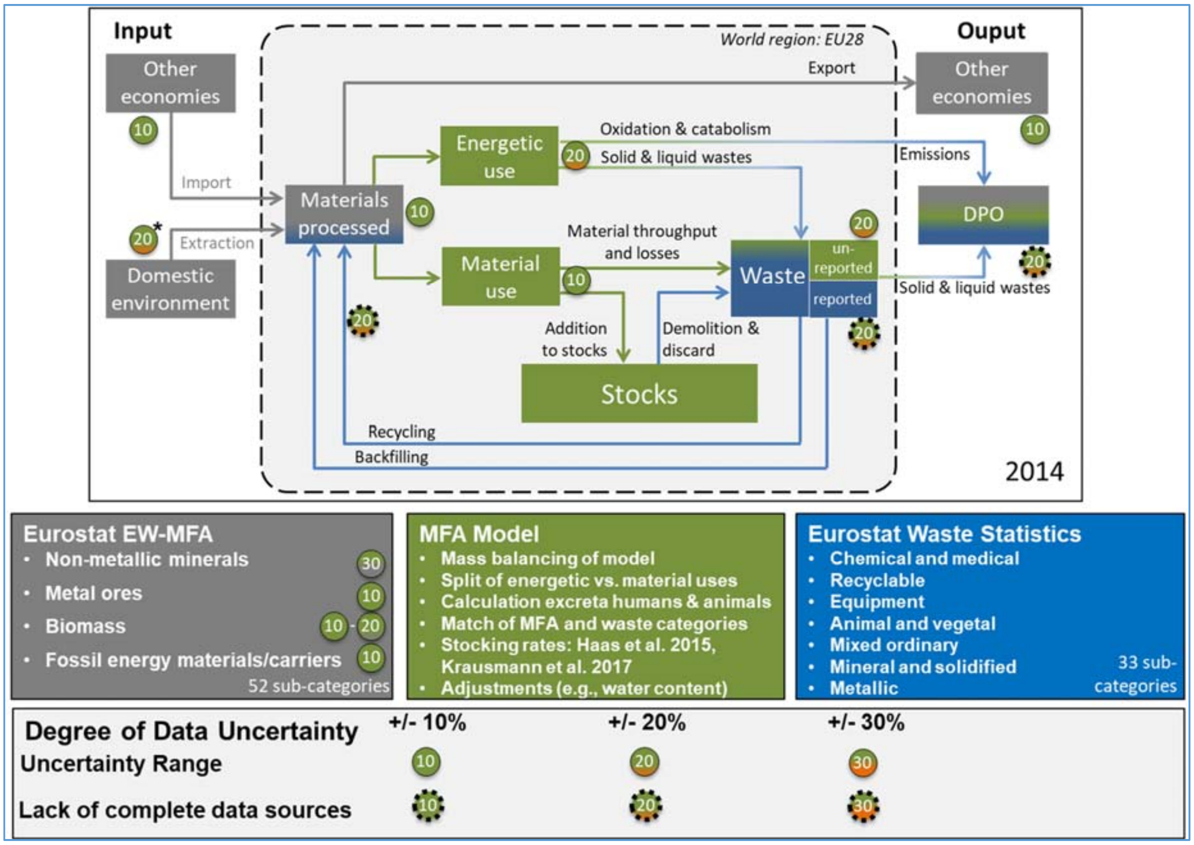

Figure 15.3: Data and sources for assessing the circularity of the EU28-economy, including estimates of uncertainty ranges and completeness of data sources. *Uncertainty ranges between 10-30%.

For some material groups, such as many metals, fossil energy carriers, and biomass, a broad knowledge of the material system and solid data exist. For other materials the data situation is less satisfying and the level of uncertainty is considerable, in particular for recycling rates and flows of non-metallic minerals (i.e. construction minerals).

Data on stocks, addition to stocks, and the separation between energetic and material use, which are not reported by Eurostat material flow statistics, are estimated based on available information gathered in a broad literature survey. Flows that are not reported but estimated, e.g. for the biomass category (by-products and residues as well as biomass grazed by ruminant livestock) and industrial & construction minerals (bulk mineral flows), are acknowledged to add uncertainty to the model.

Further, in relation to waste flows, there are three issues that cause a certain level of uncertainty. First, Eurostat waste statistics, which are collected based on the Waste Statistics Regulation, do not comprise all flows that are included on the input side (EW-MFA). In order to balance this lack of completeness, these flows are estimated and included under the category "un-reported waste flows". These flows are mainly from agriculture, comprise largely biomass, and have consequently the same degree of uncertainty as the biomass input data (i.e. 20%). More specifically, these are excretions of humans and livestock which can be modelled but which are only reported to a very limited degree. The second source of uncertainty is related to the right allocation of waste flows to the different environmental media. The outflows into the environment are a matter of simplification. In the modelling, they are treated as if they all sooner or later disperse as solid or liquid waste into the environment (e.g. via leachate). In reality, landfills and incineration plants divert a large share into emissions to air. According to expert assessments, medium uncertainty is assigned to these flows. A third source of uncertainty is related to recycling itself. While data on recovered flows are more or less reliable, it remains uncertain to a higher degree, how much of the recovered materials become secondary material to replace primary raw materials, how much consists of downcycling[29] [30], and how much become losses during the preparation phase.

In sum, it is acknowledged that there are considerable uncertainties in the results presented. Nonetheless, the authors conclude that the data reliability is sufficient to provide a rough but comprehensive assessment of the circularity of the economy at the level of material groups. Due to the assumptions made, it is generally considered that the model overestimates the circular use of materials in the EU economy.

[29] 'Downcycling' refers to reprocessing, where the new product from these recycled materials has a lower material quality than the original product (e.g., plastic bottles become street boundary posts).

[30] Haas, W., Krausmann, F. Wiedenhofer, D. and Heinz, M. 2016. '*How Circular is the Global Economy? A Sociometabolic Analysis*'. In: Social Ecology: Society-nature Relations across Time and Space (Eds.) Haberl, H., Fischer-Kowalski, M., Krausmann, F. and Winiwarter V., Springer, Cham Heidelberg New York Dordrecht London)