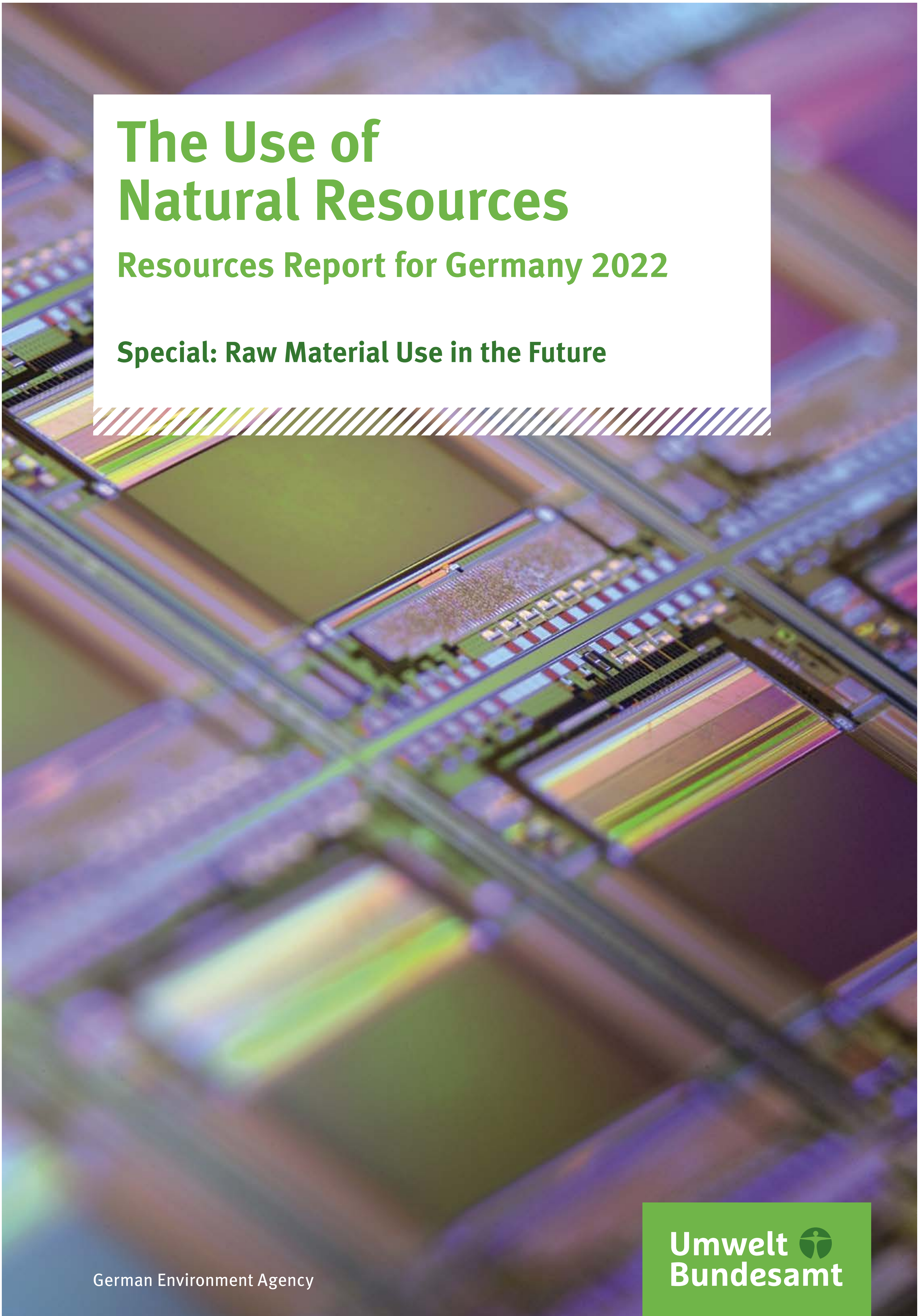
The Use of Natural Resources

Resources Report for Germany 2022

Special: Raw Material Use in the Future



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The Use of Natural Resources

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Special: Raw Material Use in the Future

Dear Readers,

Exactly fifty years ago, the “The Limits to Growth” report by the Club of Rome triggered a broad international debate about the natural limits of an economy focused on growth.

Although not all the forecasts in this report came to pass, one thing is clear: we are already exceeding certain planetary boundaries, thereby limiting future generations in their potential development. As this third “UBA Resources Report” illustrates, there is a direct connection here with the excessive use of natural resources.

According to information provided by the United Nations “International Resource Panel” (IRP), global raw material extraction has increased more than threefold over the past five decades and, without appropriate counter-measures, will continue its rapid rise in the future. Global environmental problems such as climate change, soil degradation, water shortages and loss of biodiversity are exacerbated by raw material extraction. According to calculations by the IRP, 40 per cent of greenhouse gas emissions in Germany are attributable to the extraction and initial processing of raw materials alone.

German raw material consumption, i. e. our raw material demand at home and abroad, has remained almost constant over the past ten years, but at a level that is much too high. In 2019, we used 30 per cent more raw materials than the global average. The only time there was a slight decline was during the initial years of the coronavirus pandemic. To improve resource efficiency and move closer to the goal of sustainable resource use, we must develop and implement ambitious policy measures.

Against the tragic background of the war in Ukraine, the debate on the future supply of energy and raw materials and the phasing out of fossil fuel use is gaining momentum again. In the final chapter of this report, therefore, we venture a glimpse into raw material use in the future, with the aim of achieving a sustainable level of usage and greater global justice. In order to accomplish the absolute reduction in our raw material consumption necessary for this by 2050, we need an ambitious resource policy in conjunction with technological measures for promoting material efficiency, lifestyle changes and sustainable consumption. This will enable us to reduce raw material consumption in Germany by up to 70 per cent in comparison with the values for 2010.

I hope you will find the report an interesting and informative read!

Prof. Dr. Dirk Messner
President of the German Environment Agency

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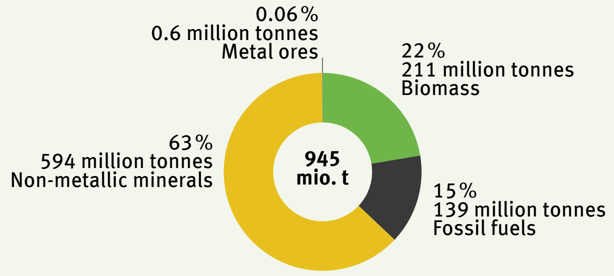
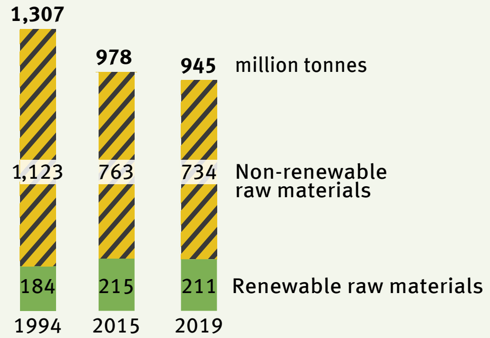
There has been an overall decline in the **domestic extraction** of raw materials since 1994. Two opposing trends are apparent: a long-term decrease of 35 % in the extraction of abiotic raw materials, and an increase of 15 % in that of biotic raw materials.

Used raw material extraction, 2019





Sources: Destatis, 2021 h

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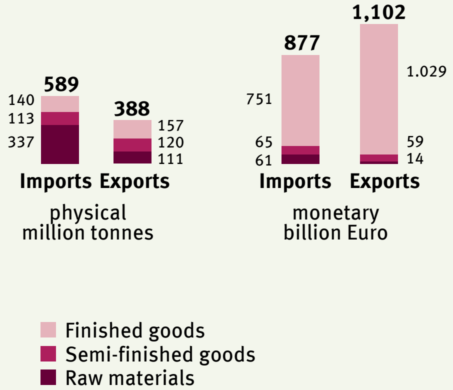
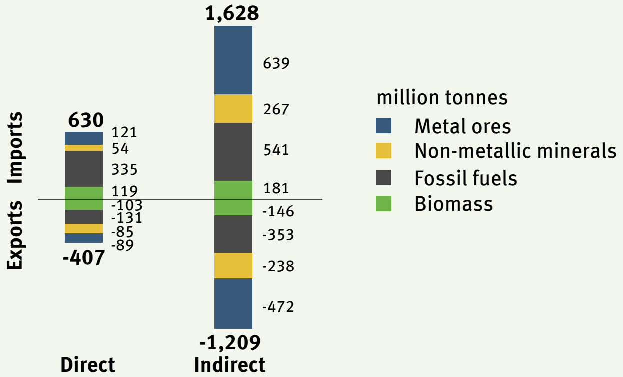
Germany benefits from **global trade**: although it imports, both directly and indirectly, more raw materials and goods than it exports, there is a considerable surplus in its monetary trade balance.

Direct trade, 2020



Direct and indirect trade of raw materials, 2019



Sources: Destatis, 2021 h; Dittrich et al., 2022 a

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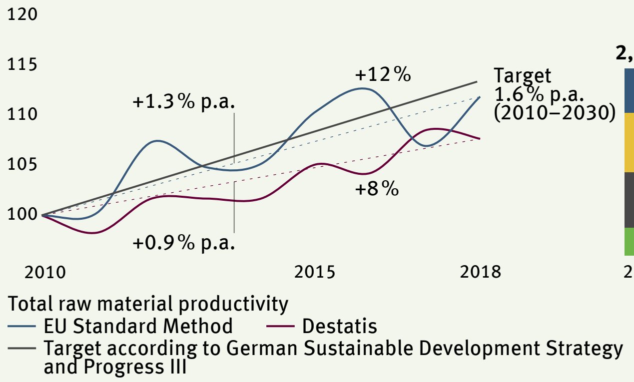
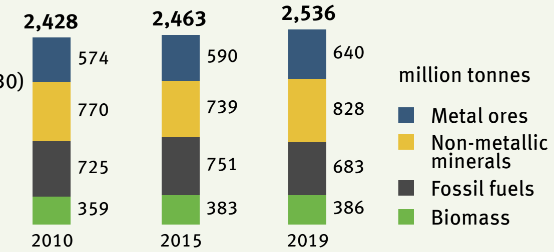
The **raw material input of the German economy** barely altered between 2010 and 2019, and stabilised at a high level in 2019, at 2,536 million tonnes. By 2018, total raw material productivity had risen by 12 % (calculation according to Destatis: 8 %).

Total raw material productivity



Raw material input (RMI) EU Standard Method



Sources: Destatis, 2021 f, 2022 c; Dittrich et al., 2022 a

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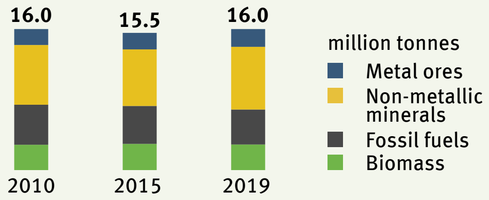
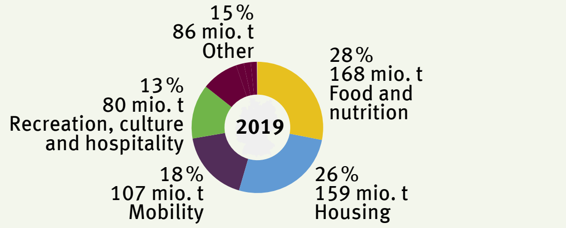
In 2019, Germany's **raw material consumption** amounted to 1,328 million tonnes, or 16.0 tonnes per capita. The consumption of raw materials by private households was largest in the areas of food, housing and mobility.

Raw material consumption (RMC)



Raw material consumption (RMC) of private households, 2019



Sources: Destatis, 2021 f, 2021 h; Dittrich et al., 2022 a

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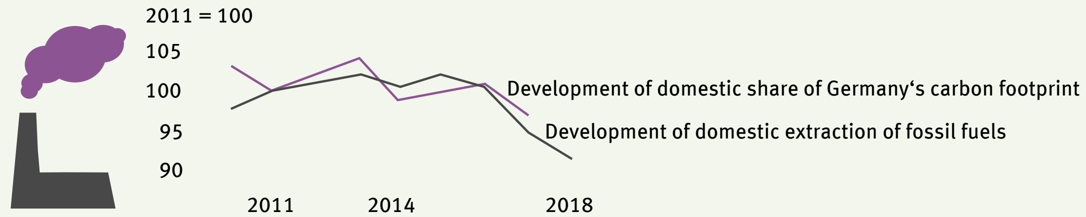
The extraction and use of raw materials is often associated with negative **environmental impacts**. In Germany, 40% of greenhouse gas emissions are attributable to the extraction and initial processing of raw materials.



Sources: Destatis, 2021 f, 2021 g, 2021 h

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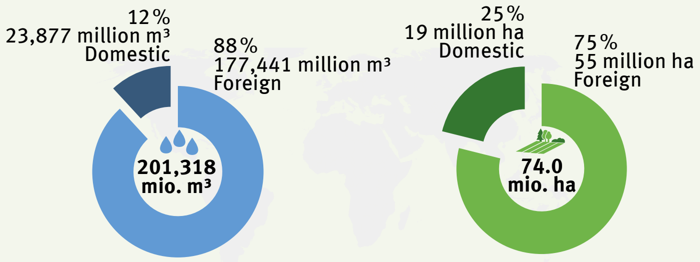
There is a **nexus (latin for connection) between the use of raw materials and other natural resources**. Due to its international supply chains, Germany shares responsibility for the utilisation of resources in other parts of the world.

Germany's water footprint, 2021 **Germany's land footprint, 2018**



Sources: Bunsen, 2021; UN Life Cycle Initiative et al., 2022

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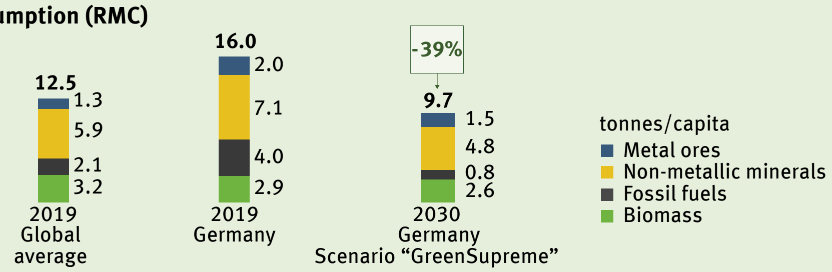
With an ambitious raw materials policy, there is every possibility of considerably more sustainable **raw material use in the future**. By 2030, Germany could potentially reduce its raw material consumption by more than a third of the amount in 2019.

Raw material consumption (RMC)



Sources: Dittrich et al., 2020 b; Dittrich et al., 2022 a; UNEP IRP, 2022

Introduction

Since 2016, the German Environment Agency has regularly published reports on the use of natural resources in Germany. The present Resources Report 2022 is now the third edition in this series (UBA, 2016a, 2018).

The UBA Resources Report examines statistics and trends in the field of resource and raw material use, analyses and discusses the manifold interconnections, and summarises individual subtopics. The current report takes a modular approach, i. e. in the form of "double pages", to around 30 subtopics relevant to resources.

The third Resources Report, like the two previous ones, is focused on the examination and analysis of renewable and non-renewable raw materials. This involves a discussion of the four main raw material groups: "non-metallic minerals", "biomass", "metal ores" and "fossil fuels". A further chapter on the topic of the "nexus" is concerned, inter alia, with the use of natural resources, water and land, but also with the interfaces between resource categories. This third Resources Report also introduces the topic of the "environmental consequences of raw material use" and the special topic of "raw material use in the future".

The Resources Report is targeted at a specialist audience and at people with a professional interest in the areas of economics, civil society (including education), politics and administration. On the one hand, the report is intended as a source of data information and a reference book; on the other, it sets out important arguments for science-based policy consulting and the development of measures for ecologically sustainable resource management.

The development of the Resources Report 2022 was accompanied by research developing important scientific foundations (Lutter et al. 2022). In particular, the accompanying research project improved the database and examined the relevant methodological background. For important core indicators, this report applies a new methodology (the EU Standard Method) and compares its results with the figures from public statistics (Destatis). The Resources Report 2022 generally uses the years 2019 and 2020 as statistical base years, i. e. as the years for which the most current information and statistical data were available at the editorial deadline (December 2021).

In order to facilitate comparison between the current developments in resource use in Germany and the previous Resources Reports, the present report also incorporates – along with medium- and long-term trend analyses – statistical comparisons of the current figures with data from the years 2014 and 2015. It should be noted, however, that the bases of the data and the methods for its statistical collection have, to some extent, changed, so in some cases comparisons are either not possible, or only partially so.

This report (in German and English), the results of the accompanying research project, and further information materials are available online at: www.umweltbundesamt.de/resourcesreport2022

Methodological bases

The focus of the present Resources Report 2022 is the use of raw materials. It is based on data from, in particular, the Federal Statistical Office of Germany and the German Environment Agency, as well as on model calculations of indirect raw material flows (according to the EU Standard Method). An accompanying research report (Dittrich et al., 2022 a) documents these calculations. For reasons of data availability, the basis year for the Resources Report is 2019; data for 2020 is also occasionally included. The most important methods and data sources for the various indicators in the Resources Report 2022 are explained below.

Direct raw material use

Direct raw material use comprises the volume of extracted raw materials and trade goods. Based on their main component, the latter are classified under one of the four main raw material groups (biomass, fossil fuels, metal ores, and non-metallic minerals).

Method: In Germany, the Federal Statistical Office (Destatis) collects data on raw material use for the macroeconomic material accounts within the framework of the System of Environmental-Economic Accounting (SEEA) – analogous to the system of national accounting, which depicts the monetary flows within an economy.

Data sources: The data for this report is taken from the most recent version of the environmental accounts (EA; published on 26.11.2021) available at the editorial deadline (Destatis, 2021 h). This includes data on domestic raw material extraction up to and including 2019, and data on direct trade up to and including 2020.

Data on raw material extraction by each of the German states is published in the environmental-economic accounts of the German states by Destatis and the Statistical Offices of the Federal States. The data on domestic extraction that was available at the editorial deadline was for the period up to and including 2019; the data available on trade was for the period up to and including 2020. The data is taken from the November 2021 edition (Statistische Ämter der Länder, 2021).

For the purpose of comparison with Member States of the European Union (EU-27), data on domestic raw material extraction provided by Eurostat (Eurostat, 2021) was used. Data for up to and including 2020 was available at the editorial deadline. Destatis, too, reports data on domestic extraction to Eurostat, covering the period up to and including 2020. Due to methodological differences, this data differs slightly from the EA values, but was published prior to the EA. In order to arrive at a forecast for domestic extraction in Germany for 2020, the EEA values for 2019 were used to extrapolate the figures for 2020 based on the trend evident within the data published by Eurostat.

Note: Due to a change in methodology, the EA report new values for all years retrospectively. Hence, because the values in the Resources Reports 2016 and 2018 (UBA, 2016a, 2018) are based on an older version of the EEA, they are not directly comparable with the values in the 2022 report.

The EEA of the German states (version 2021) has not yet implemented the methodological adjustments of the national EEA. This is why the total volume of domestic raw material extraction in the German federal states differs from the national values.

Indirect raw material use (calculated according to the EU Standard Method)

The analysis of indirect raw material use – known as "raw material equivalents" (see glossary) – includes all the raw materials extracted along international trade and production chains for products traded, processed or consumed in Germany or other countries. The sum total of all the raw material equivalents of goods consumed in Germany is also referred to as the "raw material consumption" or the "material footprint".

Method: To calculate the raw material requirements of goods traded internationally, these are converted into "raw material equivalents", i. e. into the volume of all the raw materials used throughout the entire value chain (RME; see glossary). Because goods traded internationally are very heterogeneous and their supply chain highly complex, this calculation is model-based – applying an input-output approach (see p. 11).

Data sources: The EA (Destatis, 2021 f) contain data on raw material equivalents for the period 2010 to 2018. This data, however, is based on a methodological and conceptual approach that was developed exclusively for Germany, which makes comparison with other countries difficult. The present Resources Report therefore uses own model calculations according to what is known as the EU Standard Method for the period 2008–2019. These calculations were carried out as part of an associated research project (Dittrich et al., 2022 a). For key indicators, this report compares the results of the EU Standard Method with the EEA figures from Destatis. Projections for 2020 are likewise based on the EU Standard Method.

Comparisons with EU Member States (EU-27) are based on data from Eurostat, and international comparisons are based on the multiregional input-output model developed for the United Nations International Resource Panel (GLORIA) (Lenzen et al., 2021), published in the online tool SCP-HAT (UN Life Cycle Initiative et al., 2022).

Other natural resources

The natural resources include – in addition to raw materials – the physical space (land area), the environmental media of water, soil and air, flow resources, and all living organisms. The present report devotes a separate chapter to the use of land, water and flow resources. It analyses indirect use of the resources water and land ("water footprint" and "land footprint").

Method: Destatis publishes its own specialist series on the extraction or use of water, as well as on the actual use of land, across different sectors (see below). Indirect use, i. e. the demand for water and land for the production of goods along all supply chains, is calculated by means of global input-output tables. Here, the monetary tables on the economic interdependency of production and consumption are expanded to include data on water and land usage.

Data sources: Data on direct water use is taken from the most recent version of the special series (19, series 2.1.1) available at the editorial deadline (Destatis, 2019 a), and is valid through to 2016. Data on land use is taken from the most recent version of the special series (3, series 5.1) (published 20.09.2021; data through to 2020) available at the editorial deadline (Destatis, 2021 d). The time series on the development of renewable energies in Germany (BMWI, 2021; valid as of February 2021) and the SHARES tool (Eurostat, 2019) form the basis of the values for the flow resources. Data from Eurostat and SHARES (2019) was used for the purpose of comparison with EU Member States.

Data on the blue and green water footprint in the present report was calculated using the input-output database EXIOBASE 3.8.1 as part of the UBA project "Conceptual Development of the Water Footprint" (Bunsen, 2021). The grey water footprint is not depicted in this report. The values presented for 2021 are forecasts based on data from 2011.

The land footprint is calculated based on the input-output database developed for the United Nations International Resource Panel (GLORIA) (Lenzen et al., 2021) published in the online tool SCP-HAT (UN Life Cycle Initiative et al., 2022). The land footprint does not include industrial land.

The RME model for Germany (EU Standard Method)

As part of an accompanying research project, the calculations for the Resources Report were made using a raw material equivalents (RME) model for Germany in accordance with what is known as the EU Standard Method. This is an environmental-economic raw material model based on a hybrid approach (Dittrich et al., 2022 a). As a national model, it includes Germany's imports and exports in the depiction of its national economy.
This methodology is derived from the RME model for the EU by Eurostat (Schoer et al. 2020 b), which is used to calculate RME at the EU level, and also from the RME country tool (Schoer et al. 2020 a), which Eurostat puts at the disposal of Member States. This means there can be direct comparison between the RME data for Germany and other EU Member States.
The model is based on Germany's input-output tables (IOT), with precise monetary values for the economic interdependency of production and consumption. These show which economic sectors exchange products with one another, and which products serve the final demand. For raw-material-intensive sectors or groups of goods (agriculture, mining, basic industries, construction materials industry, etc.), the model was expanded to include the raw material flows in the German economy, depicting these in detail in physical units.
The German imports from the European Union are calculated using the average RME coefficients of the EU-27; the imports from non-EU countries are calculated using the RME coefficients of the EU-27 imports from the European Standard Method. The exports, as well as the final domestic use, are calculated on the basis of the German interdependency matrix, which takes imports into account and is calculated based on the Leontief model.

Excursus: Indirect raw material use – comparison of two methods

Indirect raw material use in Germany (also referred to as "raw material equivalents"; RME) can be calculated using different methodological approaches: (1) input-output models, (2) coefficients for the resource intensity of individual goods, and (3) "hybrid" approaches. Hybrid approaches use both input-output models and coefficients, and also partly replace monetary quantities with physical information.

The Resources Report 2022 uses RME calculations for Germany based on the Standard Method for the period 2008 to 2019 (Dittrich et al., 2022 a) (see info box). The results are compared with the RME model by Destatis (Maier, 2018) published as part of the EEA (Destatis, 2021 f).

Both the EU Standard Method and the Destatis model are based on hybrid approaches. Nonetheless, the results diverge due to the different assumptions and concepts underlying the two models.

Significant differences between the two models or data sources

The important differences between indirect raw material use according to the EU Standard Method (Dittrich et al., 2022 a) and Destatis (Maier, 2018) are (1) the inclusion of secondary raw materials, and (2) assumptions about the production technology for imported goods.

Model calculations according to the EU Standard Method quantify the extraction of primary raw materials for a particular country's consumption, i. e. the "raw material consumption" or "material footprint" (see glossary). Secondary raw materials processed in imports or exports are not included in the results. This means that, the higher the share of secondary raw materials in the economic system, the smaller the raw material equivalents. Whereas the share of secondary raw materials in Germany is known, when it comes to imports, a global average quota is assumed. In the case of exports, a pro-rata allocation is made for the import quotas and the domestic shares.

Destatis calculates secondary raw materials differently: German quotas for the use of secondary raw materials are applied to the imports, and raw materials recycled in Germany are exclusively credited to raw material consumption in Germany.

Hence, Destatis deviates from the original definition for raw material equivalents (RME) (Eurostat, 2022), and the RME of the imports, and especially of the exports, turn out to be higher than suggested by the EU Standard Method.

The assumptions concerning production technology are also different: the EU Standard Method usually bases its calculation of the RME of imports on the production technology in the regions of origin. For imports from the European Union, it assumes the average production technology of the EU. Likewise, it takes EU production technology as a basis in the case of imports from non-EU countries. In the case of particularly raw-material-intensive imports, it additionally employs region-specific information.

By contrast, the Destatis model bases calculations for imports, in principle, on German technology, but it also includes information for individual raw materials and semi-finished products that are not produced in Germany (e.g. metal ores). It therefore includes in the calculation the raw material volumes that would be necessary if foreign countries used the same production techniques as in Germany.

Domestic raw material extraction

978 million tonnes	**945** million tonnes	**Used raw material extraction, 2015 and 2019**
11.4 tonnes per capita		**Used raw material extraction in Germany, 2019**
11.9 tonnes per capita		**Used raw material extraction, EU-average, 2019**
22 per cent	**22** per cent	**Share of renewable raw materials in total extraction, 2015 and 2019**
78 per cent	**78** per cent	**Share of non-renewable raw materials in total extraction, 2015 and 2019**
194 million tonnes	**139** million tonnes	**Used raw material extraction of fossil fuels, 2015 and 2019**
1.2 kilogram per square metre		**Used raw material extraction per unit area in Saarland, 2019**
6.3 kilogram per square metre		**Used raw material extraction per unit area in North Rhine-Westphalia, 2019**
16 per cent		**Share of sands in total used raw material extraction, 2019**

Sources: see p. 14–23

Domestic extraction: non-renewable raw materials

Natural raw materials are the basis of our economy and society. They are either extracted from nature in the country itself or imported. In Germany, extraction accounts for almost a billion tonnes a year. This amount is mostly made up of non-renewable raw materials, especially construction minerals.

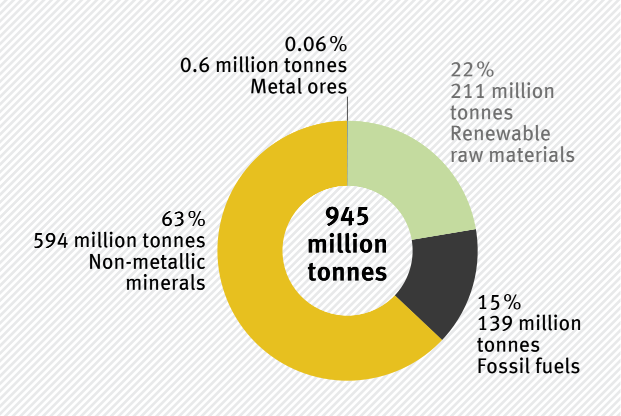
In 2019 (base year for the report), a total of 945 million tonnes of raw materials were extracted in Germany. As in previous years, non-renewable raw materials made up the greatest share, amounting to 734 million tonnes or 78 % (Figure 1). Of the non-renewable raw materials, non-metallic minerals comprised 594 million tonnes (63 %), i. e. almost two thirds, followed by fossil fuels (139 million tonnes or 15 %) and metal ores (0.6 million tonnes or 0.06 %).

The high proportion of non-metallic minerals reflects the strong demand for raw materials from the German construction industry for constructing and maintaining buildings and infrastructure. These minerals are used in various ways, e.g. as an aggregate for building materials like concrete (see p. 42/43). The extraction volume of construction minerals such as construction sands is therefore also an indicator of construction activity and raw material security (see p. 22/23).

The mining of fossil fuels continues to play a major role in Germany (15 %), but this is declining sharply. Lignite constituted over 90 % of this material group.

Figure 1

Share of non-renewable raw materials in used raw material extraction in Germany, 2019



Source: Destatis, 2021 h

Metals are needed in the German construction sector and other industries (see p. 36/37). However, the mining of metal ores is of little importance in Germany since there are few (profitable) deposits. Similar to the EU as a whole, Germany almost exclusively imports metals (see p. 26/27 and p. 28/29).

Since 2015, the domestic extraction of non-renewable raw materials has risen by a total of 34 million tonnes (+3.5 %).

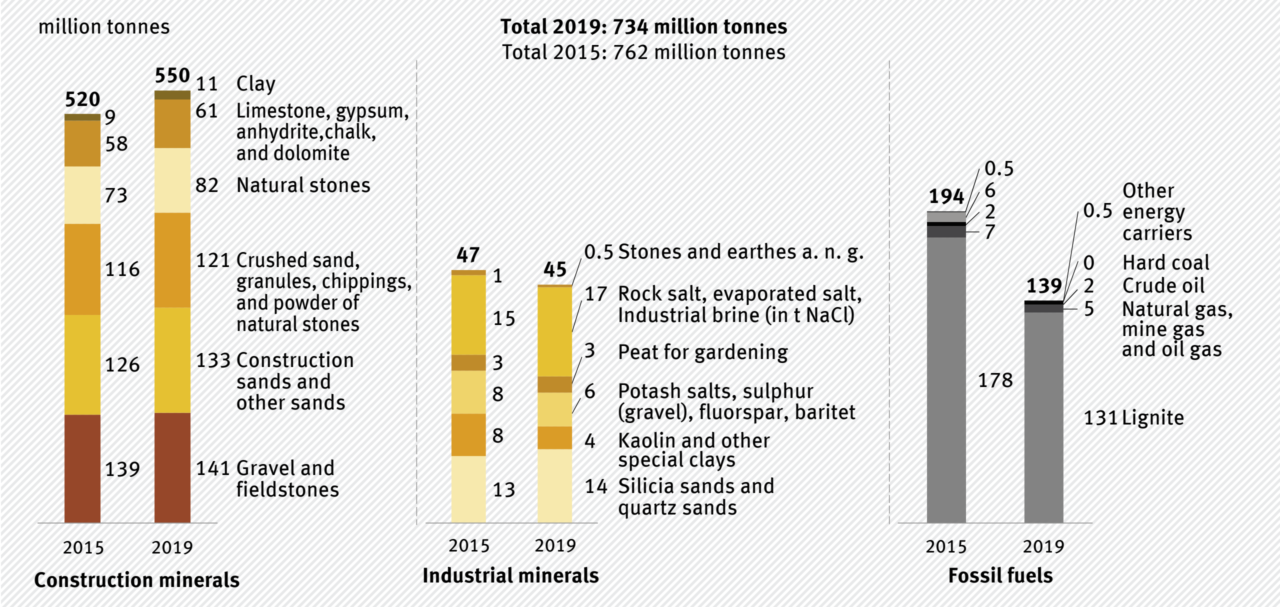
This increase is mainly due to non-metallic minerals. There are similarities in the trends of the individual raw material groups from 2015 onwards. The extraction of construction minerals rose accordingly by 6 % on average to 549 million tonnes (Figure 2). Construction sands, gravel, fieldstone and crushed sand, which together make up 42 % of total domestic extraction, increased by 4 %. In contrast, the extraction of industrial minerals, which are less significant in terms of volume – for example, special sand for the production of glass – fell by 6 % between 2015 and 2019.

A clear downward trend can be observed in Germany with regard to fossil fuels, yet these still play a major role. Extraction fell by 29 % from 194 million tonnes in 2015 to 139 million tonnes in 2019, mainly due to reduced lignite production. The period from 2015 to 2019 alone accounted for two thirds of the entire decline in lignite production over the last 25 years. This rapid decrease illustrates the acceleration of the energy transition (see p. 18/19).

It is interesting to compare raw material extraction in Europe (Figure 3). In 2019, Germany was slightly above the European average in the extraction of non-renewable raw materials per capita. Among all Member States, the Netherlands and Luxembourg recorded the lowest per-capita extraction volumes, and Estonia and Sweden the highest.

Figure 2

Share of non-renewable raw materials in used raw material extraction in Germany, 2019

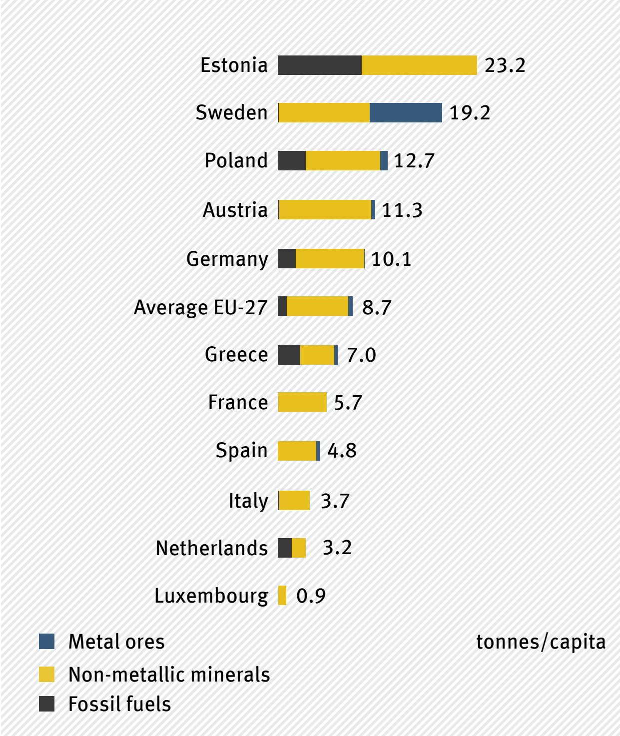


For reasons of visual clarity, the bar height of the three categories depicted in the figure is not strictly proportional.
Data based upon revised version of the economy-wide material balance from November 2021.
Values in this figure are not directly comparable to the previous Resources Reports (UBA, 2016 a; UBA, 2018).

Source: Destatis, 2021 h

Figure 3

Comparison of used extraction of non-renewable raw materials per capita in Germany with selected EU Member States and the EU average, 2019



Sources: Destatis, 2021 c, 2021 h; Eurostat, 2021

Similar to in Germany, non-metallic minerals represented the largest share of the combined per-capita extraction of all EU Member States. When it comes to extracting fossil fuels, the frontrunners within the EU are Estonia (oil shale) and Poland (coal). Germany is among the five EU countries in which the mining of fossil fuels continues to play a more significant role. In Sweden, metal ores like copper, zinc and silver are extracted in large quantities – a unique occurrence in Europe. France extracts almost exclusively non-metallic minerals. Mining of fossil fuels or metal ores is negligible here.

In terms of non-renewable raw materials, the European Member States are heavily dependent on imports (see p. 34–43). This primarily concerns fossil fuels and metal ores. Renewable energy and other developments such as electromobility will reduce dependency on imports of fossil fuels, but will increase it in the case of metals or critical raw materials.

Domestic extraction: renewable raw materials

The second main category for domestic extraction in Germany is renewable raw materials from agriculture, forestry, hunting and fishing. These make up around a quarter of the total raw material extraction. They are used as feed and foodstuffs, building materials and paper, or as a source of energy.

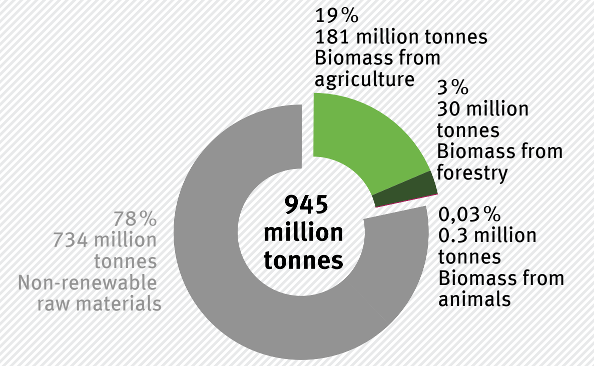
The extraction of renewable raw materials yielded a total of 211 million tonnes in 2019, which equates to 22 % of the total extraction (Figure 4). Agriculture accounted for 181 million tonnes, forestry for 30 million tonnes, and fishing and hunting for just 0.3 million tonnes.

Domestic extraction of renewable raw materials in Germany fell slightly by 2 % in the period from 2015–2019.

This trend is mainly explained by agricultural extraction, which fell by 7 million tonnes, or 4 %, between 2015 and 2019 (Figure 5). This was caused by drought-related declines in yield of cereals from 85 to 81 million tonnes and catch crops (from 56 to 48 million tonnes). However, the period from 2015 to 2019 is only a snapshot. In the long term, the extraction of renewable raw materials in Germany is steadily increasing (see p. 18/19).

Figure 4

Share of renewable raw materials in used raw material extraction in Germany, 2019



Source: Destatis, 2021 h

Cereals account for the largest share in the extraction of renewable raw materials (37 %). This also reflects the importance of livestock farming for German agriculture, as this category includes green fodder and forage crops such as maize. After Spain and France, Germany is among the EU countries with the most pigs and cattle (FAOSTAT, 2020; Heinrich-Böll-Stiftung et al., 2020). Of the total cereals available in Germany in the 2018/2019 financial year, the largest proportion (57 %) was used as animal feed, 19 % for energy production and industrial use, and only 18 % was used directly as plant food (BLE, 2020 a).

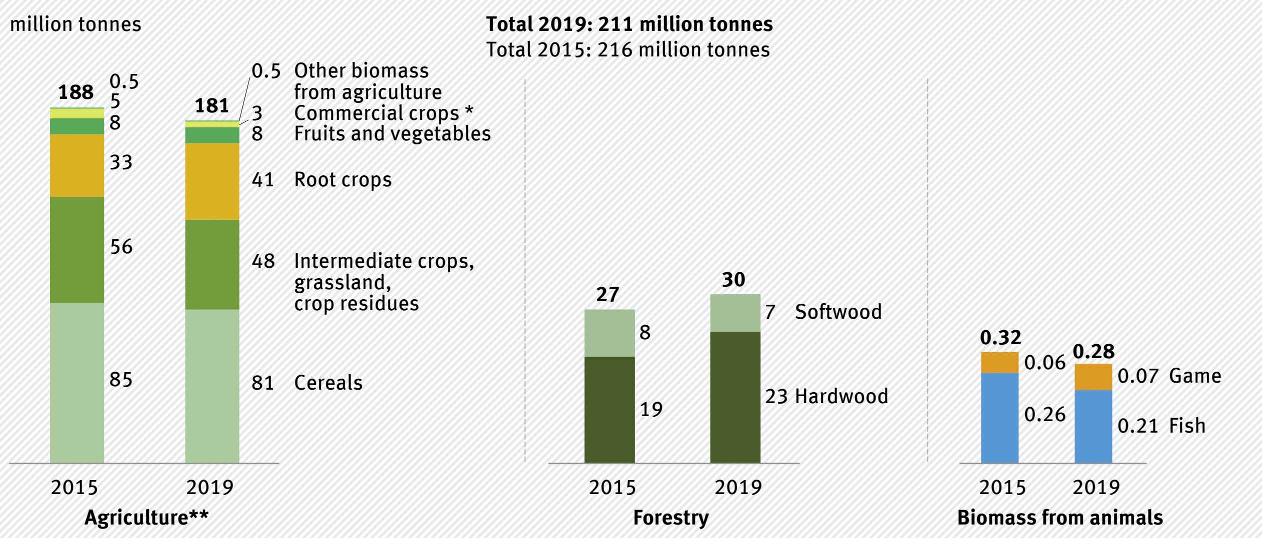
Root crops such as sugar beet, potatoes or fodder root crops accounted for the third largest share (19 %) of agricultural extraction. An increase from 33 million tonnes to 41 million tonnes was recorded here.

In addition to cereals, domestic animal husbandry also uses grassland feed. Concentrated feed for pigs and poultry plays only a minor role (12 % of feed). The fodder for domestic livestock comes almost exclusively from domestic sources. In 2017, 20 million tonnes of feed came from domestic production (90 %), while 2 million tonnes were imported (10 %, mainly concentrated feed) (Destatis, 2019d). The German livestock industry therefore indirectly uses land abroad (see p. 70/71).

Germany's extraction from agriculture fell by 4 % between 2015 and 2019, while extraction from forestry increased by 10 %. However, the latter represented only 17 % of the total biotic extraction. The increase was due to the increased felling of softwood: around three quarters (76 %) of the softwood volumes from 2019 were due to forest damage such as insect infestation (Destatis, 2020).

Figure 5

Used extraction of renewable raw materials in Germany, 2015 and 2019



For reasons of visual clarity, the bar height of the three categories depicted in the figure is not strictly proportional.

* Commercial crops comprise oil seeds such as rape, sunflower and soy, hop, tobacco, plant fibres as well as medical, aromatic and spice plants.

** Data based upon revised version of the economy-wide material balance of November 2021. Direct comparison with reports from 2016 (UBA, 2016 a) and 2018 (UBA, 2018) not possible, as categories of Environmental Accounts were changed after 2018: The categories "fodder crops and grassland" and "straw" are no longer used. Fodder crops like maize are now allocated to the category "cereals".

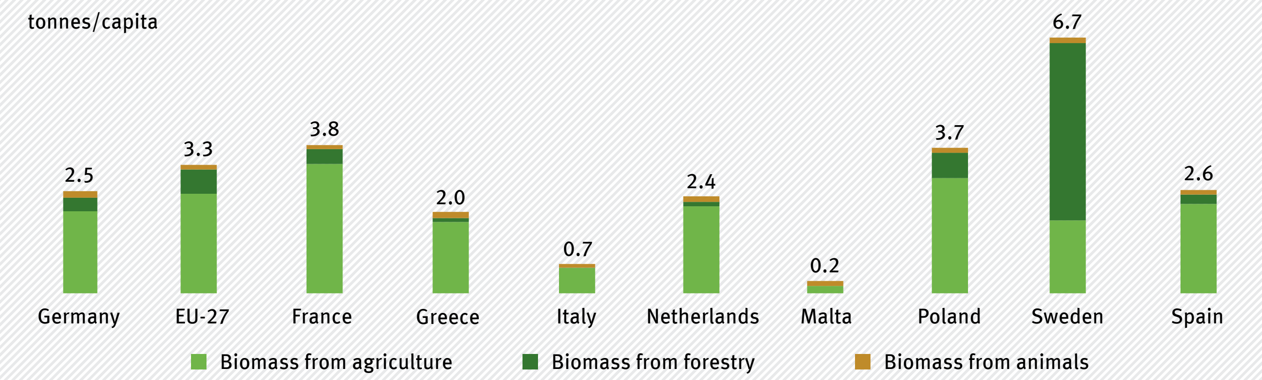
Source: Destatis, 2021 h

In per-capita numbers, Germany's extraction of renewable raw materials was 2.5 tonnes in 2019, below the European average of 3.3 tonnes (Figure 6). Among all EU Member States, Sweden had the highest per-capita value (6.7 tonnes), mainly due to forestry. Malta, however, extracted the least amount of renewable raw materials (0.2 tonnes/capita).

Renewable raw materials play an increasingly important role in the decarbonisation of the economy as a means of reaching climate protection goals. But even they are not available in infinite quantities. There are trade-offs, such as the limited amount of land available for cultivation or the environmental impact of cultivation (see p. 54–63).

Figure 6

Comparison of used extraction of renewable raw materials per capita in Germany with selected EU Member States and the EU average, 2019



Sources: Destatis, 2021 c, 2021 h; Eurostat, 2021

Trends in raw material extraction

Analyses of long-term trends in raw material development provide insight into the effectiveness of raw materials policy. In Germany, total raw material extraction has been falling since 1994. The extraction of non-renewable raw materials fell sharply, while extraction of renewable raw materials increased.

Since the start of environmental accounting in 1994, total raw material extraction has fallen from 1,307 million tonnes to 945 million tonnes in 2019 (Figure 7) – a decrease of 28 %. The long-term decline in overall raw material extraction has continued since the previous Resources Report (UBA, 2018). There are many reasons for this. For example, higher productivity in the use of raw materials (see p. 40/41), but also the increased use of secondary raw materials (see p. 42/43) and the relocation of production processes abroad (see p. 28/29).

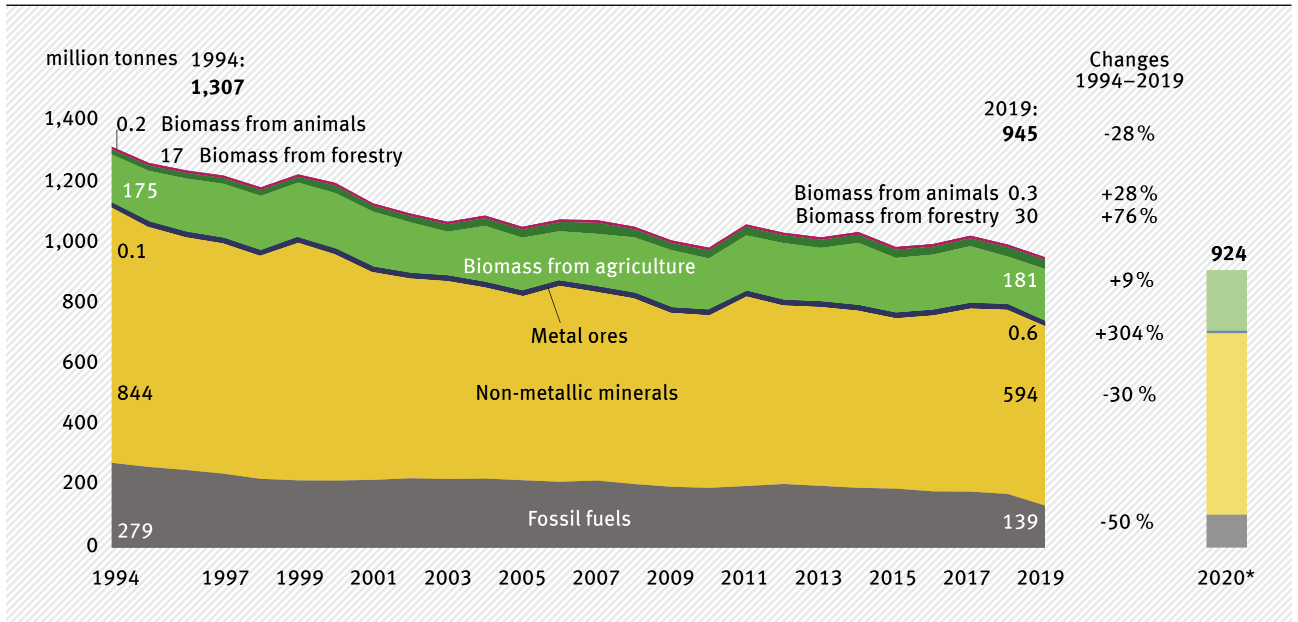
A comparison of the most important raw material groups shows very clear differences. In the dominant category of non-renewable raw materials, despite fluctuations, the extraction of non-metallic minerals alone fell by 250 million tonnes (-35 %). This was mainly due to the construction industry. The construction of new infrastructure after German reunification generated enormous demand for building minerals, which, however, was gradually met over the years (see p. 22/23).

Fossil fuels, on the other hand, have fallen sharply by almost half since 1994 as a result of the energy transition (from 279 million tonnes to 139 million tonnes).

In contrast, a rising trend can be observed for renewable raw materials over the same period. Here, however, extraction is subject to strong fluctuations, since weather conditions (e.g. drought, hail, strong winds, etc.) are of central importance in agriculture and forestry.

Figure 7

Development of used raw material extraction in Germany, 1994–2020

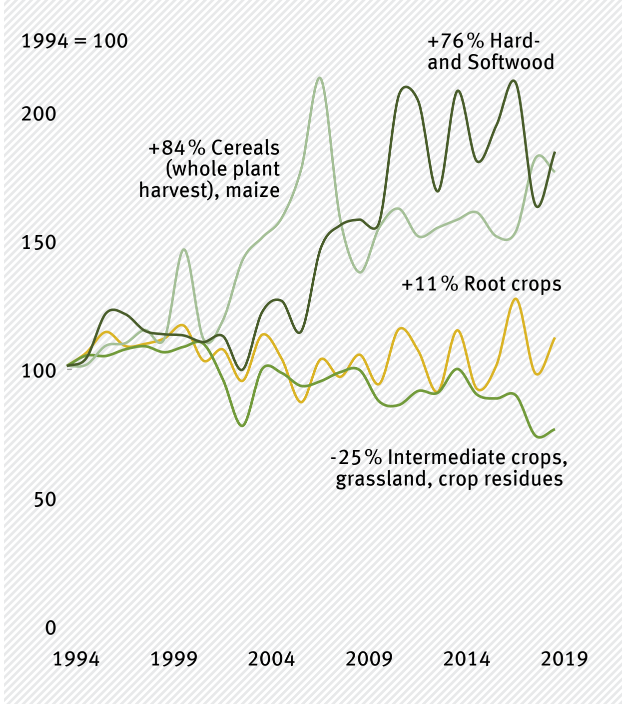


Data based upon revised version of the economy-wide material balance of November 2021.
Values in this figure are not directly comparable to the presious Resources Reports (UBA, 2016 a; UBA, 2018).
* Estimate based on trends of domestic extraction as reported by Eurostat, 2021.

Source: Destatis, 2021 h

Figure 8

Trends in used extraction of individual sub-categories of renewable raw materials in Germany, 1994–2019



Source: Destatis, 2021 h

The extraction of renewable raw materials rose by 15 % over the long term.

From 1994 to 2019, extraction of renewable raw materials rose from 184 million tonnes to 211 million tonnes.

The trend of renewable raw materials is caused partly by increasing extraction in forestry. The increased use of wood, especially softwood, led to a rise of 13 million tonnes (+76 %).

Agricultural raw material extraction went up by 11 million tonnes (+9 %), with the poor harvests in 2018 and 2019 curbing the increase. Reasons for this development include the rising demand for animal feed and the higher material use of biomass as an alternative to fossil fuels in production processes.

However, the increasing extraction volumes are also partly due to the use of biomass in biogas plants. For example, the extraction of cereals for the whole-plant harvest (e.g. maize, wheat or winter rapeseed) has increased by 84 % over the long term (Figure 8).

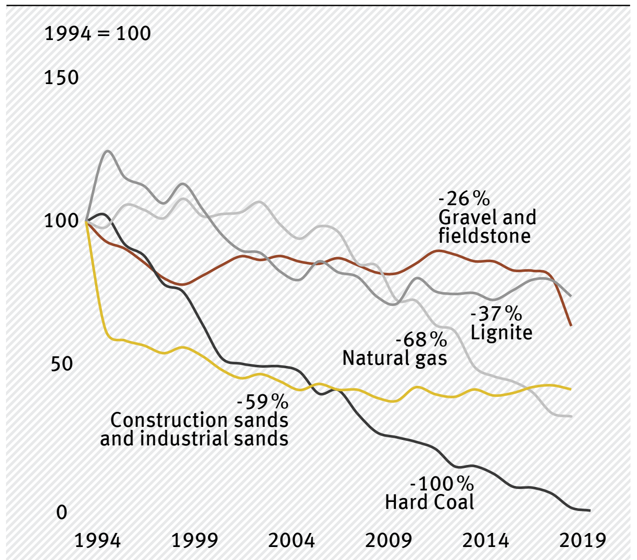
This has had ramifications for land use – 35 % of the maize cultivation area was used for biogas production in 2019 (FNR, 2019). The consequences: if energy crops are used in biogas plants instead of liquid manure or organic waste, they compete with food and plants for material use for cultivation areas. As a result, existing areas are used more intensively and fertilised to a greater extent. This in turn can exacerbate environmental impacts such as nutrients leaching into groundwater (see p. 62/63).

The long-term downward trend in the extraction of fossil fuels can also be seen in individual subcategories (Figure 9). The decline was greatest for hard coal, which saw mining phased out. It was also significant for natural gas (-68 %) and lignite (-37 %), however. Although lignite still plays an important role, according to the Bundestag resolution of July 2020, the last lignite-fired power plants will be shut down by 2038 at the latest.

The industrial and political development of German society is reflected in the long-term trends in the extraction of raw materials. In the future, in addition to the energy transition, new mobility concepts as well as the circular economy and the overarching European Green Deal (European Commission, 2019) are likely to be reflected in these trends.

Figure 9

Trends in used extraction of sub-categories of non-renewable raw materials in Germany, 1994–2019



Source: Destatis, 2021 h

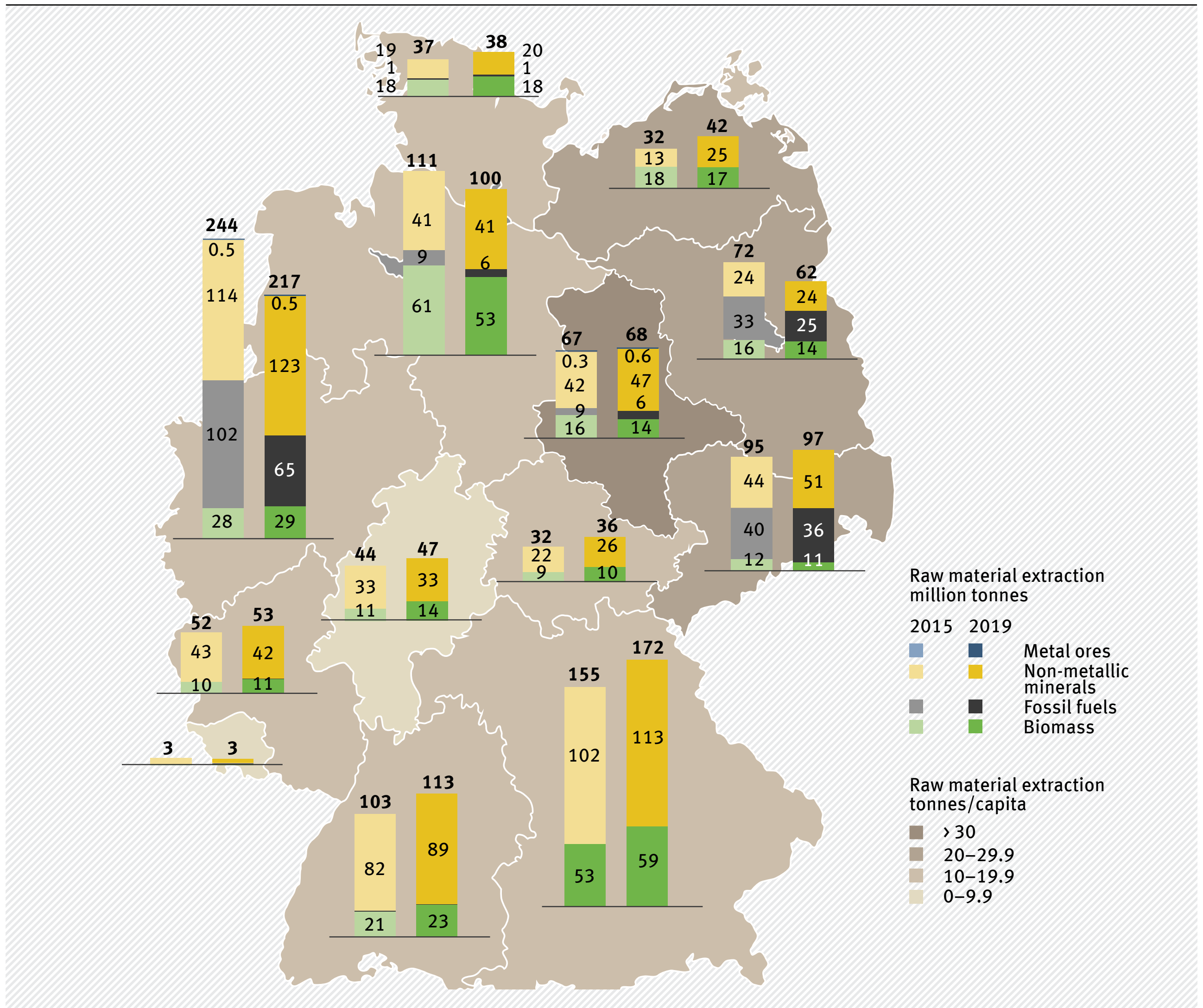
Extraction of raw materials by the federal states of Germany

Domestic raw material extraction is distributed differently across the German federal states. Large amounts of non-renewable raw materials are only obtained from a few German states. The determining factors are area, geological conditions, accessibility and population density.

In 2019, North Rhine-Westphalia extracted 217 million tonnes – over a fifth (21 %) of the total figure in Germany, followed by Bavaria with 172 million tonnes (16 %) and Baden-Württemberg with 113 million tonnes (11 %). Raw materials are also extracted in the small city-states, although their combined contribution to the total volume only amounts to 0.3 %. Hence, for city-states in particular, supply from the surrounding area or via trade plays a major role. The lowest extraction volume – apart from the city-states – was recorded in Saarland, which accounted for 3 million tonnes in 2019 (0.3 % of the total extraction) (Figure 10).

Figure 10

Used raw material extraction in the German federal states, 2015 and 2019



Excluding federal city states, due to very low levels of extraction. The federal statistical offices did not implement the methodological changes as realised in the national accounts (see p. 9–11). Therefore, the sum of material extraction reported by the federal states deviates from the national accounts by ~10 %.

Source: Statistische Ämter der Länder, 2021

The top-three federal states extract large amounts of non-renewable raw materials. In North Rhine-Westphalia (which has the largest mining area in Europe: the Rhenish lignite mining territory), the mining of fossil fuels is particularly significant. In 2019, 65 million tonnes – around half of the total amount mined in Germany – were extracted from this area. Saxony and Brandenburg also play a major role (36 and 25 million tonnes respectively), predominantly on account of the Lusatian lignite mining region.

In contrast to fossil fuels, the extraction of biomass is important in all federal states. The extent depends on land availability, soil quality and management practices. Particularly large quantities were extracted in 2019 in Bavaria (59 million tonnes), Lower Saxony (53 million tonnes) and North Rhine-Westphalia (29 million tonnes). These states cover a large total area, yet (in the case of Lower Saxony and North Rhine-Westphalia) they also have large areas with uniform crop cultivation, which simplifies management. These three states together extracted around half of total German volumes.

Over the long term, the extraction of renewable raw materials increased in all federal states. Between 2015 and 2019, however, there was a decreasing trend in many cases – attributed to the drought in 2018 and 2019 (see p. 16/17). In Lower Saxony, extraction even fell by 13 % from 61 million tonnes to 53 million tonnes.

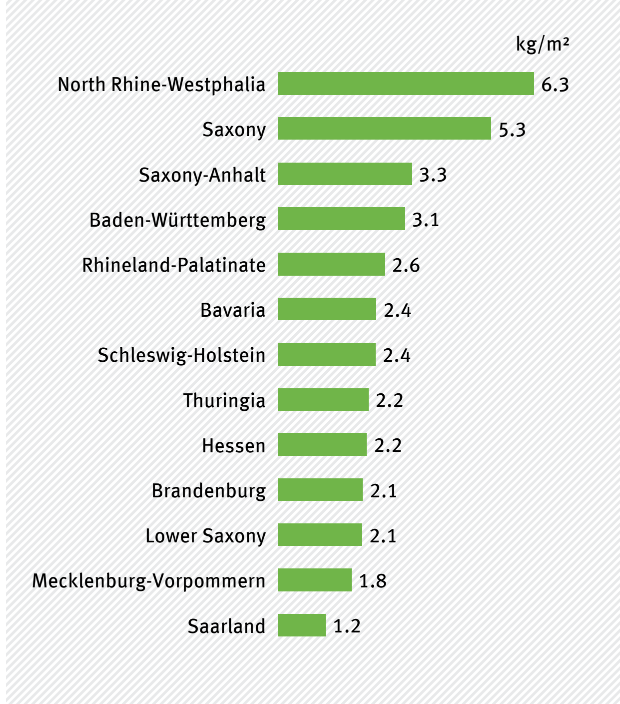
Calculating extraction per capita is a good way to put the absolute extraction figures into perspective. Saxony-Anhalt recorded the highest per-capita extraction (31.0 tonnes) in 2019, more than double the national average of 15.9 tonnes. This is not least due to this federal state having a low population density.

The per-capita perspective can be supplemented by considering the area-related raw material intensity by comparing the total raw material extraction in a federal state with its area (Figure 11). The federal states that produce large amounts of non-renewable raw materials stand out from the rest. When extracting non-metallic minerals, the intensity is often high: e.g. 27 tonnes/m² for sand and gravel or 14–45 tonnes/m² for lignite (UBA, 2021c). This results in comparatively high average values for North Rhine-Westphalia (6.3 kg/m²) and Saxony (5.3 kg/m²). In Saarland and Mecklenburg-Western Pomerania, with the lowest absolute extraction, the smallest amounts of raw materials were extracted in relation to the area, too (1.2 kg/m² or 1.8 kg/m²).

Regional supply is coming back into focus, not least because of increasingly fragile global supply chains. At the same time, increasing urbanisation and the phasing out of coal mining are already leading to significant structural change in some federal states. The final report of the “Growth, Structural Change and Employment” commission set up by the federal government highlights the need for regional development concepts and defines the principles of a structural development strategy (Kommission “Wachstum, Strukturwandel und Beschäftigung”, 2019). This will also affect the raw material extraction of the federal states, for example through the increased use of biotic raw materials.

Figure 11

Raw material extraction of the German federal states per unit area, 2019



Source: Statistische Ämter der Länder, 2021

Domestic extraction: sand

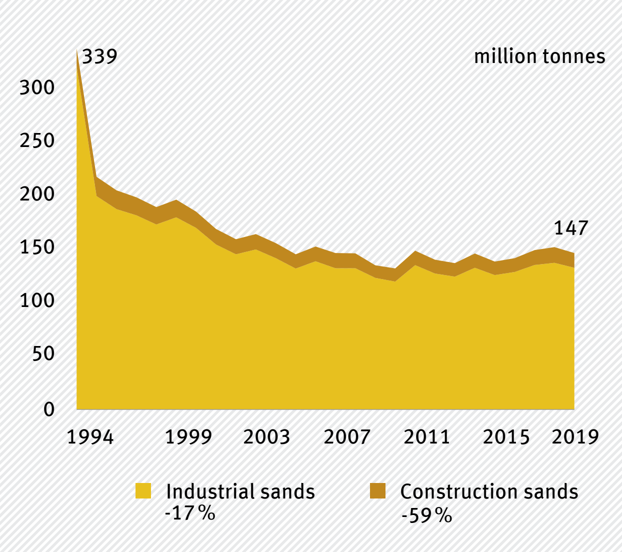
Sand is a key raw material for the global economy, especially regarding the construction and maintenance of buildings and infrastructure. In Germany, sand mining accounts for a large share of overall raw material extraction. However, due to limited local availability and negative environmental impacts alternatives are being sought.

The use of sand in the world economy is a marker of the Anthropocene period – the current geological age in which humans have become one of the most important influencers on the natural processes on Earth (Steffen et al., 2007). Today, twice as much sand is extracted worldwide every year as is supplied by natural erosion processes and rivers (UNEP, 2014).

Sand extraction is measured internationally along with gravel and quarried stones, mostly using estimates based on cement consumption. Sands, gravel and quarried stones together accounted for around 45 % of global raw material extraction in 2019 (UNEP IRP, 2022). In Germany, these three material groups made up 40 % of domestic raw material extraction, whereby sand alone accounted for 18 %.

Figure 12

Extraction of construction- and industrial sands in Germany, 1994–2019



Source: Destatis, 2021 h

In Germany, the extraction of sand has declined sharply over the long term and fell by 57 % in the period from 1994–2019.

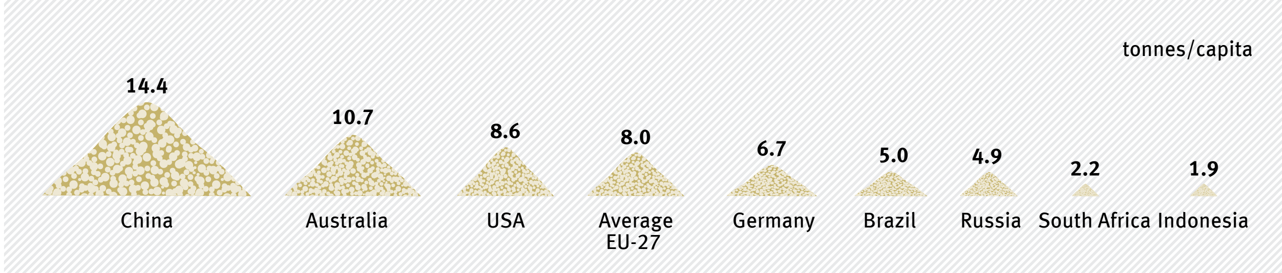
The reason for the large amounts of sand extracted up until 1994 was the construction of infrastructure and housing in the course of rebuilding the eastern parts of Germany following reunification (Figure 12). This peak phase in the construction sector was followed by a cyclical decrease from 1995 onwards (BKS, 1996; Die Naturstein-Industrie, 1996). The declining trend in sand mining continued until 2010 (133 million tonnes). Extraction volumes rose slightly thereafter until 2019.

Construction sands are used together with gravel as an aggregate in the production of cement and concrete. However, sand is also required in technical infrastructure for the bedding of pipes and cables (see p. 42/43). In 2018, around two thirds of the sand mined in the German Baltic Sea (2.6 million tonnes) was used in the Nord Stream 2 pipeline trench (Elsner and Szurlies, 2020). Sands with a high quartz content (“quartz sands” or “industrial sands”) are required for glass and semiconductors, or are used in paints, solar systems and computer chips (Elsner, 2016). In 2019, however, they only made up a very small share of German sand mining, accounting for just 9 %.

At 6.7 tonnes of sand extraction per capita in 2019, Germany came in below the EU average of 8.0 tonnes (Figure 13). By way of comparison: China extracted 14.4 tonnes per capita – almost twice as much. This is due to the enormous need for new infrastructure that still exists China has by far the largest cement production in the world and thus also records the largest extraction volumes of sand, gravel and crushed natural stones (48 % of global extraction) (UNEP IRP, 2022).

Figure 13

Comparison of per-capita extraction of sand, gravel and quarried stones in Germany with selected countries, 2019



For comparability reasons, in this figure, data published by the UNEP IRP (category “non-metallic minerals – construction dominant”) was used for all countries, including Germany. Consequently, data for Germany deviate from the data of the national environmental accounts due to methodological differences.

Sources: UNEP IRP, 2022; Weltbank, 2021 a

Yet in other countries, too, sand mining is steadily increasing as a result of urbanisation and industrialisation, which has already led to occasional shortages (see info box). Sand is a bulk commodity with relatively low economic value. Since transport over long distances is not very profitable, sand is mainly traded regionally (BGR, 2019). In 2020, Germany exported 8 million tonnes of sand. The majority was transported a short distance to neighbouring countries including The Netherlands, Belgium and Switzerland. On the other hand, 3 million tonnes of sand were imported (Destatis, 2021h). However, on a global scale, trade in sand is more significant, especially for countries that have very little of it, as well as for countries with excessive demand. For example, Singapore is constantly expanding its land area through embankment and has imported more than 500 million tonnes of sand in the past 20 years (UNEP, 2019).

Sand mining results in different environmental consequences depending on the process used. Opencast mining destroys soils and landscapes, and thus habitats. Extraction from inland waters or the sea also has direct consequences for the respective ecosystems, which are changed or destroyed. Furthermore, sand extraction can redirect the course of rivers, erode riverbanks or lower the groundwater level (see p. 56/57).

Globally, the highest demand for sand comes from the construction industry. In Germany, sand will continue to play a crucial role, especially due to the renewal of existing infrastructure. Moreover, although sand as a raw material is not scarce from a geological point of view, there are already many regions worldwide where sand is not available in sufficient quantities due to the global construction boom. In these instances in particular, we need to search for alternatives to sand as an aggregate (see info box).

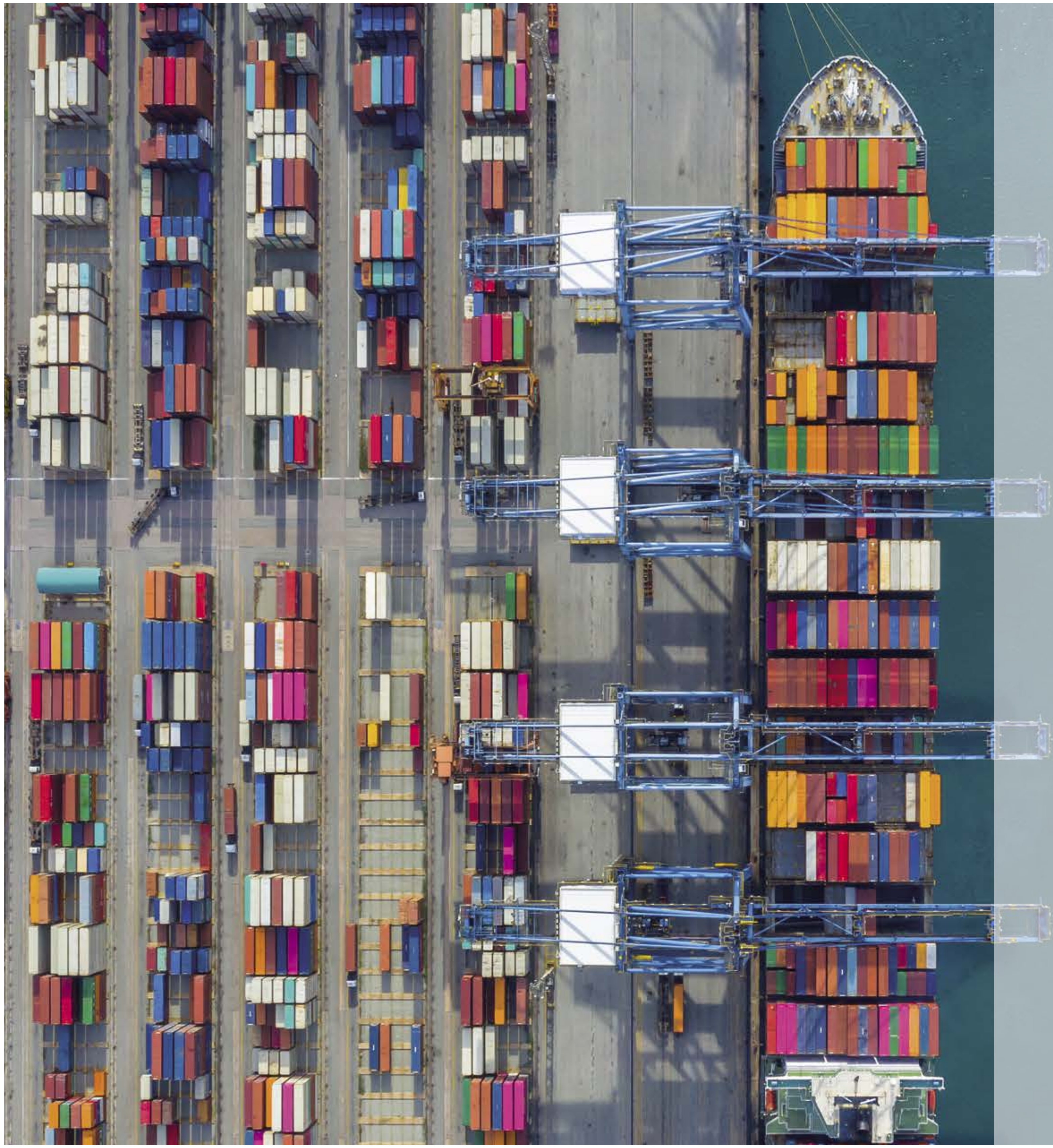
Alternatives to mining sand and gravel

Not all types of sand and gravel can be used in the construction industry. Desert sand, for example, is not (yet) suitable for concrete production, due to its shape. However, there is already intensive research going into technologies that make it usable.

Gravel, too, is increasingly being replaced by alternative raw materials such as flax, hemp or wood. In addition, secondary building materials such as recycled construction waste are often used. This can make an important contribution to conserving resources. Alternative building materials such as wood also enable a reduction in greenhouse gas emissions from the construction industry (see p. 84/85).

In Germany, around 81 % of road demolition and construction waste was recycled in 2018 (UBA, 2021 a). The majority of the recyclate (secondary raw material) replaces gravel in the construction of roads, paths and landscapes, where it is used for bedding or for joints of cobbled roads. Only a small proportion is reused as higher-quality recycled concrete in building construction (UBA, 2016b). This means Germany still has a lot of potential to unlock in the processing of building rubble (Elsner and Szurlies, 2020).

Germany’s share in global raw material trade



243 million tonnes	**202** million tonnes	**Physical import surplus, 2015 and 2020**
265 billion Euro	**225** billion Euro	**Monetary export surplus, 2015 and 2020**
620 million tonnes	**630** million tonnes	**Direct imports, 2015 and 2019**
1,497 million tonnes	**1,628** million tonnes	**Direct and indirect imports (RME), 2014 and 2019**
376 million tonnes	**407** million tonnes	**Direct exports, 2015 and 2019**
1,192 million tonnes	**1,209** million tonnes	**Direct and indirect exports (RME), 2014 and 2019**
64 Prozent		**Share of imports in raw material input (RMI), 2019**
27 million tonnes		**Exports of plastic and plastic goods, 2019**
1.1 million tonnes		**Exports of plastic waste, 2019**

Sources: see p. 26–33

Direct imports and exports

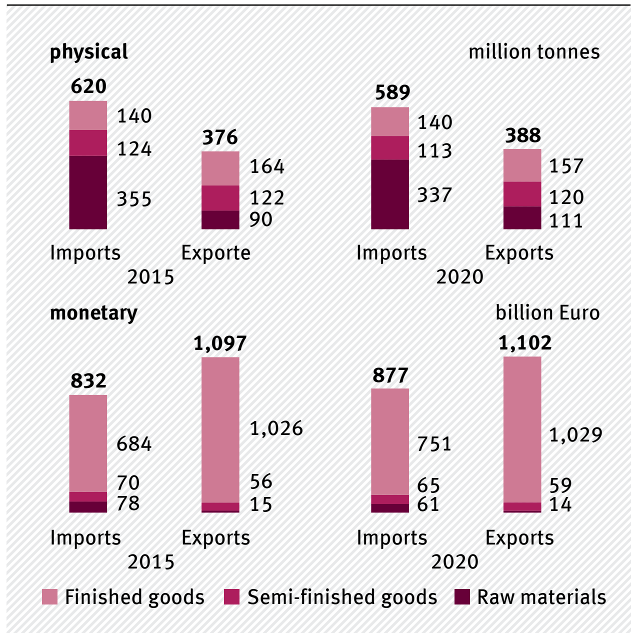
The German economy is strongly integrated into international trade: on the one hand, Germany is one of the biggest exporters worldwide, in terms of monetary trade volumes. On the other, it is highly dependent on imports of different metals, fossil fuels and other raw materials.

In 2020, Germany directly imported raw materials, semi-finished and finished goods to an actual weight of 598 million tonnes and a monetary value of 877 billion Euro. In comparison, its direct exports totalled 388 million tonnes and 1,102 billion Euro (Figure 14).

Germany therefore imported more raw materials and goods than it exported. The physical import surplus amounted to around 200 million tonnes. At the same time, exports generated more value than was spent on imports, which resulted in a monetary export surplus of 225 billion Euro. This was due to differences in the degree of processing required for import and export goods: Germany imports material-intensive goods and exports higher-value goods.

Figure 14

Germany's direct trade flows in physical and monetary terms in 2015 and 2020



The figures provided exclude the food industry, for which no data are reported for individual product types.

Sources: Destatis, 2021 h; Dittrich et al., 2022 a

In 2020, as in previous years, raw materials represented the greatest proportion of imports, followed by finished goods and semi-finished goods. In contrast, finished goods represented the largest share in exports, followed by semi-finished goods and raw materials. In Germany, therefore, raw materials are "refined", i.e. turned into higher-value goods (see p. 36/37).

In the statistics on physical trade, semi-finished and finished goods are classified according to the raw material group that best represents their material composition. Raw materials and goods based on fossil fuels such as natural gas and crude oil represent the largest proportion: in 2020, this was approximately half the imports. These materials and goods serve as fuels as well as chemical source materials for plastic or fertilisers. Fossil fuels were also the dominant component in the exports.

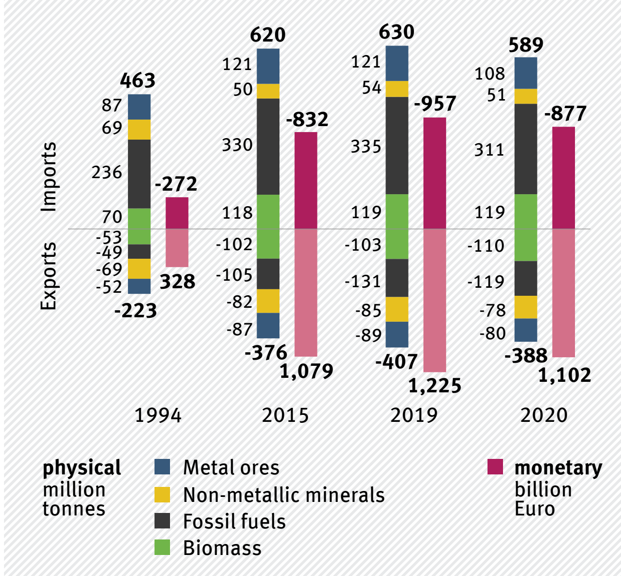
Raw materials and goods based on biomass were imported and exported in similar amounts. The most important imports were rapeseed, wood and waste paper. Examples of exports were wheat, wood and paper.

In the case of metal ores, the German economy is almost entirely dependent on imports. Germany also imports semi-finished and finished goods such as car parts and cars – in 2020, 108 million tonnes in total. Likewise, the automotive industry plays a major role in exporting metal ores or goods based on metal ores (80 million tonnes). In 2020, in fact, motor vehicles and motor vehicle parts represented Germany's most important exports (13 % of exports).

Between 2015 and 2020, imports decreased by 5 % overall, whereas exports increased by 3 %. Looking at the long-term trend, globalisation is increasing the physical trade volume in almost all raw material groups (+43 % overall) – more so for exports than for imports (+74 % versus +27 %) (Figure 15).

Figure 15

Development of direct imports and exports in Germany – monetary and physical, by raw material group, 1994–2020



The sum of imports and exports contains "other goods". The shares of the raw material groups, however, refer to imports and exports excluding "other goods".

Sources: Destatis, 2021 h; Dittrich et al., 2022 a

In monetary terms, both imports and exports have doubled, which means the trade volume has now quadrupled.

The period 2019 to 2020 was atypical because of the coronavirus pandemic: physical imports of raw materials, semi-finished and finished goods fell by 6 % from 2019 to 2020, and exports fell by 5 %. This was also reflected in the monetary values.

Germany trades with many countries (see p. 30/31). The European Union is its main trading partner, accounting for 62 % of Germany's physical trade volume. Among the G7 countries, France is Germany's most important trading partner (Figure 16). In this group of countries, Germany's exports exceed its imports only in the case of France and Italy (trade surplus: 4 million and 2 million tonnes, respectively). The remaining G7 countries – above all, the USA (15 million tonnes) – have a physical trade deficit towards Germany.

Along with the EU and the G7, Russia is also an important trading partner for Germany, with a 9 % share of Germany's trade volume in 2020.

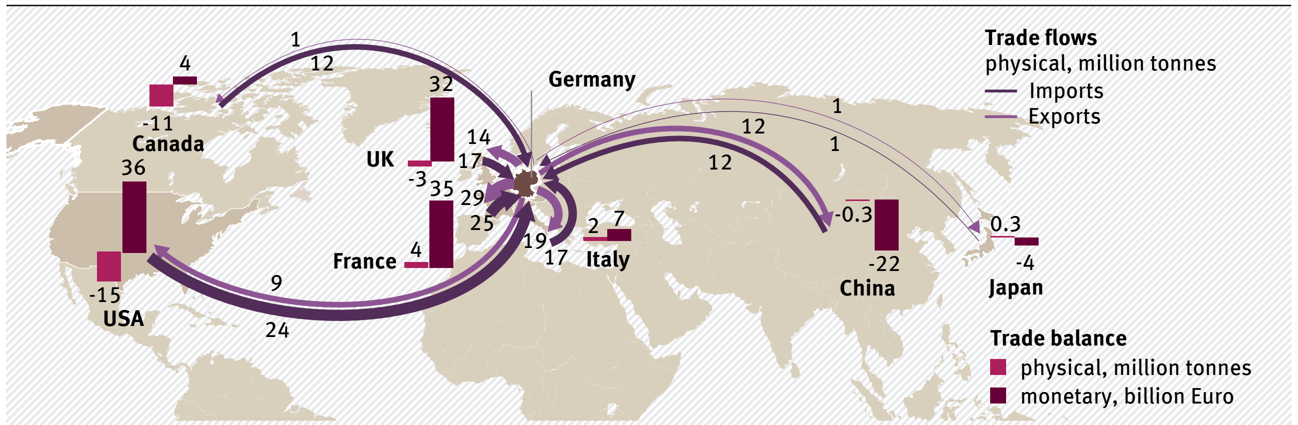
Notably, Germany's trade with Russia involves 25 times more physical imports than exports. Germany mainly imports natural gas, crude oil and hard coal.

In terms of monetary trade volume, China has been by far Germany's most important trading partner for around the past 5 years, with a trade balance deficit of 22 billion Euro in 2020. The low level of physical trade shows that Germany's trade with China is focused on higher-value goods.

As a location for processing, Germany outsources raw material extraction as well as the attendant environmental effects. Taking into account the "indirect" imports gives us a fuller picture of the raw materials used in Germany's economy and consumption (see p. 28/29).

Figure 16

Physical and monetary trade balances of Germany with G7 countries and China, 2020



Source: Destatis, 2022 a

Direct and indirect trade

Traded goods are based on various upstream services, including all the raw materials used along the supply chains. "Indirect raw material flows" represent these raw materials used, including for traded goods that involve a higher degree of processing.

Germany trades in higher-processed products. Their raw material demand can be calculated in "raw material equivalents" (RME; see glossary) or "indirect flows". This is the sum of all raw materials used in the life cycle of a product right through to its point of use. This sum shows that the production of semi-finished and finished goods requires far more raw materials than their weight suggests. For example, the average car alone (actual weight 1.5 tonnes) is associated with indirect flows of around 15 tonnes (Müller et al., 2017).

It is worth noting that in trade statistics, imports and exports are classified according to the raw material groups that best represent their material composition, e.g. a car is classified under metal ores. Raw material equivalents, on the other hand, show the actual amount of metal ores and other materials needed for the production of a car. The results of these methods are therefore not directly comparable, but some common trends are identifiable.

In 2019, direct imports (see p. 26/27) amounted to 630 million tonnes, while the raw material equivalents of these imports – i. e. the indirect imports – amounted to 1,628 million tonnes (Figure 17). The raw material equivalents of the exports were in fact three times larger than those of the direct exports.

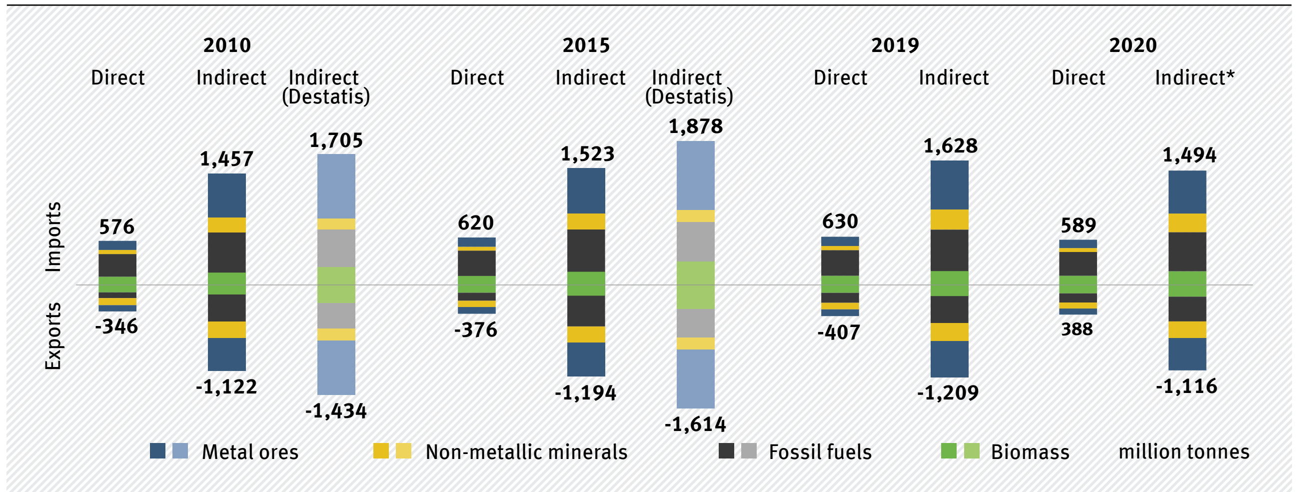
If we take raw material equivalents into account, Germany's physical trade volume increases threefold.

The difference between the direct and indirect trade balance has increased sharply since 2014. Like the direct trade balance, the balance in raw material equivalents showed a surplus in 2019 (419 million tonnes).

Metals have particularly large indirect flows associated with them. This is because, in their production, large amounts of ore with low metal content are

Figure 17

Development of Germany's direct and indirect imports and exports by raw material group, 2010–2020

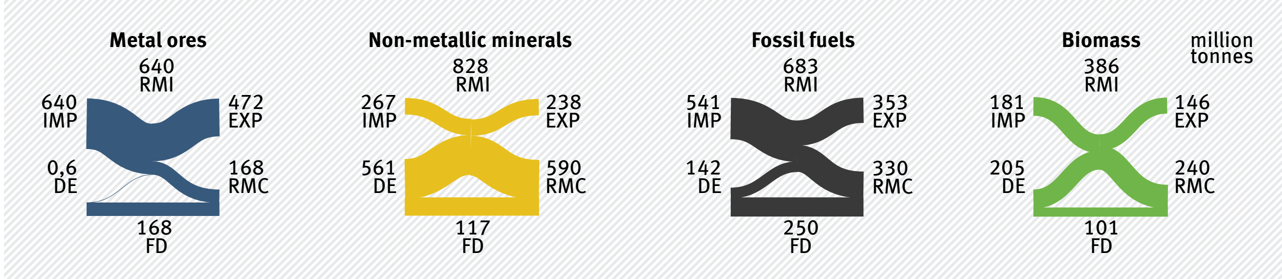


Due to conceptual differences, calculations based on Destatis and the EU Standard Method respectively yield different results (see p. 9–11).
The sum of direct imports and exports contains "other goods".
The shares of the raw material groups, however, refer to imports and exports excluding "other goods".
* Preliminary estimate based on changes in direct material flows as reported by Eurostat, 2021. (Dittrich et al., 2022 a)

Sources: Destatis, 2021 h; Dittrich et al., 2022 a

Figure 18

Direct and indirect raw material flows through the German economy, by raw material group, 2018



IMP: Imports DE: Domestic extraction RMI: Raw material input FD: Final demand EXP: Exports RMC: Raw material consumption

Source: Dittrich et al., 2022 a

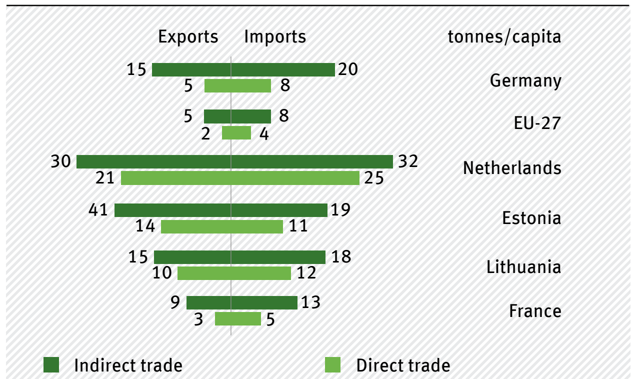
extracted and subjected to elaborate (i. e. energy-intensive) further processing. The raw material equivalents of imports and exports are therefore over five times larger than their actual weight.

In the case of fossil fuels, the ratio of direct to indirect imports is lower (1.6) than that of exports (2.7). This is because Germany imports large amounts of crude oil and natural gas but uses these fuels in the domestic production of goods for export.

Indirect trade flows can be calculated using different methods (see p. 10/11). In the EU standard method, only primary raw materials feed into the calculated raw material equivalents. If, however, secondary raw materials are included (Destatis method), the number of imports and exports rises.

Figure 19

Comparison between Germany's direct and indirect raw material imports and exports and those of selected EU Member States, 2018



Eurostat reports raw material trade data according to the residence principle. For comparability reasons, data for Germany is also depicted according to this principle. These values do not correspond with raw material trade data as used elsewhere in the report (territorial concept).

Sources: Eurostat, 2021; Dittrich et al., 2022 a

The trend in recent years (2014 to 2019) points to a sharper increase in the raw material equivalents of the imports (+9 %) in comparison to those of exports (+1 %). This is mainly due to the presence of non-metallic minerals.

According to estimates, indirect trade flows should, like direct trade flows, reduce in 2020. In the future, the increased use of non-physical (digital) goods (see p. 50/51) may lead to relocation effects, e.g. digital providers increasingly resorting to data processing centres outside Germany.

In the case of indirect raw material flows, three quarters of the metal ores used are processed into semi-finished or finished goods and then exported. The same is true of fossil fuels: around half of them are used in the production of export goods (Figure 18).

A comparison with other EU countries shows that the difference between direct and indirect trade is particularly pronounced in Germany (Figure 19). The Netherlands has the largest physical trade volume (including in raw material equivalents), with a relatively modest difference between direct and indirect flows. This is due to the fact that many of the goods transported by sea reach the European mainland via the Dutch port of Rotterdam and are then exported on to other countries.

In a globalised economy with international supply chains, indirect trade flows are particularly relevant. A country that is strongly integrated into international supply chains, such as Germany – which is a net importer of raw material equivalents – is indirectly co-responsible for the extraction of raw materials abroad (see p. 30/31).

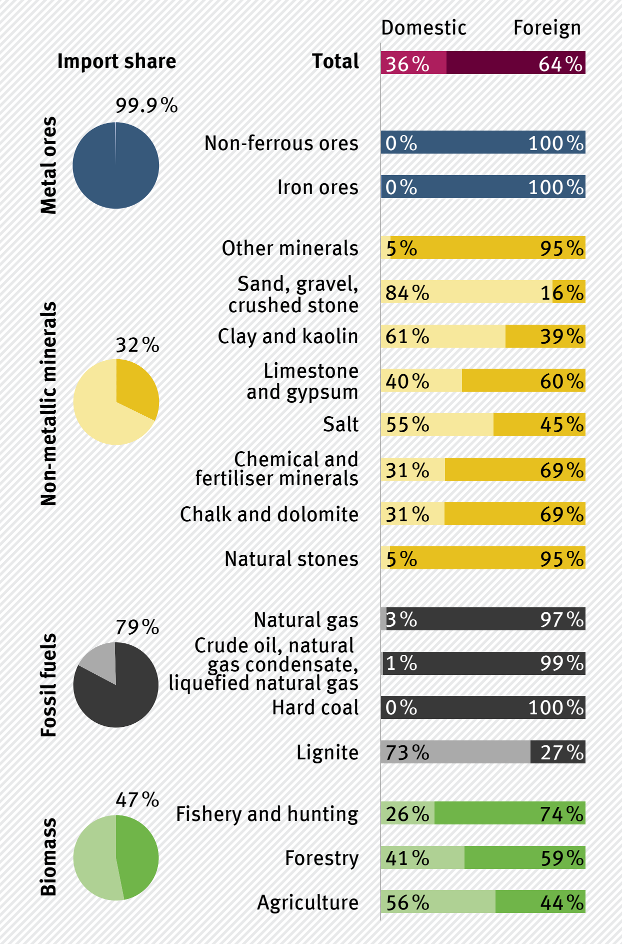
The origin of raw materials

Due to imports, Germany shares responsibility for raw material extraction and its effects in many world regions. Analysis of indirect flows associated with Germany's raw material demand for its economy and consumption identifies regions that supply large amounts of raw materials via international value chains.

If we consider indirect raw material flows, Germany imports more than it exports. As a net importer, Germany is dependent on foreign countries when it comes to meeting its domestic raw material demand (see p. 28/29). In 2019, around two thirds of the German raw material input (RMI; see glossary) came from imports. The share in imports, however, varies depending on the raw material group (Figure 20).

Figure 20

Domestic and foreign share in raw material input (RMI) of Germany by raw material groups, 2019



Sources: Destatis, 2021 h; Dittrich et al., 2022 a

In the case of metal ores, Germany's economy is almost entirely (99.9 %) reliant on foreign imports.

For the construction minerals gravel and crushed stone, the demand in 2019 was mainly met by domestic extraction (84 %). The transportation of mass raw materials of relatively low value, e.g. sand, is generally less profitable in comparison with other raw materials (see p. 22/23).

Looking at fossil fuels, the import share of raw material input in 2019 amounted to 36 % – with significant differences between the subgroups. Lignite, for example, came mainly (73 %) from domestic extraction. However, this share is declining due to Germany's exit from domestic coal mining. In the case of all other fossil fuels, however, the import share was particularly large. Although the German energy mix has been developing in favour of renewable energies over the past few years, in 2019, fossil fuels were still dominant in the energy supply (AGEB, 2020).

In contrast, the raw material category biomass shows a balance between imports (47 %) and domestic extraction (53 %).

If, instead of the raw material input for the economy (RMI), we consider domestic raw material consumption (RMC; see glossary) (i.e. subtracting the exports), model calculations enable a differentiated analysis of indirect raw material flows by region. The results show that the share of raw materials of German origin has decreased sharply since 1994. In 2018, it amounted to merely 25 % (Figure 21).

Around half the raw materials needed for German consumption in 2018 came from countries outside the European Union.

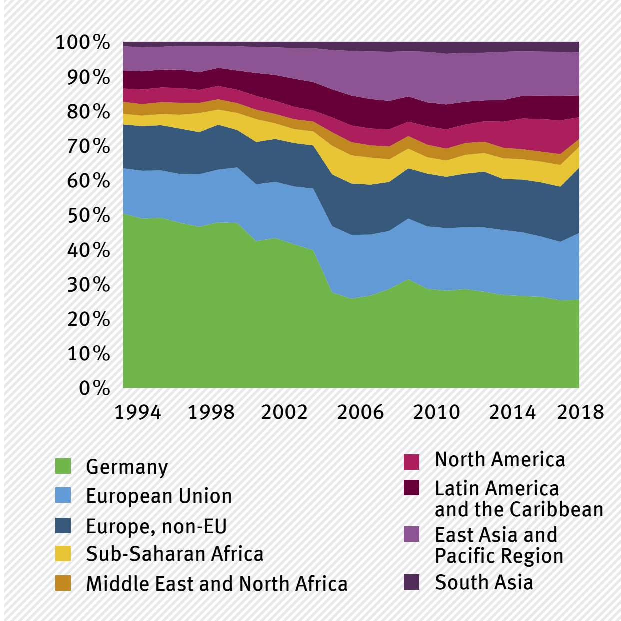
In total, two thirds of the raw materials for German consumption came from abroad, above all from the European Union (19 %). Here, specific aspects can be identified: for example, Germany's imports from its neighbour, France, largely comprise biomass products, e.g. wine and cheese.

In addition, East Asia and the Pacific (12 %) played an important role as a supplier region for raw materials, especially metal ores and fossil fuels. This region has become one of Germany's most important trading partners, especially since the rise of China. Latin America and the Caribbean delivered 6 % of the raw materials consumed, particularly metal ores. The most important countries of origin here were Brazil and Chile.

Imports constitute a large share in raw material consumption not only in Germany but also in the other G7 countries and China (Figure 22). For example, the majority of fossil fuels exported from Canada (in RME) (785 million tonnes) are used in raw material consumption in the USA. In contrast, the USA exports only 82 million tonnes of fossil fuels to Canada. On the other hand, the USA exports large amounts of raw materials and goods with associated fossil fuel inputs to the rest of the world.

Figure 21

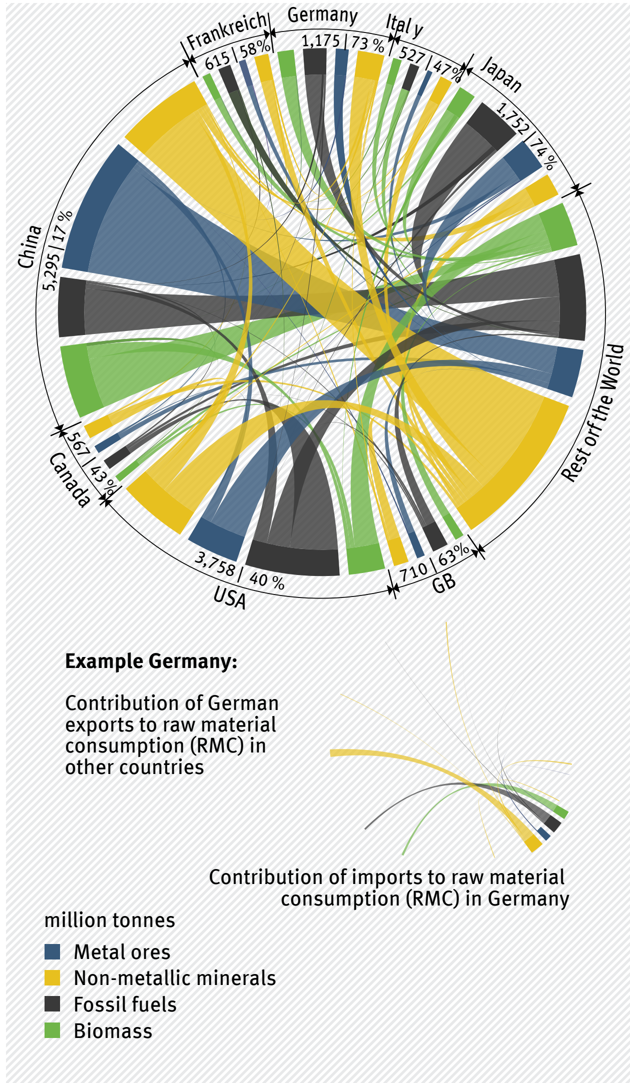
Origin of raw material consumption (RMC) in Germany by world region, 1995–2018



Source: UN Life Cycle Initiative et al., 2022

Figure 22

Contribution of imports to raw material consumption (RMC) in Germany, the G7 countries, and China, 2018



The depicted trade flows correspond to 99 % of the total amount. Trade flows below 14 mio. tonnes are not included. Due to methodological differences, values in this figure are not comparable with the results on p. 28/29.

Source: UN Life Cycle Initiative et al., 2022

Germany is reliant on the use of raw materials from abroad. Some of the economically most important sectors, e.g. the metal processing and plastics industries (see p. 32/33), in fact almost exclusively process raw materials or semi-finished goods based on these materials that are never, or only seldom, available domestically and hence must be imported from different regions of the world. This is precisely why countries such as Germany have a duty to promote ecologically sound and socially responsible conditions in raw material extraction both at home and abroad (see p. 56/57).

International interdependencies: the example of plastic

Synthetic material – generally known as “plastic” – is usually made from crude oil. Due to its versatility and longevity, it is used in many different ways and traded on the global market. If plastic ends up in the environment, this can have a negative impact on ecosystems.

The importance of plastic in the global economy has been continually increasing since the 1950s. Whereas, in 1950, annual production of plastic was still around 1.7 million tonnes, it rose to 368 million tonnes (excl. PET, PA and polyacrylic fibres) by 2019. Around half the plastic ever manufactured has been produced since 2000. And around a third of global production in 2019 took place in China, with Europe accounting for 16 % (PlasticsEurope, 2021).

In 2019, primary plastic production in Germany totalled 18 million tonnes, accounting for just over 30 % of the entire production of the European Union (58 million tonnes). The main raw materials are crude oil and natural gas, but Germany is reliant almost entirely on imports for these (see p. 30/31). It does produce recycled plastic (secondary plastic), but the amount (2 million tonnes) is still very low in comparison to primary plastic manufacture (Figure 23).

Some of the plastic produced domestically is exported. In 2019, exports amounted to 14.3 million tonnes (Figure 24). In contrast, 10.8 million tonnes were imported. Germany is therefore a net exporter of plastic. It trades mostly with neighbouring countries or within the European Union. Both imports and exports have been increasing for 20 years.

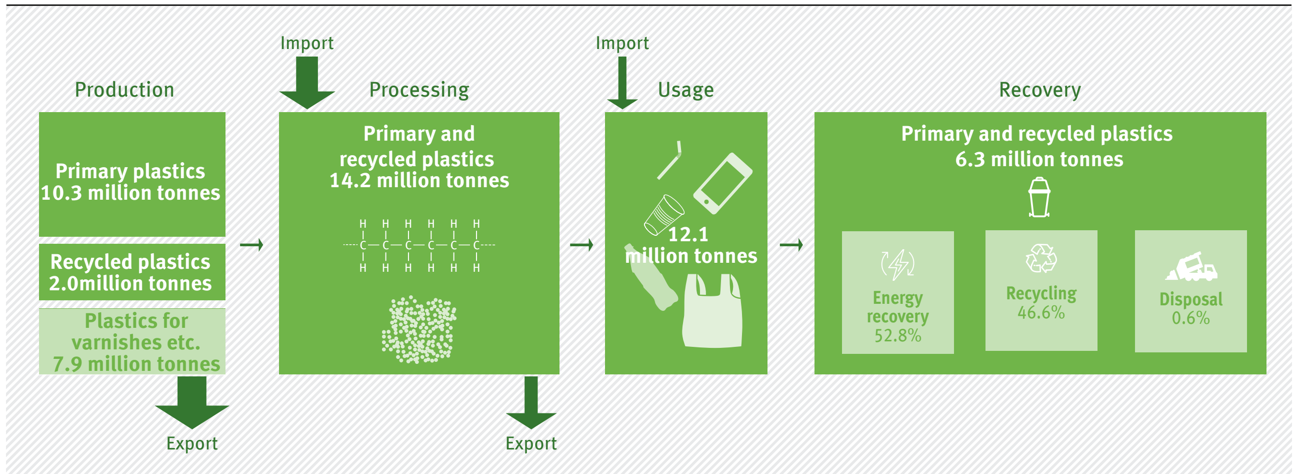
Germany’s plastic processing industry produces a range of semi-finished and finished goods. In 2019, the majority of plastic (31 %) was further processed into packaging. Another important consumer of plastic, however, ist the construction industry is an important consumer of plastic (25 %) (Conversio Market & Strategy GmbH, 2020).

Trade in plastic goods has also been increasing since 2001: exports have risen by 80 %, imports even by 124 %. In 2019, 7 million tonnes of plastic goods were exported and 5 million tonnes imported (Figure 24).

Overall, the trade volume in plastic and plastic goods rose by 62 % between 2001 and 2019.

Figure 23

Production, processing, usage and recovery of plastics in Germany, 2019

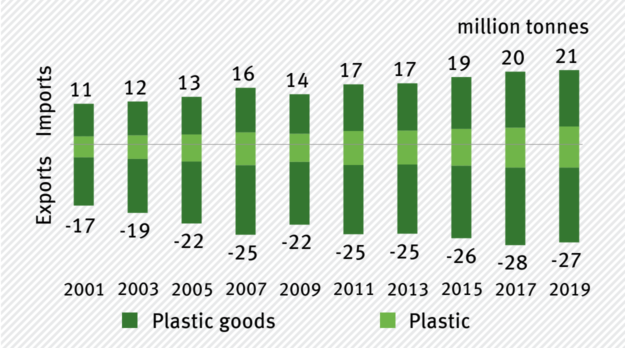


Plastics for coatings, fibers, adhesives, etc. are not included in values for processing, usage and recovery.

Sources: Conversio Market & Strategy GmbH, 2020; Destatis, 2020 b; UBA, 2021 e

Figure 24

Germany’s imports and exports of plastics and plastic goods, 2001–2019



Source: Destatis, 2020 b

As the global production of plastic increases, so does plastic waste. From 1994 to 2019 alone, plastic waste in Germany more than doubled (UBA, 2021 e). This is explained by the increased consumption of plastic products with a short lifespan, such as packaging or single-use products, which, if they are not disposed of properly, can accumulate in the environment (see info box). This is why, in 2019, the EU Parliament banned certain single-use plastic products where alternatives made from other materials are available (“Single-Use Plastics Directive”; European Parliament and Council of the European Union, 2019).

Plastic is an extremely durable material that decays very slowly and does not fully decompose (UBA, 2017). If it is not properly collected and recycled, it passes into the environment and damages ecosystems and living organisms. Across the world, the main cause of plastic ending up in the environment is poor waste and wastewater management. Other causes are traffic, the construction industry and agriculture, as well as people carelessly throwing away plastic products (littering) (UBA, 2019b). Every year in Germany, 150,000 to 266,000 tonnes of plastic end up in soils, inland waterways, the sea and the air. Tyre abrasion represents by far the largest proportion of this (Jepsen et al., 2020).

Waste avoidance and management is crucial in reducing the production of primary plastic and the raw material demand associated with it, as well as in reducing the amount of plastic that ends up in the environment. Thus far, however, only less than half (47 %) of Germany’s plastic waste is recycled and (minus losses from the recycling process) returned to the economic cycle. The majority of the plastic waste (53 %), however, is used for energy production, i. e. burned. This is problematic from an ecological perspective due to the production of greenhouse gases and other substances that damage the environment. Furthermore, a significant proportion of plastic waste is exported (see info box). This means Germany loses materials it could potentially recycle (i. e. by preserving the plastic material). Germany could recycle much more plastic than it is currently doing (Maletz et al., 2018).

Increased circulation of plastic would conserve primary raw materials and reduce dependency on foreign raw materials. At the same time, it could curtail CO_2 emissions.

Plastic waste exports

In 2019, Germany had a share of 1.8 % in the global generation of plastic waste (353 million tonnes). It exported 1.1 million tonnes and imported approx. 0.5 million tonnes (UBA, 2022b). The resulting export surplus represented around 9.4 % of all German plastic waste (Conversio Market & Strategy GmbH, 2020).
Plastic waste with low levels of contamination may be recycled in foreign countries following the respective domestic regulation, without intensive monitoring by German authorities. In the case of countries outside the OECD, regulations are not aligned, and there is therefore no absolute guarantee that the materials will be recycled appropriately. Plastic waste may pass into the environment from unmanaged landfills and through littering or open burning. It is estimated that, worldwide, there are 78 million tonnes of this unmonitored persistent plastic waste in the environment, i.e. 22 % of the total global generation of plastic (OECD, 2022).
In 2019, approx. 0.38 million tonnes of plastic waste were sent from Germany to non-OECD countries (UBA, 2022b). According to estimates by the German Environment Agency, unmonitored persistent plastic waste may at worst amount to approx. 10 % of this volume.
Measures to counter the possible ecological consequences of this are currently being discussed at EU level.

Raw materials for the economy

2,518 million tonnes / **2,536** million tonnes	**Raw material input (RMI) in the German economy, 2014 and 2019**
8 per cent	**Increase in total raw material productivity according to Destatis, 2010–2018**
12 per cent	**Increase in total raw material productivity according to the EU standard method, 2010–2018**
1.7 Euro/kilogram	**Total raw material productivity in Germany (EU Standard Method), 2018**
2.2 Euro/kilogram	**EU average of total raw material productivity (EU Standard Method), 2018**
16 per cent	**Reduction in raw material input through secondary raw materials (DIERec), 2013**
820 million tonnes	**Annual growth in anthropogenic stock in Germany**

Sources: see p. 36–43

Raw material input in the economy

Raw materials are an important factor in the production of goods. Each economic sector differs, however, in terms of how many raw materials are used. Depending on the type and amount of raw materials required, both domestic extraction and imports have a major role to play.

The physical basis of a national economy is mostly determined by two key indicators: direct material input (DMI; see glossary) and raw material input (RMI; see glossary). The DMI measures direct imports and the raw materials obtained from domestic extraction, whereas the RMI also takes into account the materials embedded in the imports, converted into raw material equivalents (RME; see p. 30/31 and 9f.). The latter paints a more comprehensive picture, as it quantifies the raw material requirements of the economy in the production of goods intended for domestic final demand or for export. These also include intermediate products that are processed abroad and turned into products for final demand.

In 2019, Germany's RMI amounted to 2,536 million tonnes (Figure 25). This differed only slightly from the amount in 2010 (+4 %) and also in 2014 (+1 %). If we include estimates for 2020, we observe a downward trend in the long and medium term (-3 %).

However, different developments underlie the trends: from 2015 to 2017, there was an above-average sharp increase in raw material input (+10 %), mainly because of greater demand for non-metallic minerals and metal ores, e.g. due to more investment in the construction industry. Thereafter, however, the raw material input decreased again – in particular, the input from fossil fuels declined by 11 % between 2017 and 2019.

Each individual raw material group's share in the RMI over the entire period has remained around the same since 2010. In terms of quantity, bulk materials such as sand and gravel play a major role – these are mainly used by the construction industry, whereas fossil raw materials are mainly used in energy production. Economic activity in the construction sector and energy policies therefore have a considerable influence on raw material input.

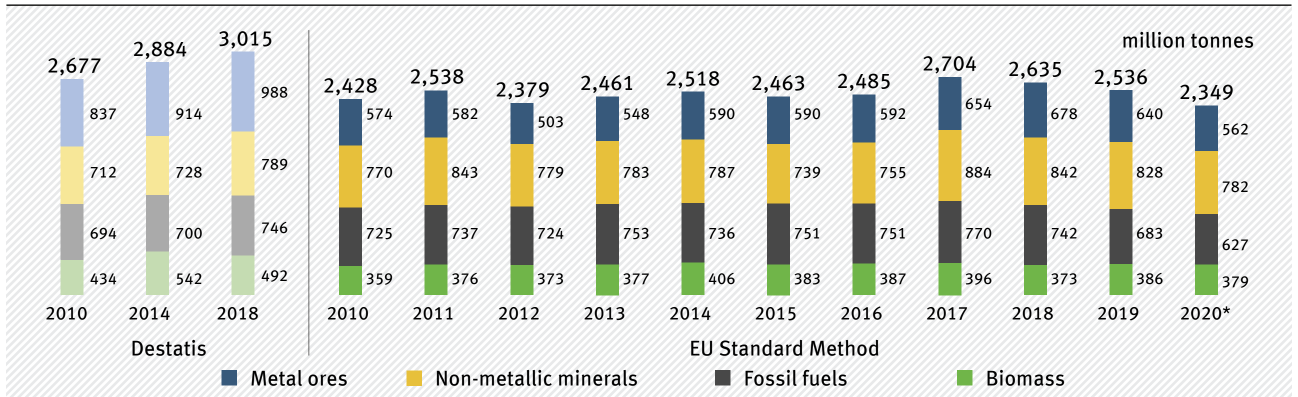
From 2010 to 2019, over the entire period almost all raw material groups followed the RMI trend. Fossil fuels were an exception.

The raw material input from fossil fuels decreased by 6 % between 2010 and 2019.

In this report, we use model calculations based on the "EU Standard Method" to estimate raw material input (see p. 10). This method only takes into account the input of primary raw materials. If we include secondary raw materials in the calculation, the RMI is higher (the Destatis method). For example, the German Federal Statistical Office (Destatis) has shown a 13 % higher RMI (3,015 million tonnes) for the year 2018. Changes can also be seen, however, in the shares of the individual raw material groups. For example, in 2018, metal ores had a higher share (33 %) when calculated by the Destatis method than they had by applying the EU Standard Method (26 %) (Figure 25).

Figure 25

Raw material input (RMI) in Germany by raw material groups, 2010–2020



Due to conceptual differences, calculations based on Destatis and the EU Standard Method respectively yield different results (see p. 9–11).
* Preliminary estimate based on changes in direct material flows as reported by Eurostat, 2021. (Dittrich et al., 2022 a)

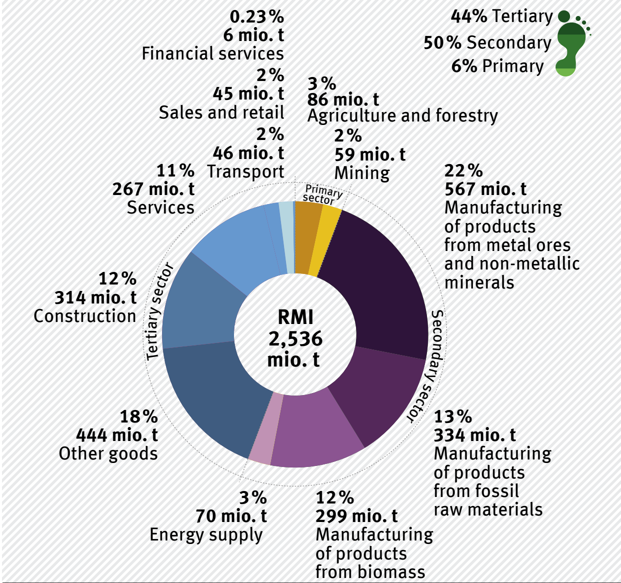
Sources: Destatis, 2021 f, 2022 d; Dittrich et al., 2022 a

In 2019, the German economy used most of its raw materials – around a quarter of its entire raw material input – for products based on metal ores and non-metallic minerals (Figure 26). In addition to the metal ores and non-metallic minerals themselves, these products contain other raw materials that are added in along the production chain. As well as the iron ores needed for steel production, for example, large amounts of fossil fuels are needed to power the blast furnaces. Products of the metal and mineral processing sectors, such as the steel industry, are used inter alia in car manufacturing and machine construction, both of which are key industries in Germany (Jungmichel et al., 2020). In addition, large amounts of raw materials are used in products based on fossil fuels and in the building industry.

The product categories and their raw material demand can also be classified under the primary, secondary and tertiary sector. In the primary sector, for example, agriculture and forestry extract raw materials directly from the environment. In 2019, the primary sector had a relatively small share in the overall raw material input (6 %). Extracted raw materials are only classified under the primary sector if they proceed directly to final consumption or to export without significant further processing. This applies, for instance, to agricultural products sourced directly from the producer.

Figure 26

Raw material input (RMI) in Germany by commodity groups, 2019



Due to methodological differences, values in this figure are not directly comparable to figure 25 in the previous Resources Report (UBA, 2018)

Source: Dittrich et al., 2022 a

The secondary sector processes raw materials into semi-finished and finished products (e.g. car parts). The tertiary sector, e.g. the construction industry, provides services. In contrast to the primary sector, the secondary and tertiary sectors contributed 50 % and 44 % to the RMI respectively.

This distribution of raw material input reflects the German economy's focus on the manufacturing industry and the service sector. Both sectors generate high profits based on low direct raw material input (see infobox). That is why both sectors have a central role to play in the circular economy, the aims of which are twofold: to reduce raw material input as a driver of environmental damage, and to increase the value added of each unit of primary material used (see p. 42/43).

Raw material consumption of economic value added

As an alternative to raw material input (RMI), the physical basis of the economy can also be measured by the "raw material consumption of economic value added". The method behind this indicator involves allocating raw material consumption along global supply chains not to final demand but to the respective sectors depending on their share in the value added created (Piñero et al., 2019). This method shows that Germany has a greater responsibility than the raw material input (RMI) or the raw material consumption (RMC) might suggest. The reason for this is the fact that the processing industry and the service sector generate high profits on the basis of low direct raw material input.

The development of total raw material productivity

Total raw material productivity is an important indicator for raw material efficiency. It represents the sum of the gross national product and the imports divided by the raw material input, and it indicates whether a decoupling of economic growth from raw material input has been achieved.

In Germany, decoupling economic growth from raw material usage has been a political goal ever since the first Sustainability Strategy of 2002 (Federal Government, 2002). Since 2012, this goal has also been anchored in the German Resource Efficiency Programme (ProgRess) (BMU, 2012). Initially, "raw material productivity" served as the indicator (see p. 36/37 in the Resources Report for 2018; UBA, 2018). It was then expanded into the broader indicator "total raw material productivity" and eventually replaced by this.

In addition to value creation (GDP), total raw material productivity takes into account the value of imports and the raw material input (RMI), i. e. the raw material input of the entire domestic and foreign production chain (including indirect material flows). It therefore takes account of the German economy's increasing global interdependencies.

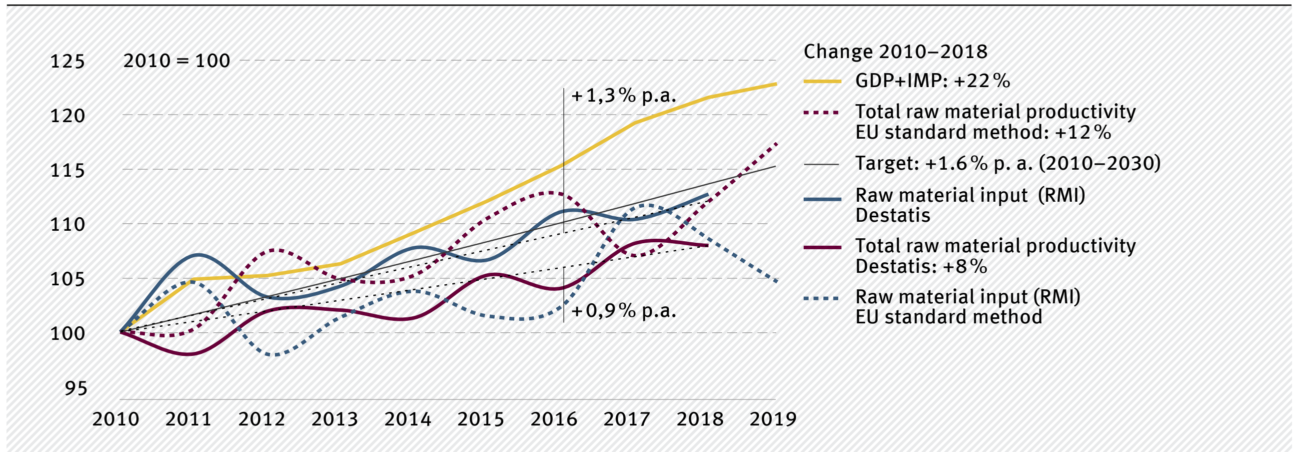
The German Sustainable Development Strategy (Federal Government, 2021) and ProgRess III (BMU, 2020a) have set out their goal: to ensure that the growth rate of total raw material productivity observed in the period 2000 to 2010 (1.6 % per year on average) continues through to 2030. For the overall period of 2010 to 2030, this represents an increase of 30 %. The actual annual growth in total raw material productivity from 2010 to 2018 (0.9 %) fell below the desired goal of 1.6 % per year (Destatis; Figure 27).

Overall, total raw material productivity increased by 8 % from 2010 to 2018.

To meet this goal set out for 2030, total raw material productivity needs to increase by a further 22 %. If, however – as in the model calculations based on the EU Standard Method –, only primary raw materials are included in the calculation (see p. 9–10), the RMI comes out as significantly lower. According to this method, total raw material productivity from 2010 to 2018 would in fact have increased by 12 % – an annual growth of 1.3 %. When comparing the methods in this way, however, we must take into account the fact that the sustainability strategy's goal is based on the Destatis method.

Figure 27

Development of total raw material productivity in Germany – comparison of two methods, 2010–2018

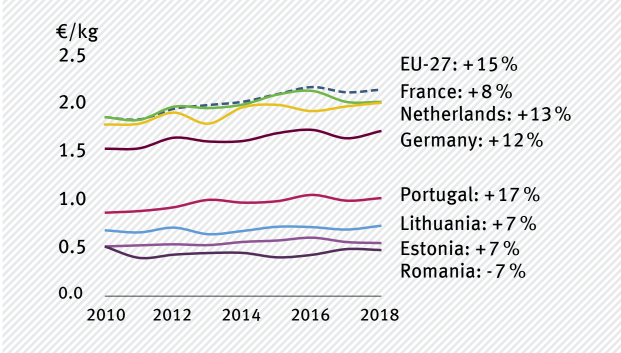


Due to conceptual differences, calculations based on Destatis and the EU Standard Method respectively yield different results (see p. 9–11).

Sources: Destatis, 2021 f, 2022 d; Dittrich et al., 2022 a

Figure 28

Development of total raw material productivity – EU comparison, 2010–2018



At the editorial deadline, data for the calculation of the total raw material productivity for the period 2010–2018 were available only for the Member States depicted in the figure.

Sources: Eurostat, 2021; Dittrich et al., 2022 a

The increase in total raw material productivity is in principle very positive. However, this alone does not mean that the pressure has been taken off the environment in reality. This is because, in Germany, the increase in total raw material productivity was mainly due to growth in GDP and imports (+22 %). Raw material input also increased, although not as much (+9 % by the EU Standard Method). This means that relative, but not absolute, decoupling was achieved.

The EU comparison shows that, in 2018, Germany's total raw material productivity of 1.7 Euro per kilogram (EU Standard Method) fell below the EU average of 2.2 Euro per kilogram. France and the Netherlands achieved higher values (each 2.0 Euro/kg). Together with the Netherlands and Portugal, Germany is one of the countries with the highest growth in productivity since 2010 (Figure 28).

At the international level – and particularly as regards the goals for sustainable development (UN SDG) – the approach to identifying decoupling trends is different. Economic output (GDP) is compared *inter alia* with raw material consumption (RMC). In this approach too, when raw material consumption increases at a slower rate than GDP, this is relative decoupling, but if raw material consumption decreases and GDP increases, absolute decoupling has been achieved.

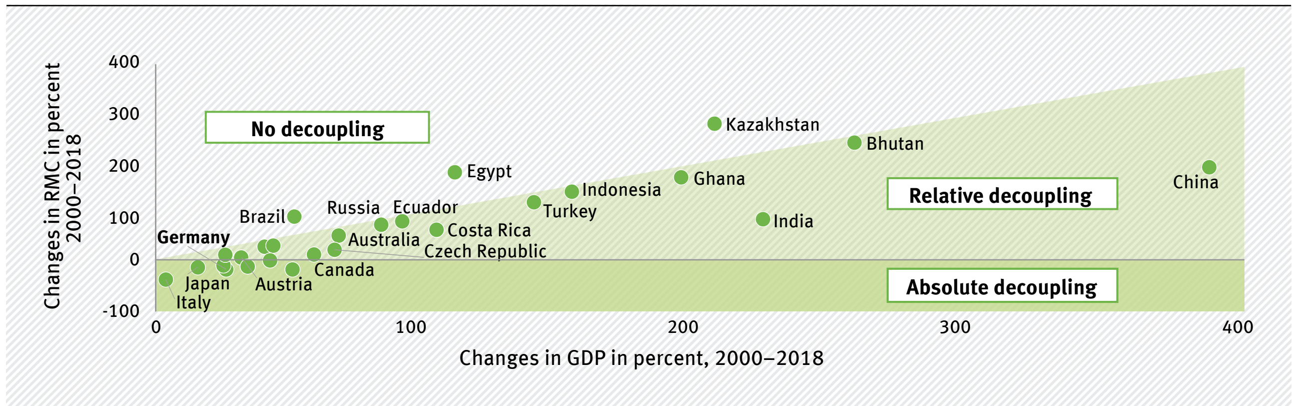
In the period 2010 to 2018, numerous countries achieved relative decoupling, e.g. China, India, Australia and Croatia (Figure 29). Absolute decoupling was less common. Examples here are Germany, South Africa and Japan.

This may suggest that countries like Germany had eased the pressure on the environment, but we must also take into account the absolute sizes of the indicators. These show that Germany and many other European countries still lie significantly above the global average for raw material consumption or raw material input.

Against this background, there is increasing discussion about political strategies that focus on achieving, in addition to higher productivity, lower raw material consumption in absolute terms, e.g. as in the current coalition agreement of the governing parties in Germany (SPD, Bündnis 90/die Grünen and FDP, 2021) and the Netherlands (Langsdorf and Duin, 2021; Ressourcenwende-Netzwerk, 2021).

Figure 29

Decoupling trends of raw material consumption (RMC) from gross domestic product (GDP), 2000–2018



Source: UN Life Cycle Initiative et al., 2022

The role of waste in the circular economy

Closed material cycles in production and consumption are an important component in strategies for conserving resources and protecting the environment. The aim of a circular economy is to avoid and recycle waste in order to reduce the demand for primary raw materials.

The term “circular economy” has been used for a long time in Germany, mainly in the context of waste management. A cross-sectoral transition to a circular economy in addition to effective waste management has, been anchored in the German Resource Efficiency Programme (BMU, 2012, 2016b, 2019) as a guiding principle right from the start. According to this, the important components in closed material cycles are the design of durable and repairable products as well as alternative business models such as leasing and sharing. This is also the approach taken at the EU level by the Circular Economy Action Plan (European Commission, 2020).

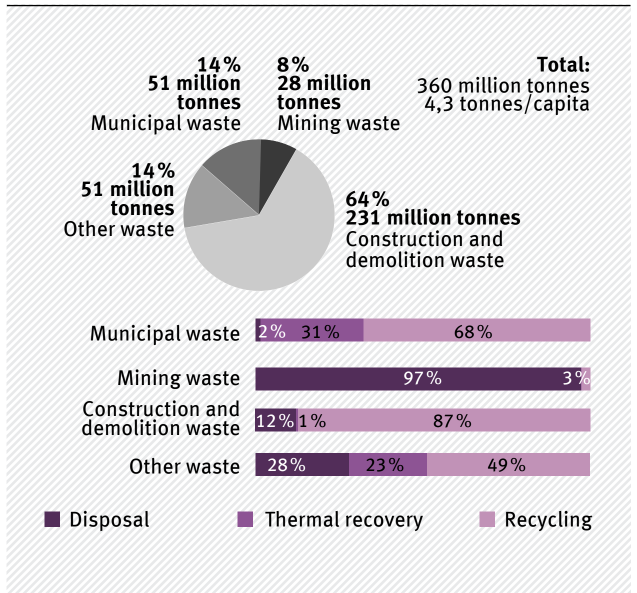
In the context of the circular economy, the indicator “total net waste generation” (“waste generation” for short) measures the actual amounts of waste.

In Germany, waste generation decreased by 6 %, down to 360 million tonnes (Figure 30), in the period 1996 to 2019. Since 2009, however, there has in fact been an upward trend. One reason for this is the increased use of online shopping (see p. 50/51) and the attendant increase in packaging waste. With 4.3 tonnes per capita in 2019, Germany was within the middle range in comparison with European countries (Eurostat, 2021). Most of this waste (64 %) came from construction and demolition, such as rubble, broken-up road surface and excavated soil.

One of the useful methods for assessing the success of the circular economy is “substitution quotas”. There are different approaches to determining these, e.g. the indicator “Circular Material Use Rate” at the European level. It measures the share of recycled materials in overall material use, which, in 2019, amounted to 12 %.

Figure 30

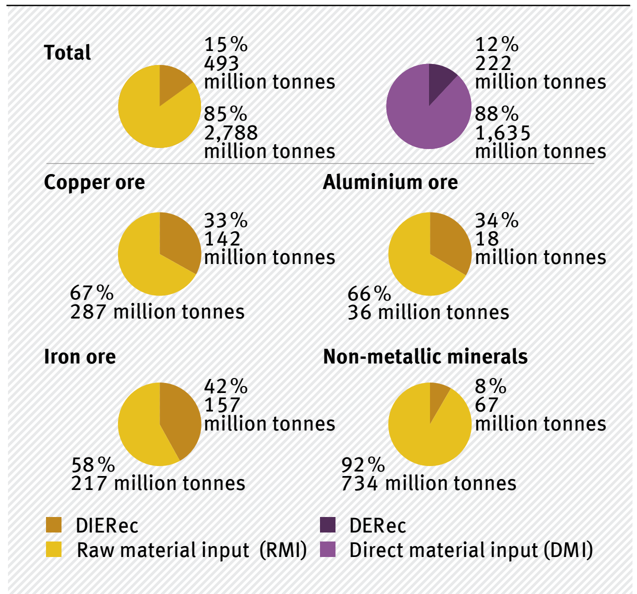
Net waste generation in Germany by type of waste, and waste types by shares of thermal recovery, recycling and disposal, 2019



Source: Destatis, 2021 e

Figure 31

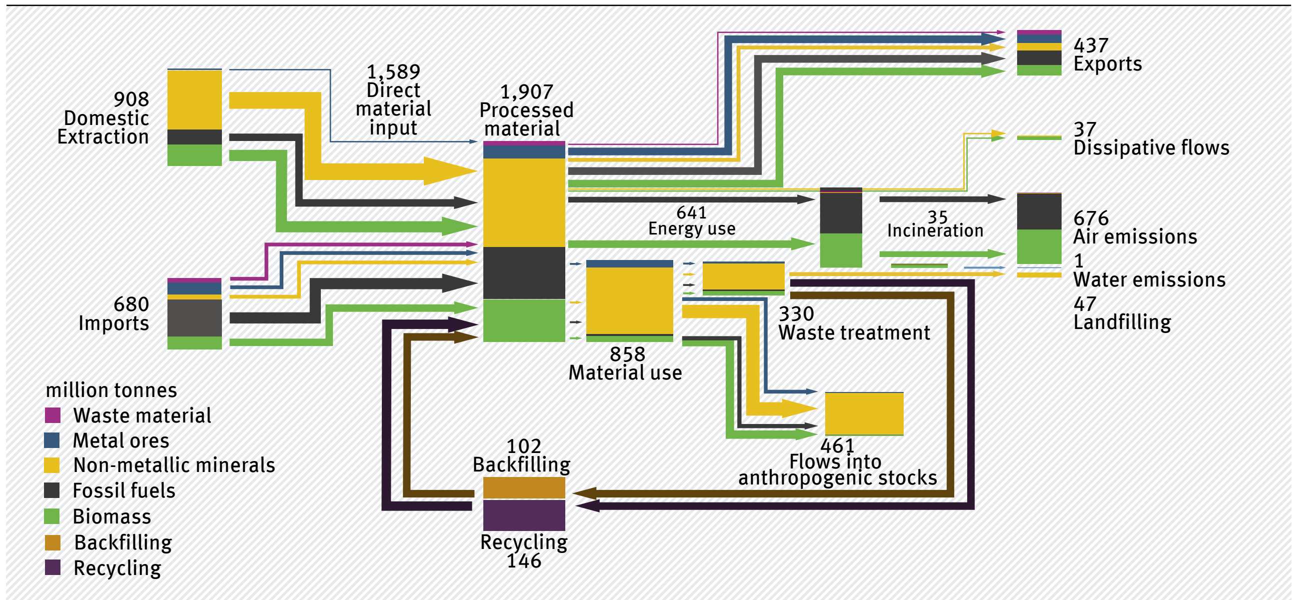
Contribution of secondary raw materials to direct and indirect raw material demand (DERec and DIERec) for selected materials, 2013



Source: Steger et al., 2019

Figure 32

Direct raw material flows through the German economy, by raw material group, 2019



Due to methodological differences, results are not comparable to Figure 33.
Data as reported by Eurostat.

Source: Dittrich et al., 2022 b

In contrast, the “DERec” (Direct Effects of Recovery) and “DIERec” (Direct and Indirect Effects of Recovery) indicators, developed in Germany, represent the conservation of primary raw materials through recycling and energy recovery. The DERec calculates how many primary raw materials are directly conserved through secondary raw materials (i. e. without upstream material inputs). The DIERec in turn also takes into account primary raw materials conserved along global value chains (see p. 28/29).

Using secondary raw materials saved around 12 % of the direct raw material input (222 million tonnes) in 2013 in Germany.

If, in addition, we consider the raw materials used along global supply chains, the raw material input in 2013 was reduced by 15 % due to recycling. Mass metals such as iron play a particularly important part in this, but secondary raw materials contribute considerably to meeting the demand for materials in the case of copper, too. The RMI only implicitly takes this into account. For example, the RMI would have increased in 2013 by 157 million tonnes, if scrap steel and scrap stainless steel had not been used. In the case of non-metallic materials, however, the savings made, e.g. by using recycled aggregate and asphalt granulate, are less significant (Figure 32).

Some materials, though, are not suitable for recycling: fossil raw materials, for example, are burned in order to produce energy, and renewable raw materials serve as feed and foodstuffs. Around half of the materials utilised flow into the anthropogenic stock (Figure 32). Such materials, which are bound up for a long time in the form of buildings or consumer goods, are not immediately recyclable; it will be a long time before they become available again as secondary raw materials – at the end of their life cycle (see p. 42/43).

However, recycling, or a specific focus on the waste sector, is not enough to conserve primary raw materials. Additional concepts are needed, such as extending product use and changing consumer behaviour (see p. 82/83). Furthermore, a broader understanding of the circular economy includes all phases of the material and product life cycle (Müller et al., 2020). Consequently, the German economy, with its strong international division of labour, must also take into account the environmental effects along the value chains of imported goods, as well as the disposal requirements of export goods. In addition, new strategies such as urban mining will play a greater role in the future in steering the circular economy towards climate neutrality.

Anthropogenic stock in the circular economy

A large share of the raw materials used in Germany remain bound long-term in buildings, infrastructure and durable goods – in the so-called "anthropogenic stock". Over the decades, this material stock has been growing considerably. The aim of urban mining is to recover these raw materials after use.

"Anthropogenic stock", or "material stock", is an important factor in the use of raw materials. First of all, this stock plays a major role in the depletion of raw materials that remain bound up for the long term in durable goods such as infrastructure. Once they are constructed, these stocks require further materials such as energy and water for their use, maintenance and renewal.

To estimate the size of the anthropogenic stock, the balance of input and output material flows must be calculated over a very long period of time. Only flows and stocks that are "stock-relevant" are included, i. e. only those bound up in durable goods. However, "through-flows", e.g. input and output flows in the form of foodstuffs and fuels, are not taken into account.

The estimate of Germany's anthropogenic stock for 2010 was a remarkable 51.7 billion tonnes (Figure 33). More than 80 % of this accrued in the period 1960 to 2010 alone.

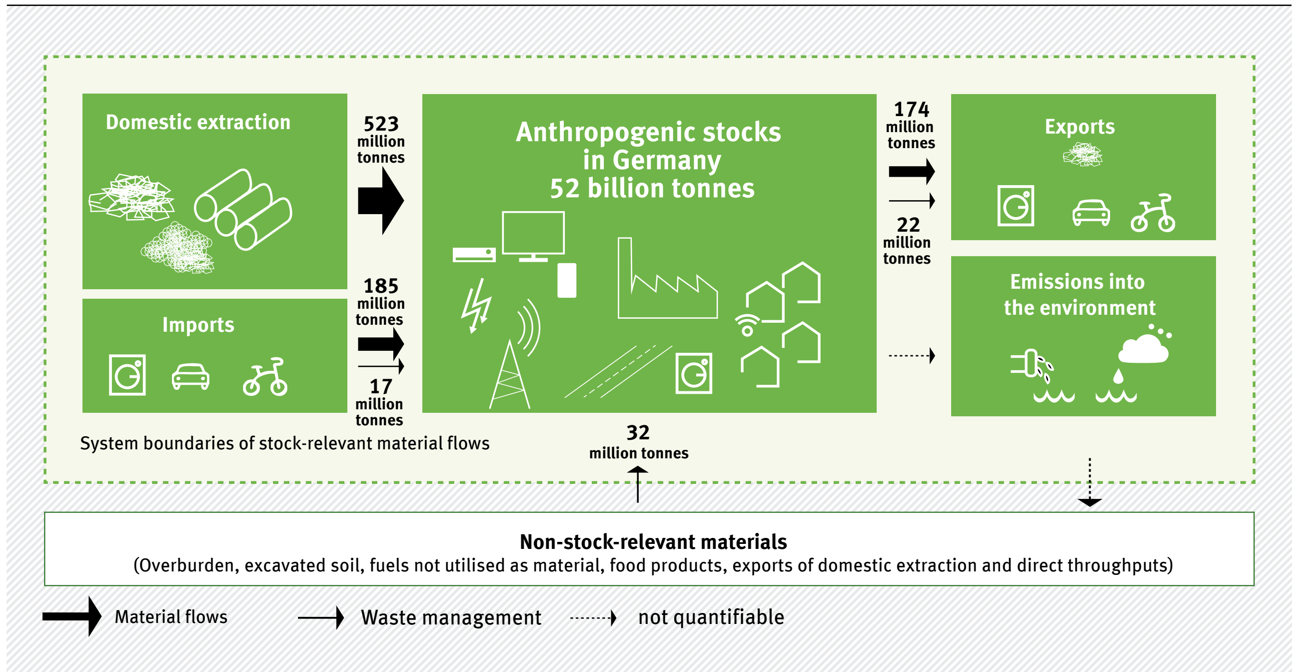
In Germany, material stock in buildings, infrastructure and consumer goods grew annually by around 820 million tonnes, or 10 tonnes per capita.

By way of comparison, raw material extraction in 2019 amounted to 733 million tonnes. This means that, on the domestic level, annual growth in stock and annual raw material extraction were similar in terms of volume (see p. 70/71).

Anthropogenic stock is an important source of secondary raw materials. The integrated management of this is called "urban mining", its aim being to obtain secondary raw materials from durable goods. High-grade recycling is only possible, however, if technical, legal and logistical strategies are put in place in time. This means the material quantities must be assessed as early as possible – before they become waste.

Figure 33

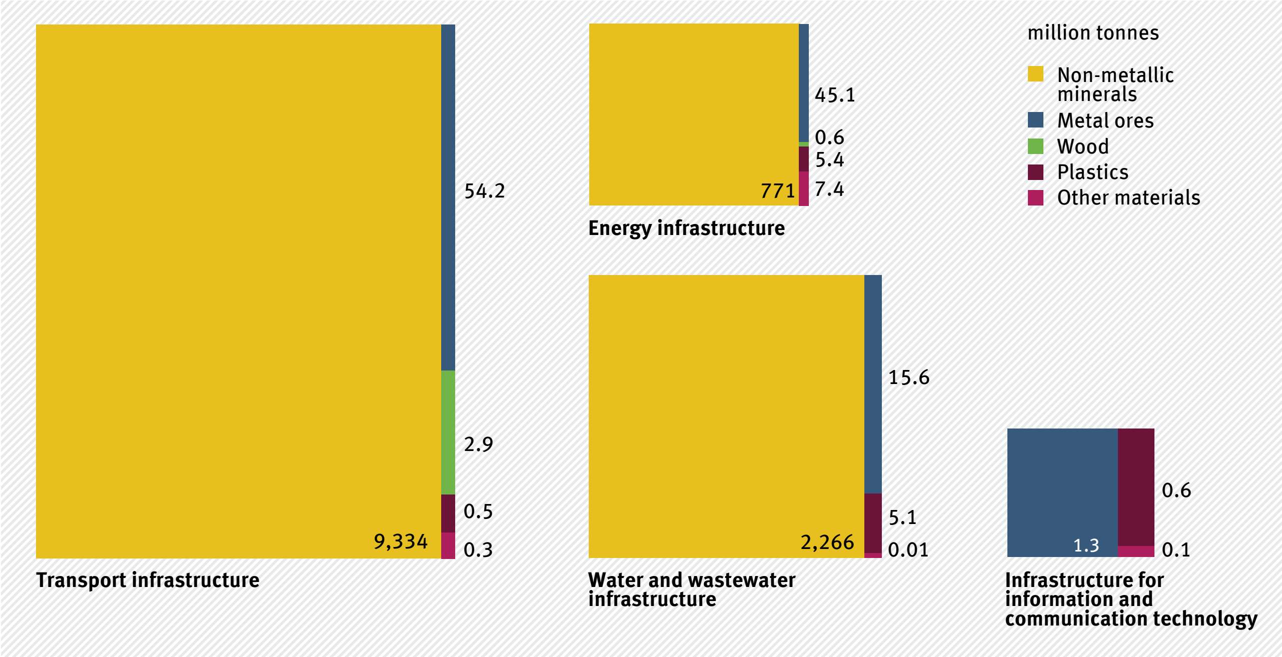
Input and output material flows of anthropogenic stocks in Germany, 2010



Source: adapted from Schiller et al., 2015

Figure 34

Comparison of material stocks of different types of infrastructure in Germany, 2010



The material stocks for the information and communication technology infrastructure were calculated excluding raw materials for buildings and sand beddings.

Source: Schiller et al., 2015

Urban mining has some advantages over the extraction of primary raw materials: many metallic raw materials are either not present in Germany's geological landscape, or are only present in very limited quantities. In other cases, traditional primary mining has been discontinued because it is no longer profitable. Furthermore, secondary raw materials, such as demolition materials, accrue predominantly in places where there is also the highest demand – e.g. in urban areas with high levels of construction and economic activity –, and this saves on transportation. Last but not least, where raw materials are used in anthropogenic structures, they usually occur in significantly higher concentration than they do in the natural environment. This generally reduces the amount of work involved in processing, which is of great ecological benefit.

A review of the material stocks of different types of technical infrastructure shows the potential of urban mining in Germany. The stock mainly consists of mineral raw materials in the form of concrete or bedding for pipes and cables (Figure 34). By far the greatest amount of material stock in underground engineering is accounted for by transport infrastructure, at almost 10 billion tonnes. Infrastructure in the areas of energy, water and wastewater, as well as information and communication technology (ICT), also plays a major role. Increased development of infrastructure brings with it corresponding growth in its stock.

At present, urban mining is worth the effort particularly when it comes to metallic raw materials. There is, however, already a focus on less valuable materials such as minerals from demolition as well as on smaller amounts of technologically important metals ("critical raw materials"): the framework conditions for better recycling are being increasingly adapted and improved.

For the future, we can expect an increase in output flows from anthropogenic stock, especially in the case of building materials. Compiling material inventories and material registers, for example, facilitates their usage as secondary raw materials (Schiller et al., 2022). Sourcing guidelines must ensure that the components used in the construction of a buildng can be separated and reused in the case of demolition.

Raw materials for consumption

1,277 million tonnes	1,186 million tonnes	**Domestic material consumption (DMC) in Germany, 2014 and 2019**
1,327 million tonnes	1,328 million tonnes	**Raw material consumption (RMC) in Germany, 2014 and 2019**
-10 per cent		**Development of domestic material consumption per capita in Germany, 2008–2019**
-5 per cent		**Development of raw material consumption per capita in Germany, 2008–2019**
16.4 tonnes per capita	14.5 tonnes per capita	**Raw material consumption in Germany and in terms of the EU average, 2018**
28 per cent		**Share of the consumption area of food in the raw material consumption of private households in Germany, 2019**
26 per cent		**Share of the consumption area of housing in the raw material consumption of private households in Germany, 2019**
18 per cent		**Share of the consumption area of mobility in the raw material consumption of private households in Germany, 2019**

Sources: see p. 46–53

Developments in raw material consumption

Germany needs large quantities of raw materials in order to supply the goods and services it consumes. These are extracted at different points along national and international supply chains. When compared with other countries, Germany's raw material consumption per capita has remained consistently high.

A country's raw material consumption can be described by two different indicators. Firstly, by domestic material consumption (DMC; see glossary), which comprises domestic extraction and direct trade flows (see p. 26/27). In 2019, this amounted to 1,186 million tonnes, or 14.3 tonnes per capita (Figure 35) for Germany. Secondly, by raw material consumption (RMC; see glossary), which paints a more comprehensive picture of material consumption: it does not consider trade flows in terms of their actual weight, rather it translates these into their raw material equivalents (RME; see glossary).

According to the EU standard method (see p. 10) applied in this report and measuring only primary raw materials, German raw material consumption amounted to 1,328 million tonnes, or 16.0 tonnes per capita (2014: 1,327 million tonnes, or 16.4 tonnes per capita) in 2019. By comparison, calculations by Destatis also take into account secondary raw materials (see pp. 10/11). For 2018, these show a 3% decrease in raw material consumption.

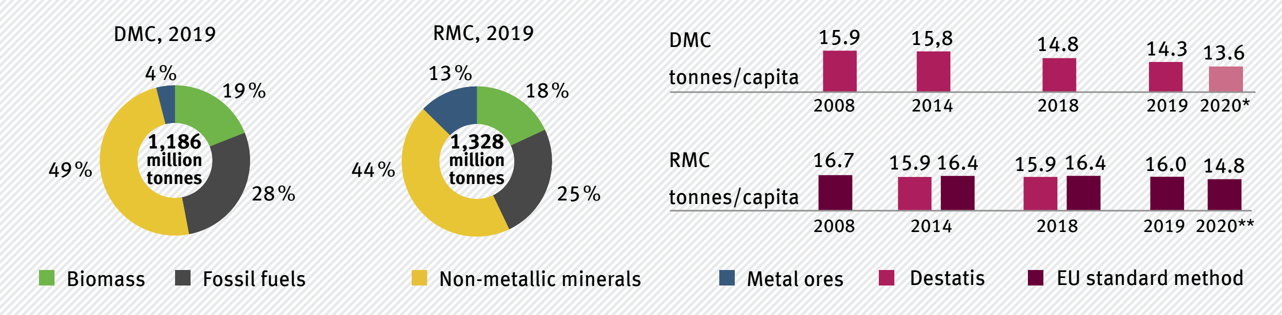
According to both methods of calculation, raw material consumption is higher than domestic material consumption. This difference shows that the goods consumed in Germany are also based on raw material extraction abroad. Overall, imports measured as raw material equivalents (i.e. indirect flows) are bigger than the exports.

Another difference between DMC and RMC consists in the shares of the individual raw material groups. Although metal ores represent the smallest share under both indicators, their share in domestic material consumption is, at 4%, considerably smaller than their share in raw material consumption (13%). This is due to the fact that goods based on metal ores have relatively large associated indirect flows, since the metal content in the extracted ores is often very low. Compared with the total amount of mined ore, the weight of the metals in the goods that are produced from them is low.

The consumption indicators show different trends: in terms of per-capita values between 2008 and 2019, domestic material consumption shows a stronger decline than raw material consumption (-10% and -5% respectively).

Figure 35

Domestic material consumption (DMC) and raw material consumption (RMC) in Germany, in absolute values by raw material group, 2019; and per capita, 2008–2020



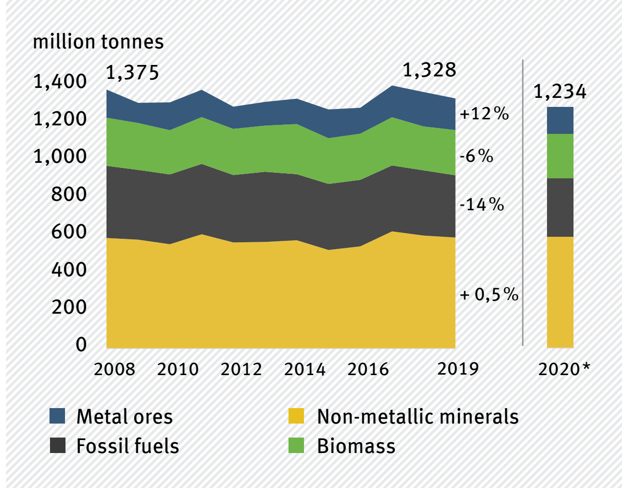
Due to conceptual differences, calculations based on Destatis and the EU Standard Method respectively yield different results (see page 9–11).
* Projected data based on trends as reported by Eurostat, 2021.
** Preliminary estimate based on changes in direct material flows as reported by Eurostat, 2021. (Dittrich et al., 2022 a).

Sources: Destatis, 2021 f, 2021 h; Dittrich et al., 2022 a

Germany's raw material consumption fell between 2008 and 2019 from 16.7 to 16.0 tonnes per capita.

Figure 36

Development of raw material consumption (RMC) in Germany by raw material group, 2008–2020



* Preliminary estimate based on changes in direct material flows as reported by Eurostat, 2021. (Dittrich et al., 2022 a)

Source: Dittrich et al., 2022 a

Both indicators therefore reflect the downward trend since 2000, which has already been described in the 2016 and 2018 resource reports (UBA, 2016a, 2018). This trend intensified from 2019 to 2020: according to estimates, raw material consumption per capita fell by 8% in only one year due to the coronavirus pandemic.

Differences were observed across the consumption trends of the individual raw material groups. Particularly striking is the decline in raw material consumption of fossil fuels since 2008 (-14%) due to increased use of renewable energies (see p. 74/75) (Figure 36). Biomass raw material consumption, too, fell by 6%. By contrast, metal ore consumption increased by 12%. Non-metallic minerals stayed approximately the same.

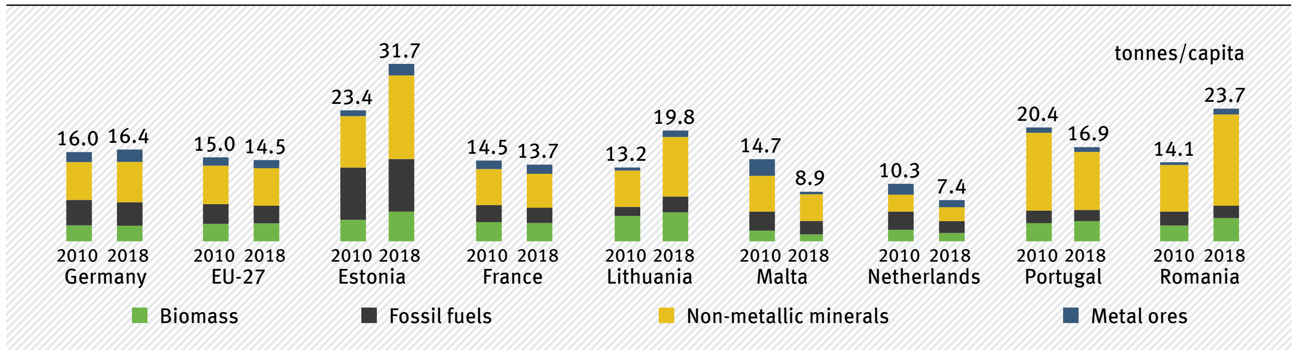
In the ten years before the pandemic (2010–2019), there was only a negligible decrease in the German and EU averages for raw material consumption. However, at 16.4 tonnes per capita in 2018, Germany's raw material consumption was 13% higher than the EU average of 14.5 tonnes per capita (Figure 37).

There were differences between the raw material consumption trends among the Member States. In the Netherlands, Malta and Portugal, raw material consumption fell by up to 40%. Other countries, however, such as Estonia, Lithuania and Romania, recorded an increase. At 68%, the increase in Romania was the most pronounced. The primary reason for this was the increasing consumption of non-metallic minerals due to the sharp upturn in activity in the construction sector.

Germany's above-average raw material consumption could be brought down, if measures are implemented that create incentives for resource-saving production and consumption. A detailed analysis of final demand and the individual consumption areas may make it easier to devise these measures and may reveal areas with specific saving potential (see p. 48/49).

Figure 37

Comparison of per-capita raw material consumption (RMC) in Germany with selected EU Member States and the EU average, 2010 and 2018



At the editorial deadline, Eurostat RMC data for selected Member States were available up to 2018.

Sources: Eurostat, 2021; Dittrich et al., 2022 a

The composition of raw material consumption

Germany's raw material consumption can be subdivided into different areas of final demand. Private households and their activities are the main contributors to this demand. The majority of raw materials are needed for food, housing and mobility.

Raw material consumption comprises the raw material demand across the final demand categories of investment, consumption and changes in stocks. Investment is made in buildings, infrastructure and equipment, such as machinery (573,000 tonnes in 2019). Consumption includes expenditure by the state, private households and private non-profit organisations (733,000 tonnes in total in 2019). Changes in stocks (23,000 tonnes in 2019) play a relatively minor role.

Within the final demand category of consumption in 2019, more than three quarters (81.9%) of raw material consumption were accounted for by private households. The state, too, needed large quantities of raw materials (17.6%) to cover its provision of services (Figure 38), however.

The areas of food, housing and mobility represent almost three quarters of private households' raw material consumption.

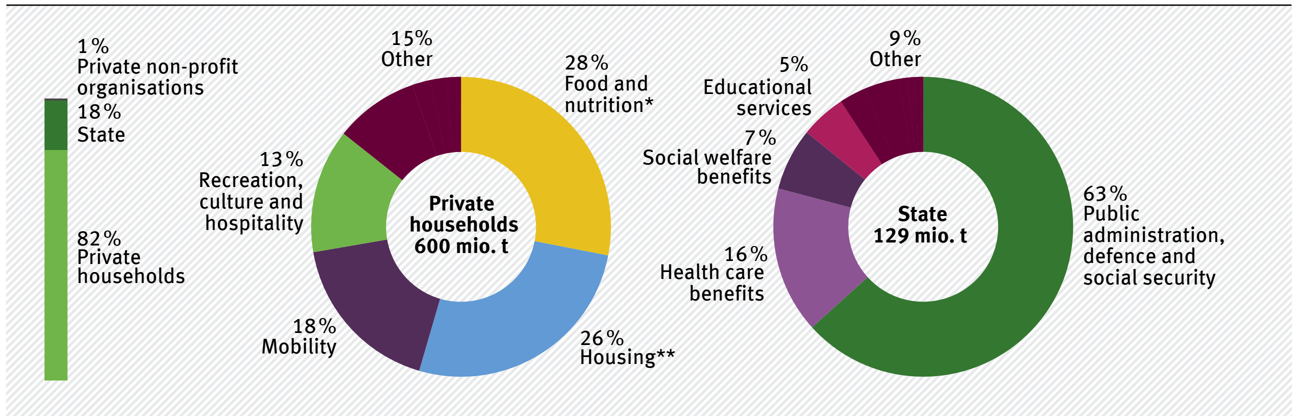
The consumption areas of food and housing represent the largest share in private consumption (28% and 26% respectively). The consumption area of mobility follows in third place (18%) (Figure 38).

Administration, defence and social security (63%) and healthcare (16%) are the biggest contributors to public raw material consumption. Healthcare in particular has a highly complex supply chain structure, with products made from fossil raw materials, such as medicines and protective clothing, as well as those made of metals, such as medical instruments (see p. 48/49 in the resource report 2018; UBA, 2018).

In terms of private consumption, utilisation of raw materials in the consumption areas of food and housing is similar, but the focus is on different raw materials. In 2019, German food consumption averaged 169 kilograms of raw materials per capita per month. Less surprisingly, biotic raw materials dominated this area of consumption. Furthermore, fossil fuels are needed for e.g. operating agricultural machinery and heating greenhouses, and non-metallic minerals are used as fertiliser or in food preservation.

Figure 38

Raw material consumption (RMC) by sub-category, and raw material consumption of private households and the state by consumption areas, 2019

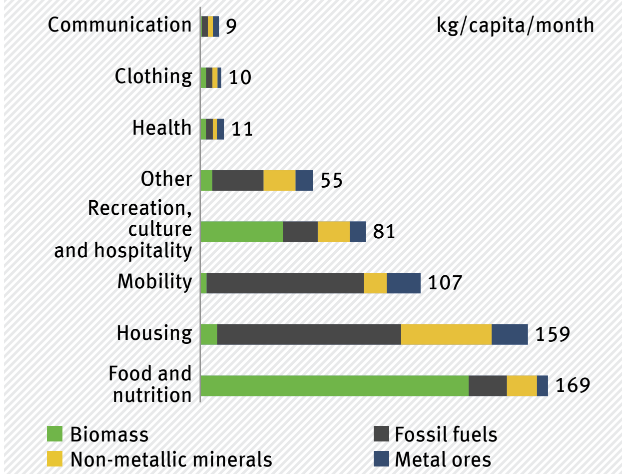


In addition to the categories Investments and Consumption, the statistical system also includes a category Changes in stocks. However, this category plays only a minor role.
* Raw materials for food stuffs, which are consumed in gastronomy and in state-owned facilities, such as canteens, are not included.
** Including maintenance (rehabilitations), usage (in particular, heat and electricity), furniture and rental services. The construction of buildings is not included.

Source: Dittrich et al., 2022a

Figure 39

Monthly raw material consumption and per-capita spendings in Germany, by consumption area and raw material group, 2019



	Spending		Raw material consumption	
	Euro	%	kg	%
Total	1,287	100%	601	100%
Food and nutrition	178	14%	169	28%
Housing	516	40%	159	26%
Mobility	176	14%	107	18%
Recreation, culture and hospitality	221	17%	81	13%
Other	60	5%	55	9%
Health	52	4%	11	2%
Clothing	53	4%	10	2%
Communication	33	3%	9	2%

Due to methodological differences, values in this figure are not directly comparable to figure 37 in the previous Resources Report (UBA, 2018).

Sources: Destatis, 2020a; Dittrich et al., 2022a

In the consumption area of housing (159 kilograms of raw materials per capita per month), around half the consumption was accounted for by raw materials serving, in particular, the heating and electricity supply. Mineral raw materials, on the other hand, play a secondary role since the construction of buildings is not included here. In terms of the raw materials utilised in the area of mobility (107 kilograms per month), fossil fuels account for as much as three quarters of these. The demand for fuel for private motor vehicles is a significant contributor here (see p. 52/53).

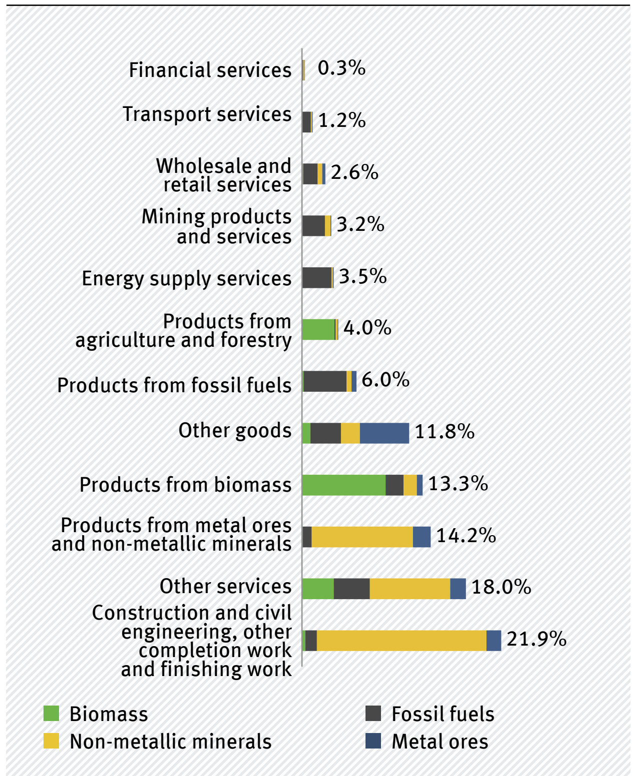
There are only a few parallels between raw material consumption and expenditure in the different areas of consumption of private households (Figure 39). The area of housing, for example, is both resource-intensive and costly: it accounts for most of the expenditure (40%) as well as much of the per-capita raw material consumption (26%) of private households. Measures such as a reduction in per-capita living space could therefore save on both raw materials and expenditure (see p. 90/91).

A comparison of contributions to raw material consumption across commodity groups shows that raw materials for construction work above and below ground – especially those that consist of non-metallic minerals (e.g. building sand and cement) – had, at 21.9%, the largest share in raw material consumption (Figure 40). Services accounted for a total of 18% of raw material consumption. Although services are less material-intensive than the manufacturing industry, they, too, have large indirect flows associated because of their upstream services, e.g. communication technologies or electricity and heating.

This analysis of raw material consumption "hotspots" also highlights where potential savings can be made. Because the respective areas of consumption (e.g. mobility) often affect several resources (mobility not only consumes fuel but also produces emissions, which ultimately impact on the planet's natural reserves), conserving resources may generate positive synergies.

Figure 40

Shares of commodity groups in the raw material consumption of final demand in Germany, by raw material group, 2019



Source: Dittrich et al., 2022a

Raw material consumption: the example of digitalisation

Digitalisation is transforming almost every sphere of our lives, including patterns of production and consumption: in some areas it is saving resources; in others, rapid technological development is generating new resource consumption.

Digitalisation is the transition from analogue to digital processes (UBA, 2019a). The digital transformation began back in the mid-20th century, and it has gained considerable momentum over the past few years and decades. Consumption, too, is increasingly taking digital form, e.g. via online retailing or streaming activities. Digitalisation is promoting the utilisation of services that are often physically located abroad (e.g. data centres).

The ecological opportunities and risks of digitalisation are not only a hot topic in Germany (WBGU, 2019). The buzzword "dematerialisation" articulates, on the one hand, the possibilities of resource conservation, e.g. the streaming of music and films is replacing physical storage media such as CDs and DVDs. On the other hand, digitalisation is increasing the demand for raw materials and energy in the production and operation of devices that connect to the internet (Kassenböhmer et al., 2019).

There has been a sharp rise in the number of digital terminals such as smartphones and laptops in recent decades. For example, in Germany in 1998, only one in five people owned a computer and only one in ten owned a mobile phone. In 2018, on average, every German owned a computer and a mobile phone (Figure 41).

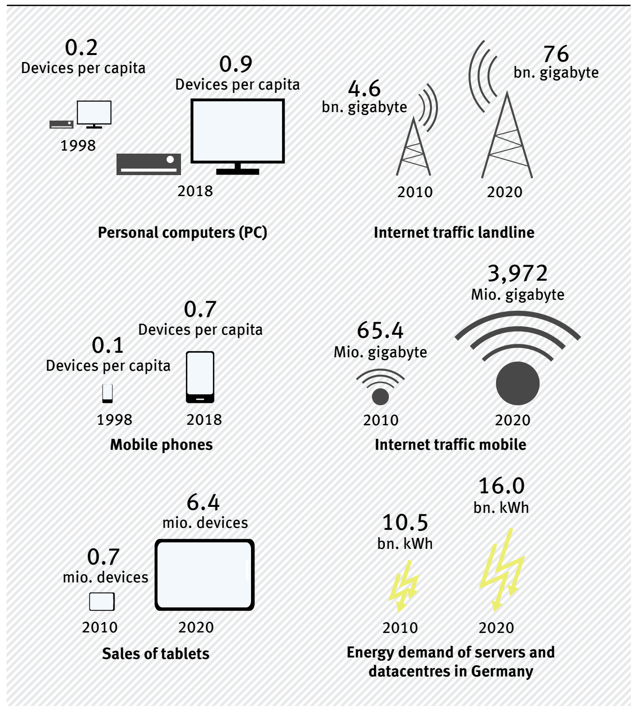
The digital age: mobile internet traffic increased by a factor of 60 in the period 2010–2020, from 654 to 3,972 million gigabytes.

Resource demand in information and communication technology (ICT) depends, inter alia, on the type and quantity of the devices used and the intensity of use. We are still lacking, however, appropriate methods for analysing the raw material intensity of the ICT sector, which is statistically very difficult to differentiate. This is because contributions to the raw material demand come, on the one hand, from the production of digital technology, and, on the other, from the utilisation phase of digital devices – the latter particularly in the form of energy consumption. According to initial estimates based on the EU standard method (see p. 10), around 37 million tonnes of raw materials were consumed by ICT-related commodity groups and services in Germany in 2019, i.e. 3% of the total raw material consumption (Figure 42). The usage phase is not included in this figure.

The ICT sector comprises various commodity groups. At 39%, the majority of raw materials were consumed by "data processing devices, electronic and optical products" (e.g. smartphones, laptops, televisions) and electrical equipment such as cables and batteries (Figure 42). Metal ores accounted for 41% of the raw materials in ICT goods. Aluminium, steel and copper account for 37% of the materials that make up the average smartphone (Figure 43) (Rizos et al., 2019). Other metals, such as gold, cobalt and coltan, are only present in small amounts, yet they usually have large indirect flows associated with them and a greater environmental hazard potential (see p. 56/57).

Figure 41

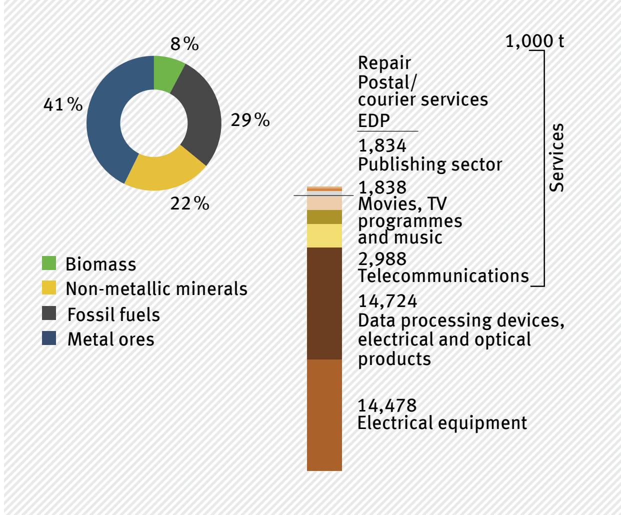
Development of information and communication technology in Germany



Sources: IDC et al., 2020; Bundesnetzagentur, 2021; Destatis, 2021 b; Hintermann, 2021

Figure 42

Raw material consumption (RMC) for goods of the information and communication technology by commodity groups and raw material group, 2019



Source: Dittrich et al., 2022 a

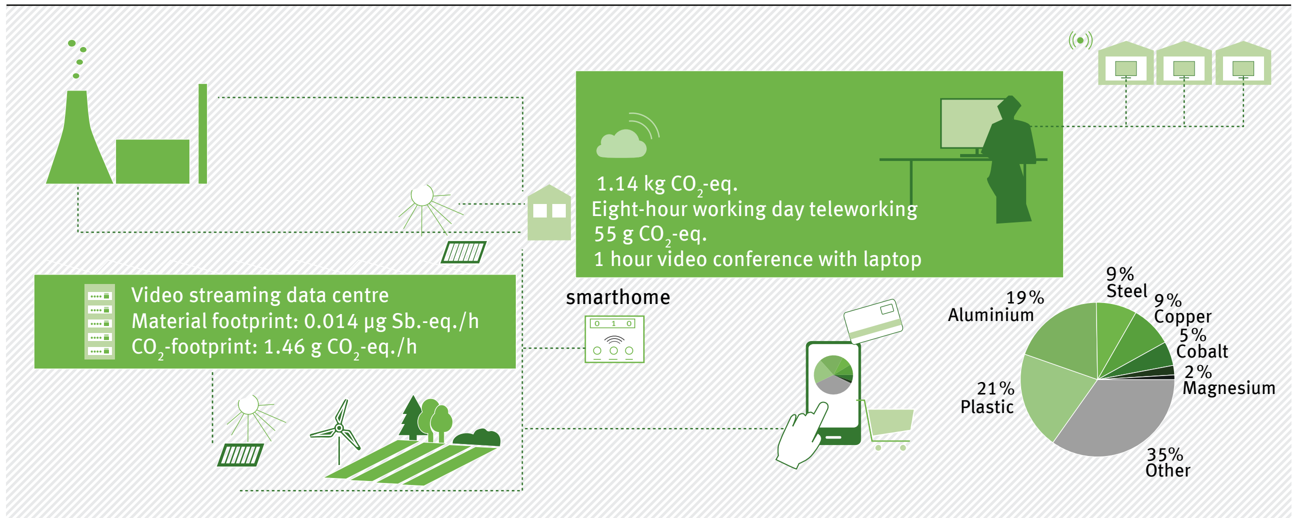
Many studies on the topic of digitalisation focus on individual products and processes, or on the energy demand or CO_2 emissions. In the case of the latter, it is mainly the choice of energy source that influences the raw material input. A data centre, for example, produces the same emissions for streaming a two-hour blockbuster as a car journey of 10 metres (Gröger et al., 2021). It is not only the data centre, however, that consumes energy and therefore resources: the telecommunications network and the terminals transmitting the content do, too. If this is taken into account, then a one-hour video conference has a carbon footprint of up to 90 grams of CO_2 equivalents. In fact, an average eight-hour working day in a home office has as a carbon footprint equal to an eight-kilometre car journey (Gröger et al., 2021).

Streaming, online shopping and other forms of digital consumption are easily accessible. There is a risk here, however, of what is known as the "rebound effect". This is where the ecological advantage over material consumption is counterbalanced or even outweighed by easy accessibility and intensified usage (Frick and Gossen, 2019). Greater accuracy of measurement is therefore even more important when determining the raw material demand of digitalisation – this is the focus of a current study on Germany (UBA, 2022 a).

The overall impact of digitalisation on the environment is still difficult to estimate, but it is certainly set to continue its sharp upward trajectory in terms of its societal relevance and its utilisation of raw materials. Is the digital transformation proceeding in a sustainable way? Can it pave the way for more sustainable lifestyles and patterns of consumption in the future? This is fundamentally dependent on how it is managed and the policy instruments employed in the process.

Figure 43

Selected examples on the raw material demand of digitalisation



Sources: Rizos et al., 2019; Gröger et al., 2021

Raw material consumption: the example of mobility

Mobility is a basic prerequisite for everyday provisions, work, education and participation in society. Rising prosperity and globalisation have been increasing the volume of traffic in Germany for years. This has led to a rise in raw material demand and emissions.

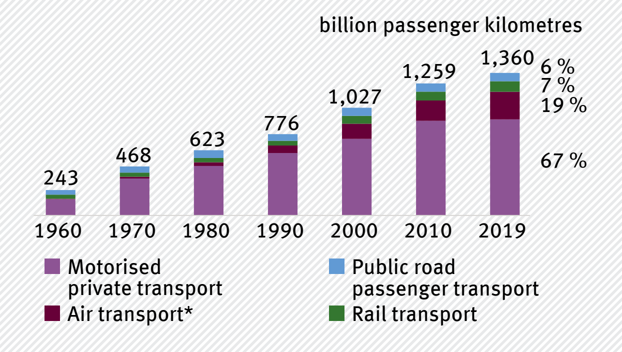
The key indicator for the mobility of individuals is "passenger transport volume". It consists of the number of individuals transported, multiplied by the distance covered. The passenger transport volume in Germany increased almost fivefold in just under 60 years (1960 to 2019) (Figure 44). This was primarily due to motorised private transport, particularly cars.

The "modal split", i.e. the distribution of transport volume across the means of transport, is changing over time, too. Motorised private transport has an increasingly dominant share in passenger transport: in 2019, this share amounted to 67%. Rail transport and public road and passenger transport, by contrast, had a share of under 10%. Air traffic – not yet significant in 1960 – was already up to 19% in 2019.

Increasing mobility not only causes greenhouse gas emissions; it also requires large amounts of raw materials. Mobility is therefore, after food and housing, the area with the highest raw material consumption (see p. 48/49).

Figure 44

Passenger transport volume by mode of transport in Germany, 1960–2019



* Departing flights up to first arrival

Sources: BMVI, 2021; TREMOD, 2021

The consumption area of mobility accounts for around a fifth of the raw material consumption of private households.

Of the 107 million tonnes of raw material consumption by private households in the area of mobility, 84% was accounted for by private transport (Figure 45). It should be noted here, however, that the raw material consumption for mobility includes raw materials for maintaining but not building infrastructure. The majority of raw material consumption was accounted for by fuels, i.e. fossil fuels, in the case of both private transport (70%) and public transport (80%). In the period 2008 to 2019, the raw material consumption of private households in the area of mobility decreased overall by 14%.

Differences between private and public transport can also be observed in the material requirements of individual forms of mobility (including infrastructure) (Allekotte et al., 2020). At 85 grams per passenger kilometre, cars had the highest cumulative raw material consumption (KRA; see glossary), above all in the form of fossil fuels for energy supply and infrastructure (Figure 46). In addition, metallic raw materials play an important role in vehicle production, as do mineral raw materials in infrastructure (each around 51 grams per passenger kilometre). For example, 27,659 tonnes per kilometre of construction material are used in road superstructure for German federal motorways (Knappe et al., 2015), which represents a major contribution to the "anthropogenic stock" (see p. 42/43).

Rail transport has a material-intensive infrastructure, so mineral raw materials have the largest share in overall KRA (between 96 grams per passenger kilometre for trams and 122 grams per passenger kilometre for local rail transport).

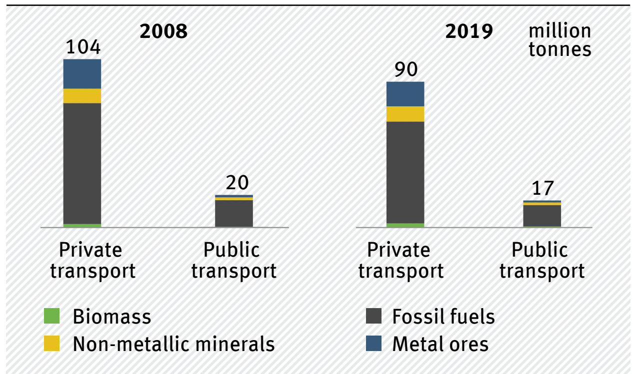
Air traffic, however, has high cumulative energy consumption (KEA; see glossary). At 2.8 megajoules, domestic flights require the most primary energy per passenger kilometre. Because of their high fuel consumption, aeroplanes and cars both have a more negative impact on the climate than trains. In a comparison of KRA per passenger kilometre, however, air traffic usually comes off better than other public transport because it uses neither rail tracks nor roads. On the other hand, because aeroplanes generally cover greater distances, their KRA often comes off worse in an absolute comparison of e.g. holiday journeys. Cycling consumes the fewest raw materials and generates the fewest greenhouse gases.

There is an uneven distribution of transport use in Germany; the higher the income, the greater the use of transport such as cars and aeroplanes, which consume large amounts of raw materials and have a negative impact on the environment – there is almost a linear connection here. Higher-income households cause considerably more harm to the environment due to their mobility behaviour (Oehlmann et al., 2021).

Not only passenger transport but also goods traffic is increasing overall, and a large proportion of this is road haulage. The raw material intensity of freight transport is calculated by comparing tonnes per kilometre, with larger juggernauts and articulated lorries coming off better than smaller trucks (Allekotte et al., 2020).

Figure 45

Raw material consumption (RMC) of private households for the consumption area mobility in Germany, 2008 and 2019



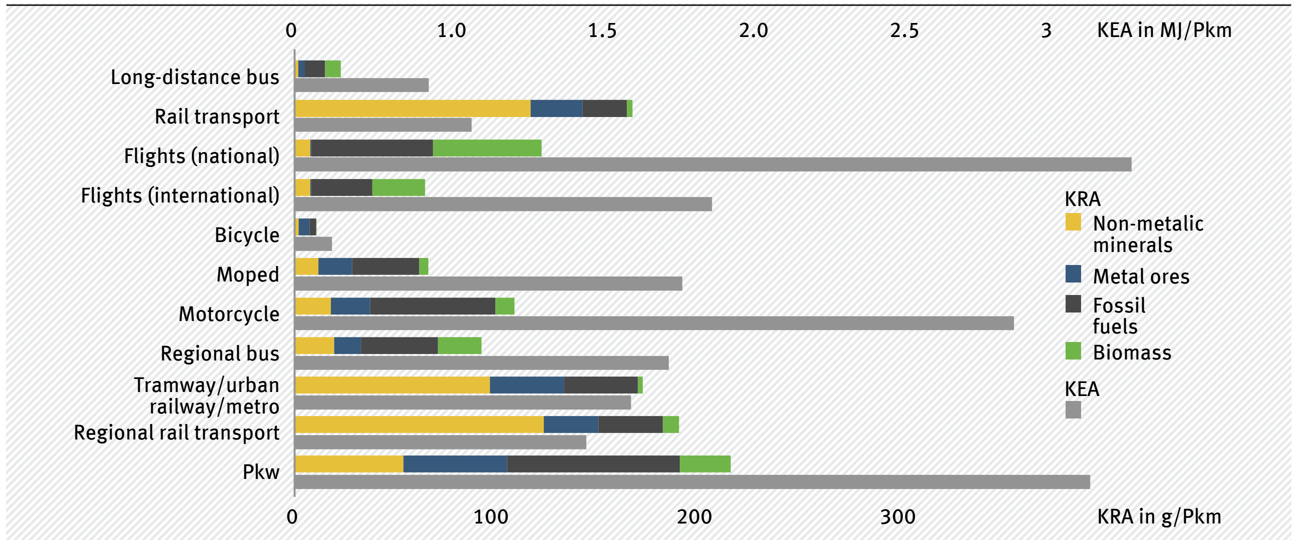
Source: Dittrich et al., 2022 a

Energy and raw material input (Figure 46), however, are merely two important indicators. A comprehensive ecological comparison would require further detailed analyses.

Several aspects are important in ensuring sustainable mobility, e.g. the transition to sustainable forms of transportation as well as transport concepts with a lower proportion of private motor vehicles or freight transport on the roads. Political measures such as pricing emissions or abolishing subsidies that harm the environment (e.g. diesel privilege) may accelerate such a transformation.

Figure 46

Cumulative raw material consumption (KRA) and Cumulative energy demand (KEA) for passenger transport in Germany by mode of transport, 2017



Pkm: passenger kilometres

Source: Allekotte et al., 2020

Environmental consequences of raw material use

40 per cent	**Contribution of extraction and initial processing of raw materials to total greenhouse gas emissions**
- 14 per cent	**Reduction in greenhouse gas emissions between 2010 and 2019**
- 16.5 per cent	**Reduction in fossil fuel consumption between 2010 and 2019**
+ 4 per cent	**Increase in nitrogen fertiliser usage between 2010 and 2018**
17 per cent	**Proportion of groundwater measuring points that exceeded the threshold value for nutrient inputs in 2015–2017**
10 per cent	**Exceedance of threshold value for surplus nitrogen per hectare of land used for agriculture (2015–2017)**
2	**Number of planetary boundaries exceeded worldwide – nitrogen and phosphorus cycles and loss of genetic diversity**
2	**Number of planetary boundaries exceeded in Germany – land use change and nitrogen cycles**

Sources: see p. 56–63

Environmental hazard potential of raw materials from mining

The extraction of raw materials through mining is inevitably associated with interference in natural systems, often with negative environmental and social consequences. This especially affects countries with weak government leadership, which supply some of the raw materials for the German market.

The extraction and use of mineral resources from natural deposits for our economic system can damage the environment. Known consequences include, for example, decreasing groundwater levels, soil pollution due to heavy metals, and the partly irreversible destruction of ecosystems. Incidents also include extreme events with high numbers of deaths and far-reaching pan-regional damage (e.g. toxic mudslides as a result of dam ruptures). The nature and extent of the damage depends on many factors. These are, among others, the type of raw materials extracted and the deposits, mining and processing technologies, local environmental conditions and, last but not least, the effectiveness of local environmental regulations (Figure 47).

Germany is dependent on imports from other countries for the large part (two thirds) of the raw materials currently required.

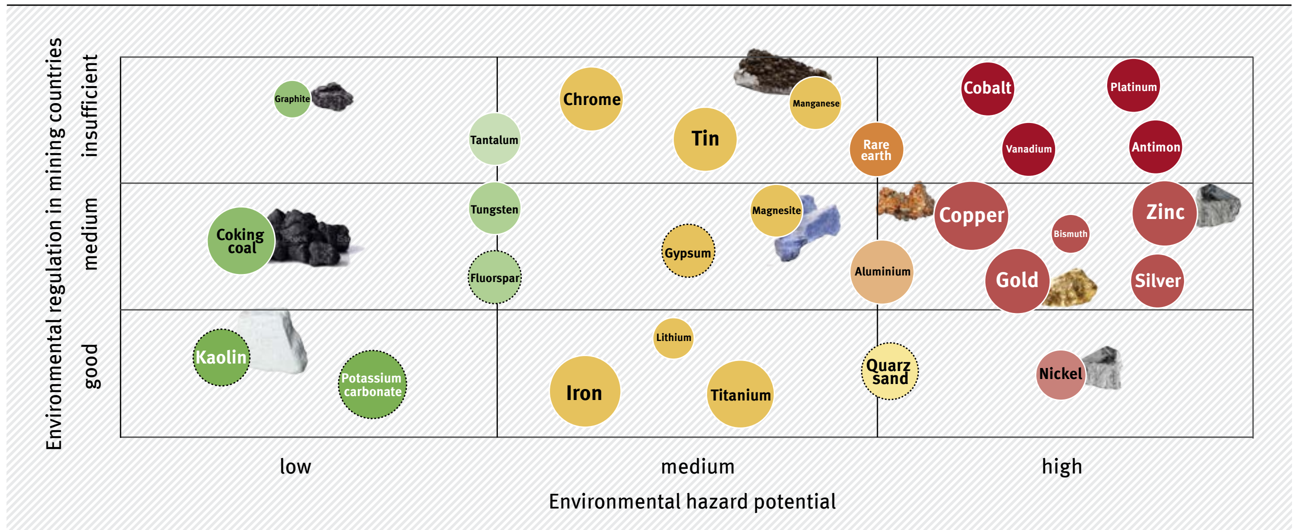
When it comes to energy sources, this figure rises to as much as 80 % of the amounts used. Germany imports almost 100 % of its metal ores (see p. 26/27). While the government counteracts the environmental risks associated with the mining of domestic raw materials through appropriate national regulations (e.g. the Federal Mining Act), it can only exert an indirect influence on imported raw materials (see info box).

To assess the environmental hazards associated with the mining of diffrent raw materials, Dehoust et al. (2020) developed a procedure that determines the "environmental hazard potential" (EHP). Among other things, the risk of acidic mine water , the release of heavy metals or radioactive substances, and accidents caused by natural phenomena are all taken into account (Table 1).

In addition, the procedure assesses the following factors for each raw material: the environmental regulations in the producing countries, the relevance for small-scale mining, the type of by-products, and

Figure 47

Environmental hazard potentials (EHP) and environmental regulation in mining countries, by raw material



The size is proportional to global material and energy flows associated with the raw material (three-stage scale).
Raw materials with a black outline show relevant extraction quantities also in Germany.

Sources: Dittrich et al., 2022 b basend on data of BGR, 2020 a; Dehoust et al., 2020

Table 1

Environmental hazard potential (EHP) indicators for Kaolin, Iron, Lithium and Copper

Indicator	Kaolin	Iron	Lithium	Copper
Acid mine drainage	low	medium	low	high
Heavy metals	low	medium	low	high
Radioactive materials	low	medium	medium	medium
Extraction method	medium	medium	high	medium
Auxiliary materials	low	medium	mittel	high
Risk of critical incident	low	medium	high	high
Water scarcity	medium	high	medium	high
Biodiversity	low	high	low	medium
Aggregated EHP	**low**	**medium**	**medium**	**high**

Source: Dehoust et al., 2020

the scope of the global material and energy flows to estimate the extent of the environmental hazards.

Case study: copper. Copper plays a central role of systemic importance for the energy transition on account of its high conductivity. As Europe's most important producer of copper products, Germany has the third highest demand for copper in the world – after China and the USA. However, Germany is almost completely dependent on raw material imports from other countries.

Copper is a raw material with a high EHP (Table 1). Copper ore mining requires huge volumes of rock to be moved: it takes up to 150 tonnes of mined copper ore to produce one tonne of copper. Depending on the mine, the average copper content is only around 1.5 % or less. Huge amounts of overburden are created during mining, often up to 500 tonnes or more per tonne of copper (BGR, 2020 b). Often, this waste material from the mining process is so contaminated with heavy metals and chemicals that it is considered toxic. In addition, sulphur-containing ores can form pools of acidic mine water when they come into contact with water and oxygen. This mine water damages the environment through acidity and the mobilisation of bound heavy metals. In addition, there is significant disturbance to the local water balance during mining: Mines and adits need to be drained, and ore processing often involves intensive use of water. Copper mining – especially in areas with scarce water supply – can therefore come into competition with agriculture, the drinking water supply and nature conservation.

For Germany, a globally significant importer of raw materials, the EHP analyses of individual raw materials have a number of consequences. The use of raw materials with a high EHP should be reduced as far as possible, e.g. through recycling or more efficient production. If such materials are indispensable – especially for technical applications for the energy transition – protective measures in the mining countries should be given greater support. The federal supply chain law is a step in this direction (see info box).

Supply chain law

How can Germany ensure that domestic consumption of raw materials does not lead to environmental and social problems in mining countries? Germany does not have direct political influence on regulations in force in mining countries. Nonetheless, the federal supply chain law, which was passed by the Bundestag on 11 June 2021, is a first step in this direction. It obliges German companies to pay attention to environmental and human rights along their supply chains and to continuously improve.
However, the law regulates environmental aspects only to a limited extent. The condition for this is that they must either be directly related to a human rights violation or relate to specific international agreements (on mercury and on persistent organic pollutants).
The concern is therefore that the law will have little positive effect on the extraction of raw materials – especially since it limits the due diligence to the direct supplier, while the extraction of raw materials usually takes place earlier in the value chain. In this regard, companies only have to take action if they are aware of possible violations (BMZ 2021).

Raw material use and climate change

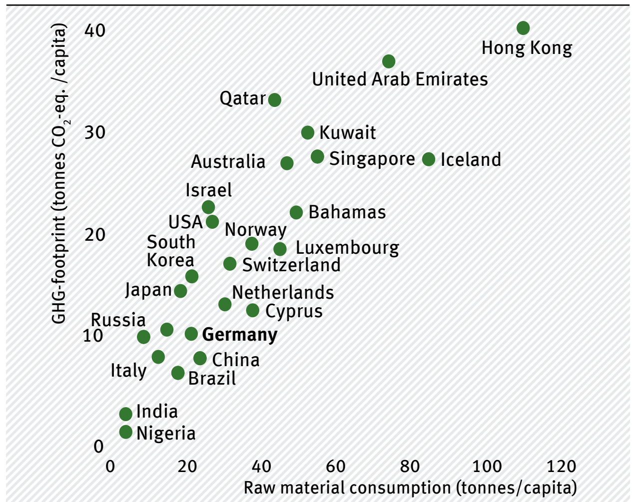
Advancing climate change, caused by large amounts of greenhouse gas emissions from human activity, is one of the most pressing environmental problems of our time. Sustainable management of raw materials is important for climate protection, because raw material use has a strong impact on the climate.

With increasing prosperity, both the extraction of raw materials and the emission of greenhouse gases have risen sharply worldwide – to new global highs (UNEP IRP, 2019 a; IPCC, 2022). Countries' raw material consumption and greenhouse gas emissions are often proportional to each other (Figure 48). India, for example, a country whose raw material consumption (RMC) amounts to only around 5 tonnes per capita annually, emits fewer than 5 tonnes of CO_2 equivalents per capita per year. The population of the United Arab Emirates, on the other hand, consumes on average around 76 tonnes of raw materials and emits 37 tonnes of CO_2 equivalents per capita per year.

The link between raw material consumption and greenhouse gas emissions is not always the same, however. For example, the same consumption of raw materials may be accompanied by different levels of greenhouse gas emissions, as the country comparison shows (Figure 48). Or similar amounts of greenhouse gas emissions may coincide with different levels of resource consumption, such as in Iceland and Singapore.

Figure 48

Greenhouse gas emissions-footprint and raw material consumption (RMC) per capita in different countries, 2017



Germany: only CO_2-emissions

Sources: Destatis, 2021 g, 2021 f; UNEP IRP, 2022

A key factor for the connection between raw material consumption and greenhouse gas emissions is the way in which energy is generated. Still, fossil fuels dominate worldwide. Globally, on average, each person consumes around 2 tonnes of oil, natural gas or coal per year. Consumption is higher in wealthy countries. In the United Arab Emirates or the USA, around 26 and 10 tonnes respectively of fossil raw materials are consumed per capita annually; in India or Bolivia, the figure is only 0.8 tonnes and 1 tonne respectively per capita. In China, the world's largest emitter of greenhouse gases, consumption is 3 tonnes per capita, while the corresponding figure for Germany is 4 tonnes (Dittrich et al., 2022 a; UN Life Cycle Initiative et al., 2022; UNEP IRP, 2022).

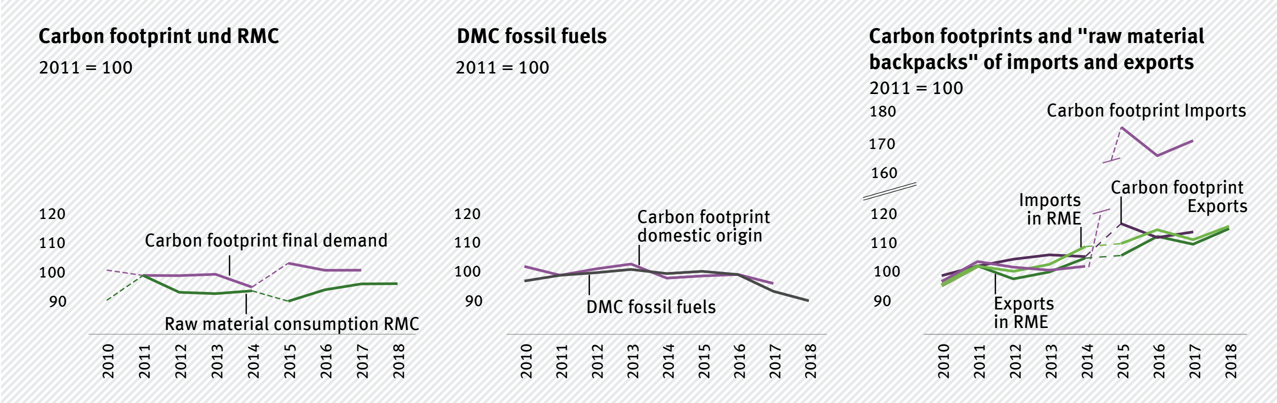
In Germany, the trends for raw material consumption and greenhouse gas emissions have differed in recent years (Figure 49, left). Why? Firstly, because the effects of the energy transition are evident. Between 2010 and 2019, the consumption of fossil fuels in Germany fell by 16.5 % (from 396 to 330 million tonnes), whereby domestic CO_2 emissions decreased (Figure 4, centre). Secondly, the relationship between imports and exports changed: while the CO_2 footprint of exports up to 2014 was greater than that for imports, this trend was reversed between 2015 and 2017 (Figure 49, right). It should be noted here that the figures are only comparable to a limited extent, because the national accounts (VGR) were updated from 2015.

Around 40 % of all Germany's greenhouse gas emissions can be attributed to the extraction and processing of raw materials.

In 2015, the global average was almost 55 % (UNEP IRP, 2019b, 2019a). In addition to fossil fuels, greenhouse gas emissions are also caused by the extraction and processing of other raw materials. For example, limestone is de-acidified as part of cement production, which produces CO_2. Iron is reduced when manufacturing steel, and CO_2 forms here, too. Methane is released during the extraction and transport of natural gas, but

Figure 49

Development of raw material consumption (RMC), domestic material consumption (DMC) and carbon footprint of Germany and depiction by components, 2010–2017/2018



RME: raw material equivalents (see glossary); Dotted lines indicate a revision of the system of national accounts.

Sources: Destatis, 2021 f, 2021 g, 2021 h

also during rice cultivation and animal husbandry. This greenhouse gas has a shorter life but its effects on the climate are 25 times stronger than those of CO_2. Nitrous oxide – a greenhouse gas 298 times more climate effective than CO_2 – is produced as a result of agriculture and in the production of fertilisers.

Consequently, greenhouse gas emissions can be significantly reduced, if fewer primary raw materials are used. Possible options include, firstly, lower product demand, e.g. by having more durable products; secondly, by replacing raw materials that produce large quantities of greenhouse gases with other raw materials, for example in the construction sector (see info box); or, thirdly, by increasing recycling of raw materials. In the case of metals, for example, recycling is already generally widespread. The advantage: recycled secondary steel produces between 62 and 90 % fewer greenhouse gas emissions than primary steel. Aluminium fares even better, with 80–96.5 % fewer emissions.

The UBA study "RESCUE" (Purr et al., 2019) examined the links between raw material consumption and greenhouse gas emissions. The GreenSupreme scenario demonstrates that, by 2050, appropriate measures could save 97 % of greenhouse gas emissions (compared to 1990) and 70 % of raw material input (compared to 2010) at the same time (see p. 84/85). The combination of protecting resources and climate action is therefore critical for Germany to achieve greenhouse gas neutrality in the near future. In addition to the energy transition, a resource transition is also contributing to climate action. This involves a circular economy, the efficient use of raw materials, the replacement of emission-heavy raw materials, and sufficient (frugal) management.

The relevance of raw materials and climate to the construction sector

Construction demands large amounts of raw materials – around 500 million tonnes annually in Germany alone (Destatis, 2021 h). This accounts for approx. 38 % of total raw material consumption. 14 % of metals, 75 % of non-metallic minerals and 7 % of fossil raw materials are used directly or indirectly by the construction sector. Since non-metallic minerals produce fewer greenhouse gases than other raw materials, the 50 million tonnes of CO_2 emitted by the sector (2017) "only" equal 5.6 % of Germany's total CO_2 footprint. The biggest sources of CO_2 are energy, steel and cement. In 2018, the industry used 29 million tonnes of cement and 14 million tonnes of steel. One tonne of cement generates c. 745 grams of CO_2. Of this, 400 grams are process-related emissions, resulting directly from the chemical reaction during limestone de-acidification (VDZ, 2019). Each tonne of steel generates c. 1.74 tonnes of CO_2 equivalents. A more eco-friendly alternative is wood from certified sources. Long-term use of wood for building means CO_2 is stored in buildings, while the regrowing forest captures more carbon (Schütze et al., 2016).

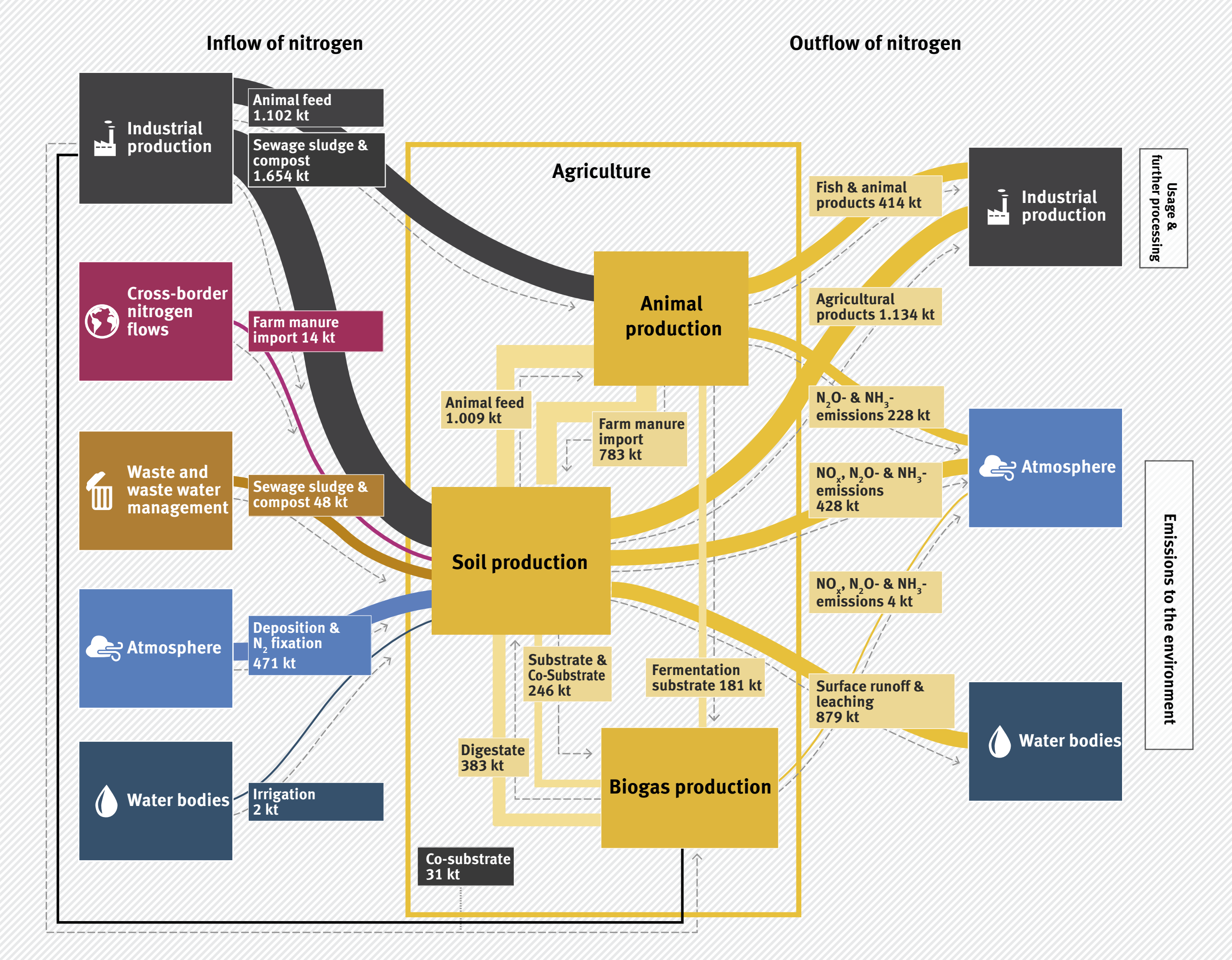
Environmental impacts of raw materials: the example of nitrogen

Nitrogen is an indispensable raw material in agricultural production for the cultivation of plant and animal products. However, due to inefficient use of this valuable resource, reactive nitrogen also ends up in the environment. The negative repercussions can be serious.

In order to be able to use nitrogen (chemical element with the symbol N), it must be converted from its elementary form as a component of air into reactive nitrogen, which can be absorbed by plants, for example. In the form of different compounds, nitrogen is used not only in agriculture but also in the energy sector and in industry. However, the compounds created through chemical reaction (nitrate, nitrogen dioxide, ammonia and nitrous oxide) can also have negative impacts on the environment. On average, around 1.6 million tonnes of reactive nitrogen are released as emissions in Germany every year (2010–2014). Almost two thirds of these emissions come from agriculture alone; the remaining third is produced as a result of energy production, industry and transport, as well as wastewater and surface run-off (rainwater).

Figure 50

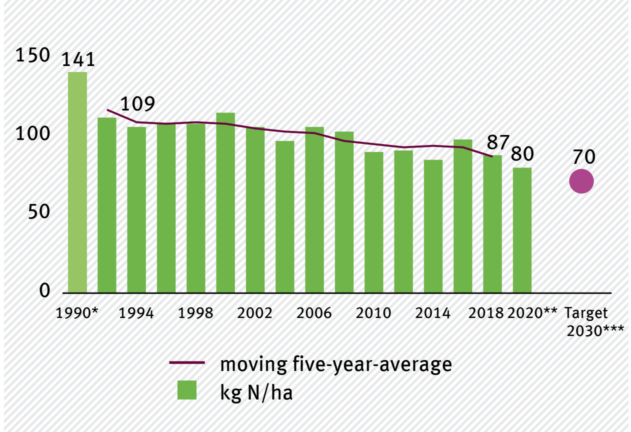
Sub-section „Agriculture“ in the national nitrogen accounts: in- and outflows of nitrogen in thousand tonnes of nitrogen (kt N) per year as average of the years 2010–2014



Source: grafically adapted from illustration by Bosch & Partner and kopfarbyte based on data of UBA, 2022 e; Bach et al., 2020

Figure 51

Nitrogen surplus of the national farm-gate balance in relation to the area in use, 1990–2020



Annual surplus based on the mean year of a 5-year period (calculated from rounded annual values).
* Data partially uncertain and of only limited comparability with the following years.
** Preliminary data.
*** German Sustainable Development Strategy, new edition 2016: 70 kg N/ha.

Source: BMU, 2022 b

Nitrogen inputs by humans affect ecosystems in water and on land, change the biodiversity of these ecosystems and the climate, and have a detrimental impact on human health. If reactive nitrogen enters groundwater and leaches into rivers or seas, it can cause eutrophication (nutrient enrichment) in coastal ecosystems. The subsequent growth of algae leads to oxygen-poor ocean zones and corresponding threats to marine life.

Global population growth and increasing prosperity are significantly increasing the need for food. To ensure harvests, nitrogen is an important raw material and nutrient for agriculture and enters the production chain via feed and fertilisers. In farm fertilizers, nitrogen is also used as a reusable resource from animal production (slurry, manure) for the cultivation of crops. In animal and plant production, however, high nitrogen surpluses occur, which are released into the environment as ammonia emissions or nitrate inputs (UBA, 2021 g).

Around 1.1 million tonnes of nitrogen are used in animal production in Germany due to animal feed from industrial production and imports. In addition, around 1 million tonnes of nitrogen from staple feeds are produced in the agricultural sector itself (Figure 50). Mineral fertilisers for growing crops contain a little more, namely 1.7 million tonnes. This flow has been reduced significantly to 1.3 million tonnes in recent years (Destatis, 2022 c). In addition, 0.7 million tonnes of nitrogen come from manure of animal origin, as well as from fermentation residues of biogas plants (UBA, 2022 c). In total, the nitrogen supply in Germany via mineral and organic fertilisers has increased by 4 % over the past decade (2010 to 2019) compared to the previous two decades (BMU, 2022 a).

The nitrogen surpluses resulting from the balance of nitrogen supply and removal are of key importance for the extent of environmental pollution, e.g. excessive nitrate levels in groundwater. For the period of 2016–2020, the average nitrogen surplus was 87 kilograms per hectare (Figure 51). Due to different livestock densities and the resulting accumulation of agricultural manure, the figures can vary greatly regionally and between individual farms. The federal government has set itself the goal of reducing the nitrogen surplus in agriculture to 70 kilograms per hectare by 2030. Despite a decrease since 1990, the 2030 target is unlikely to be reached, if the trend of the past decade continues.

In view of the numerous environmental impacts, it is clear that the raw material nitrogen must be handled with the greatest care. In order to further reduce nitrogen loss in agriculture, consistent implementation and control of the existing regulatory requirements is crucial. It is likewise important to implement a broad mix of technical and efficiency-promoting measures in crop production and animal husbandry, but also in other pollutant sectors, such as the energy sector, industry and transport. Citizens can also have a direct influence, for example by reducing consumption of animal products and wasting less food, because a large part of the individual nitrogen footprint is due to nutrition (UBA, 2022 c).

Raw material use within planetary boundaries

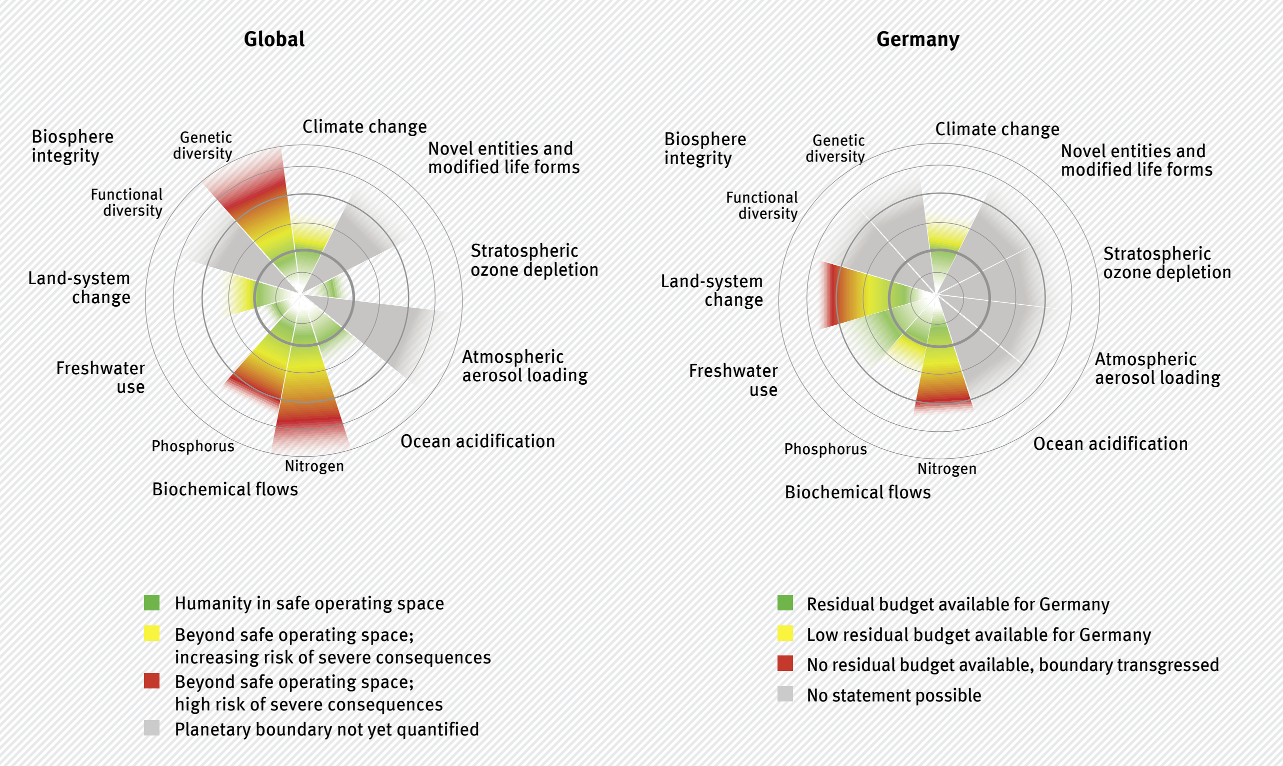
The concept of Planetary Boundaries illustrates barriers to global environmental pollution. If the limits are exceeded, the stable conditions for human life may change irreversibly. Most of the nine defined planetary boundaries are directly or indirectly related to resource use.

The concept of Planetary Boundaries (Rockström et al., 2009a; Steffen et al., 2015) defines a safe operating space in which sustainable living is possible. It identifies the load limits or tipping points for nine ecological dimensions. If these are exceeded, the resilience and functionality of the earth system may change irreversibly, havong fundamental restriction of human livelihoods as a consequence. The nine dimensions include climate change, biosphere integrity, land use change, and ocean acidification (Figure 52).

At the global level, specific limit values have already been formulated for six of these dimensions, and further limit values are under discussion. These limits are currently exceeded in at least two dimensions: regarding global nitrogen cycles and the loss of genetic diversity. Recent research indicates that limit values for freshwater use and novel entities may also have been exceeded (Persson et al., 2022; Wang-Erlandsson et al., 2022). The planetary boundaries for the dimensions of climate change and land use change have not yet been exceeded – but the safe operating space has already been passed, which means that the risk of going beyond the exceeding the boundaries rises sharply.

Figure 52

The planetary boundaries-concept applied to the World and Germany

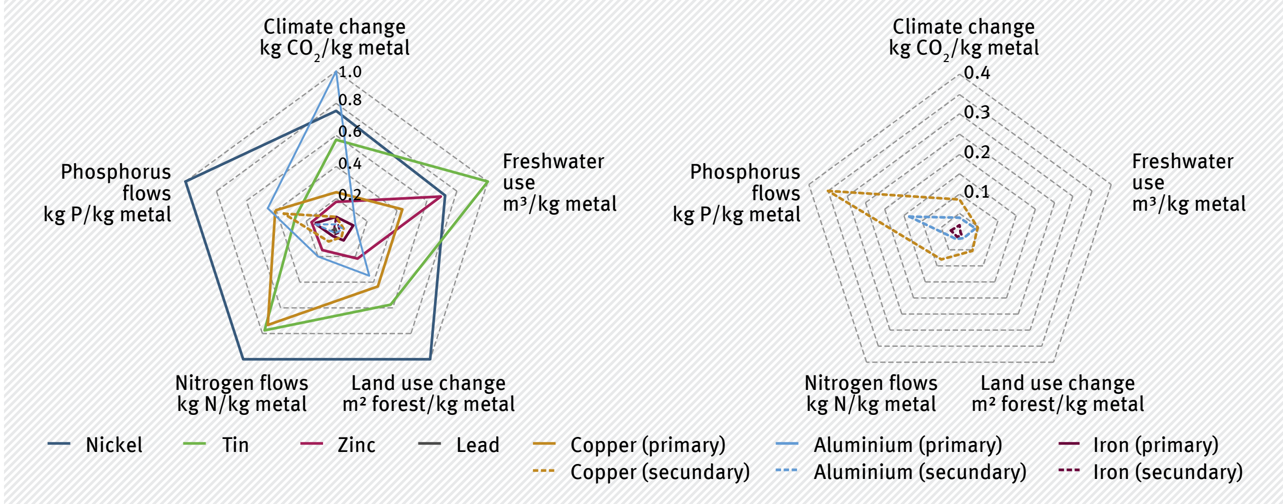


The global perspective was disaggregated for Germany following the "egalitarian principle", distributing limit values among all living humans equally. Alternative ways of allocation are based on the principle of "historical responsibility" (Countries that consumed more natural resources in the past and had a higher share in global pollution receive fewer pollution permits) or based on the "right to development" and the "sovereignty principle".

Sources: World: adopted from Steffen et al., 2015; Germany: Dittrich et al., 2022

Figure 53

Consequences of processing of primary and secondary metals for the dimensions of the planetary boundaries



The radar chart shows specific environmental impacts resulting from the processing of metal ores to pure metal ("cradle-to-gate") per kilogram metal.
The axes of each category are normed; the highest value of each category (environmental impacts of primary and secondary processing) are set to 1.

Source: Dittrich et al., 2022 b

In Germany, according to the principle of equality, the limit values have already been exceeded in two dimensions: regarding the nitrogen cycles and in land use change. For land use change, the global limit has been set at retaining 75 % of the original forest area. This limit varies when regional vegetation zones are included. In a temperate zone like Germany, the limit is 50 % of the original forest area (Steffen et al., 2015). Only a third of the formerly thickly forested territory of Germany is still dense forest today – and almost nowhere the forest is in its original state (Figure 52).

When it comes to the dimensions of the phosphorus cycle and climate change, there is a risk that Germany will exceed the limits. Regarding the latter, only a small greenhouse gas budget is left, if the residual global budget is distributed equally among all people.

Raw material use is directly and indirectly connected to the planetary boundary dimensions. Water, land and energy, among other things, are required for the extraction, preparation, processing, use and disposal of raw materials and goods made from them. This in turn leads to the emission of greenhouse gases and changes in nitrogen or phosphorus cycles (see p. 58/59 and 60/61).

By conserving raw materials and developing the circular economy, it is possible to prevent the global load limits from being exceeded. For example, utilising waste makes a significant contribution to reducing the use of natural resources – as well as reducing the corresponding environmental impacts caused by the extraction, processing and production of semi-finished and finished goods. This applies in particular to base metals, which can theoretically be reused almost infinitely, often without functional losses. The processing of iron, copper and aluminium scrap is less harmful to the environment than the extraction of these metals from ores (Figure 53): the extraction of copper from copper ore generates per kilogram of metal around 3.7 kilogram of CO_2 and uses 0.23 cubic metre of fresh water, while the processing of copper scrap only produces 1.3 kilogram of CO_2 and uses 0.02 cubic metre of fresh water (Ecoinvent, 2021).

Raw materials policy can thus contribute to economic activity within the planetary boundaries. However, it is important to consider which of the planetary dimensions should govern decision-making. The answer is straightforward according to the precautionary principle: the limit that is most likely to be exceeded – or that has already been exceeded – applies.

Nexus: other natural resources and their connection to raw materials

850 litres	**796** litres		Water extraction in Germany per capita per day, 2013 and 2016
6,152 litres	**6,633** litres		Water extraction in Germany per capita per day, 2011 und 2021
52 hectares per day			Increase in settlement and transport area, 2019
‹30 hectares per day			Target for increase in settlement and transport area according to the German Sustainable Development Strategyfor 2030
75 per cent	**75** per cent		Share of foreign land in Germany's land footprint, 2010 and 2018
572 petajoule	**789** petajoule		Primary energy production from flow resources, 2015 and 2019
99 grams per kilowatt-hour			Average raw material input for onshore wind turbines across their entire life cycle
55 per cent	**32** per cent	**37** per cent	Foreign share in raw material consumption, land and water footprint of foodstuffs consumed in Germany

Sources: see p. 66–79

Water use in Germany

Along with raw materials, water plays an important role in resource use in Germany. The water use of private households represents only a small proportion of this. The biggest user in Germany is the energy sector. Water extraction across Germany has been decreasing since 1991.

On average, sufficient water resources are available in Germany. However, there are differences in regional distribution, and the resources are subject to sharp fluctuations caused by the weather – both over the course of the year and in terms of the annual average. (UBA, 2020b). In 2018, the available water resources (ground and surface water) amounted to only 119 billion cubic metres (2013: 181 billion m³), whereas the long-term average is 188 billion cubic metres (Bfg, 2016).

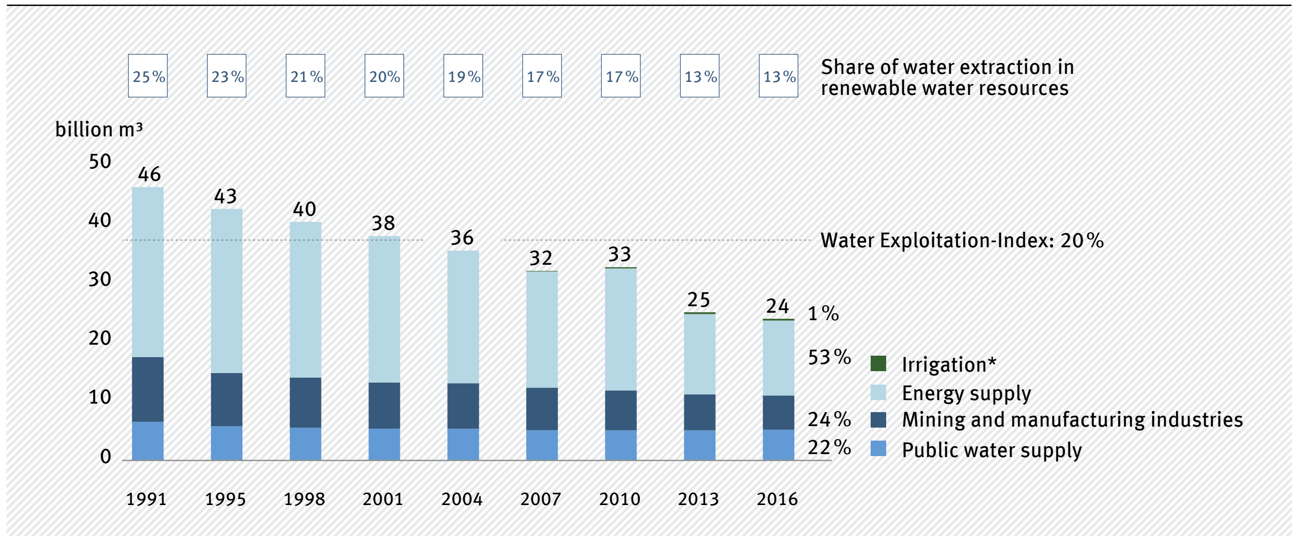
In Germany, most of the water is extracted by the energy sector for the purpose of cooling thermal power plants (53 %), by the mining and manufacturing industries (24 %), by public water suppliers (22 %), and by agriculture for irrigation purposes (1 %) (Figure 54). A crucial criterion for sustainable water use is the share of overall extraction in the water resources available in the long term – also called the "water exploitation index" (see glossary). This index was at 13 % in Germany in 2016, therefore remaining below the 20 % threshold for water stress. In 1991, the water exploitation index for Germany was still at 25 %. This improvement is due to the decrease in water use in all areas, but especially in the energy sector. Reduced demand for cooling water – a consequence of the phasing out of nuclear energy – has played a major part in this.

Water extraction from ground and surface water halved in Germany between 1991 and 2016.

Overall, water extraction fell by 48 % to 24 billion cubic metres from 1991 to 2016. These values represent the average water extraction per year across the whole of Germany. Types of water use, as well as rainfall, evaporation, and therefore groundwater recharge, are subject to both regional and seasonal variation. Seasonal peaks are caused, for example, by additional water consumption for irrigation in the dry summer months.

Figure 54

Water extraction by economic sector in Germany, and share in total renewable water resources, 1991–2013



* Data available from 2007 onwards. At the editorial deadline, data on water extraction and on renewable water sources were available up to 2016.

Sources: Destatis, 2019 c; Bfg, 2020

In 2019, every person in Germany was using around 128 litres of drinking water per day in the household (this includes the use by small businesses). The majority of this was used for personal care (36 %) and toilet flushing (27 %) (Bdew, 2021).

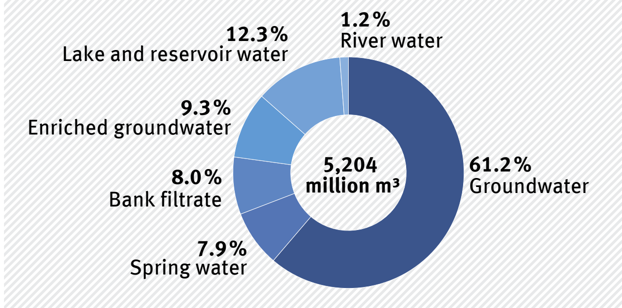
Just under 70 % of drinking water extracted by the public water supply (5 billion m³) is ground and spring water. The rest comes from surface water, bank filtrate and enriched groundwater (Figure 55).

Overall water use, converted into per-capita water extraction, as well as the distribution across the different sectors are dependent on several factors, e.g. the industrial and agricultural structure of a country, as well as its climatic conditions. In 2016, Germany was one of the countries in the European Union that used a large share of the extracted water for the purpose of generating electricity (143 m³ per capita, Figure 56), whereas relatively little water was used for agricultural irrigation (4 m³ per capita). A different picture emerges in southern European countries: Greece, for example, extracted 752 cubic metres per capita – or 80 % of the total volume – for the purposes of agricultural irrigation. It should be noted, however, that these numbers also include the water use for agricultural exports.

We can assume here that climate change will, in future, have a significant impact on the domestic water balance. This may exacerbate existing regional or seasonal water shortages (see info box). It remains essential, therefore, that care is taken with the resource water.

Figure 55

Water extraction for public water supply in Germany by type of water, 2016

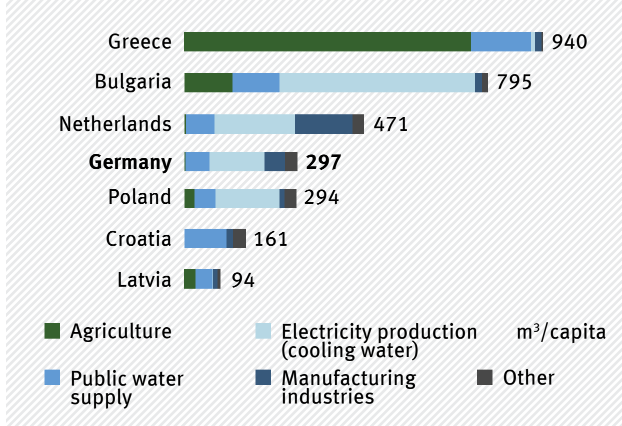


Water extraction for public water supply also includes water extraction by private companies that exclusively redistribute water.

Sources: Destatis, 2019 a; Bdew, 2021

Figure 56

Comparison of per-capita water extraction by economic sector in Germany with selected EU Member States, 2016



Due to different system boundaries, Eurostat data on „Electricity production (cooling water)" deviate slightly from Destatis data on "energy supply".

Sources: Destatis, 2019 a, 2019 b; Eurostat, 2021

Water use and climate change

Climate change impacts on water supplies and water management in various ways. In the long term, for example, higher air temperatures increase evaporation. There is also a greater probability of droughts and heavy rains – as the frequency and extent of extreme weather events in recent years illustrate (UBA, 2021i). Furthermore, because groundwater also comes from rain, prolonged periods of dryness mean less groundwater recharge – because the groundwater reservoirs no longer fill up again in autumn and winter.
The possible repercussions of this are competition for water resources between individual sectors (agriculture, industry and drinking water supply) and environmental damage. The draft of the first national water strategy by the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection explores the challenges of water management. It addresses impending use conflicts and the definition of use priorities as much as the necessity of adapting water management to climate change at an early stage (BMU, 2020 b).

Germany's water footprint

In addition to direct water use, another important indicator is Germany's significantly larger water footprint. It also includes the water used in the global value chains of goods consumed in Germany – most of it abroad.

On the one hand, water is used in the production of goods, but on the other, plants need it for growth and the development of agricultural crops. When calculating the water footprint of a country, the type of water used is differentiated. So-called "Blue water" consists of extracted surface water or groundwater, e.g. for irrigation. "Green water" is rainwater that is stored in the uppermost soil layer, is absorbed by plants, and evaporates. Finally, "grey water" is the hypothetical water volume required to sufficiently dilute polluted water.

In 2021, the sum total of Germany's blue and green water footprint was 201 billion cubic metres – an increase of 21 billion cubic metres since 2011 (Figure 57).

Germany's consumption causes a water footprint of more than four times the volume of Lake Constance.

At 6,633 litres per capita per day, the footprint for blue and green water in 2021 was far higher than direct domestic water use in German households (123 litres per capita per day in 2016). Most (88 %) of the German water footprint was attributable to water use abroad (indirect imports), whereas only 12 % was of domestic origin.

Green water had the largest share in Germany's water footprint. Only 11 % was accounted for by blue water (22 billion m^3). In the case of indirect imports of blue and green water, the ratio differs depending on the country of origin. Where the blue water share is higher, this is primarily due to irrigation-intensive agricultural products. This is the case, for example, with goods from Spain, where irrigation is common because of low rainfall. Worldwide, as much as around 40 % of all foodstuffs are grown on irrigated land (World Bank, 2021a).

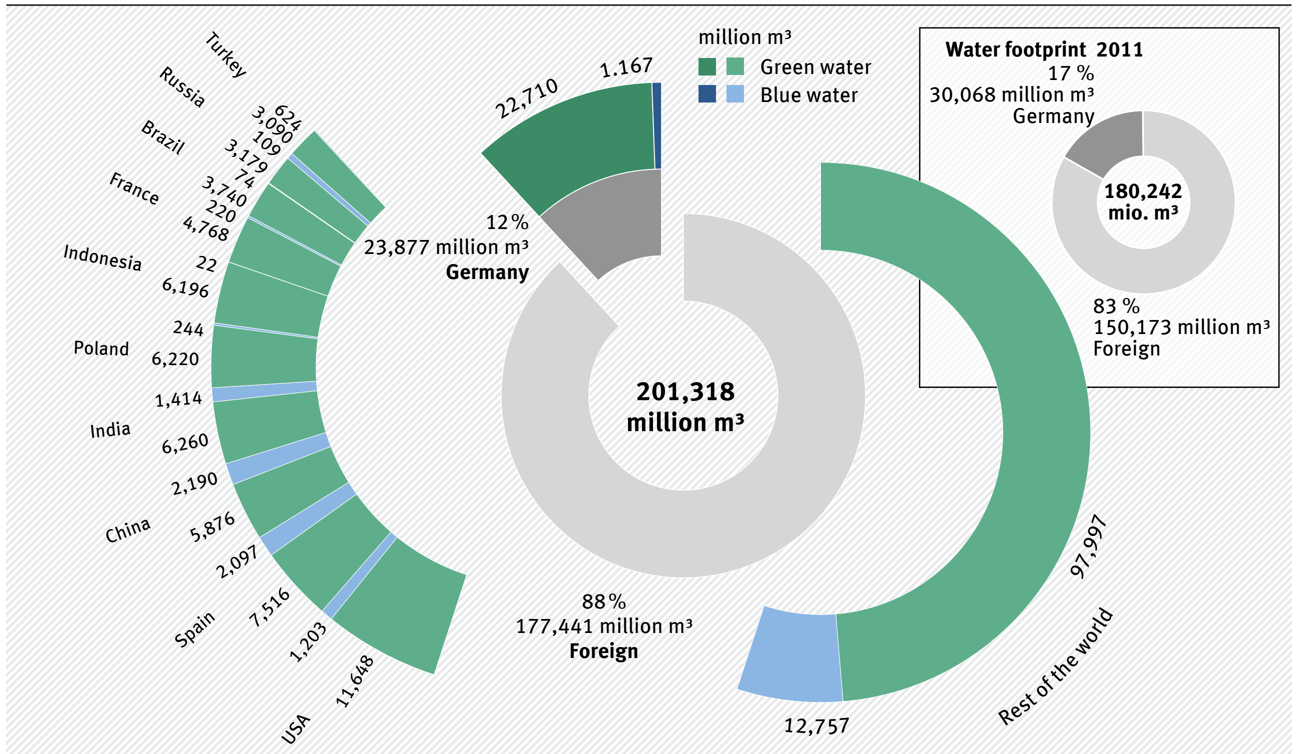
Indirect water imports from China were the biggest contributors to Germany's blue water footprint (2,190 billion m^3) – primarily due to the production of wheat and rice for German consumption.
At 27 %, blue water had a considerably larger share in the indirect water imports from China than in he domestic water footprint (5 %). Other major contributions to the blue water footprint came from Spain (2,097 billion m^3), India (1,413 billion m^3) and the USA (1,203 billion m^3). The products primarily responsible for this were fruit and vegetables in Spain, sugar cane and sugar beets in India, and water-intensive oilseeds in the USA.

But what about the impact of water-intensive imports on their countries of origin? In this context, not only the overall volume of the indirect water imports is of relevance, but also the local water availability (dependent on the climate zone). This mainly affects the blue water flows, since only blue water is used directly by humans. Overexploiting it – e.g. in the production of goods for export – can have a serious impact on the living conditions of local people.

In 2021, Germany – a country rich in water – also imported goods from regions with scarce water resources. German consumption contributed to water stress particularly in the catchment basins of the Nile, the Ganges and the Indus (Figure 58). Furthermore, significant volumes in the German blue water footprint originate from the watersheds of the Mississippi, the Yangtze and the Paraná (2 %, 1.9 %, 0.6 %). However, these areas have no water stress, so these imports are less critical. The water footprint and its contribution to local water scarcity are therefore important indicators for environmental damage in foreign countries caused by imports to Germany.

Figure 57

Germany's water footprint by origin and type of water, 2021

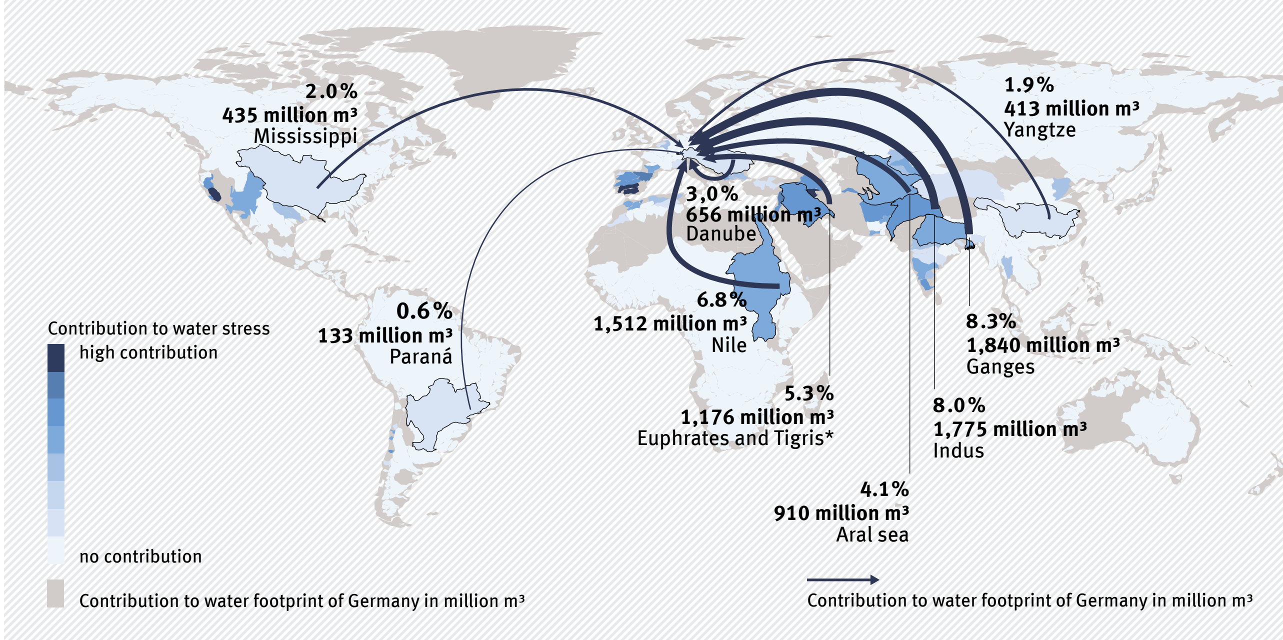


Values for 2021 are projected based on data from 2011.
Due to methodological differences, values in this figure are not directly comparable to figure 45 in the previous Resources Report (UBA, 2018).

Source: Bunsen, 2021

Figure 58

Contribution of individual river basins to the blue water footprint of Germany and the impact on local water stress, 2021



* Including the river basin of the Shatt-al-Arab.
Values for 2021 are projected based on data from 2011.

Source: adopted from Bunsen, 2021

Land use in Germany

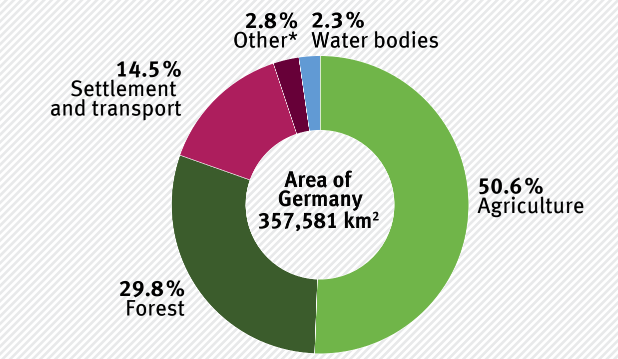
Land area is another natural resource used by society. In Germany, the largest areas are used for agriculture and forestry. In addition, settlement and transport areas are built at the expense of agricultural land – with far-reaching repercussions for the environment.

In 2020, Germany's area amounted to around 357,581 square kilometres. On average, each square kilometre has 233 people living on it. The structure of land use has barely altered in comparison with 2015 (see p. 54/55 in the 2018 Resources Report; UBA, 2018). Around half of the land (50.6 %), or 180,934 square kilometres, was used for agricultural purposes in 2020 (Figure 59). Forest land followed in second place at 29.8 % (106,666 km²). Transport and settlement areas occupied 51,693 square kilometres – remarkable 14.5 % of the German territory. Water bodies (2.3 %), unused areas of vegetation, and "wasteland" such as stony ground (2.8 %) played a secondary role.

Land use in Germany's different federal states varies regarding the distribution of the different types of land (Figure 60). Agriculture has the largest share in the total surface area in all federal states (apart from in the city-states), but its share varies considerably between the federal states: from 41 % (8,087 km²) in Rhineland-Palatinate through to 68 % (10,821 km²) in Schleswig-Holstein. The way in which the land is cultivated is a factor in potential environmental damage – for example, the decline in biological diversity on the land (UBA, 2021 h). There is an increasing focus on organic farming as a means of ensuring sustainable use of agricultural land. Organic farming, too, varies regarding its share in overall agricultural land use across Germany. In 2020, for example, Hessen (14 %), the Saarland and Brandenburg (each at 12 %) had the largest shares. Lower Saxony, at 4 %, and North Rhine-Westphalia and Thuringia, each at 6 %, had the smallest. Overall, with just under 10 % of its agricultural land being used for organic farming, Germany is still far behind the EU frontrunner, Austria (23 %). The German government's coalition agreement, however, provides for an increase to 30 % by 2030 (SPD, Bündnis 90/die Grünen and FDP, 2021).

Figure 59

Land use in Germany by type of usage, 2020

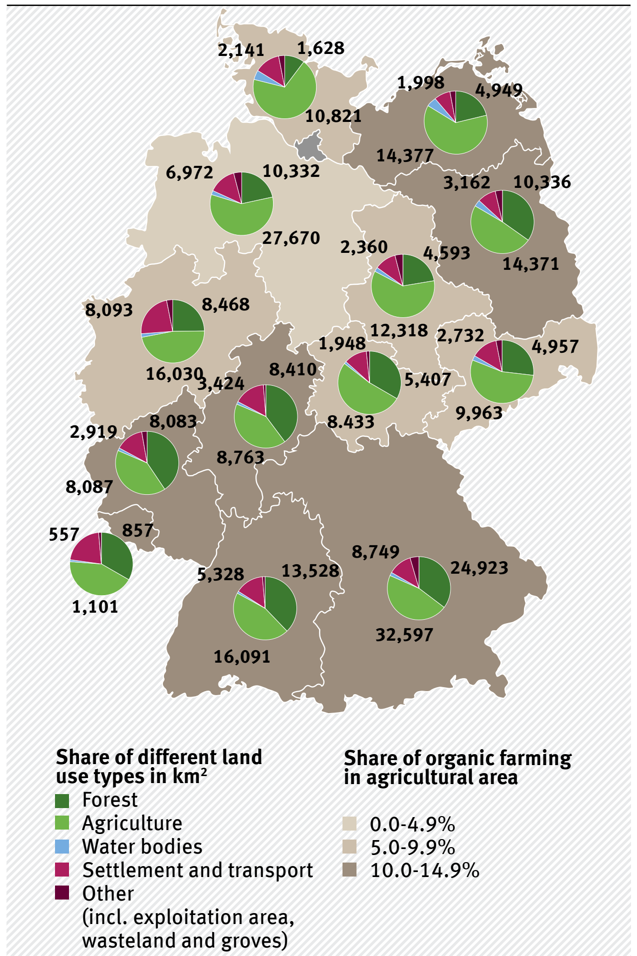


* including exploitation area, wasteland and groves.

Source: Destatis, 2021 d

Figure 60

Land use of the German federal states by type of usage and share of organic farming in total agricultural area, 2020



Sources: Destatis, 2021 d; BLE, 2020 b

Forest land accounts for the second largest share in land use throughout Germany, apart from in the city-states and Schleswig-Holstein. In 2020, Rhineland-Palatinate was the frontrunner at 41 %, whereas forest land accounted for only 10 % of land use in Schleswig-Holstein. In absolute terms, Bavaria had the largest areas of agricultural and forest land in Germany as a whole (32,587 km² and 24,923 km² respectively).

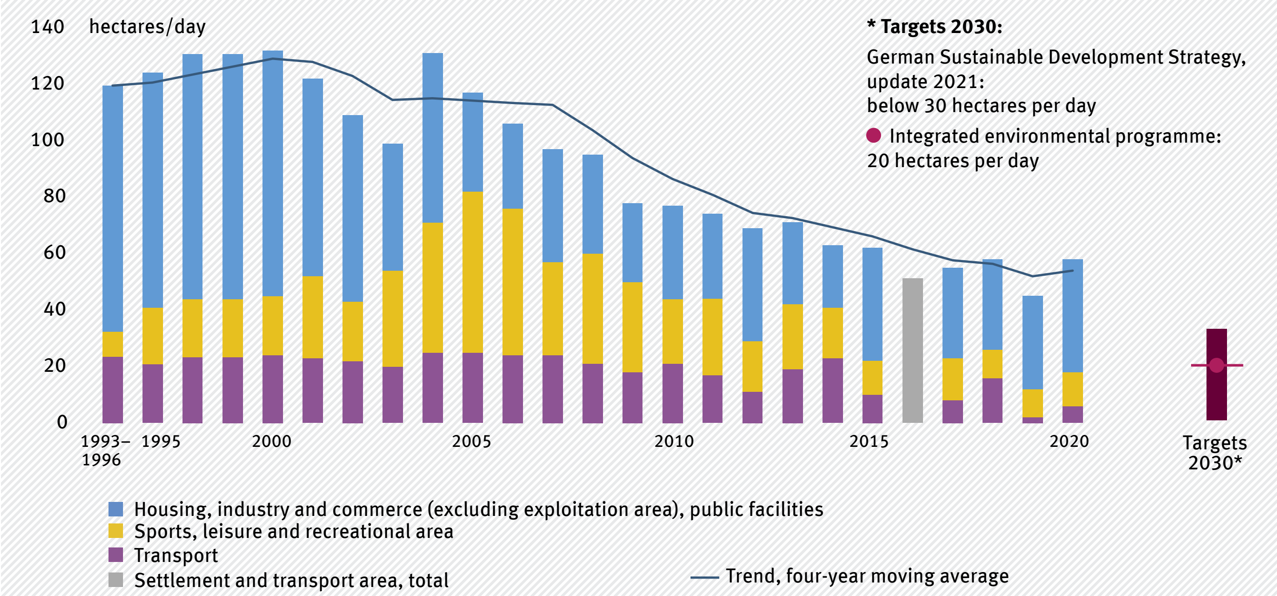
A longer-term trend shows that Germany's agricultural land is being increasingly encroached upon by settlement and transport areas, the expansion of which has many negative repercussions, e.g. urban sprawl, decline in town centres, and a rise in traffic volume and soil sealing. It is estimated that 45 % of Germany's settlement and transport areas are covered with buildings, concreted over or fortified in other ways, and are therefore considered "sealed" (UBA, 2021 b). Soil sealing is closely connected with high raw material requirements. In addition, it compromises the soil's basic functions: it is not able to store as much water, which means heavy rainfall more frequently entails flooding; furthermore, there is no cooling effect from plant cover, resulting in more heat traps in urban areas.

Expansion of new settlement and transport areas is decreasing, but at 58 hectares per day (2020), it is still too high.

Despite a decrease of 6 % since 2015 (62 hectares per day), the threshold value of 30 hectares per day – set as a target for 2020 in the climate protection plan (BMU, 2016 c) – was exceeded. As part of its 2016 national Sustainable Development Strategy, the German government set itself the target of lowering the expansion of settlement and transport areas to below 30 hectares per day (German Federal Government, 2016). The environment ministry's integrated environmental programme goes one step further, setting the threshold value for 2030 at an increase of just 20 hectares per day (BMU, 2016 a). At 54 hectares per day, the average for the period 2017 to 2020 still far exceeds these targets (Figure 61). A whole host of policy measures is needed to ensure sustainable land use. This includes fiscal instruments such as land tax or targeted land use planning, which reduces new development outside of settlements.

Figure 61

Expansion of settlement and transport area in Germany, 1993–2019



Further details on land survey and calculation of the indicator can be found at: https://www.umweltbundesamt.de/en/data/environmental-indicators/indicator-land-take-for-settlements-transport

Sources: Destatis, 2021 a, 2022 b

Germany's land footprint

Like the water footprint, the land footprint indicates Germany's indirect resource use through global trade. It includes land used at home and abroad for goods consumed in Germany. Primarily imported products from agriculture and forestry increase the land footprint.

Germany imports many renewable raw materials as well as products made from these (see p. 26/27): food, fibres, plant-based synthetics, wood products, etc. To produce these goods, land in foreign countries is needed. In 2018, all the agricultural, pasture and forest land used worldwide for goods consumed in Germany amounted to a land footprint of 74 million hectares.

The German land footprint is more than twice as large as Germany's entire land area.

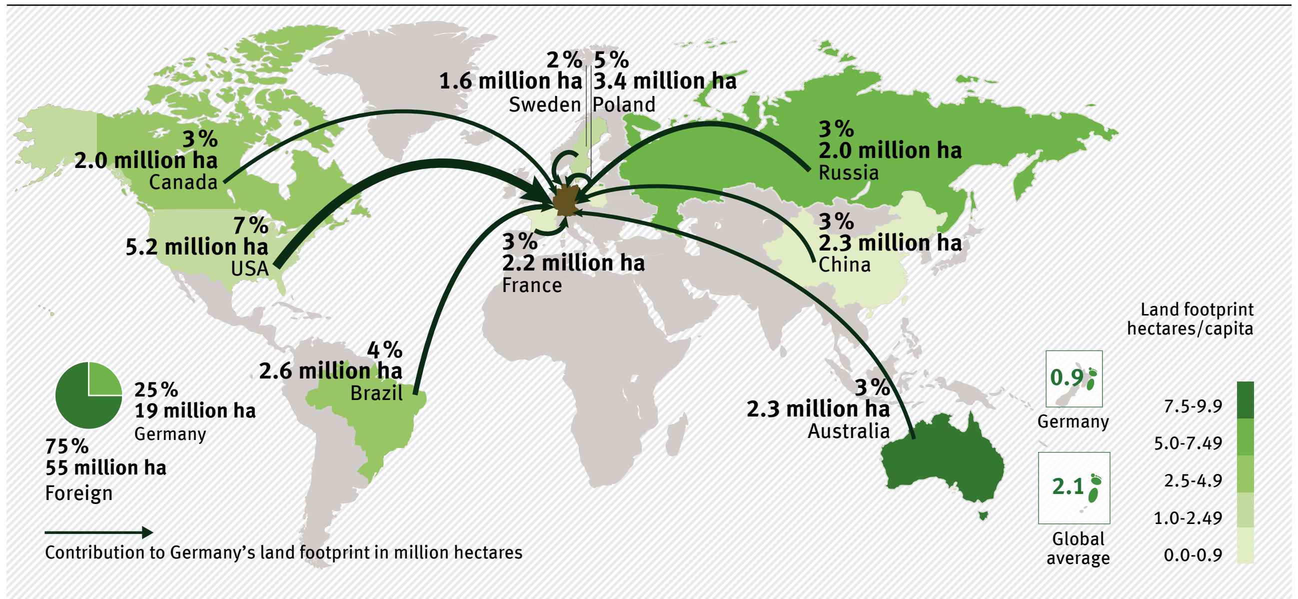
With an average land footprint of 0.9 hectares per capita, Germany came in under the global and the EU average – both 2.1 hectares per capita. Countries such as Australia (9.6 hectares per capita) or Kazakhstan (10.6 hectares per capita) have a particularly high land footprint, which is due to their extensive animal husbandry. Countries such as India (0.2 hectares per capita) or Egypt (0.1 hectares per capita), on the other hand, have smaller land footprints.

Analysis of the German land footprint from the point of view of its origin reveals that, overall, foreign land accounted for 75 % , and German areas for only 25 %. By far the largest land area used for German consumption was in the USA (5.2 million hectares, Figure 62). Other countries where Germany contributed significantly to land use were Poland (3.4 million hectares) and Brazil (2.6 million hectares). Most of the land used in Brazil was forest land (63 %), e.g. in the production of wood pulp for the German paper industry.

In 2018, at 28 million hectares, forest land still had the largest share in Germany's total land footprint, although a decrease of 22 % was recorded between 1990 and 2018 (Figure 63). The grassland footprint, too, shrank by half (18 million hectares). One possible cause of this is the intensification of animal husbandry on reduced areas of foreign land. The cropland footprint (25 million hectares) barely altered during this period (-9 %).

Figure 62

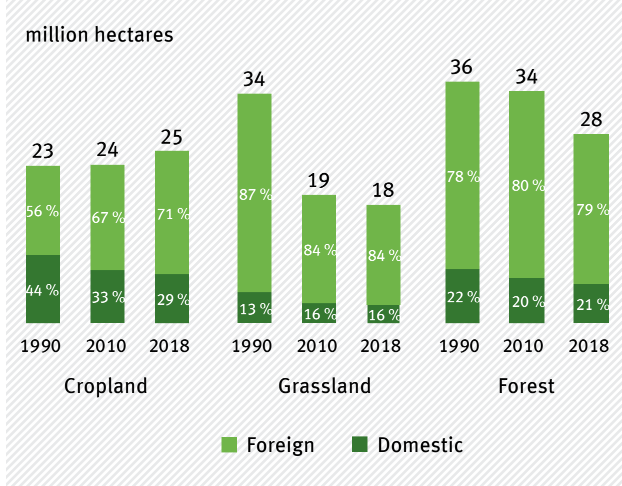
Contribution of the ten biggest countries of origin to the land footprint and international comparison of the per-capita land footprint, 2018



Source: UN Life Cycle Initiative et al., 2022

Figure 63

Development of cropland, grassland and forest footprint of Germany, 1990 and 2018



Due to methodological differences, values in this figure are not comparable to the previous Resources Report (UBA, 2018).

Source: UN Life Cycle Initiative et al., 2022

These three land use categories differ not only in terms of size and trend but also in terms of the domestic share in their respective land footprint. Only 16 % of grassland use was attributable to domestic cultivation, and also the forest footprint's domestic share was similar (21 %). On the other hand, regarding the production of agricultural goods domestic land had a 29 % share, but the shift from Germany to foreign countries is particularly pronounced in comparison with 1990 (when the domestic share was 44 %). New consumer habits in Germany are the cause of this. The increased use of renewable raw materials for bioenergy, for example, requires more land. Also the consumption of food of animal origin contributes to the increasing foreign land footprint (see p. 78/79).

The relocation of agricultural production to foreign countries becomes apparent in a similar way in the water footprint. Where, for instance, foreign foodstuffs are produced with the aid of irrigation and exported to Germany, this is reflected in Germany's water footprint (see p. 68/69).

The use of land in foreign countries has serious consequences. The cultivation of sugar cane, palm oil and coffee often go hand in hand with an extensive loss of ecological diversity (Baan et al., 2013). Import countries such as Germany therefore indirectly contribute to land use change and environmental impact in the exporingt countries (Bringezu et al., 2020). The "land rucksack" indicator is used to qualitatively assess the potential repercussions of the manufacture of goods (see info box).

Indicators such as the land rucksack or the land footprint take into account not only land use in Germany but also land use in foreign countries that is attributable to German consumption, along with the consequences for the local population. In so doing, they provide an important basis for policy decisions towards a sustainable land use.

The land rucksack

The "land footprint" provides a purely quantitative statement of land use at home and abroad. It lacks, however, information on the effects of land use. By contrast, the "land rucksack" provides a qualitative assessment of the land use and the potential environmental impacts of the manufacture of goods. This indicator quantifies both temporary land use and land use change. In addition, it evaluates the effects of human intervention in comparison with the original ecosystem (referred to as "naturalness" or "hemeroby"). This calculation of hemeroby produces the "distance-to-nature potential" indicator, which assesses the potential environmental effects of products across their entire life cycle (Fehrenbach et al., 2021). In chapter on page 76/77, the land use and distance-to-nature potential indicators are used to compare different energy sources.

Flow resources

Wind, sun and water, known as "flow resources", are an alternative to fossil energy sources, and as such are important contributors to Germany's energy transition. Their usage takes pressure off the environment but is still also associated with the use of raw materials or natural resources.

Germany is redesigning its energy system, with a focus on reaching greenhouse gas neutrality by 2045 – a target anchored in its Climate Change Act – Flow resources will play a key role in this: energy production does not directly emit environmentally damaging greenhouse gases, and it also uses fewer raw materials and water across its entire life cycle than production from other energy sources (see p. 76/77). In 2019, primary energy production from flow resources in Germany amounted to 789 petajoules – a rise of 38 % since 2015, the previous reporting year (Figure 64).

Primary energy production from flow resources has increased more than tenfold in Germany since 1990.

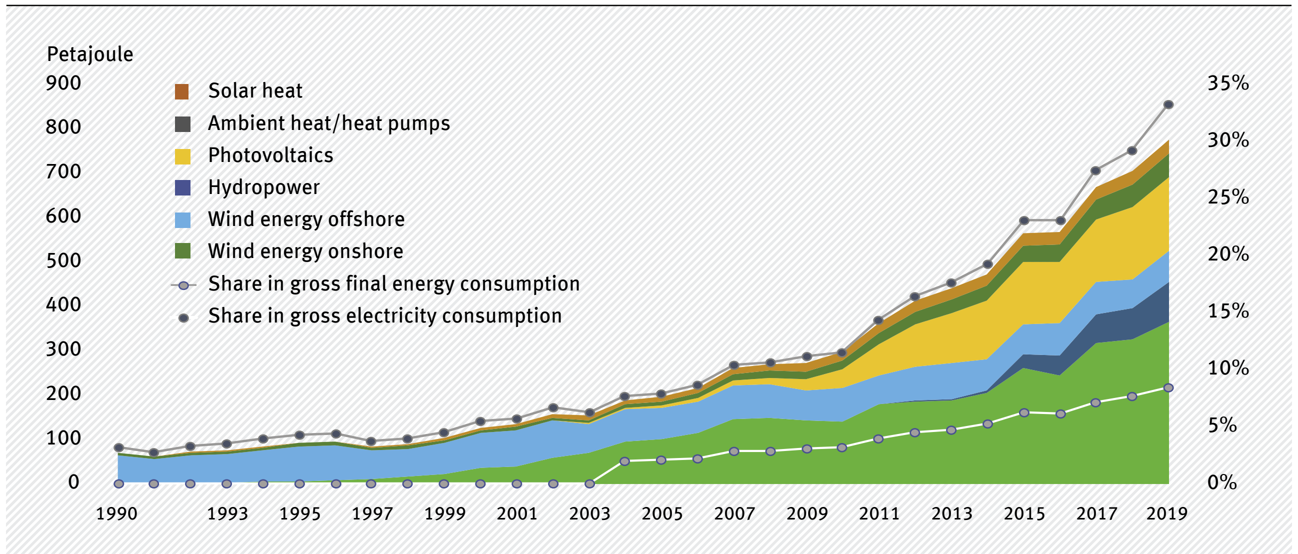
The most important flow resource for Germany is wind energy. It has a 57 % share in primary energy production from flow resources. The annual production of energy from wind power rose from 290 to 453 petajoules between 2015 and 2019 alone.

At 80 %, wind turbines on land (onshore) had the largest share. Turbines in the sea (offshore) are catching up, however, due to the higher wind speeds and the attendant greater energy yield. In addition, their energy production is more constant, which is increasingly important considering the growing share of flow resources in the energy system (see info box). The development of offshore wind farms resulted in a rise in annual primary energy production from 0.1 to 89 petajoules between 2009 and 2019. The development of onshore wind farms, however, saw a strong decline after 2017. Nonetheless, onshore primary energy production also continued to rise to 362 petajoules in 2019 – thanks, among other things, to the fact that it was a windy year (Deutsche WindGuard, 2020 b, 2020 a).

In 2019, energy from photovoltaic plants had, at 167 petajoules, the second largest share in flow resources. Here, too, there was a considerable rise between 2015 and 2019 (+20 %). A comparison of the installed power with its economic potential shows there is still significant scope for further (environmentally friendly) development – a possible tenfold increase (Purr et al., 2019).

Figure 64

Primary energy production from flow resources in Germany and shares in gross electricity consumption and gross final energy consumption, 1990–2019



Sources: Eurostat, 2019; BMWI, 2021

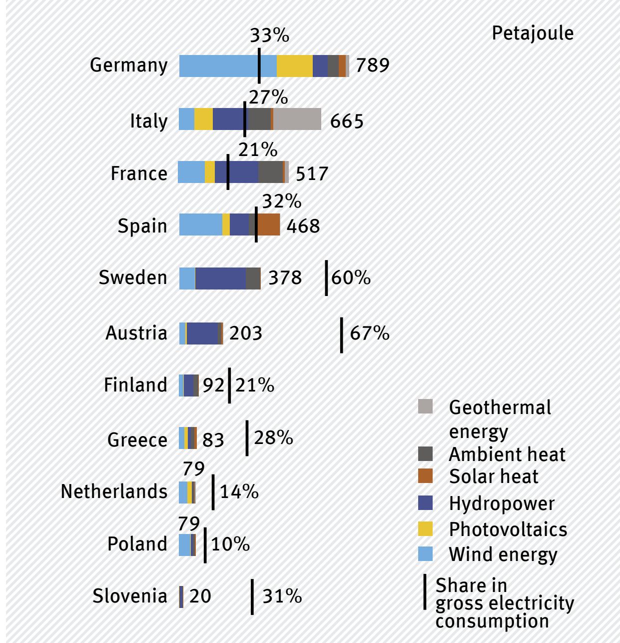
Flow resources in Germany primarily provide electricity; they are of only negligible significance in heating and transport. Accordingly, their share in gross electricity consumption in 2019 was, at 33 %, significantly higher than their share in gross final energy consumption (8 %).

Within the EU and the Member States, primary energy production from flow resources is dependent on availability of land, settlement density, topography, and technical and political possibilities. In addition, the share of flow resources in electricity consumption is highly variable (Figure 65). At 789 petajoules, Germany was the EU frontrunner in 2019 both for total primary production from flow resources and for wind and solar power. Sweden, on the other hand, along with France, Italy and Austria, was a trailblazer for hydropower.

Climate neutrality can only be achieved if the energy supply is fundamentally transformed. This transformation has been underway for a few years now. Compared with fossil energy sources, wind, solar and hydropower cause less carbon emission, are less resource-intensive and therefore ecologically more beneficial. Additionally, replacing fossil fuels with renewable energy reduces dependency on fossil imports from other countries (e.g. natural gas).

Figure 65

Comparison of primary energy production from flow resources and shares in gross electricity consumption in Germany with selected EU Member States, 2019



Sources: Eurostat, 2019, 2021

Flow resources, however, are not without their own problems. On the one hand, these problems are of a technical nature (see info box); on the other, even renewable systems have an ecological footprint in the form of raw materials for the energy infrastructure, land (for pipes and plants), or rare raw metals for technology (e.g. neodymium for magnet rotors), the majority of which are imported. The footprint of renewable systems is nonetheless significantly smaller than that of fossil systems (see p. 76/77).

Flow resources in the future

Wind and solar energy are currently playing a leading role in the development of renewable energies in Germany – and thanks to their economic potential, they will continue to do so in the future. However, with energy production becoming increasingly decentralised, energy flows are becoming more complex. This requires an upgrading of the network capacity. Moreover, the volume of electricity produced by wind and sun is not constant. This means surplus energy must be stored for less productive periods. This task is currently performed by pumped storage power stations (UBA, 2021 d). In the future, synthetic fuels and carbon carriers produced using renewable energy will play a major role, too, since some industrial sectors will continue to require liquid or gaseous energy sources and raw materials. With technologies such as "Power-to-Gas" (PtG) und "Power-to-Liquids" (PtL), storable fuels and carbon carriers, such as hydrogen and methane as well as liquid fuels can be produced from electricity. These processes may also, however, have an undesirable impact on the environment (Liebich et al., 2020).

Energy and the nexus with raw materials, water and land

Resources such as raw materials, water and land are tightly interwoven in terms of their usage. These interconnections (the "nexus") between the individual resource categories emerges all the more clearly in the case of energy production and supply.

In debates on environmental policy, the term "nexus" ("conjunction" or "connection") describes the reciprocities between resource categories, economic sectors or different policy areas. The aim in analysing the nexus is to identify synergies and mitigate usage conflicts early on.

For example, climate protection measures should not be implemented at the expense of resource efficiency, or vice versa. Higher resource efficiency, in fact, usually makes a positive contribution to climate protection (Purr et al., 2019). In addition, comparison of cumulative raw material input for different sources of electricity shows that renewable energy sources generally require significantly fewer raw materials across their entire life cycle than fossil fuels. In other words, they have lower material intensities (Figure 66). This is because electricity generation based on fossil fuels has a relatively high fuel demand (coal, natural gas, crude oil). This is not the case with most renewable energies. However, the materials needed for construction and infrastructure are of more consequence here (concrete, steel, etc.). In addition, sometimes materials are used that have a higher environmental hazard potential, e.g. copper, selenium or neodymium (see p. 56/57).

Electricity produced from lignite needs a raw material input ten times higher across its entire life cycle than wind power.

Lignite and hard coal power plants require the highest volume of raw materials per generated kilowatt-hour across their entire life cycle. Of the renewable energies, photovoltaics have the highest raw material intensity, yet it is still almost four times lower than that of a hard coal power plant. In addition, the raw materials used in renewable energies – unlike in combustible fossil fuels like hard coal – can to some extent be recycled. In some cases, the intensities of raw material, water and land use vary considerably among the different electricity sources (see Figure 66).

Of all the energy sources taken into account, it is photovoltaic power plants that demonstrate the highest land intensity per unit of electricity produced. The land used must also, however, be assessed in terms of its respective qualitative change (see info box, p. 69). Open-space photovoltaic power plants require large amounts of land, but it depends on the type of open space they are installed in. Erecting them on agricultural land reduces naturalness in comparison to the original state. The same does not apply, however, if they are installed on land that is already mostly non-natural, such as landfill sites.

The water consumption of renewable energies is above all attributable to upstream processes, and only to some extent directly to the plant,. Global analyses show that renewable energies (except biomass) have a lower water intensity than fossil fuels (Terrapon-Pfaff et al., 2020). There are, however, major differences.

Nuclear energy (8,693 kg/MWh) and energy from lignite and hard coal (10,329 kg/MWh and 3,273 kg/MWh respectively) are particularly water-intensive. The reason for this is the direct water demand for the cooling processes. To some extent, hydraulic processes in upstream chains also have a role to play (e.g. drainage in coal mining).

The nexus approach can also include qualitative aspects, e.g. the extraction and return of cooling water or the regulation of river courses for hydropower plants. Also the lowering of the water level downstream from the point of extraction, as well as the return flow of warmed cooling water, play a part in altering the local living conditions for flora and fauna.

A comprehensive ecological comparison would require further detailed analyses.

Figure 66

Comparison of average values of raw material input, land use and water input throughout the life cycle of different energy sources

	RAW MATERIAL INPUT g/kWh	LAND USE m^2*a/MWh electricity – Temporary land occupation	LAND USE – Distance-to-nature potential	WATER INPUT kg/MWh
WIND ENERGY				
onshore	99	1.4	0.7	4 [v]
offshore	121	**	**	4 [v]
PHOTOVOLTAICS				
Open space	228*	22.5	7.9	421 [v]
Rooftops	228*	0.0	0.0	421 [(V)]
HYDRO POWER				
Reservoir and pumped-storage	25	**	**	32,810 [(V)]
Run-of-river	94	**	**	42 [(M)]
FOSSIL FUELS				
Lignite	1,181	6.3	5.7	10,329 [(M)]
Hard coal	827	3.2	1.5	3,273 [(M)]
Crude oil	263	0.8	0.4	4,075 [(M)]
Natural gas	187	0.8	0.2	2,219 [(M)]
NUCLEAR POWER without disposal/ final storage	35	1.5	1.0	8,693 [(M)]

* Average raw material input for photovoltaic modules of different sub-technologies on open spaces or roof areas..
** Hydropower and offshore wind power were excluded from the analysis due to the lack of approaches for evaluating land use and distance-to-nature potential on water areas (inland waters and sea).

Values in this figure are based upon different studies that, to some extent, apply different calculation methods:

Raw material input: Data consider the entire life cycle (manufacturing, maintenance and repair, and disposal) of the power generation plant, including transmission losses to the grid connection point.
Source: Wiesen et al, 2017 (reference year 2013).

Land use: Data include areas for raw material extraction of energy sources and infrastructure (thermal power plants and transmission grids).
Source: Fehrenbach et al., 2021 (reference year 2017).

Water use: Average values referring to energy production in the EU. Data include blue and green water and consider the entire life cycle (construction and operation of the power plant, fuel supply and energy production).
(V) Source: Vanham et al., 2019 (reference year 2015).
(M) Source: Manstein, 1996 (reference year 1991).

Sources: Manstein, 1996; Wiesen et al., 2017; Vanham et al., 2019; Fehrenbach et al., 2021

Food and the nexus with raw materials, water, land and emissions

The consumption area of food is interconnected with different resource categories. The production and supply of foodstuffs require large volumes of renewable and non-renewable raw materials. Water and land are used, too, and CO_2 emissions released.

Increasing prosperity, shifts in social structures, globalisation and urban growth lead to new lifestyles and dietary habits. Since the post-war years, a resource-intensive food culture involving high levels of meat consumption has established itself in Germany (Schrode et al., 2019). Recently, Germany's food-related raw material consumption has at least declined by 5 % (Figure 67). This could be due to improved efficiency in production or to new dietary habits. However, the consumption area of food still has the largest share (28 %) in the raw material consumption of private households (see p. 48/49).

The majority of the raw materials used for food (77 %) are accounted for by biomass, above all by the production of cereals and animal products (Figure 67), but fossil fuels and mineral raw materials, too, are indirectly required for the production of foodstuffs, e.g. for operating agricultural machinery, for constructing farm buildings, or in the food sector's supply chains.

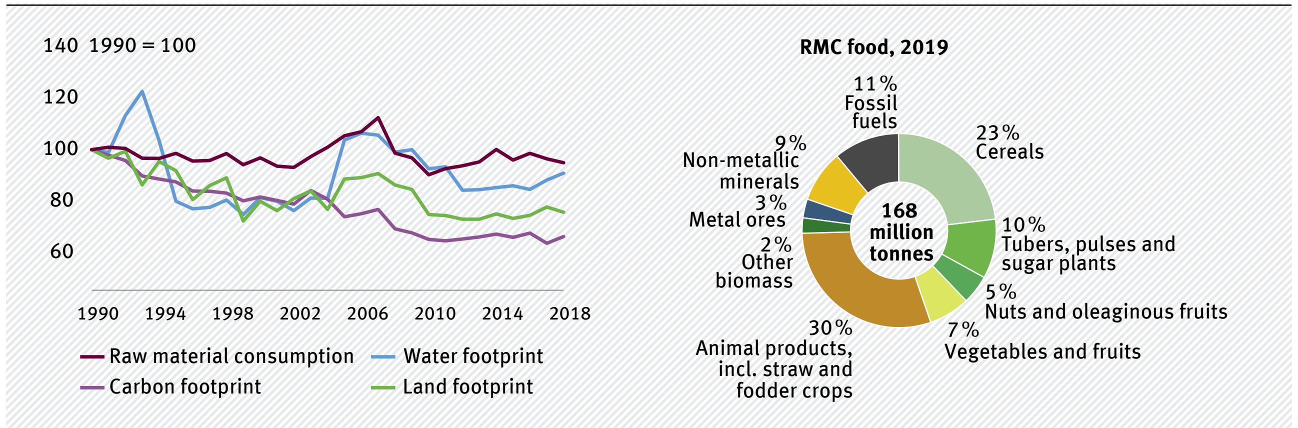
Like raw material consumption, the land and water footprint of food decreased significantly after 1990 (-24 % and -9 % respectively). The greenhouse gas emissions generated by the production, processing and transportation of foodstuffs consumed in Germany fell by 34 % across the entire period (Figure 67).

In its food production, Germany indirectly utilises many resources in foreign countries: in 2019, over half of the raw materials for foodstuffs consumed in Germany came from abroad (Figure 69). 68 % of the water footprint, too, was attributable to foreign countries (values for 2014). It is a similar picture when it comes to cropland: in 2017, only 37 % of the cropland used for foodstuffs was located in Germany.

In 2017, just under two thirds of the land used for the production of foodstuffs consumed in Germany were located in other countries.

Figure 67

Development of raw material consumption (RMC) and the carbon, land and water footprint, 1990–2018 (left) and raw material consumption (RMC) of private households by material and product group, 2019 (right) for the consumption area "food"



Sources: Dittrich et al., 2022 a; UN Life Cycle Initiative et al., 2022

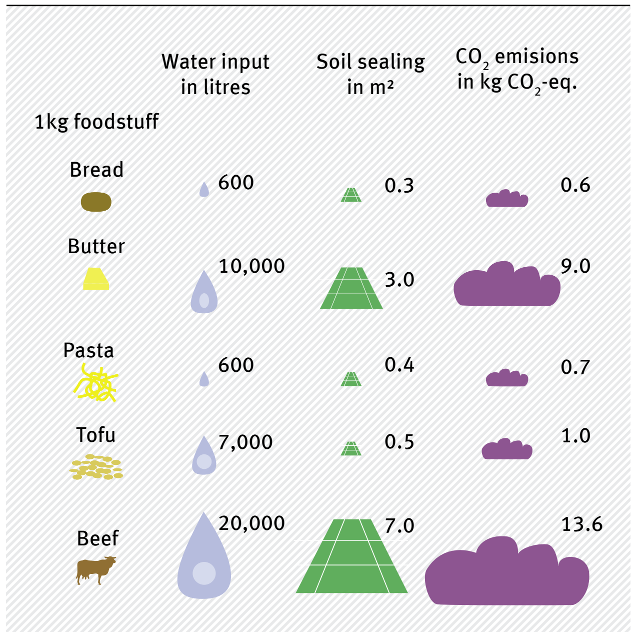
There are primarily two reasons why the foreign share is higher for water and land than it is for raw materials. Firstly, agricultural imports often come from irrigated cropland. Secondly, the yield per unit area is relatively high in Germany, in part because farm animals are kept indoors, whereas in other countries pasture grazing is prevalent.

The absolute demand for resources for food, but also the import share, are closely connected with dietary habits. As the Resources Report 2018 has already shown (UBA, 2018; Figure 39, p. 47), different foodstuffs vary greatly in their resource intensity.

Animal feed in particular often requires a higher resource input. Whereas one kilogram of noodles accounts for an average of 600 litres of water, a sealed soil area of 0.4 m² per year and 0.7 kg of CO_2 emissions across its entire life cycle, the values for the same volume of beef are significantly higher: 20,000 litres of water, 7 m² of land and 13.6 kg of CO_2 emissions. Figure 68 and Figure 70 show selected key figures on resource intensity for the production of different foodstuffs.

Figure 68

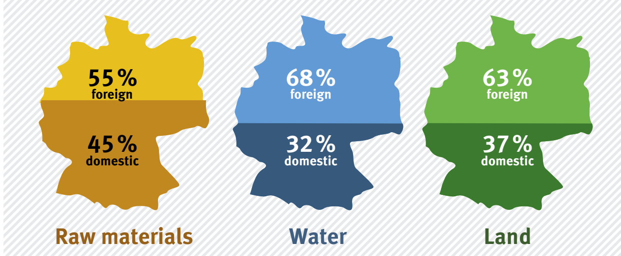
Water input, CO_2-emissions and soil sealing for different food products (along the entire life cycle)



Source: Reinhardt et al., 2020

Figure 69

Domestic and foreign share in selected raw material footprints of food products consumed in Germany



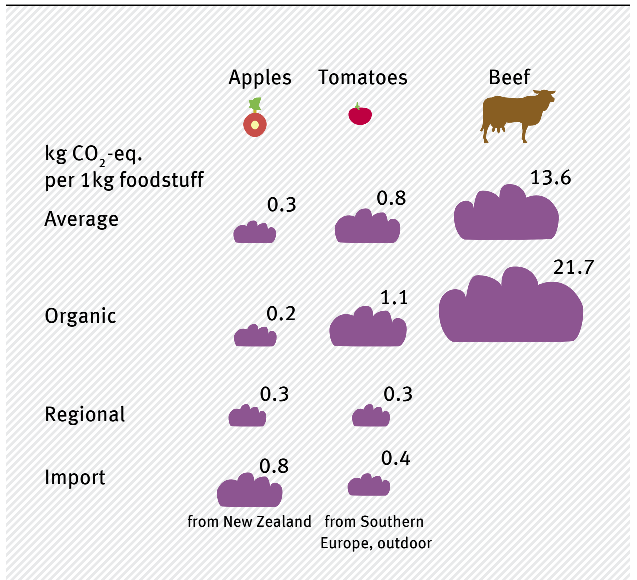
Values in this figure are based upon different studies that, partly apply different calculation methods.

Sources: Raw materials (results for 2019): Dittrich et al., 2022 a; Water (Results for 2014): Jungmichel et al., 2021; Land (Results for 2017): Destatis, 2019 d

In addition to the type of foodstuff, also production methods, packaging and transportation play a major role. The carbon footprint of an apple imported from New Zealand, for example, is around twice as big as that of a German apple. In addition to these selected resource categories, a comprehensive ecological comparison would require further detailed analyses. Seen through the lens of a nexus analysis in particular, though, dietary habits certainly provide an important point of calibration for resource and climate protection (see p. 86/87).

Figure 70

Comparison of the carbon footprint of different food products by origin and production method



Footprints are average values of foodstuffs sold in Germany, weighted by the shares in domestic production and in imports (from different countries), by cultivation method and by mode of transport.

Source: Reinhardt et al., 2020

Special: raw material use in the future

Scenarios regarding the development of raw material consumption (RMC)

Potential decrease in raw material consumption by 2050 compared to 2010 if

-68 per cent	all known technological options to increase material efficiency are implemented
-63 per cent	everyone adopts a sustainable lifestyle
-70 per cent	both the technological options and lifestyle changes are implemented

Technology change as a lever

Potential decline in total raw material consumption (RMC, base year 2010)

-1.9 per cent	if 80 % (instead of 33 %) of iron and steel production is manufactured from scrap iron and steel
-1.0 per cent	if 90 % (instead of 56 %) of copper is manufactured from scrap copper
-0.3 per cent	if 90 % (instead of 54 %) of aluminium is manufactured from scrap aluminium

Climate and raw materials policies as levers

Potential decline in raw material consumption (RMC) from 2019 to 2050 under ambitious climate and raw materials policies

-37 per cent	**-84** per cent	**-92** per cent
in the area of nutrition	in the area of housing	in the area of mobility

Sources: see p. 82–91

Future raw material use

In future, raw material use will need to be based even more on sustainability principles. Through an ambitious resource policy, Germany can reduce its consumption of raw materials to around 10 tonnes per capita in the medium term and thus to a more sustainable and globally fair level.

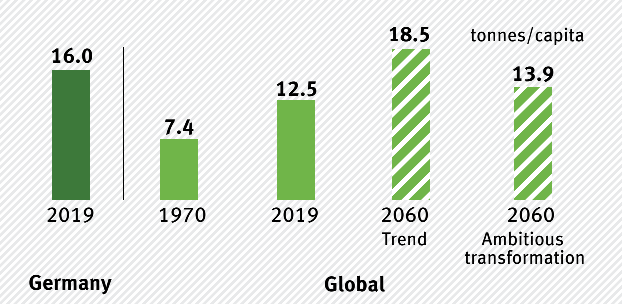
Since 1970, raw material use has more than tripled worldwide. The main reasons behind this are our more resource-intensive way of life and the growing global population, which has doubled over the same period. The global average annual raw material consumption figure (RMC, see glossary) increased from 8.4 tonnes to 12.5 tonnes per person between 1970 and 2019 – a rise of around 50 %. In the coming decades, the world's population and prosperity will continue to grow over the long term, as will demand for raw materials and other natural resources (UNEP IRP, 2019 a).

If the trends of recent decades continue, the average consumption of raw materials per person worldwide is forecast to rise to 18.5 tonnes in 2060. This would be an additional increase of around 50 % compared to 2019, and as much as 120 % compared to 1970 (UNEP RP, 2019a). However, a decline in raw material consumption is urgently needed, especially in view of the Paris climate targets, since the handling of natural raw materials has a significant influence on greenhouse gas emissions (see p. 84/85).

The International Resource Panel (IRP) of the United Nations Environment Program (UNEP) has drawn up a global scenario for greater sustainability and resource conservation ("Towards Sustainability").

Figure 71

Raw material consumption (RMC) per capita in comparison



Sources: UNEP IRP, 2019a, 2022; Dittrich et al., 2022a

With ambitious climate action, innovations, raw material taxes and uniformly high standards pertaining to the use of raw materials, a potential raw material consumption figure of "only" 13.9 tonnes per person may be possible by 2060 (Figure 71).

If today's raw material consumption of 16 tonnes per person in Germany is to fall significantly, a combination of many different measures is necessary. This is the only way to reduce the consumption of raw materials to a fairer and more sustainable level globally.

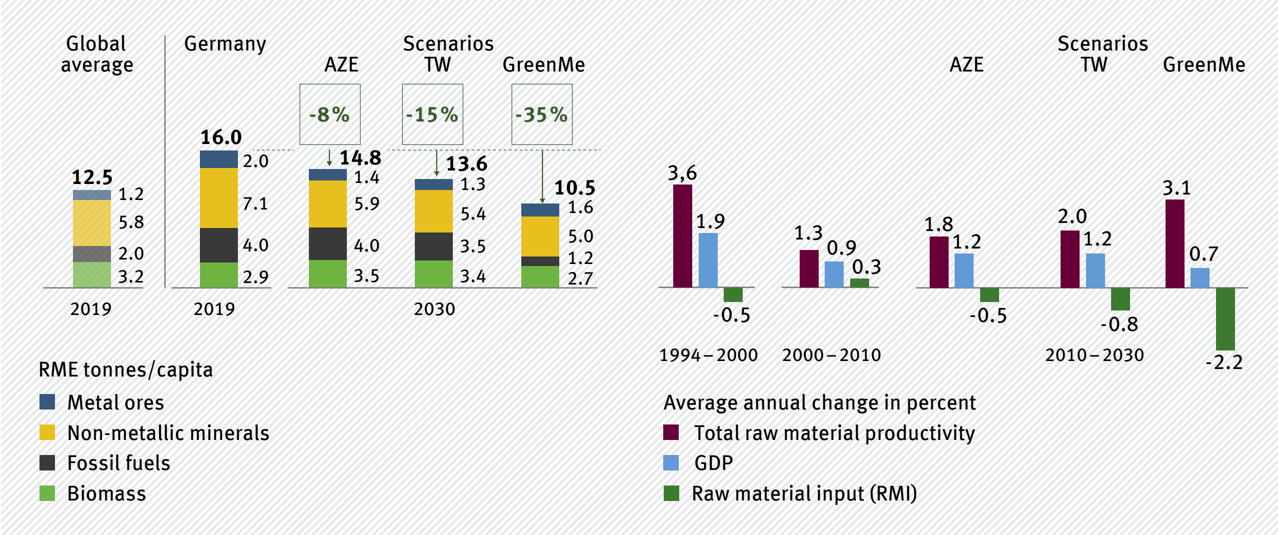
There are various scenarios for the future use of raw materials in Germany, but they do not represent exact forecasts or predictions for the future. Rather, science uses scenarios to examine possible developments and methods of exerting influence at an early stage.

According to these scenarios, the consumption of raw materials in Germany may fall in the coming decades: firstly, because the population will decrease in the medium term, and, secondly, due to the energy transition and technological progress. Three different scenarios (AZE and TW from the DeteRess project; GreenMe from the RESCUE project) serve as examples of the consequences of a more or less ambitious raw materials policy (Table 2).

In contrast to the "Expected Future Development (AZE)" scenario, with a moderately ambitious raw materials policy and energy transition, raw material consumption per capita could fall by 15 % (instead of 8 %) by 2030 compared to 2019, and total raw material productivity could rise by 2.0 % annually (instead of 1.8 %) ("Technological Change (TW)" scenario). Important influencing factors are power generation with less coal, more recycling in building construction and civil engineering, and lightweight construction methods in the vehicle and building sector. This reduces the consumption of fossil raw materials and non-metallic minerals in particular.

Figure 72

Germany's raw material consumption (RMC) per capita, 2019 and 2030 and average annual change in total raw material productivity in different scenarios



Sources: Dittrich et al., 2018; Dittrich et al., 2020 b; Dittrich et al., 2022 a; UNEP IRP, 2022

An ambitious raw materials and climate policy would allow Germany to reduce consumption by over a third in the medium term.

With a highly ambitious raw materials policy and energy transition, as in the "GreenMe" scenario, German raw material consumption could even drop by up to 35 % compared to 2019, to 10.5 tonnes per person – below the current global average. Total raw material productivity would increase by 3.1 % per year. An ambitious energy transition would significantly reduce the consumption of fossil fuels. In addition, since primary biomass would no longer be used for energy purposes, biomass consumption would decrease more than in the other scenarios. In contrast, the raw material consumption of metals would be higher than in the other scenarios due to the sharp increase in the number of wind farms and photovoltaic plants.

Will future resource consumption in Germany remain above the global average? Or will the country actually consume less? That depends to a large extent on businesses' ability to innovate, on private consumer behaviour and, last but not least, on political courage.

Table 2

Overview of the most relevant assumptions in the different scenarios

	Expected Future Development (AZE)	Technological Change (TW)	GreenMe
Population in 2030	79 million	79 million	79 million
Average GDP growth from 2010	1.2 % p.a.	1.2 % p.a.	0.7 % p.a.
Transformation of the energy sector	slow; e.g. share of lignite and renewable energies in electricity mix: 21 % and 58 % respectively	medium; e.g. share of lignite and renewable energies in electricity mix: 13 % and 61 % respectively	ambitious; e.g. share of lignite and renewable energies in electricity mix: 1.5 % and 73 % respectively, and no energy usage from primary biomass
Material efficiency increase (without structural effects	stable (1.0 % p. a.)	high (1.2 % p. a.)	high (1.2 % p. a.)
Recycling	moderate increase	strong increase	very strong increase
Substitution/lightweight construction	Continuation of trend, e.g. the rise in wooden construction methods	Increased substitution efforts towards light and wooden construction	Significant substitution efforts towards light and wooden construction and in other sectors

Sources: Dittrich et al., 2018; Dittrich et al., 2020 b

Future raw material use and climate protection

Ambitious climate protection and efficient use of raw materials work in tandem with each other. Reductions of 97 % of greenhouse gas emissions and 70 % of raw material consumption are possible long-term by 2050.

In order to limit climate change, humankind must consistently, drastically and quickly reduce the emission of greenhouse gases. This also concerns the use of raw materials: for example, the burning of fossil fuels must stop completely. Instead of fossil fuels, climate-friendly, next-generation technologies such as wind power or photovoltaic plants, however, require other resources – as do storage facilities. At the same time, an efficient use of raw materials helps reduce greenhouse gas emissions.

These links were examined in detail for Germany in the "RESCUE" research project (Purr et al., 2019) using six different ambitious transformation pathways. All transformation pathways reduce greenhouse gas emissions by at least 95 % compared to 1990. Likewise, the use of energy and materials will be changed in all pathways, so that fossil fuels will be substituted by biotic raw materials or those that are produced with renewable energies. However, the transformation pathways differ in their level of

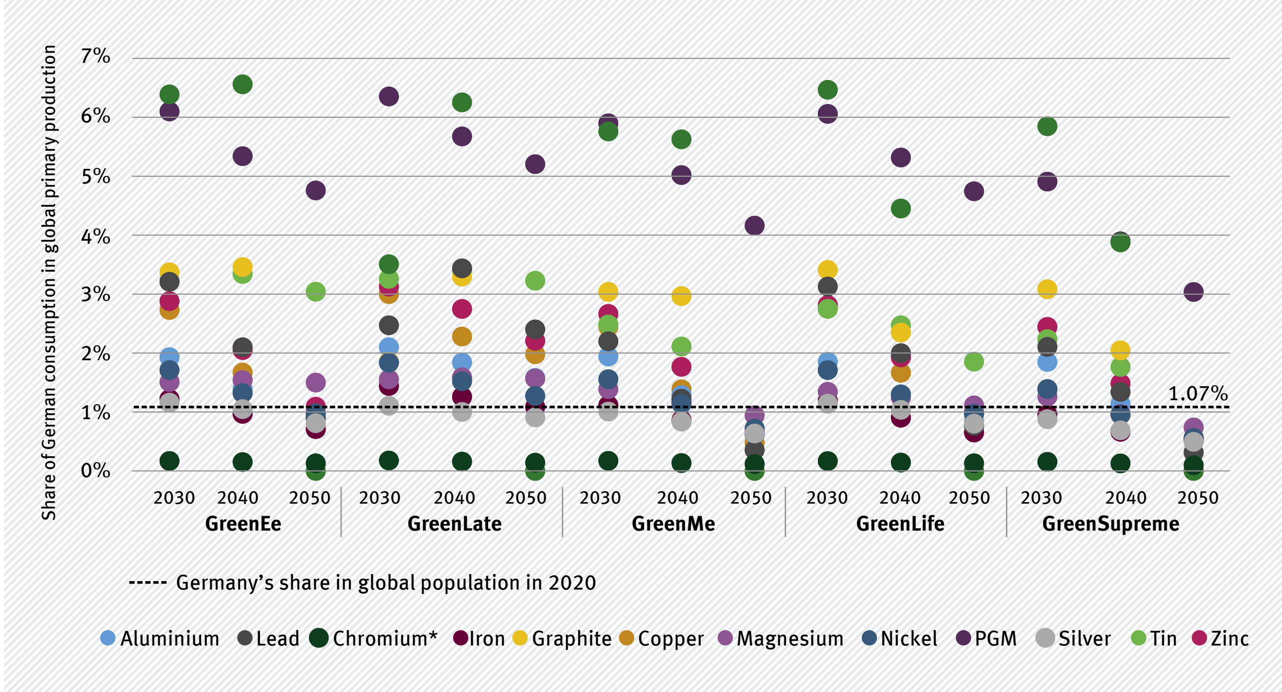
Figure 73

Reduction of greenhouse gas emissions and raw material consumption (RMC) in Germany compared to 1990 and 2010 in different scenarios

Sources: Purr et al., 2019; UBA, 2021 f; Dittrich et al., 2022 a

Figure 74

Development of the share of German raw material consumption (RMC) in global primary production (reference year 2018) for selected raw materials in different scenarios



* Demand considered only for batteries in mobility. A description of the scenarios can be found on p. 86/87.

Sources: Purr et al., 2019; Dittrich et al., 2020 a

ambition when it comes to exploiting energy and material efficiency as well as innovations. They also assign different transformation speeds in Germany and elsewhere, and unequal levels of action on sustainability (see p. 90/91).

If climate change is to be limited, greenhouse gas emissions need to fall rapidly and sharply in the coming years. In a rapid transformation, as described in the "GreenSupreme" scenario, both greenhouse gas emissions and raw material consumption can be significantly reduced by 2030. In the "GreenSupreme" scenario, greenhouse gas emissions would fall by 70 % compared to 1990 and raw material consumption by 44 % compared to 2010 (Figure 73).

A win-win situation: climate and raw materials policies are mutually beneficial.

The results show that greenhouse gas emissions and the need for primary raw materials can not only be reduced at the same time, but that the reductions are even mutually advantageous (Figure 73). A more efficient use of raw materials saves energy that would otherwise be required for the extraction, processing, transport and disposal of additional raw materials. In return, the conversion of mobility from fuels to direct electricity use requires batteries that contain raw materials such as lithium, cobalt, graphite and nickel. Wind turbines contain neodymium or dysprosium, depending on the type of construction, while photovoltaic plants run on silicon metal and silver. Copper is also almost impossible to replace in many applications.

The fight against climate change is a global challenge. The transformation requires raw materials for key technologies such as batteries, wind power and photovoltaic plants – not only in Germany, but all across the world. The increasing demand for these raw materials in turn has a negative impact on the environment (see p. 54–63). The further development of resource-saving technologies and the development of closed raw material cycles – including efficient recycling systems – are therefore important aspects of the transformation. Ultra-efficient use of raw materials and highly ambitious climate action can significantly reduce the demand for scarce or environmentally harmful raw materials, as shown in particular in the "GreenSupreme" scenario (Figure 74).

The Green scenarios

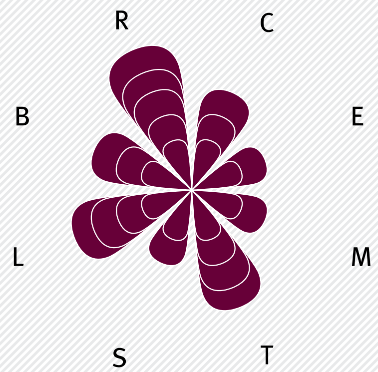
Six "green scenarios" describe transformation pathways towards a Germany that is greenhouse gas-neutral and uses resources efficiently. The pathways have different levels of ambition. The most ambitious transformation pathway, "GreenSupreme," brings Germany closest to the 1.5-degree target and demonstrates the highest savings of primary raw materials.

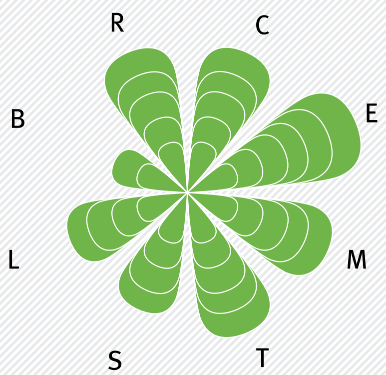
Figure 75 a

RESCUE – Green-scenarios for achieving a greenhouse-gas neutral and resource efficient Germany

GreenLate Germany
resource efficient and GHG neutral
Late transition

describes a transformation pathway on which the necessary climate action measures are only intensified at a late stage, and energy and material efficiency potentials are only partially exploited. Therefore, the energy demands from industry, commerce, trade, services and private households is higher than in the other scenarios. In addition, many synthetic raw materials will be needed in 2050 for heat generation and mobility. Raw material consumption falls more slowly and is higher in all years than in the other Green scenarios.

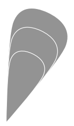




GreenEe1 und GreenEe2 Germany
resource efficient and greenhouse gas neutral
Energy efficiency

is based on the "Greenhouse gas-neutral Germany 2050" project. The focus is on developing energy efficiency potential in all applications, for example in the generation and use of electricity and heat, as well as in industrial processes and mobility. Energy consumption decreases as a result. The population eats sustainably and healthily. While in "GreenEe1" the industry as a whole is continuously increasing its production capacities and exports continue to increase, in "GreenEe2", trade is more balanced, so the national production capacities in various economic sectors decrease.

Level of ambition



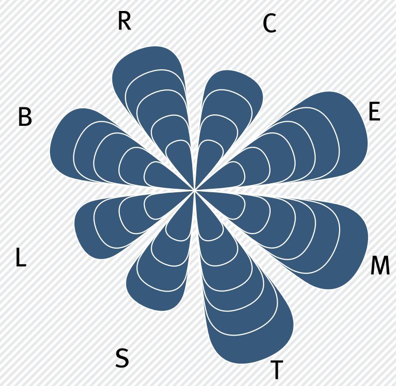
3	very, very high	E	Energy efficiency	L	Liberation from economic growth
2,5	very high	M	Material efficiency	B	Balancing of global technological levels
2	high	T	Technological innovation	R	Reduction of land use in the path
1,5	medium	S	Sustainable action	C	Climate protection efforts in the path
1	low				

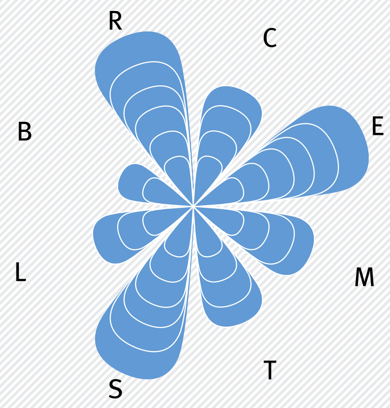
Figure 75 b

RESCUE – Green-scenarios for achieving a greenhouse-gas neutral and resource efficient Germany

GreenMe Germany
resource efficient and GHG neutral
Material efficiency

efficiency builds on "GreenEe2". This pathway assumes high material efficiency in all areas, for example through material-saving technologies and products, secondary raw materials, lightweight construction methods in construction and transport, more durable products, or the substitution of material- and emission-intensive raw materials for more beneficial ones. In addition, more and more resource-saving and greenhouse gas-neutral technologies are being used worldwide, so the material and CO_2 rucksacks of imports are greatly reduced.



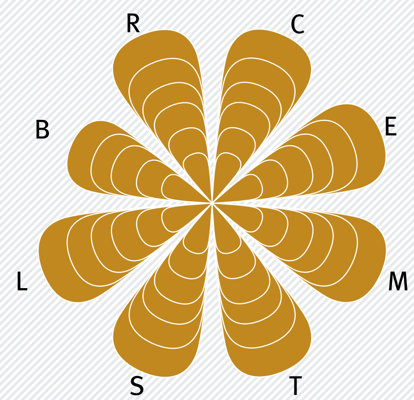


GreenLife Germany
resource efficient and GHG neutral
Lifestyle changes

analyses what contribution behavioural changes can make to reducing greenhouse gases and conserving resources if they complement "GreenEe2". To this end, trends and environmentally conscious behaviour that can already be seen today are continued to a greater extent, for example car sharing, ride sharing services or cycling. Domestic flights are increasingly replaced by buses and trains; long-distance travel by trips to destinations closer to home. People live on less area and use repairable, durable products. Dietary habits are sustainable and healthy, revolving around seasonal and regional products.

GreenSupreme Germany
resource efficient and GHG neutral
Minimizing future greenhouse gas emissions and raw material consumption

combines the ambitious technological changes of "GreenMe" with the sustainable lifestyles of "GreenLife". This pathway also illustrates the positive effects of very rapid transformation on total greenhouse gas emissions and raw material consumption by 2050. A rapid and far-reaching shift of technologies and lifestyles, as well as an exemption from macroeconomic growth saves an especially considerable amount of greenhouse gas emissions and thus comes closest to the 1.5-degree target.



Source: Purr et al., 2019

Resource conservation via technology change

On the journey to sustainable use of raw materials, the way products and services are provided and used must undergo far-reaching change. With the help of technological developments, product design and production processes can conserve raw materials.

Changing production technologies in particular can decrease raw material use and thus achieve better material efficiency. The result: the amount of materials used is decoupled from negative social and ecological consequences. With this in mind, the German Resource Efficiency Programme (ProgRess I, II, III; (BMU, 2012, 2016b, 2020a) has been outlining goals, guiding principles and approaches for the protection of natural resources since 2012, and, among other things, promotes material and energy-efficient production processes (see p. 36–39).

The manufacturing industry estimates the potential material savings achievable through resource efficiency to be at least 7 % (Jacob et al., 2021). There are different starting points, such as product design, process technologies and recycling.

The product design approach aims to ensure that companies consider material intensity, reparability and recyclability when designing the product. The lightweight-construction concept is based on lightweight construction as a constructive principle, thereby reducing the use of materials (Hackfort et al., 2019). Bionics uses nature as a model for technical solutions. One example is vault structures that mimic honeycombs and, in addition to material savings, also achieve improved heat resistance, dimensional stability and durability (Hackfort et al., 2019): in the areas of construction, automotive and lighting technology, they enable material savings of 30–40 % (Dr. Mirtsch Wölbstrukturierung GmbH, n.d.; VDI ZRE, 2017).

The starting points of the process technology are primarily aimed at guaranteeing lower reject rates and constant quality control through an increased degree of automation. Technologies like 3D printing make product designs that are complex yet minimally demanding of materials a reality (Hackfort et al., 2019).

The starting point for recycling refers to production systems that form closed loops with secondary raw materials. Closed-loop circulation significantly reduces the pressure on primary raw materials and thus also on ecosystems (see p. 40/41). As a rule, the production of recycled raw materials goes hand in hand with a lower environmental impact, as shown in the example of metal processing, below.

A higher proportion of secondary raw materials often reduces both GHG emissions and water and land requirements.

In Germany, the recycling system currently conserves large amounts of primary raw materials, e.g. base metals. An expansion of secondary copper production from its current level of around 56 % to, for example, 90 %, would, c.p., result in around 0.4 million tonnes fewer CO_2 emissions. More copper recycling worldwide would reduce the consumption of metallic raw materials by up to 8.6 % (Figure 76).

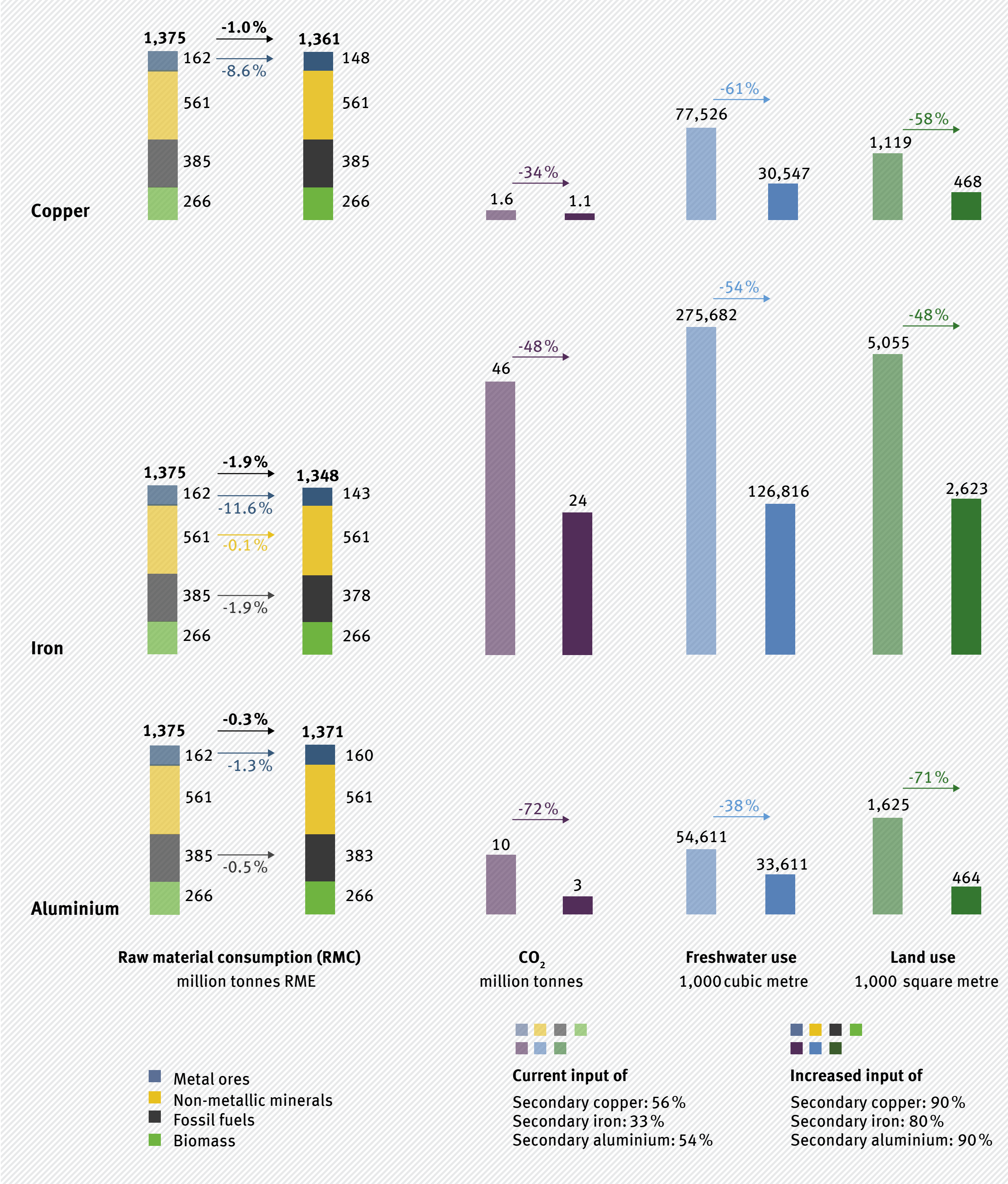
The picture is similar when it comes to iron and aluminium: a significant increase in the share of secondary material to 80 % (or 90 % for aluminium) would, c.p., lead to a reduction in the consumption of metallic raw materials of up to 11.6 % (or 1.3 %). Water and land resources would also be conserved.

Further change is necessary for sufficient secondary raw materials in all sectors, e.g. for efficient sorting and separation techniques in the recycling industry. It is also important to include the city as an anthropogenic source of raw materials – also termed “urban mining” (see p. 42/43).

From all this it is clear that conserving raw materials cannot be achieved with just one kind of technology. Rather, it requires a whole raft of technological changes. Raw materials policy must take sufficient account of feedback from new technologies (e.g. higher demand for critical raw materials) and any potential rebound effects.

Figure 76

Impacts of increased secondary usage of copper, iron and aluminium on raw material consumption (RMC) and resulting environmental impacts, base year 2010

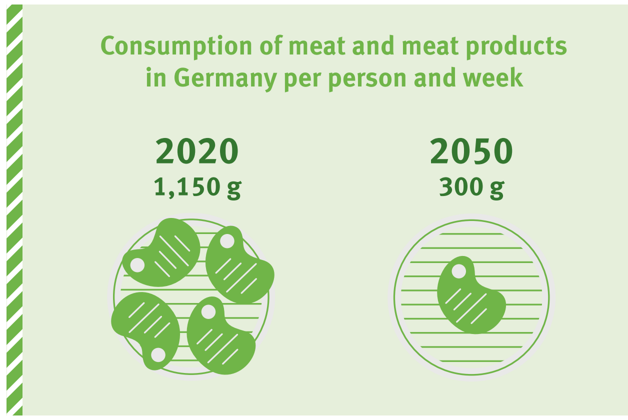


Source: Dittrich et al. 2022 b

Lifestyle changes to achieve the green transition

To conserve resources and be greenhouse gas-neutral, lifestyles and consumption also need to change. Consumers can actively help shape the path to a sustainable future. The way people eat, live and move today will shape the society of the future.

Consumers can exert a particularly effective influence on the consumption of raw materials through their behaviour and purchasing decisions relating to nutrition, housing, household and mobility (Figure 77). The way consumers spend their free time, how they travel and how they dress also affects the demand for raw materials and the corresponding emissions that have an impact on the climate.

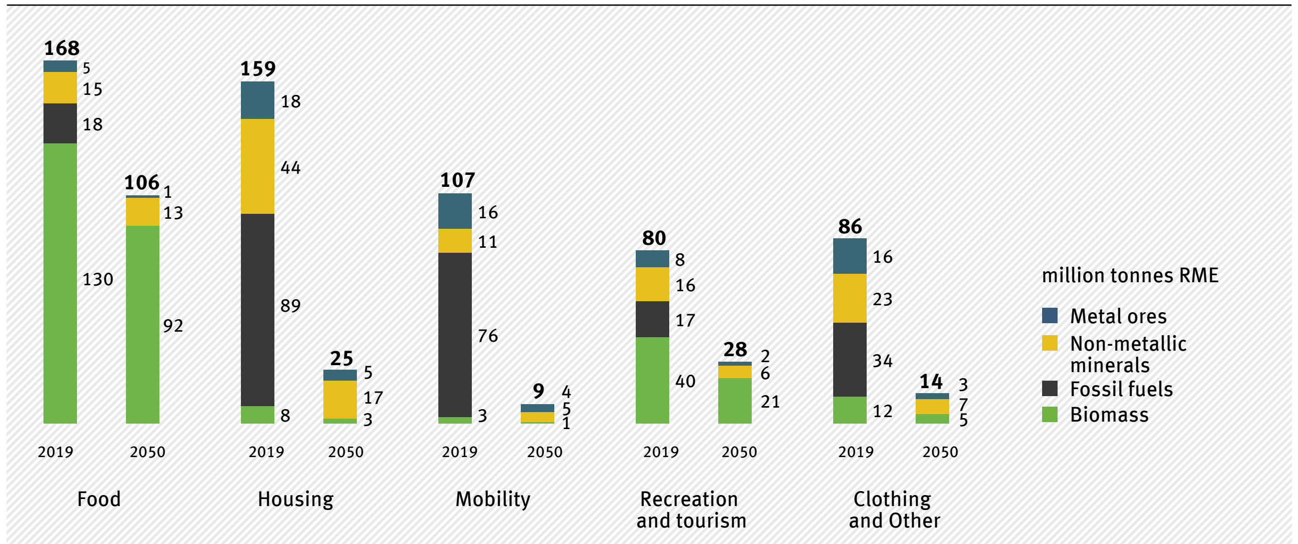


Source: Mundhenke et al., 2020

In the area of nutrition, the amount of food waste must be reduced significantly. In addition, consuming more plant-based and fewer animal-based products would have great benefits – both for the environment and on people's health. Around 202 million tonnes of raw materials or 2.4 tonnes per capita are used in Germany every year as food in or outside the home – either out and about or in restaurants. Food consumption, especially meat and animal products, causes significant levels of greenhouse gas emissions and occupies large areas of land (– and unnecessarily, because, according to the recommendations of the German Society for Nutrition, 300 grams of meat or animal products per week is sufficient for a healthy diet. If agricultural production was improved at the same time, and if consumers preferred regional and seasonal products, the annual raw material requirement for food in a Germany that was greenhouse gas-neutral and conserved resources would only be around 105 million tonnes in total, or 1.9 tonnes per capita (see p. 78/79) .

Figure 77

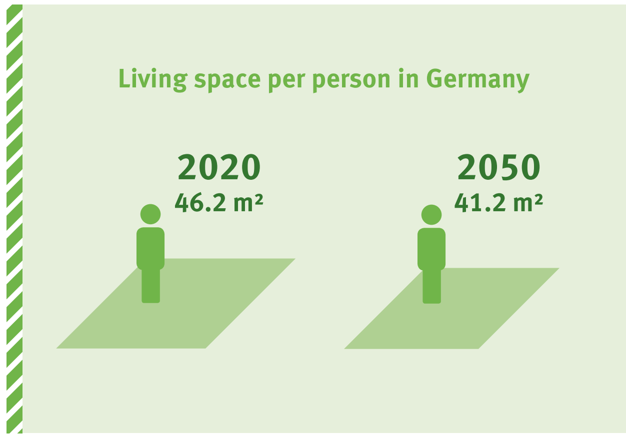
Development of raw material consumption (RMC) by consumption area in the scenario "GreenSupreme", 2019 and 2050



Quantities below 5 million tonnes are not depicted.

Sources: Dittrich et al., 2020c; Dittrich et al., 2022a

Improvements are also possible, if people live differently: in buildings with high energy standards, with the appropriate building services, and with materials that improve the indoor environment and at the same time save raw materials and minimise greenhouse gas emissions. For example, high rates of building renovation, heat pumps or district heating can reduce the energy requirement from an average of 84 kilowatt-hours to just 24.4 kilowatt-hours per square metre. More recycled building materials, lightweight or timber construction, and more flexible, modular construction methods can also reduce raw material consumption and greenhouse gas emissions. If primary wood is no longer burned, but predominantly used as a building material, the CO_2 stored within the wood is only released back into the atmosphere after a considerable amount of time – houses thus become carbon sinks.

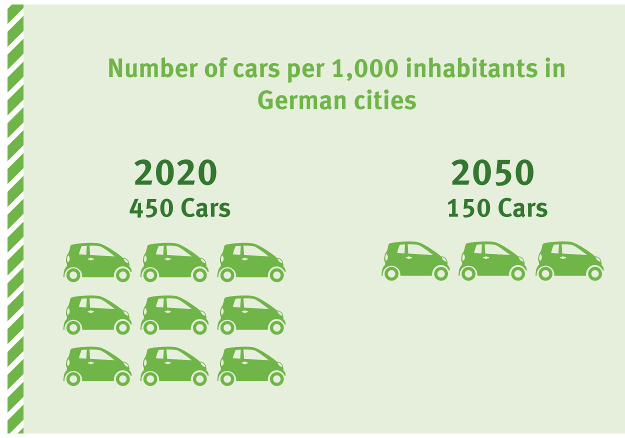


Source: Mundhenke et al., 2020

The average living space in Germany is currently 47.7 square metres per person, often in resource-intensive single-family homes (UBA, 2021j). Private households use around 159 million tonnes of raw materials (or around 1.9 tonnes per person) in their domestic lives every year. This includes raw materials for heating, electricity, repairs and refurbishments, as well as furniture. This figure does not include the raw materials for the construction of the buildings themselves. With technological improvements, an average living space of 41 square metres, for example, and a higher proportion of apartment buildings, the raw material consumption of private households in their domestic lives could be reduced by 85 % to a total of 25 million tonnes, or 0.35 tonnes per person.

Citizens can also influence the consumption of raw materials and greenhouse gas emissions in other areas of consumption. When it comes to mobility, the increased use of public transport, bicycles and car sharing is an important lever for lower consumption of raw materials and lower greenhouse gas emissions. By 2050, changing mobility behaviour could reduce the number of cars per 1,000 city dwellers by a third (and the proportion of cars with combustion engines could drop to 10 %). This would not only help to protect the climate and improve air quality, but also enable new types of use for parking spaces. Previously sealed areas could be greened and, for instance, be made into play areas – with new space for people to interact.

Each individual can also further conserve raw materials and greenhouse gases by, for example, choosing holiday destinations that can be reached by bus and train.



Source: Mundhenke et al., 2020

Combined with technological changes (see p. 88/89), a sustainable lifestyle can significantly reduce the demand for raw materials in all areas of consumption. A lifestyle that conserves resources certainly does not mean forgoing important needs. Rather, it is about new ways of meeting needs in the future while staying within Earth's load limits. The task of politics is to create central prerequisites that enable and support the necessary changes in behaviour across the whole of society.

Glossary

This glossary is mainly based on the glossary of the second German Resource Efficiency Programme (BMU, 2016 b) and the glossary on resource conservation of the German Environment Agency (Kosmol et al., 2012), including updates.

Biomass: Category of material flow analysis: Comprises all organic matter, which accrues or is produced by plants or animals. Fossil fuels and peat are not included in this category. Where biomass is used to produce energy, a distinction is made between renewable raw materials (energy crops such as rape, maize or cereals) and organic residues and waste materials.

Carbon footprint: Sum of all carbon dioxide emissions occurring both within and outside a country along the value chains of goods and services serving final demand. According to ISO 14067 (ISO, 2018), besides carbon dioxide (CO_2) also methane (CH_4) and nitrous oxide (N_2O) are taken into account and made comparable by means of conversion into CO_2-equivalents (Stocker et al., 2013).

Circular economy: An economic model that minimises resource input and waste generation, emissions and energy waste by closing, slowing and reducing energy and material cycles. An important component is on one hand product design, with a focus on extending the lifespan of goods, reparability, and potentials for reuse and recycling. On the other hand, new business models that aim at achieving common use of goods (sharing) and the purchase of services instead of goods are intended to ensure more efficient production and use.

Cumulative energy consumption (KEA): Total amount of primary energy that is required for manufacturing, usage and disposal of a product. Apart from utilisation for energy production, also non-energy related use (e.g. crude oil for production of plastics) and material-bound energy content are included.

Cumulative raw material consumption (KRA): Total amount of raw materials (including energy resources) required across value chains for manufacturing and transport of a product,. Non-commercially used substances or mixtures of substances (e.g. unused extraction) are not included.

Decarbonisation: Transition of an economic system or economic sector (in particular the energy sector) aiming at reducing or ending the emission of fossil carbon dioxide (CO_2).

Decoupling – relative / absolute: The removal or reduction of a quantitative link between interdependent developments. In the context of sustainability assessments, the term refers to the use of natural resources increasing at a lower rate than the economy (relative decoupling). Absolute decoupling is observed where resource use and associated environmental impacts even decline while the economy continues to grow.

Direct material input (DMI): Material flow indicator for the mass of materials directly entering a national economy, which are either further processed or consumed within it. Calculation: the sum of the mass of domestically extracted raw materials plus imported raw materials, semi-finished or finished goods (cf. “Direct raw material flows”).

Direct raw material flows: Comprise the actual weight of extracted raw materials and traded products. The latter are assigned to one of the four main raw material groups (biomass, fossil fuels, metal ores or non-metallic minerals), depending on their primary component.

DMC: Material flow indicator: see “Domestic material consumption (DMC)”.

DMI: Material flow indicator: see “Direct material input (DMI)”.

Domestic material consumption (DMC): Material flow indicator: Describes the mass of those materials that are directly used within a country. Calculation: the sum of domestic extraction plus the mass of directly imported raw materials, semi-finished and finished goods, minus the mass of directly exported raw materials, semi-finished and finished goods (see “Direct raw material flows”).

Efficiency: The relationship between a particular use, product or service and the outlay or raw material input that it requires.

Extraction: Material flow indicator: The extraction of raw materials from the environment or their displacement within the environment as a result of human activities. Calculated as the total mass of (1) harvested biomass, (2) mined non-metallic minerals and metal ores, and (3) extracted fossil fuels. A distinction is made between used and unused extraction. Extraction is defined as used where the extracted material is exploited economically. Unused extraction refers to extracted raw material that remains in the environment, e.g. deposited overburden from coal mining. Common synonym: “domestic extraction”

Final demand: Goods and services that are not further processed within an economy. This comprises goods and services for consumption, capital investments, changes in stocks and exports to other countries.

Flow resources: Comprise wind, hydro, geothermal, tidal and solar energy. Although these resources cannot be exhausted, their utilisation requires the input of exhaustible resources. For instance, the construction and installation of wind turbines or photovoltaic cells requires energy, raw materials and land.

Fossil fuels: Category of material flow analysis: Comprises animal- or plant-based energy resources found in geological deposits, such as coal, crude oil or natural gas. Fossil fuels are classified as non-renewable raw materials.

Indirect raw material flows: Mass of all raw material inputs along the entire value chain of traded goods. Traded goods are converted into so-called “raw material equivalents” (RME). The sum of all domestic and foreign extraction for goods for the domestic final demand is also termed “raw material consumption” or “material footprint” (see “Raw material consumption (RMC)”).

KEA: See. „Cumulative energy demand (KEA)“.

KRA: See. „Cumulative raw material consumption (KRA)“.

Land footprint: The sum of all land areas used along value chains both in and outside a country for the production of goods and services for final demand in that country. This land use indicator for products of agriculture and forestry is sub-divided into three categories: cropland, grassland and forest land.

Metal ores: Category in material flow analysis: Includes all metallic minerals.

Monetary trade balance: Value of imports minus value of exports. Indicates a trade surplus (exports greater than imports) or deficit (imports greater than exports) of a national economy. In contrast to the monetary perspective, for the physical trade balance imports are denoted with a positive, and exports with a negative sign respectively.

Natural resources: Resources available in the natural environment and used by humans. These include renewable and non-renewable raw materials, physical space (or area), flow resources (e.g. geothermal energy, wind, tidal and solar energy), environmental media (water, soil, air), and ecosystems (VDI 2016).

Non-metallic minerals: Category in material flow analysis: Comprises industrial minerals such as clay minerals, quartz or kaolin, and construction minerals such as sand, gravel, etc.

Planetary boundaries: Scientific concept defining nine dimensions or environmental processes, that are essential for the stability of the global earth system. Environmental impacts from human activities can lead to transgressing these boundaries and therewith critical tipping points leaving the so-called “safe operating space”. This can result in fundamental constraints of human live on earth (Rockström et al., 2009b).

Primary raw materials: Raw materials that are extracted from nature. Renewable and non-renewable primary raw materials are distinguished. Despite the lack of a consistent definition of the period, the distinction between “renewable” and “non-renewable” usually lies between 100 and 1,000 years.

Raw materials: Substances or mixtures of substances in an unprocessed or unfinished state, which are used as inputs to a production process. A distinction is made between primary and secondary raw materials (see respective glossary entries).

Raw material consumption (RMC): Material flow indicator: Comprising the mass of raw materials input along the value chains for goods and services for final demand in a country. Calculation: the total mass of domestic extraction and imports of raw materials, semi-finished and finished products in RME, minus exports of raw materials, semi-finished and finished products in RME (see “indirect raw material flows”).

Raw material equivalents (RME): Material flow indicator: see “Indirect raw material flows”.

Raw material input (RMI): Material flow indicator: Calculated as the total mass of raw material inputs along value chains for goods or services that are processed or consumed in a country or by a national economy. Calculation: the sum of domestically used extraction and the mass of direct and indirect imports (see “indirect raw material flows”).

Raw material use: An umbrella term for the use of raw materials by society. This includes the use of raw materials for both production and consumption.

Recycling: Any recovery operation, through which waste materials are reprocessed into materials, substances or products – either for their original purpose or for another use. This includes the processing of organic materials, but excludes energy recovery and reprocessing into materials that are intended for use as fuels or for backfilling operations (KrWG, 2021).

Renewable energies: Forms of energy that are produced from renewable resources. These include, for example, biomass, hydropower, geothermal energy, wind or solar energy. Fossil raw materials and peat are not included (see primary raw materials).

RMC: Material flow indicator: see “Raw material consumption (RMC)”.

RMI: Material flow indicator: see “Raw material input (RMI)“.

Secondary raw materials: Raw materials that are recovered from waste processing activities (i. e. recycling).

Total raw material productivity: A production-based indicator for the raw material efficiency of the German economy. It forms part of the German Sustainable Development Strategy and the German Resource Efficiency Programme (ProgRess III). Calculation: price-adjusted gross domestic product plus price-adjusted outlay for imports (GDP+IMP) divided by the raw material input (RMI).

Water exploitation index (WEI): Shows the level of water abstraction measured against the renewable water resources. Used to identify whether a region is experiencing water shortage or water stress. The threshold value for water stress is 20 %, while 40 % or above indicates a level of severe water stress.

Water footprint: The total quantity of water used within or outside a country along value chains for all goods and services consumed in a country. It is subdivided into a “blue” (surface water and groundwater), “green” (rainwater) and a “grey” (for dilution of polluted water) component (Hoekstra et al., 2011).

Data tables

Table A 1

Used domestic extraction of raw materials

	1994	2000	2005	2010	2015	2019	1994–2019
Total (1,000 t)	**1,307,217**	**1,188,215**	**1,044,383**	**975,782**	**978,240**	**945,095**	**-28%**
Per capita (t)	**16,1**	**14,6**	**12,8**	**12,2**	**12,0**	**11,4**	**-29%**
Abiotic raw materials (1,000 t)							
Fossil fuels	**278,796**	**220,939**	**221,508**	**196,626**	**194,428**	**138,759**	**-50%**
Hard coal	52,406	33,591	24,907	12,900	6,223	0	-100%
Lignite	207,086	167,691	177,907	169,403	178,065	131,314	-37%
Crude oil	2,988	3,069	3,573	2,516	2,428	1,927	-36%
Natural gas and casinghead gas	15,796	16,073	14,828	11,456	7,244	5,031	-68%
Other fossil fuels	519	515	292	351	468	487	-6%
Metal ores	**146**	**462**	**362**	**394**	**496**	**588**	**304%**
Non-metallic minerals	**844,349**	**751,191**	**613,043**	**575,592**	**567,738**	**594,400**	**-30%**
Construction minerals	780,495	691,853	550,431	511,407	520,384	549,799	-30%
Industrial minerals	63,854	59,337	62,612	64,184	47,353	44,601	-30%
Total	**1,123,290**	**972,592**	**834,912**	**772,612**	**762,662**	**733,747**	**-35%**
Biotic raw materials (1,000 t)							
... from agriculture	**166,903**	**190,858**	**182,582**	**176,931**	**188,304**	**181,441**	**9%**
Cereals	55,967	66,686	69,648	74,410	84,781	81,362	45%
Cereals for grain harvesting (without maize)	33,883	41,947	41,898	39,827	44,894	40,638	20%
Cereals for whole crop harvest, maize	22,084	24,738	27,751	34,582	39,887	40,725	84%
Root crops	36,442	42,214	37,507	33,874	33,180	40,527	11%
Vegetables	2,416	3,407	3,511	3,513	3,802	4,401	82%
Fruits	4,873	6,087	4,520	4,238	4,595	4,099	-16%
Commercial crops	3,288	3,765	5,213	5,878	5,174	3,030	-8%
Intermediate crops, grassland, crop residues	63,366	68,155	61,629	54,493	56,239	47,562	-25%
Other biomass	551	543	554	526	534	460	-16%
... from forestry	**16,802**	**24,503**	**26,572**	**25,955**	**26,954**	**29,621**	**76%**
Hard wood	12,413	18,497	20,255	18,748	18,688	23,093	86%
Soft wood	4,389	6,006	6,317	7,207	8,267	6,528	49%
... from animals	**222**	**262**	**316**	**284**	**319**	**285**	**28%**
Total	**183,926**	**215,623**	**209,470**	**203,170**	**215,577**	**211,347**	**15%**

Non-metallic raw materials correspond to the category „mineral raw materials" of the UGRdL.

Source: Destatis, 2021: Umweltökonomische Totalrechnung, Totalwirtschaftliches Materialkonto, Berichtszeitraum 1994–2019/2020, published on 26.11.2021

Table A 2a

Used domestic extraction of raw materials by federal states

1,000 t	1994	2000	2005	2010	2015	2019	1994–2019
Baden-Württemberg	**140,829**	**147,051**	**106,763**	**102,137**	**103,448**	**112,545**	**-20%**
Fossil fuels	384	340	294	352	469	487	27%
Non-metallic minerals	119,989	118,252	86,385	81,146	81,976	88,865	-26%
Biomass	20,456	28,459	20,084	20,639	21,002	23,192	13%
Bavaria	**193,012**	**180,835**	**148,927**	**148,396**	**155,064**	**171,873**	**-11%**
Fossil fuels	179	98	90	35	49	46	-74%
Non-metallic minerals	142,829	127,454	94,592	94,472	101,583	112,505	-21%
Biomass	50,003	53,284	54,245	53,889	53,431	59,322	19%
Brandenburg	**84,323**	**78,944**	**78,491**	**76,491**	**72,332**	**62,330**	**-26%**
Fossil fuels	47,692	40,329	40,378	37,996	32,514	24,786	-48%
Non-metallic minerals	27,388	27,568	25,196	25,062	24,099	23,578	-14%
Biomass	9,243	11,047	12,918	13,433	15,719	13,966	51%
Hessen	**54,783**	**54,860**	**43,751**	**42,967**	**44,035**	**46,503**	**-15%**
Fossil fuels	151	156	0	0	0	0	-100%
Non-metallic minerals	44,744	43,960	33,484	31,829	32,966	33,127	-26%
Biomass	9,887	10,744	10,267	11,138	11,069	13,377	35%
Mecklenburg-Vorpommern	**32,121**	**27,746**	**28,256**	**27,410**	**31,615**	**42,433**	**32%**
Fossil fuels	27	12	8	5	4	5	-80%
Non-metallic minerals	22,173	13,802	14,226	12,318	13,342	25,282	14%
Biomass	9,921	13,932	14,022	15,087	18,269	17,146	73%
Lower Saxony	**119,466**	**118,987**	**105,147**	**100,678**	**110,983**	**99,620**	**-17%**
Fossil fuels	18,786	20,109	15,617	12,859	9,170	5,573	-70%
Non-metallic minerals	61,166	52,980	42,157	38,412	41,265	41,288	-32%
Biomass	39,514	45,898	47,372	49,408	60,548	52,759	34%
North Rhine-Westphalia	**320,086**	**281,409**	**274,755**	**249,094**	**243,432**	**216,465**	**-32%**
Fossil fuels	145,091	119,496	117,454	102,492	101,604	64,919	-55%
Non-metallic minerals	150,591	135,177	131,007	121,225	113,709	122,822	-18%
Biomass	24,404	26,737	26,294	25,376	28,118	28,724	18%
Rheinland-Pfalz	**58,554**	**63,356**	**52,831**	**54,025**	**52,459**	**52,605**	**-10%**
Fossil fuels	121	78	46	104	204	150	23%
Non-metallic minerals	49,566	53,640	43,181	43,092	42,597	41,619	-16%
Biomass	8,867	9,638	9,603	10,829	9,657	10,836	22%
Saarland	**14,581**	**10,853**	**8,289**	**4,899**	**3,176**	**3,047**	**-79%**
Fossil fuels	8,676	6,018	5,128	1,452	107	95	-99%
Non-metallic minerals	5,256	4,062	2,433	2,591	2,252	2,244	-57%
Biomass	649	772	728	856	817	707	9%

Non-metallic raw materials correspond to the category „mineral raw materials" of the UGRdL.

Source: Statistische Ämter der Länder, 2021: Umweltökonomische Totalrechnungen der Länder, Indikatoren und Kennzahlen, Tabellenband Ausgabe 2021, Tabellen 7.1–7.5, 11.6

Continued on next page

Continued from previous page

1,000 t	1994	2000	2005	2010	2015	2019	1994–2019
Saxony	**140,460**	**93,969**	**98,040**	**88,716**	**94,975**	**97,373**	**-31%**
Fossil fuels	43,680	23,429	31,916	31,736	39,930	35,622	-18%
Non-metallic minerals	87,656	60,199	54,975	46,317	43,500	50,820	-42%
Biomass	9,124	10,340	11,149	10,663	11,545	10,931	20%
Saxony-Anhalt	**84,696**	**80,429**	**67,652**	**65,989**	**67,340**	**67,970**	**-20%**
Fossil fuels	12,468	9,010	6,891	7,374	9,255	6,345	-49%
Non-metallic minerals	60,535	57,677	46,862	43,593	42,208	47,439	-22%
Biomass	11,693	13,743	13,898	15,023	15,877	14,185	21%
Schleswig-Holstein	**23,933**	**28,164**	**28,611**	**32,106**	**36,750**	**38,205**	**60%**
Fossil fuels	448	1,345	3,013	1,623	1,389	1,072	139%
Non-metallic minerals	14,309	15,484	13,411	15,878	18,636	19,522	36%
Biomass	9,176	11,336	12,187	14,605	16,725	17,610	92%
Thuringia	**49,198**	**44,884**	**38,319**	**35,410**	**31,944**	**36,303**	**-26%**
Fossil fuels	53	41	26	21	16	14	-73%
Non-metallic minerals	40,980	36,145	28,984	26,254	22,478	26,425	-36%
Biomass	8,165	8,698	9,309	9,134	9,450	9,864	21%
City States	4,218	2,154	2 644	2 653	2 563	2 974	-29%

Non-metallic raw materials correspond to the category „mineral raw materials" of the UGRdL.

Source: Statistische Ämter der Länder, 2021: Umweltökonomische Totalrechnungen der Länder, Indikatoren und Kennzahlen, Tabellenband Ausgabe 2021, Tablen 7.1 – 7.5, 11.6

Table A 2b

Used domestic extraction of raw materials by federal states per capita

tonnes per capita	1994	2000	2005	2010	2015	2019	1994–2019
Baden-Württemberg	13,8	14,2	10,1	9,7	9,6	10,2	-26%
Bavaria	16,3	14,9	12,1	12,0	12,1	13,1	-19%
Brandenburg	33,3	30,6	31,0	31,0	29,3	24,8	-26%
Hessen	9,2	9,1	7,3	7,2	7,2	7,4	-19%
Mecklenburg-Vorpommern	17,5	15,7	16,7	16,9	19,7	26,4	51%
Lower Saxony	15,6	15,2	13,3	12,9	14,1	12,5	-20%
North Rhine-Westphalia	18,1	15,8	15,4	14,2	13,7	12,1	-33%
Rheinland-Pfalz	14,9	15,7	13,0	13,5	13,0	12,9	-14%
Saarland	13,5	10,2	8,0	4,9	3,2	3,1	-77%
Saxony	30,7	21,3	23,2	21,8	23,3	23,9	-22%
Saxony-Anhalt	30,7	30,8	27,6	28,6	30,1	30,9	1%
Schleswig-Holstein	8,9	10,2	10,2	11,5	12,9	13,2	48%
Thüringen	19,5	18,5	16,5	16,1	14,8	17,0	-13%

Source: Statistische Ämter der Länder, 2021: Umweltökonomische Totalrechnungen der Länder, Indikatoren und Kennzahlen, Tabellenband Ausgabe 2021, Tablen 7.1 – 7.5, 11.6

Table A 3

Direct trade

1,000 t	1994	2000	2005	2010	2015	2019	1994–2019
Imports							
Total	**463,150**	**521,179**	**563,542**	**592,545**	**645,170**	**613,232**	**32%**
Raw materials	**277,268**	**305,522**	**326,431**	**322,829**	**354,773**	**336,575**	**21%**
Fossil fuels	172,460	194,532	227,715	214,058	244,059	232,617	35%
Metal ores	47,030	51,851	47,025	47,850	47,381	39,499	-16%
Non-metallic minerals	35,689	34,110	25,516	25,588	22,143	22,351	-37%
Biomass	22,089	25,029	26,175	35,334	41,191	42,108	91%
Semi-finished goods from …	**105,324**	**112,063**	**107,016**	**120,292**	**124,367**	**113,364**	**8%**
… fossil fuels	48,410	53,453	49,238	54,207	55,312	46,718	-3%
… metal ores	9,551	12,973	16,221	17,010	16,300	13,544	42%
… non-metallic minerals	27,783	22,956	15,856	17,665	17,548	16,421	-41%
… biomass	19,580	22,680	25,702	31,410	35,208	36,681	87%
Finished goods, mainly from …	**79,944**	**102,946**	**114,520**	**132,447**	**140,424**	**139,544**	**75%**
… fossil fuels	15,425	20,159	23,685	27,696	31,019	31,571	105%
… metal ores	30,461	42,052	45,514	54,136	57,340	55,215	81%
… non-metallic minerals	5,230	7,509	8,219	10,331	10,710	12,479	139%
… biomass	28,828	33,226	37,101	40,284	41,355	40,280	40%
Exports							
Total	**223,181**	**289,251**	**357,022**	**365,296**	**398,125**	**406,752**	**82%**
Raw materials	**55,357**	**74,397**	**78,087**	**80,492**	**90,136**	**110,645**	**100%**
Fossil fuels	4,967	13,424	15,120	14,996	29,638	48,375	874%
Metal ores	171	215	147	192	292	998	483%
Non-metallic minerals	34,768	37,881	41,340	44,306	36,400	32,437	-7%
Biomass	15,451	22,877	21,479	20,999	23,807	28,835	87%
Semi-finished goods from …	**86,005**	**98,357**	**126,719**	**112,233**	**121,502**	**119,628**	**39%**
… fossil fuels	23,967	26,880	36,645	25,843	37,652	33,002	38%
… metal ores	14,943	14,697	14,841	17,665	16,331	16,453	10%
… non-metallic minerals	28,483	31,284	45,354	34,339	31,975	2,020	-93%
… biomass	18,613	25,497	29,879	34,385	35,545	39,363	111%
Finished goods, mainly from…	**81,388**	**115,898**	**144,936**	**153,252**	**164,439**	**157,365**	**93%**
… fossil fuels	20,382	26,670	33,828	35,399	37,752	37,817	86%
… metal ores	36,669	52,392	62,409	63,945	70,836	62,469	70%
… non-metallic minerals	5,510	9,162	11,369	12,916	13,469	15,126	175%
… biomass	18,827	27,674	37,329	40,992	42,383	41,953	123%

Source: Destatis, 2021: Umweltökonomische Totalrechnung, Totalwirtschaftliches Materialkonto, Berichtszeitraum 1994 – 2019/2020, published on 26. 11. 2021

Table A 4

Indirect Trade (raw material equvivalents, RME), EU Standard Method

	2008	2010	2012	2014	2016	2018	2019
Imports (1,000 t)							
Total	**1,635,158**	**1,456,943**	**1,359,816**	**1,497,108**	**1,536,991**	**1,680,708**	**1,628,002**
Biomass	163,102	160,924	158,816	172,224	177,934	182,934	180,908
Metal ores	660,039	573,589	502,412	589,344	591,283	677,739	639,228
Non-metallic minerals	226,085	197,349	187,008	198,755	205,322	257,764	266,756
Fossil fuels	585,932	525,080	511,580	536,785	562,452	562,272	541,110
Exports (1,000 t)							
Total	**1,300,819**	**1,121,648**	**1,094,517**	**1,191,666**	**1,206,452**	**1,273,727**	**1,208,671**
Biomass	120,770	124,531	128,095	139,348	142,336	140,306	146,071
Metal ores	510,736	426,614	384,964	454,918	454,622	495,841	472,022
Non-metallic minerals	254,248	216,031	214,850	212,084	212,476	241,832	238,078
Fossil fuels	415,064	354,473	366,609	385,316	397,019	395,748	352,500
Imports in per cent (2008 = 100)							
Total	**100**	**89**	**83**	**92**	**94**	**103**	**100**
Biomass	100	99	97	106	109	112	111
Metal ores	100	87	76	89	90	103	97
Total	**100**	**89**	**83**	**92**	**94**	**103**	**100**
Biomass	100	99	97	106	109	112	111
Metal ores	100	87	76	89	90	103	97
Non-metallic minerals	100	87	83	88	91	114	118
Fossil fuels	100	90	87	92	96	96	92
Exports in per cent (2008 = 100)							
Total	**100**	**86**	**84**	**92**	**93**	**98**	**93**
Biomass	100	103	106	115	118	116	121
Metal ores	100	84	75	89	89	97	92
Non-metallic minerals	100	85	85	83	84	95	94
Fossil fuels	100	85	88	93	96	95	85

Comparison of RME values according to EU Standard Method and Destatis: see table A 8

Source: Dittrich et al,, 2022: Dokumentation des RME-Modells für Deutschland, In: Lutter et al,, 2022: Ressourcennutzung in Deutschland – Weiterentwicklung des deutschen Ressourcenberichts (DeuRess II)

Table A 5 a

Raw material input (RMI), EU Standard Method

	2008	2010	2012	2014	2016	2018	2019	2008–2018	2010–2019
Total (1,000 t)	2,675,817	2,428,267	2,378,593	2,518,443	2,484,649	2,635,104	2,536,421	-2%	4%
Per capita (t)	32.6	29.7	29.6	31.1	30.2	31.8	30.5	-2%	3%
Biomass	376,100	359,201	373,217	405,883	387,366	373,311	386,000	-1%	7%
Metal ores	660,502	573,983	502,863	589,805	591,797	678,257	639,816	3%	11%
Non-metallic minerals	841,060	770,050	778,534	786,666	754,866	841,753	827,693	0%	7%
Fossil fuels	798,155	725,033	723,979	736,089	750,620	741,784	682,910	-7%	-6%

Comparison of RME values according to EU Standard Method and Destatis: see table A 8

Source: Dittrich et al., 2022: Dokumentation des RME-Modells für Deutschland, In: Lutter et al,, 2022: Ressourcennutzung in Deutschland – Weiterentwicklung des deutschen Ressourcenberichts (DeuRess II)

Table A 5 b

Raw material input (RMI) by supply groups, EU Standard Method

2019 1,000 tonnes	Biomass	Metal ores	Non-metallic minerals	Fossil fuels	Total
Construction	4,844	21,699	270,347	17,150	314,040
Mining	171	3,756	19,620	35,790	59,337
Services	51,005	26,362	129,624	59,603	266,595
Energy supply	435	1,866	3,014	64,393	69,709
Manufacturing of products from biomass	196,302	15,962	36,740	49,820	298,824
Manufacturing of products from metal ores and non-metallic minerals	3,271	294,925	204,120	64,479	566,794
Manufacturing of products from fossil fuels	16,955	59,372	65,124	192,543	333,993
Financial services	610	850	2,047	2,291	5,798
Agriculture and forestry	77,169	1,543	4,251	2,995	85,958
Other goods	29,798	204,403	80,435	129,585	444,221
Transport	2,724	2,771	3,547	37,261	46,303
Sales and retail	2,716	6,307	8,825	26,999	44,848
Total	**386,000**	**639,816**	**827,693**	**682,910**	**2,536,421**

Source: Dittrich et al., 2022: Dokumentation des RME-Modells für Deutschland, In: Lutter et al,, 2022: Ressourcennutzung in Deutschland – Weiterentwicklung des deutschen Ressourcenberichts (DeuRess II)

Table A 6 a

Raw material consumption (RMC), EU Standard Method

	2008	2010	2012	2014	2016	2018	2019	2008–2018	2010–2019
Total (1,000 tonnes)	1.374.997	1.306.618	1.284.076	1.326.777	1.278.197	1.361.378	1.327.750	-1%	2%
Per capita (tonnes)	16,7	16,0	16,0	16,4	15,5	16,4	16,0	-2%	0%
Biomass	255.330	234.670	245.122	266.534	245.031	233.004	239.929	-9%	2%
Metal ores	149.766	147.369	117.900	134.887	137.175	182.417	167.795	22%	14%
Non-metallic minerals	586.811	554.019	563.684	574.582	542.390	599.921	589.615	2%	6%
Fossil fuels	383.090	370.560	357.370	350.773	353.601	346.035	330.410	-10%	-11%

Source: Dittrich et al,, 2022: Dokumentation des RME-Modells für Deutschland; in: Lutter et al., 2022: Ressourcennutzung in Deutschland – Weiterentwicklung des deutschen Ressourcenberichts (DeuRess II)

Table A 6 b

Raw material consumption (RMC) by categories of final demand, EU Standard Method

2019 1,000 tonnes	Biomass	Metal ores	Non-metallic minerals	Fossile fuels	Total
Consumption by private housholds	193,810	63,450	107,676	234,828	599,764
Consumption by private organisations	1,194	505	944	1,597	4,240
Consumption by the State	20,723	9,221	76,900	21,749	128,592
Gross fixed capital formation	17,051	87,172	406,639	61,643	572,505
Changes in stock and net acquisition of valuables	7,152	7,446	-2,544	10,594	22,648
Total	**239,929**	**167,795**	**589,615**	**330,410**	**1,327,750**

Source: Dittrich et al,, 2022: Dokumentation des RME-Modells für Deutschland; in: Lutter et al., 2022: Ressourcennutzung in Deutschland – Weiterentwicklung des deutschen Ressourcenberichts (DeuRess II)

Table A 7

Total raw material productivity, EU Standard Method and Destatis

2010 = 100	2010	2012	2014	2016	2018	2019	2008–2018	2010–2019
EU Standard Method								
RMI	100	98	104	102	109	104	9%	4%
GDP+IMP	100	105	109	115	121	123	21%	23%
(GDP+IMP)/RMI	100	107	105	113	112	118	12%	18%
Destatis								
RMI	100	103	108	111	113		13%	
GDP+IMP	100	105	109	115	121		21%	
(GDP+IMP)/RMI	100	102	101	104	108		8%	

RMI: raw material input; GDP+IMP: gross domestic products + imports; (GDP+IMP)/RMI: Total raw material productivity (see glossary)
Comparison of RME values according to EU Standard Method and Destatis: see table A 8

Sources: Destatis, 2022: https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Umwelt/UGR/rohstoffe-materialfluesse-wasser/Tablen/Totalrohstoffproduktivitaet-Index.html
Dittrich et al., 2022: Dokumentation des RME-Modells für Deutschland; in: Lutter et al., 2022: Ressourcennutzung in Deutschland – Weiterentwicklung des deutschen Ressourcenberichts (DeuRes II)

Table A 8

Comparision of indicators, EU Standard Method and Destatis

	2008		2018	
1,000 tonnes	Destatis	EU Standard Method	Destatis	EU Standard Method
Indirect imports (raw material equivalents, RME)				
Biomass	174,000	163,102	301,000	182,934
Metal ores	780,000	660,039	987,000	677,739
Non-metallic minerals	144,000	226,085	178,000	257,764
Fossil fuels	580,000	585,932	566,000	562,272
Total	**1,677,000**	**1,635,158**	**2,033,000**	**1,680,708**
Indirect exports (raw material equivalents, RME)				
Biomass	178,000	120,770	306,000	140,306
Metal ores	705,000	510,736	801,000	495,841
Non-metallic minerals	180,000	254,248	174,000	241,832
Fossil fuels	367,000	415,064	414,000	395,748
Total	**1,430,000**	**1,300,819**	**1,695,000**	**1,273,727**
Raw material import (RMI)				
Biomass	437,000	376,100	492,000	373,311
Metal ores	780,000	660,502	988,000	678,257
Non-metallic minerals	739,000	841,060	789,000	841,753
Fossil fuels	792,000	798,155	746,000	741,784
Total	**2,748,000**	**2,675,817**	**3,014,000**	**2,635,104**
Raw material consumption (RMC)				
Biomass	259,000	255,330	186,000	233,004
Metal ores	75,000	149,766	187,000	182,417
Non-metallic minerals	559,000	586,811	615,000	599,921
Fossil fuels	425,000	383,090	332,000	346,035
Total	**1,318,000**	**1,374,997**	**1,319,000**	**1,361,378**

Values from Destatis 2008 are based on the national accounts revision 2011 and values from 2018 are based on the national accounts revision 2018.

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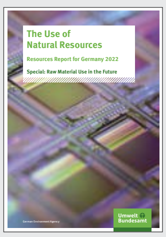

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