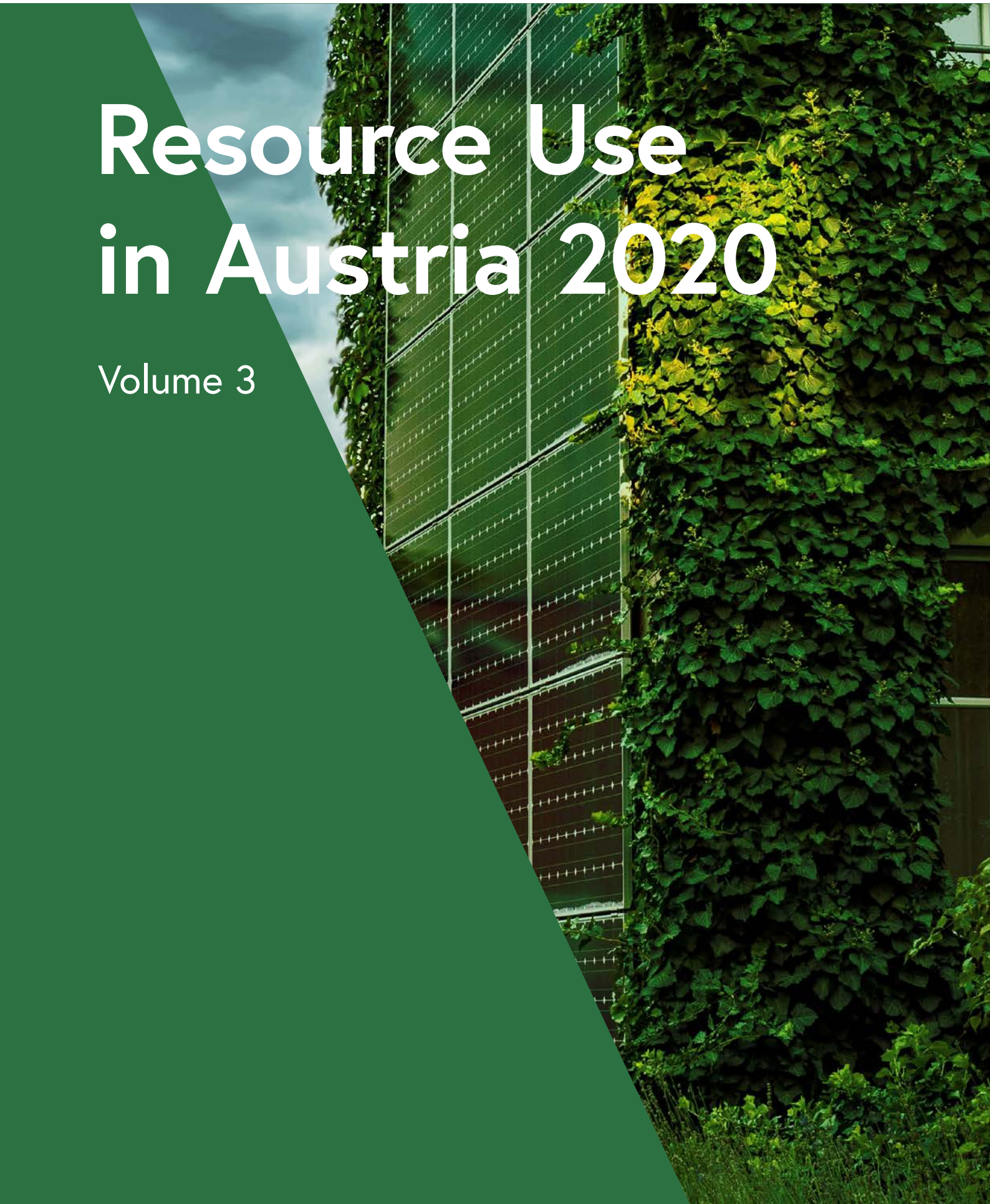


 Federal Ministry  
Republic of Austria  
Climate Action, Environment,  
Energy, Mobility,  
Innovation and Technology

 Federal Ministry  
Republic of Austria  
Agriculture, Regions  
and Tourism

# Resource Use in Austria 2020

Volume 3







**Media owner, publisher and editor:**

Federal Ministry of Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK)  
Radetzkystraße 2, 1030 Vienna  
+43 1 71162-650

**Authors:**

Nina Eisenmenger, Barbara Plank  
(Institute of Social Ecology, University of Natural Resources and Life Sciences, Vienna)  
Eva Milota, Sylvia Gierlinger  
(Statistik Austria)

**Expert coordination:**

Birgit Horvath, Dagmar Hutter, Caroline Vogl-Lang  
(Federal Ministry of Climate Action, Environment, Energy, Mobility, Innovation and Technology)  
Robert Holnsteiner, Christian Reichl, Susanne Strobl  
(Federal Ministry of Agriculture, Regions and Tourism)

**Translation:**

Ursula Lindenberg

**Layout:**

Gerda Palmetshofer

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August 2020

## Forewords



Federal Minister  
Leonore Gewessler

The resource consumption of our society plays an important role in the transformation towards a climate-neutral, circular economy. According to OECD estimates, greenhouse gas emissions directly related to the extraction, processing and use of natural resources will double by 2060. A lower consumption of valuable resources therefore also reduces harmful emissions in Austria. Measures in this respect make a decisive contribution to transforming Austria into a modern, resource-efficient and competitive economy in line with the European Green Deal. The careful and forward-looking use of natural resources today enables future generations more room for further development and thus supports a fair and smooth transition.

The provision of reliable, readily available and user-friendly data represents essential support for political decisions. The present report uses the latest data to analyse Austria's resource consumption and thus provides a valuable basis for a resource policy oriented towards sustainability. I wish all readers an informative read!

A handwritten signature in black ink, appearing to be 'L. Gewessler'.



Federal Minister  
Elisabeth Köstinger

In order to be able to guarantee the security of our livelihoods, we need sustainable and efficient resource management. A key factor in increasing resource efficiency lies in considering the entire life cycle of a raw material – from extraction to use and recycling. A modern, decarbonised, environmentally and climate-friendly energy supply requires the use of mineral raw materials as an integral part of climate-neutral solutions. The consumption of many of these necessary high-tech raw materials is increasing. Due to their high supply risk, 27 raw materials are currently classified as critical by the European Commission. The supply of mineral raw materials must therefore be guaranteed! Innovations in the raw materials sector are one of the essential success factors for ensuring Austria's long-term competitiveness.

In order to meet the central challenges of our society with sustainable and future-oriented measures, a comprehensive data situation and analysis work is required. This report, the third in the series Resource Use in Austria, focuses on the synergies between resource efficiency and climate protection, recycling management and raw materials for high-tech applications.

A handwritten signature in green ink, appearing to be 'E. Köstinger'.



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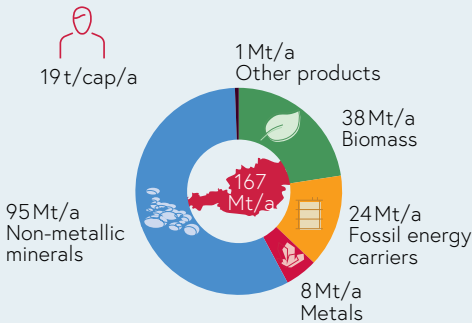
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# The essentials in brief

## Resource use in Austria – Where do we stand?

Resource use in Austria has currently stabilised at 19 tonnes per capita and thus exceeds planetary boundaries

Material consumption in Austria 2018



Austria in European comparison

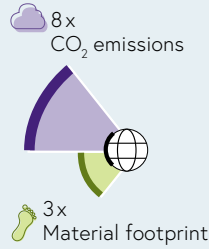
Material consumption 2018

11th position 19 t/cap/a

Material footprint 2017

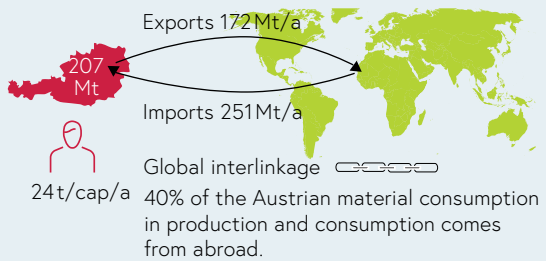
5th position 33 t/cap/a

Planetary boundaries 2019



Austria's consumption is jointly responsible for resource use in other parts of the world

Material footprint 2015



Our material-intensive economy carries primary responsibility for our excessive resource use

Domestic resource productivity 2018

€ 2,211 €/t

↑ +28% between 2000 and 2018

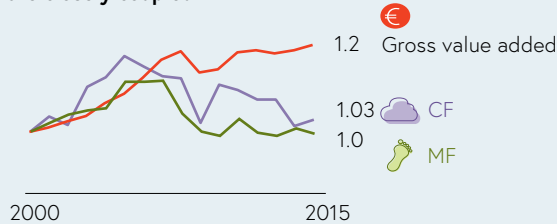
Consumption-based resource productivity 2015

€ 1,665 €/t

↑ +20% between 2000 and 2015

## Resource conservation and climate protection go hand in hand

Resource use and greenhouse gas emissions are closely coupled



Contributions of individual factors to the carbon footprint (CF)



Sectoral focus points: Construction, nutrition and health

Top 3 sectors with a high share of the respective footprint, 2015

Material footprint MF Carbon footprint CF

Construction sector 14% 8%

Food and animal feed production 9% 4%

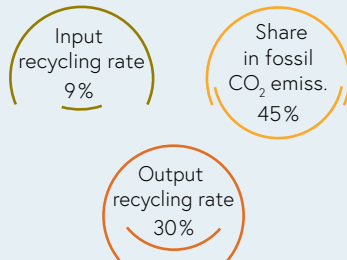
Health and social care 5% 6%

Values are rounded, rounding differences are not balanced.

## The circular economy from a macroeconomic perspective

### Recycling and recovery rates are essential indicators in the circular economy

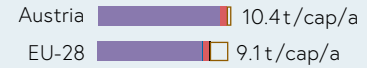
Austria in the year 2014



### Societal stocks are the driving force behind resource consumption and emissions



### With regard to the DPO, Austria is placed 12th in the EU comparison in 2016

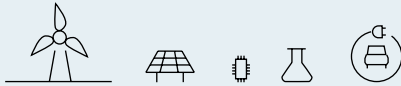


- Air emissions (e.g. carbon dioxide, methane, nitrous oxide, nitrogen oxides)
- Emissions to water
- Dissipative use of goods (e.g. fertilizer, compost, gravel, road salt)
- Dissipative losses (e.g. loss of material due to tyre and brake abrasion from vehicles, losses from leaking gas pipes, on lubricants or wear and tear of infrastructure and buildings)
- Wastes deposited in controlled landfills

## Critical raw materials play a keyrole for future technologies

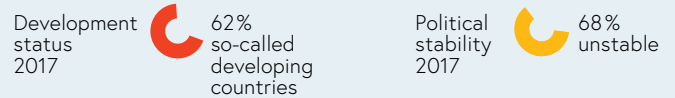
### Examples for applications for critical raw materials:

Batteries, photovoltaic systems, electronic equipment, catalytic converters, wind turbines



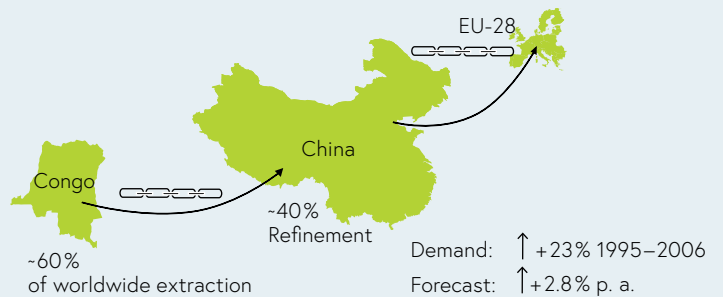
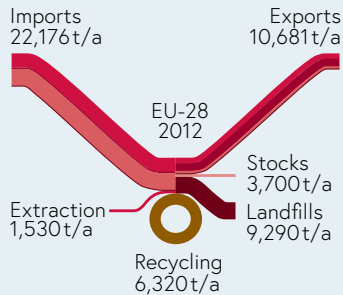
### Critical raw materials caught between supply risks and growing demand for future technologies

The production of critical raw materials takes place in a few countries; these are largely developing countries and politically unstable



### Cobalt,

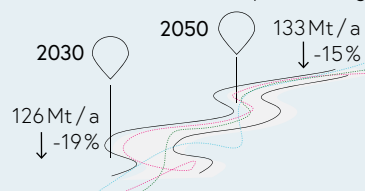
a critical raw material with a key role in the application of future technologies



## Future challenges

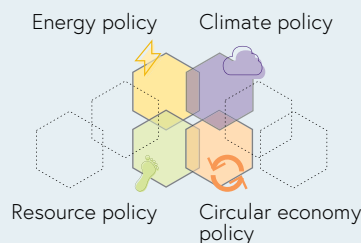
### Austria is moving the direction, but greater and faster progress is needed

Development of Austrian material consumption with decrease to the European average



European average: 14 t/cap/a

### Integrated consideration of the links between different policy areas



SDG 12 in Austria in the year 2019



# Introduction

A large number of bees are captured in flight against a warm, golden-yellow background. The bees are scattered throughout the frame, some appearing as small dark specks and others as more distinct shapes. Green leaves and branches are visible in the foreground and background, some in sharp focus and others blurred, creating a sense of depth and movement. The overall atmosphere is bright and natural, suggesting a busy hive or a large colony in a natural setting.



Over time, environmental issues have become omnipresent in sociopolitical discourse. Climate change, natural resource supply problems, volatile raw materials pricing and the pollution of water, air and soils are only some examples of the many facets through which the problems of *society's* interaction with the natural environment become visible. Underlying all these are the type and scale of *societal* interventions in natural cycles, the extraction of *resources* and the disposal of waste materials and emissions. To be able to identify problem areas and implement changes, we need to understand the relationships between *society* and nature. The data required for this can be found in the *environmental accounts*, which create a comprehensive picture of the different resource flows and allow for detailed analyses based on this.

Sustainable resource use forms an overarching goal to which various political programmes wish to contribute. Programmes to increase resource efficiency (European Commission 2011a, 2019c; OECD 2004; UN IRP 2011a) aim to ensure that natural *resources* are used more sparingly and in more targeted ways, so that stronger economic growth is not necessarily linked to greater environmental damage. The more recent programmes on the circular economy (European Commission 2014, 2015, 2020; OECD 2011) are aimed at ensuring natural *resources* remain available for *societal* use for longer, and at reducing access to primary *resources* from nature. Yet how effective are these concepts?

The report series “Resource Use in Austria” published by the Federal Ministry of Climate Protection, Environment, Energy, Mobility, Innovation and Technology (BMK) and the Federal Ministry of Agriculture, Regions and Tourism (BMLRT), brings together the current research on Austrian resource consumption for discussion. The first report in the series (BMLFUW and BMWFJ 2011) focused on construction raw materials, which constitute more than half of total resource use; the second report (BMLFUW and BMWFW 2015) focused on *biomass materials* as the backbone of a bioeconomy. The current and third report is dedicated to sustainable resource use as a cross-cutting theme linking resource efficiency, climate protection and raw materials for future technologies.

## Agenda 2030 as a global model for sustainable resource use

Societies need natural *resources* to carry out all their production processes and consumption activities. In production and consumption, we use *resources* both energetically and materially, and convert these at the end of their period of use into waste materials and emissions. Waste materials, that currently have no use in our *society*, and emissions are deposited in the natural environment and introduced into ecosystem cycles. The resource needs of a *society* can therefore be seen as analogous to those of an organism: Societies need inputs – in order to maintain their existence and to grow – and produce outputs. Our *society* and economy experience continual growth; thus many countries require ever more resource inputs and create increasing quantities of waste

materials and emissions. In the last few decades, we have reached planetary limits in tangible ways, and have exceeded some of these in recent times (Rockström et al. 2009; Steffen et al. 2015). The (local) scarcity of natural *resources*, the high concentrations of waste materials and emissions and the negative impacts upon the environment present increasing problems for the functioning of our *society*.

For a long time, environmental problems were approached as separate and singular challenges. With increasingly global environmental problems such as climate change, the loss of biodiversity and now globally interconnected production chains, it is clear that more comprehensive strategies for solving complex problems are required (UN IRP 2011 a). In the context of sustainable resource use, this means, for example, not merely focusing on the output side of waste materials and emissions but seeing these in relation to the input side of our resource needs. Input-oriented concepts such as resource efficiency on the one hand and macroeconomic concepts such as the circular economy on the other must be considered together. As part of the climate debate, the potentials of bioenergy, for example, should be analysed in the context of competition with food production or *material biomass* use. The growing demand for renewable energies, along with other factors, is also closely linked to the availability of critical raw materials. In other words, it is important to consider different perspectives in an integrated approach and then to identify synergies or trade-offs. Testing for the impacts of specific measures must consider areas beyond those in which their application is specifically targeted, and with regard to *society* as a whole.

The Agenda 2030 for Sustainable Development, published in 2015 by the United Nations and citing 17 global goals ( Sustainable Development Goals, SDGs; see figure 1, page 14; UN, 2015; see side note 1, page 14 ), calls for just such an integrated approach towards economy, ecology and *society*. This holistic development approach finds expression in the Agenda's five key messages: People, Planet, Prosperity, Peace and Partnership. Through this, the Agenda 2030 represents a common frame of reference for all states – in the global North and the global South – regarding worldwide prosperity in harmony with social justice and the ecological limits of the planet, to safeguard the basic conditions for life on earth. In Austria, this forms the guiding principle for policymaking, involving all people at state, federal province and local community level.

Sustainable resource use is anchored above all in two of the SDGs, SDG 8 “decent work and economic growth” and SDG 12 “responsible consumption and production”, embodied in the two indicators of *material flow accounting*: DMC (*domestic material consumption*; see side note 2, page 15) and MF (*material footprint*; see side note 6, page 37). The goal formulated in the SDGs says we must “improve progressively, through 2030, global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation, [... ]” (UN 2015).



Figure 1: Pictograms of the 17 Sustainable Development Goals (SDGs)

Source: UN 2020



### Side note 1: The global Sustainable Development Goals (SDGs) and their measurability

The sustainability debate gained new momentum with the ratification in 2015 by all 193 Member States of the UN of the Agenda 2030 for Sustainable Development, and the Sustainable Development Goals (SDGs; UN 2015) contained within it. For the first time, environmental goals became part of the international agenda alongside economic and social goals, and were to be treated as being of equal value, and integrated within all political processes. A total of 17 Goals and 169 Targets range from traditional development goals such as No Poverty (SDG 1) and Zero Hunger (SDG 2) through to Clean Energy (SDG 7) and Reduced Inequalities (SDG 10).

To be able to measure progress in achieving the SDGs, the UN framework defines c. 230 indicators. In international comparison, but also at European level, there are significant differences in the interpretation of these indicators and also in data quality and availability. Eurostat uses about 100 preselected indicators that adhere closely to the UN specifications. This forms the basis upon which the EU's annual progress report towards the SDGs is compiled (see Eurostat 2019 a). Thus EU Member States can be easily compared with one another, although in other combinations (for example among OECD Member States) it may be that differences in terms of indicators and background data render direct comparison impossible.



## Material flow accounting as the data and methodological basis for this report

To be able to discuss sustainable resource use, we need a data basis that allows us to identify trends and problem areas within the patterns of production and consumption in our *society*. *Material flow accounting* (MFA) has become the established basis for analysing resource use (see side note 2, or Krausmann et al. 2017 a). This considers all *materials* that are extracted from the natural environment and used in socioeconomic processes (production, consumption). Indicators from MFA describe the *material* basis or the resource use that is required to maintain the existence of our *society* and our economic processes. The average material use, often used synonymously with resource use, can also be referred to as the material living standard. Following the use and consumption of natural *resources*, i.e. at the end of the period of use, they are deposited in the form of solid, fluid or gaseous waste materials (largely as emissions) in the natural environment. Problems can arise immediately, as well as during extraction processes. These include: Overuse of a limited resource base, pollution and the disruption of ecosystems and biogeochemical cycles, for example in climate change caused by greenhouse gas emissions.

This report reflects resource use in Austria, drawing upon the most recently available data from *material flow accounting*. Data published by Statistics Austria, covering the period from 2000 to 2017 form the basis of this report (Statistics Austria 2019). In the case of 2018, the authors' own estimates are used, based on data from the official statistics for agriculture (see statistics for agriculture and forestry from Statistics Austria<sup>1</sup>), mining industry statistics (BMNT 2019 a) and extrapolations for *imports and exports*.



### Side note 2: Material Flow Accounting (MFA)

Economy-wide *material flow accounting* (EW-MFA; referred to subsequently in this report as MFA; Eurostat 2018; Fischer-Kowalski et al. 2011; Krausmann 2017a) forms the data basis for reporting and analysing *societal* resource use. *Material flow accounting* records all *materials*, which within specific system boundaries (e.g. Austria) are extracted from nature or traded with other socioeconomic systems, together with all waste materials and emissions, which are deposited into the natural environment (see figure 2, page 16). The measurement unit used to report material flows is metric tonnes per annum (t/a). All *materials*, which enter into our *society* are converted through production processes into goods or services for domestic consumption or export.

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1 [statistik.at/web\\_de/statistiken/wirtschaft/land\\_und\\_forstwirtschaft/index.html](https://statistik.at/web_de/statistiken/wirtschaft/land_und_forstwirtschaft/index.html)

*Materials* are divided in MFA into four groups – *biomass, fossil energy carriers, metals* and *non-metallic minerals* – and further sub-groups. *Societal use of materials* has two goals: *materials* are either used energetically as food or as fossil and biogenous fuels to provide technical energy. *Materials* are also used for their material value; thus *materials* are converted into products, which either enter *societal* stocks and remain there for years or decades, or in small quantities transform into waste within a single year. According to the law of thermodynamics, all physical inputs correspond to the outputs, adjusted for stock changes. This mass balance is a specific and significant strength of MFA, since it allows all inputs to be assigned to a particular output, i. e. waste flows or emissions. Environmental problems due to overload from too great a quantity of wastes or emissions are therefore direct consequences of resource flows, which we feed into our *society* on the input side.

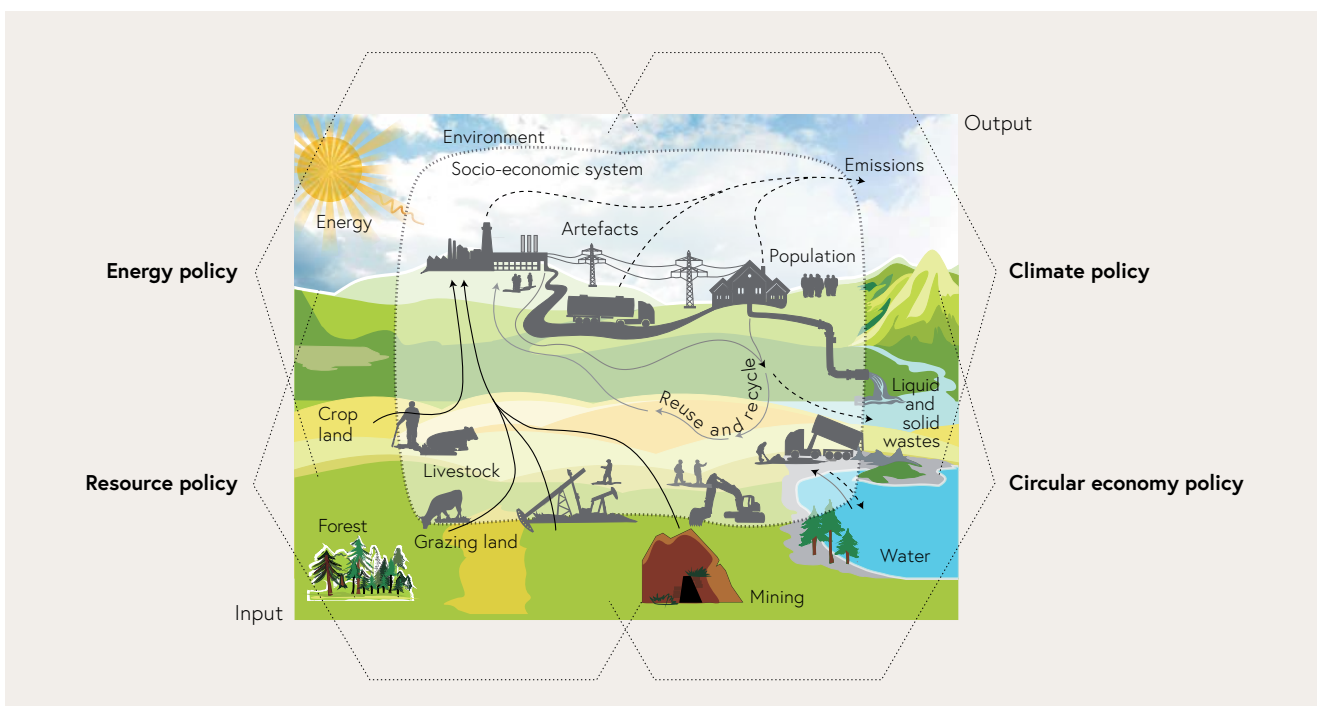


Figure 2: Scheme of societal metabolism

Source: Authors' own diagram, based on Miljana Podovac's illustration in Haberl et al. 2019

*Material flow accounting* indicators are a part of the *environmental accounts* (BMNT 2018; Eurostat 2019 c; UN 2017). The key indicator for MFA is *domestic material consumption* (DMC), which records the entire material use in production and consumption within Austria (calculated as *domestic extraction plus imports minus exports*). This enables the total quantity of *material resources* required, their composition, the development over time, pattern and interactions with other socioeconomic factors and future projections to be analysed. MFA indicators have become established as key indicators for programmes focused on sustainable resource use, e.g. the EU's resource-efficient Europe flagship initiative (European Commission 2011 a, 2011 b) or the UN Sustainable Development Goals

(SDG 8 and SDG 12; UN 2015). In Austria, the data are collected and published annually by Statistics Austria (Statistik Austria 2019).

A more detailed description of MFA methods can be found in “Resource Use in Austria. 2011 Report” (BMLFUW and BMWFJ 2011) and in relevant international handbooks (Eurostat 2018) or scientific publications (Fischer-Kowalski et al. 2011; Krausmann et al. 2017 a).

## Report structure

The huge challenges of sustainable development require that we focus on the bigger picture, with an integrated approach to the many constituent problems and the connections between them. The current report therefore focuses on a range of cross-cutting themes (see figure 2, page 16), which shape resource use in Austria.

The first chapter “Resource use in Austria – Where do we stand?” (see page 20) focuses on the general trends of the last 18 years (2000–2018). We see that although Austrian resource use has stabilised, it remains at a high level both internationally and among EU Member States.

Following on from this general overview, three cross-cutting themes are discussed, in which different social and environmental policy goals coincide: climate protection, the circular economy and critical raw materials.

In the chapter “Resource conservation and climate protection go hand in hand”, (see page 48) interlinkages and synergies between resource efficiency and climate protection are explored. Sectors and activities are identified in which (environmental) policy measures can contribute both to a reduction in resource use and to climate protection.

The chapter “The circular economy from a macroeconomic perspective” (see page 62) focuses on the concept of the circular economy from the perspective of *material flow accounting* contributing to sustainable resource use. Structural challenges for our economy and way of life are elucidated using the most recently developed methods and new prospects from an economy-wide approach.

In the chapter “Critical raw materials play a keyrole for future technologies” (see page 78) we turn our gaze to *materials*, which although they represent only small quantities within *material flow accounting* have a significant impact on future resource use and achieving sustainability. We show just how much Europe and Austria are dependent upon a few raw materials, which represent the essential ‘ingredients’ in future technologies.

The concluding chapter “Future challenges” (see page 88) links to the global sustainability goals and describes possible ways forward. Beyond the cross-cutting themes, it is clear that overarching goals for resource use are needed to provide real impetus for action.

References to programmes and initiatives or explanations of methods, indicators and data bases are summarized in excurses, while specialist terminology, *italicised* in the text, is defined in the Glossary (see page 111). Best practice examples are also set out in boxes within this report. An overview of the abbreviations and measurement units referred to here can be found on page 116 f.




### **Side note 3: On current occasion – Corona crisis**

The date of completion of this publication coincided with the worldwide spread of the novel coronavirus SARS-CoV-2.

The virus is currently changing our working and living habits at local, regional, national and global level. This crisis ruthlessly demonstrates our vulnerability in a globalized world with complex dependencies and widely ramified value chains and draws attention to the essential aspects of our lives. It reveals questions about the security of supply for products that form the basis of our lives, as well as for raw materials that are urgently needed as starting *materials* for products that are often essential and life-saving. At the current time, the consequences of the crisis cannot yet be estimated. However, not only the currently perceptible effects of the Corona crisis suggest that a transformation of our patterns of use and consumption towards a resource-efficient, respectful lifestyle based increasingly on regional supply is necessary. A re-integration of value chains to maintain domestic supply security even in times of crisis could increase the resilience of our economic and social system. These challenges certainly also create opportunities for a more sustainable Austria.



A scenic landscape of a mountain lake with a dense forest and snow-capped peaks in the background. The image is overlaid with a semi-transparent blue filter. The text is white and positioned in the upper left quadrant.

# Resource use in Austria – Where do we stand?



Natural *resources* provide the physical foundation for our *society*. We require land in order to cultivate foodstuff; raw materials to construct houses, roads and products; energy sources to power our means of transport and machinery, and water to irrigate our fields and to cool our industrial plants. As a whole *society*, our resource use exceeds many times over the sum of *resources* used by individuals. This can be clearly illustrated using the example of metabolic rate. To supply a person with their basic requirement for energy to survive, each and every one of us only needs approx. 8 megajoules (MJ) per capita per day. We meet this requirement through the food we ingest. We also refer to this basal *metabolism* as the individual *metabolism* of a human being. As a *society*, however, we also use many other forms of energy: we heat and light our homes, we construct and make use of buildings and infrastructure, such as e. g. hospitals, schools, the road network, theatres and restaurants. When we include all these energetic requirements of our *society* in the calculations, we find that Austria in 2015 had an energy requirement of more than 420 MJ per capita per day (see figure 3, page 23). This *societal* resource requirement is also defined as *societal metabolism* and far exceeds the sum of individual basal *metabolisms*

## We use and consume large quantities of natural resources

*Societies' material* and energy requirements increased rapidly following the postwar growth of the 1950s and enabled high levels of prosperity in some countries. Between 1950 and 2015 global material consumption rose by almost a factor of 7 from 13 billion tonnes per year to 89 billion tonnes per year (Krausmann et al. 2018). Increases since 1950 were also recorded for the global population (factor 3), their income (Gross domestic product, GDP; factor 8), the use of energy (factor 7) and water (factor 4) (Steffen et al. 2015). Trade relationships increasingly stretch right across the globe, and physical trade flows rose faster (factor 4) between 1970 and 2017 than the rate of material extraction in the same period (factor 3; UN IRP 2019 a). This accelerated use and consumption of *resources* leads in equal measure to rapidly increasing burdens on our environment, e.g. climate change (increase of global greenhouse gas emissions by a factor of 18 between 1900 and 2016; Anderl et al. 2018), global and especially local health burdens due to particulates (factor 1.4 between 2000 and 2011; UN IRP 2019 a), and water scarcity (factor 1.2 between 2000 and 2011; UN IRP 2019 a). The period since 1950 is thus also described as the great acceleration (Steffen et al. 2015). This rapid growth rate among today's industrialised societies was made possible above all by the use of *fossil energy carriers* (Fischer-Kowalski et al. 2014).

Average daily consumption by one Austrian person in 2015 amounted to 50 kilogrammes (kg) of *material*, 420 megajoules (MJ) of energy, 695 litres (l) of water and approx. 1 hectare (ha) of area (see figure 3, page 23). 7 kg of *fossil energy carriers* are used per person per day, which are responsible for the emission of approx. 21 kg of



carbon dioxide (CO<sub>2</sub>) per person per day in Austria. Domestic water use accounts for only 25% of total water use, with the remainder being used by industry (69%) and agriculture (6%). Austria's land area is used for a whole range of purposes, for example for agriculture, industrial sites and road networks as well as for our leisure and recreation activities. In Austria an average of 0.3 ha of land area is used per person for agriculture. This is used to extract an average of 12 kg/day of renewable raw materials per person. 2 kg of *metals* and 28 kg of *non-metallic minerals* per person are used each day in Austria to construct and maintain houses, roads, infrastructure and products.

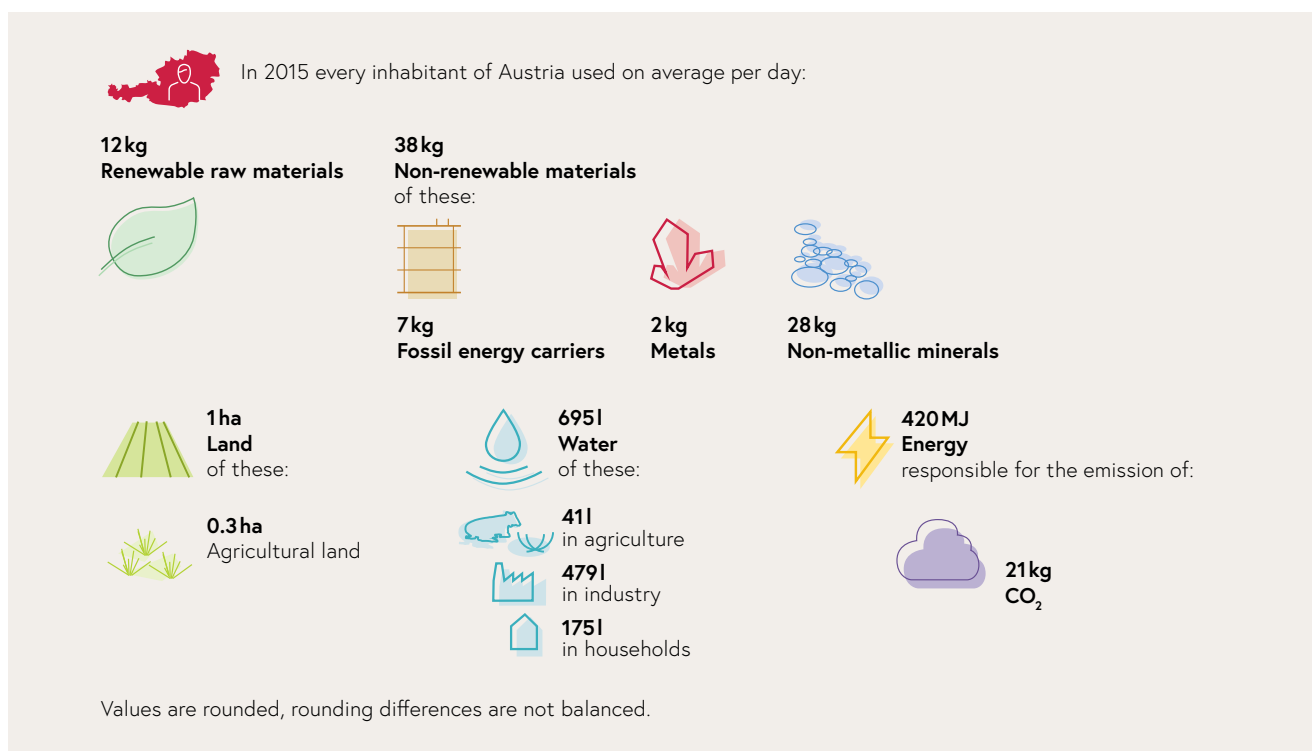


Figure 3: Resource use in Austria, 2015

Sources: Materials: Statistik Austria 2019; energy: Statistik Austria 2018b; CO<sub>2</sub>: UBA 2017; water: BMNT 2016; land: Statistik Austria 2018a

Resource use in Austria has risen rapidly over the last 60 years. In 1960, Austria consumed about 100 million tonnes of *material* per year. By comparison, material consumption rose by a factor of 1.6 by 2015 to approx. 160 million tonnes (Mt or megatonnes) per year; by 2018 material consumption rose further to 167 Mt/a. Since 1980, material consumption has stabilized at just over 160 Mt/a (with the exception of the period between 2000 and 2008, when material consumption lay at approx. 170 Mt/a). In 2007, material consumption reached its highest level to date at 177 Mt/a<sup>2</sup>. Since then, a reduction of 6% has been

2 Material flow analysis data have been revised since the previous resource report (BMLFUW and BMWFJ 2015) and now lie below the consumption reported in 2015.

recorded. This reduction is a positive development, although it should at this point be regarded as temporary and monitored further.

## Austria's consumption is co-responsible for resource use in other parts of the world

The *resources* that are used within Austria's borders (defined as *domestic material consumption*, or DMC), provide a view of Austria as a site of production and consumption. Because Austria is embedded in global supply chains, however, Austrian production and consumption activities have an impact far beyond the country's borders, and raw material extraction and production often occurs at different locations to that of their end use. Austrian consumption activities therefore have an impact on resource use in other global regions, in the same way that *resources* that are used in Austria benefit the end user in other countries through *exports*. If one wishes to analyse Austrian final consumption (consumption approach), one must broaden the perspective from national to global level. When taking a consumption approach, the *resources* that are used to produce the goods imported into Austria must be included in Austrian final consumption figures. Equally, resource use for export production must be included in the final consumption figures for those countries in which the respective end use takes place. Austria imports more than it exports. This allows Austria, as many other industrialised countries, to outsource a part of the resource requirements for goods production (and the environmental burden associated with it) to the producing countries. The *material footprint* concept allows for allocating resource use along the entire production and supply chain to the countries in which final consumption occurs. This provides new information about the global environmental consequences of Austrian final consumption (further information about the footprint indicators can be found in side note 6, page 37).

The consumption of an Austrian person in 2015 creates on average a global *material footprint* of 71 kg per capita per day, i.e. 21 kg or 40% more *material* than is consumed within Austrian borders. The greatest difference is recorded for *metals*, with at least three times as much *material* being used during production processes as will eventually be imported into Austria. The reason for this lies with the fact that there are more or less no economically usable deposits in Austria and thus, *metal* goods are overwhelmingly imported into Austria in highly processed form (for example, as machinery or vehicles). The production of these goods, from extraction through mining to manufacturing, is highly *material* and energy intensive. Furthermore, some additional quantities of *material* are required for Austrian consumption of *fossil energy carriers* and *non-metallic minerals* than are actually imported into Austria.

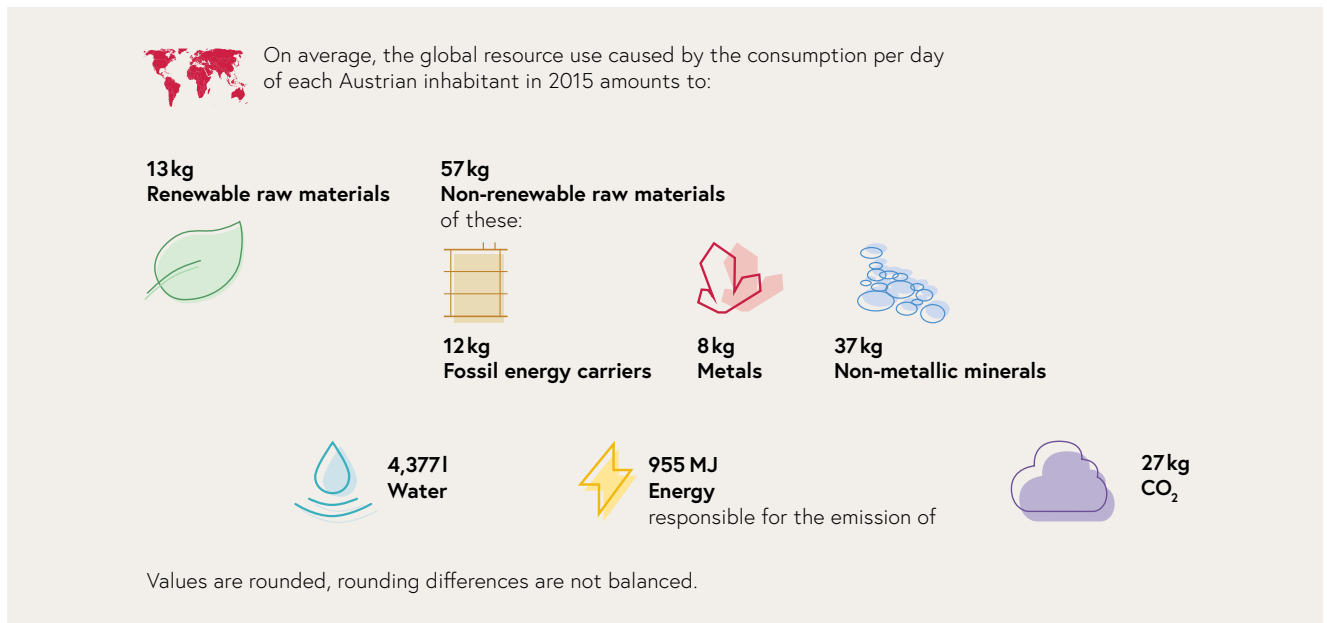


Figure 4: How much of global resources (material footprint) does Austria require to satisfy final consumption requirements, 2015?

Source: Material, energy and CO<sub>2</sub> footprints: EE-MRIO model exiobase v.3.6, Stadler et al. 2018; Wood et al. 2018; water footprint: BMNT 2019b

Similarly, the global energy footprint of the consumption of a single Austrian person is far greater than the energy consumed in Austria itself: 955 MJ are used per person per day to satisfy the Austrian requirements in 2015, more than twice as much as the energy balance suggests is directly used in Austria itself. Austrian energy use is thus globally responsible for the emission of 27 kg CO<sub>2</sub> per capita and day. The water footprint, i.e. total direct and indirect water consumption, induced through Austrian consumption amounts to 4,377 litres of water per capita and day (BMNT 2019 b), i.e. six times as much as the total water consumption within Austria.

## Our resource consumption exceeds the planetary boundaries of our planet

Austrians consume many *resources* in production and consumption and thereby burden the biogeochemical cycles of global ecosystems. In relation to the *planetary boundaries*, scientific and political endeavours are focused increasingly on being able to estimate the global impacts of our resource use and to define acceptable limits to this (Rockström et al. 2009; Steffen et al. 2015). The concept of *planetary boundaries* is based on the finite nature of natural *resources* and sinks for wastes and emissions. Exceeding just some of these boundaries can have devastating consequences. For example, agricultural *biomass* production can lead to soil erosion and degradation, phosphorus and nitrogen runoff through overuse of fertiliser, and exceeding the boundaries of biogeochemical

cycles and to biodiversity loss. We therefore need economic forms and ways of living that enable us to live within *planetary boundaries*.

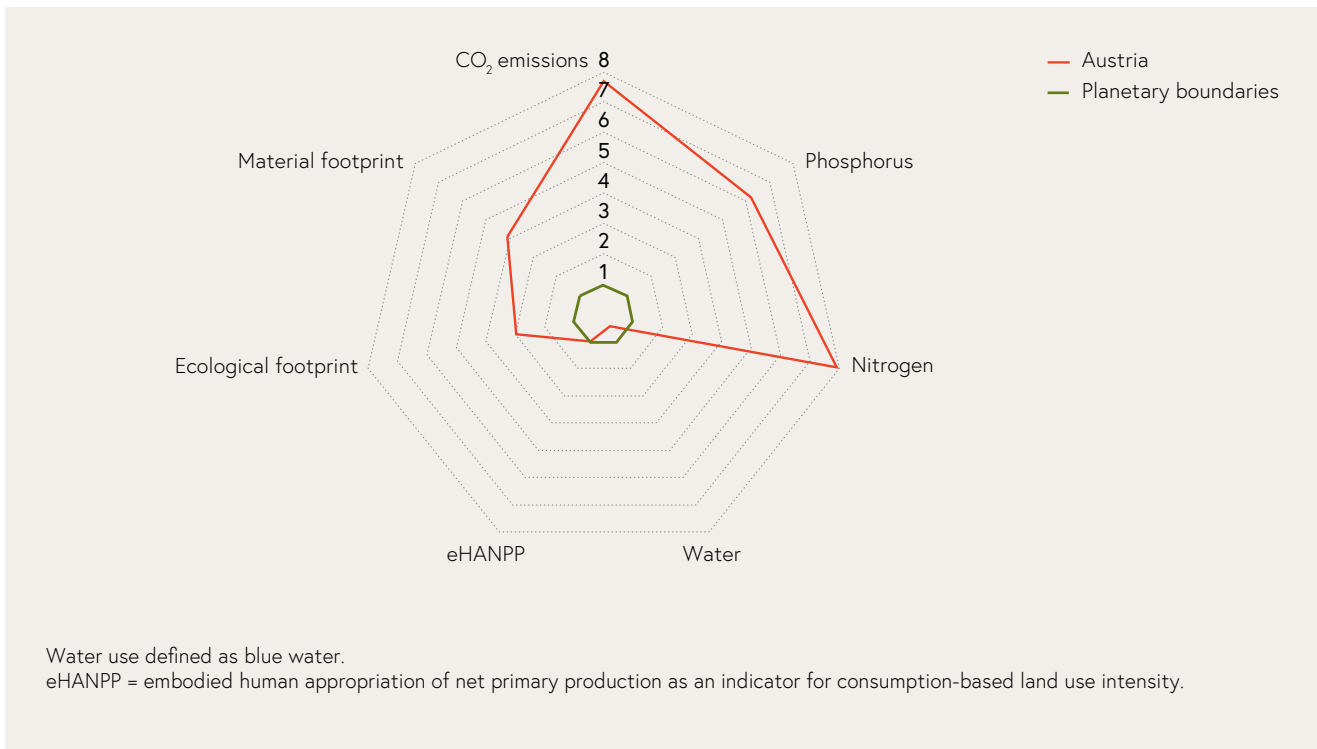


Figure 5: Austria and the planetary boundaries

Source: Authors' own diagram, data from O'Neill et al. 2018

A group of researchers around Daniel W. O'Neill (2018) has translated the globally defined *planetary boundaries* to the level of individual countries and then compared these with the resource use footprint indicators (see figure 5). The analysis shows that Austrian consumption levels far exceed the levels that are tolerable for our environment. The high CO<sub>2</sub> footprint in particular extends far beyond *planetary boundaries*. Equally, the recorded levels for phosphorus and nitrogen, large quantities of which are used in agriculture, exceed the defined pollution thresholds. Our *material footprint* and our ecological footprint exceed the critical thresholds of our planet three- or fourfold (see side note 6, page 37). In the case of our land use, we find ourselves slightly outside the acceptable limits and only our water use remains within the boundaries, which is primarily attributable to the large available water reserves found in our country.

## Our resource use has stabilised, but remains at a high level

Between 2000 and 2018, Austrian material consumption stabilised at almost 170 million tonnes (Mt/a) or 19 tonnes per capita and year (see figure 6). These 170 Mt/a are used within Austria in production and consumption, or are contained in buildings, infrastructure and durable goods. 135 Mt/a of *material* were extracted in 2018 in Austria (Domestic Extraction, DE), while the rest was imported from other countries (99 Mt in 2018). 67 Mt/a of *material* was exported to other countries in the form of manufactured goods. In other words, Austria imports more *material* than it exports and is thus a net importer, as shown in the *Physical Trade Balance* (PTB = *imports* minus *exports*, see the Glossary on page 111), which was 32 Mt in the case of Austria in 2018 (see figure 6).

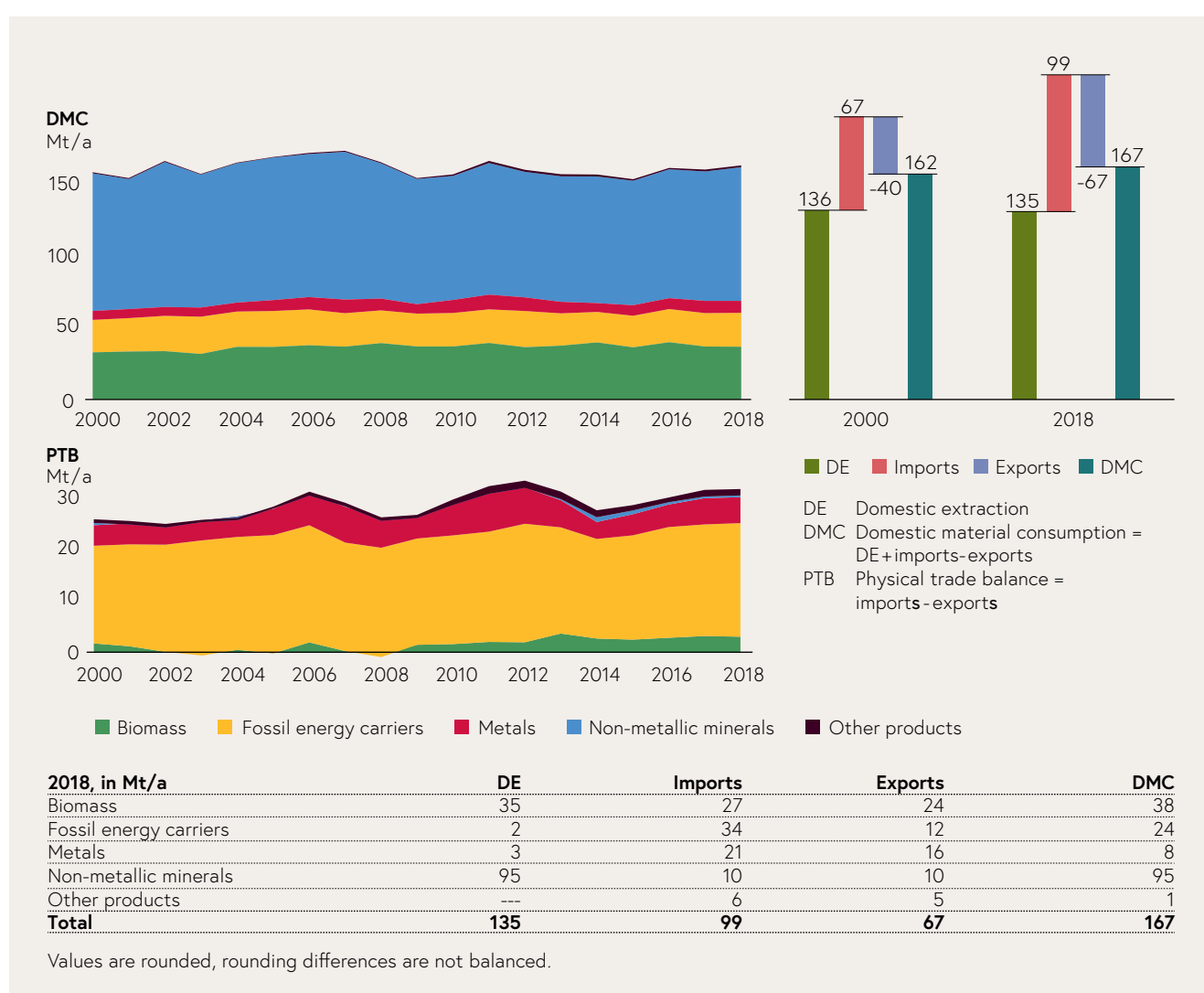


Figure 6: Material flows in Austria: material consumption and physical trade balance, 2000–2018

Source: Statistik Austria 2019

The strongest trend in Austria's material consumption levels over the last 18 years occurred due to the global economic crisis of 2008/2009 and the recession or stagnation between 2011 and 2014. During the years in which economic growth was 3% or above, material consumption also increased significantly. Only in those years in which economic growth lay below 1.5% did material consumption fall. In contrast to a planned, systematic and cautious approach to *resources* and our natural environment, the heightened inequalities and material scarcities that create a reduction in resource use during times of crisis are extremely problematic. In addition, global studies suggest that the impacts of low economic growth rates or recession on resource use are cancelled out again by subsequent economic boom phases (Shao et al. 2017; Steinberger et al. 2013; Wu et al. 2019). This means that we must focus on the ultimate goals, which are prosperity and wellbeing for each and every person. Economic growth is only one of the possible ways to achieve these goals, so we must find alternative options. Using other measurements and indicators, e.g. those of the United Nation's (Human Development Index, HDI; UNDP 2019) it is possible to show that an increase in prosperity is also achievable without a growth in resource use (BMLFUW and BMFWF 2015). Initiatives such as "Growth in Transition" – in German, "Wachstum im Wandel" – (see side note 4) identify measures that can stimulate and accelerate such development pathways.



#### Side note 4: The "Growth in Transition" initiative

The Growth in Transition or "Wachstum im Wandel" (WiW) initiative provides an independent and cross-party platform to bring together key actors from all areas of *society* – politics, civil *society*, business and academia – to debate questions of growth, prosperity and quality of life within *planetary boundaries*. WiW wants to see growth of GDP, economic growth, established as a means to achieve particular *societal* goals, rather than as the defining goal of *society* in itself. The transformation of *society* lies at the core of this initiative, as does the question of how the following goals may be achieved together:

- Ecological sustainability
- Social justice
- Good quality of life
- High rates of employment in "decent" jobs

The Growth in Transition initiative was founded by the Austrian Environment Ministry in 2008 and now involves over 30 partner institutions from politics, civil *society* and business. Events and publications relating to the Growth in Transition initiative can be found on the website: [wachstumimwandel.at](http://wachstumimwandel.at)

## Our society requires a wide variety of raw materials for many different uses

To more effectively analyse the material consumption of a country, four main material groups are distinguished: *biomass*, *metals*, *non-metallic minerals* and *fossil energy carriers* (see figure 7). The *non-metallic minerals* represent the largest category, with 95 Mt/a, constituting 57% of total material consumption in 2018. The second largest material group is *biomass*, at 38 Mt/a, responsible for a quarter or 23% of DMC in 2018. *Fossil energy carriers* (24 Mt/a or 15% of DMC) and *ores* (8 Mt/a or 5%) are relatively small categories, although they play an important role in economic policy terms.

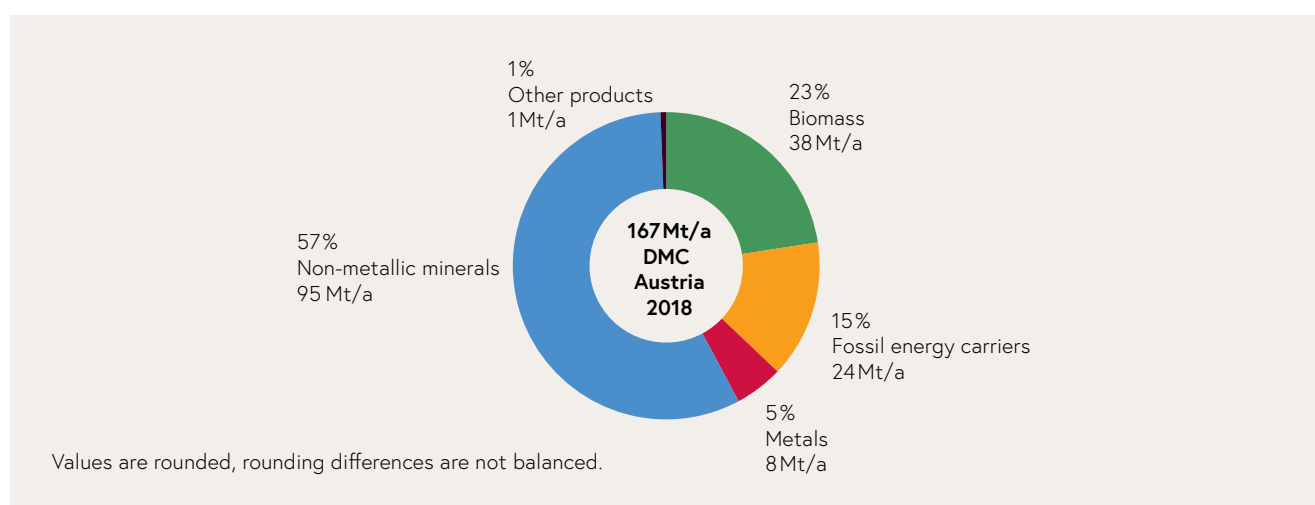


Figure 7: Austrian domestic material consumption (DMC) by material category, 2018

Source: Statistik Austria 2019

### Biomass

The *biomass* group includes all biotic raw materials constituted from organic matter, i. e. living plants, animals, microorganisms and dead organic matter (deadwood, leaves, straw, etc.). *Biomass* is often defined as the group of renewable raw materials. *Biomass materials* are used in industrialised societies primarily to feed people and animals. The largest share of agricultural produce is used as feed for livestock. In parallel to this, bioenergy has established itself as the most important renewable energy source in Austria and represents a key pillar of domestic energy supply. In Austria, forestry plays a central role in *biomass* production, with 48% of land being forested area. In terms of material recycling of wood, key sectors are the pulp and paper industry and the construction industry (BMNT et al. 2019). Fibre plants are utilised in smaller quantities, e. g. in the textile industry. *Biomass* use amounted to 34 Mt/a in 2000 and increased by 2018 by 12% to 38 Mt/a (see figure 8, page 30). The largest increase both in terms of absolute quantities and as a share of the total was observed for wood and wood products.

Renewable raw materials provide the greatest hope for a future sustainable society and the decarbonisation of the economy. On one hand, the replacement of fossil by biotic raw materials in energy production can play a part in mitigating climate change. On the other hand, *biomass materials* are increasingly replacing fossil raw materials in material consumption in the context of bioeconomy initiatives (see side note 5, page 31).

The European Union had already created a Bioeconomy Strategy by 2012, which had a strong focus upon research and scientific knowledge. The Strategy's reworking in 2018 placed it at the heart of European political strategy and introduced the sustainable use of renewable raw materials as a goal across many policy areas. To guard against new environmental problems arising (or already identified problems worsening) as a result, the production and consumption of *biomass* has to be comprehensively monitored and adapted to the global sustainability goals. These sustainability aspects are accounted for in Austria's bioeconomy strategy. Harmonisation with the sustainability goals, made binding in the Agenda 2030 agreement, has been incorporated in the guiding principles of the strategy itself.

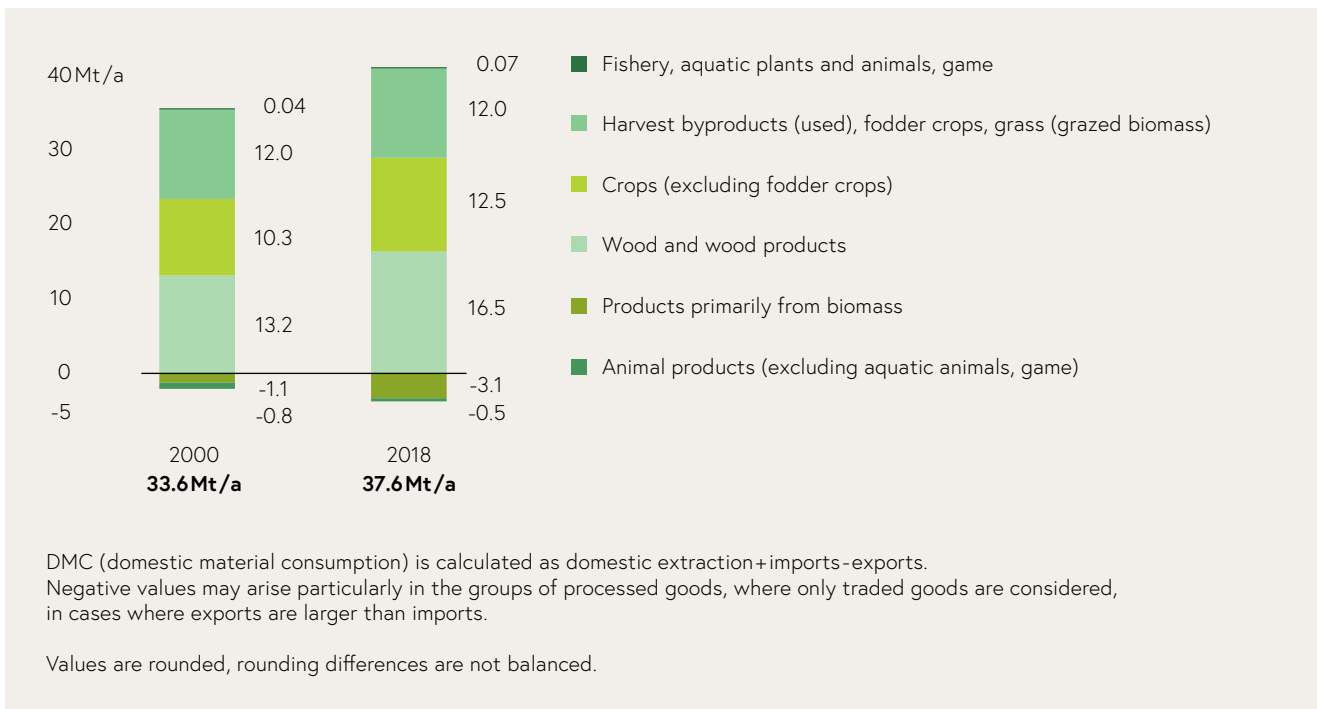


Figure 8: The group of *biomass* materials by sub-group, 2000 and 2018

Source: Statistik Austria 2019





### Side note 5: Bioeconomy – a strategy for Austria

“Bioeconomy” represents an economic concept, which aims to replace fossil raw materials with renewable raw materials in as many areas and applications as possible. It includes all industrial and economic sectors, which produce, manufacture, process or use biological *resources*. The bioeconomy thus offers a huge opportunity to respond to global challenges such as the advancing threat of climate change, food and water scarcity or increasing environmental impacts while simultaneously strengthening economic development.

Austria’s bioeconomy strategy (BMNT et al. 2019) was adopted by the cabinet in March 2019. The strategy addresses the sustainable use of raw materials from agriculture, forestry, waste and water management. It has become clear that particularly the sector of residual *materials*, byproducts and wastes must be far more strongly integrated through cascading use in the framework of the circular economy. Consumers are also explicitly addressed by the strategy, since achieving the sustainable transition of the economic system will require changes in consumer behaviours.

Areas for action are identified in the strategy, forming the basis for a subsequent action plan and the measures included within it. The bioeconomy is intended to find application across all sectors of the economy through the development of effective instruments to advance renewable energies. Further information can be found on the strategy website: [bmk.gv.at/themen/innovation/publikationen/energieumwelttechnologie/biooekonomiestrategie.html](https://bmk.gv.at/themen/innovation/publikationen/energieumwelttechnologie/biooekonomiestrategie.html)

## Fossil energy carriers

The group of *fossil energy carriers* includes all *mineral raw materials* that have been created over millions of years through geochemical processes from plant and animal remains. *Fossil energy carriers* are largely used energetically by societies. A very small share of the total (less than 5% of the total consumption of *fossil energy carriers*) are used materially, for example in the chemicals industry (to produce plastics and asphalt). Between 2000 and 2018, consumption of *fossil energy carriers* rose by 5% from 23 Mt/a to 24 Mt/a and changed in terms of composition from the use of coal to that of natural gas (see figure 9, page 32). The largest share of consumption comprised oil and oil products and showed an increase during this period.

Almost all *societal* activities related to the production or maintenance of our buildings, vehicles or machinery require the use of *fossil energy carriers*. Fossil energy consumption shows a high degree of correlation with economic growth (Steinberger et al. 2013). Fossil energy reserves are concentrated in deposits and in particular countries (see BMLFUW and BMWFJ 2011). Because of this, industrialised countries, and increasingly also rapidly growing economies, are dependent upon intensive trading relationships and continuous supply from a small number of countries. The largest environmental problem relating to the use of fossil energy concerns CO<sub>2</sub> emissions from burning fossil energy and

their contribution to climate change. In recognition of this, in the 2015 Paris Agreement (UN 2016) the 197 signatories to the Framework Convention on Climate Change agreed to limit global warming to below 2°C. The Intergovernmental Panel on Climate Change in its most recent report (IPCC 2018) drew attention to the urgency of the situation and warned that a target of 1.5°C was absolutely necessary. A complete departure from the fossil energy era by 2050 was seen as an inevitable step.

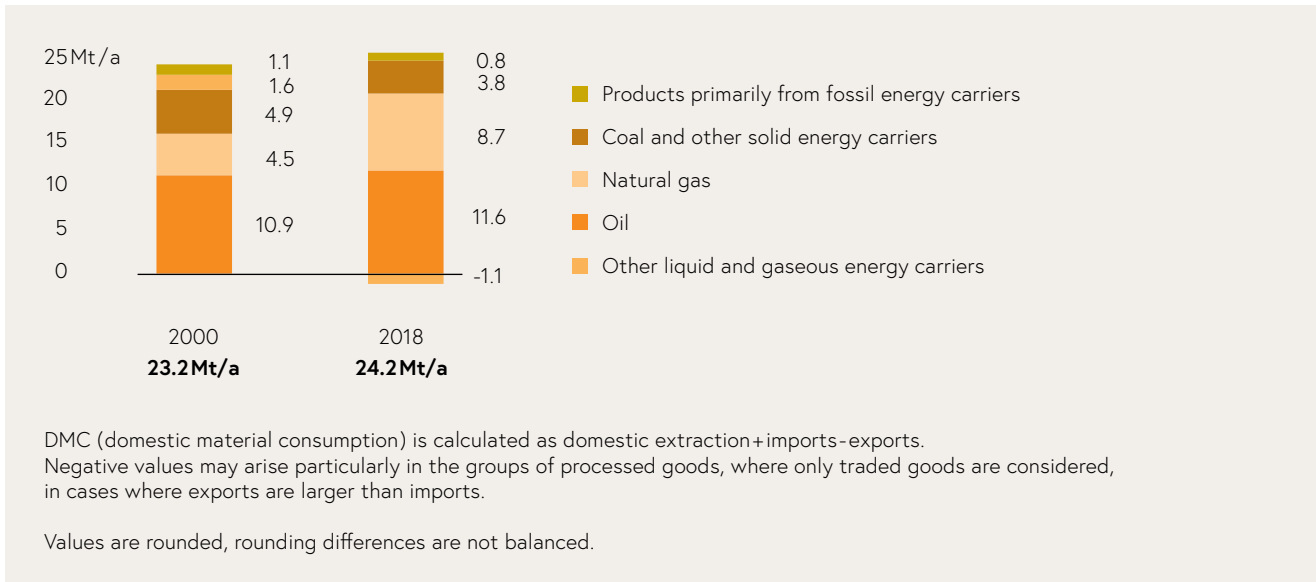


Figure 9: The group of fossil energy carriers by sub-group, 2000 and 2018

Source: Statistik Austria 2019

## Metals

*Metals* include extracted ores and highly concentrated or even pure *metals*. This group is very heterogeneous, both in terms of chemical and physical characteristics and in relation to their diverse applications in our societies: as cables and batteries in electronic devices, window frames and steel frameworks in the construction of buildings, drinks cans, smart phones, sports equipment, jewellery, etc. *Metals* are of key importance for industrial processes (Graedel and Cao 2010) and are, like *fossil energy carriers*, closely correlated with our economic and consumption activities. Between 2000 and 2018 the consumption of metallic materials rose by 34% from 6 Mt/a to 9 Mt/a (see figure 10, page 33).

Their widespread use across all countries in the world contrasts with the fact that *metals* are not found everywhere but are concentrated in deposits (ibid.). Societal problems related to *metals* can arise through supply scarcity (see chapter “Critical raw materials play a keyrole for future technologies”, page 78), through mining processes that are often area and energy intensive, through emissions and wastewater from processing, and through their retention in metal goods and waste materials. Many of the *metals* used are accumulated in *societal* stocks and remain in use for years. Since *metals* are not consumed but accumulated through their use, they remain bound in waste at the

end of their lifecycle and are potentially accessible for re-use or recycling. Aluminium for example can always be recycled and used for new purposes. Thus approximately 75% of all the aluminium so far extracted remains in use.

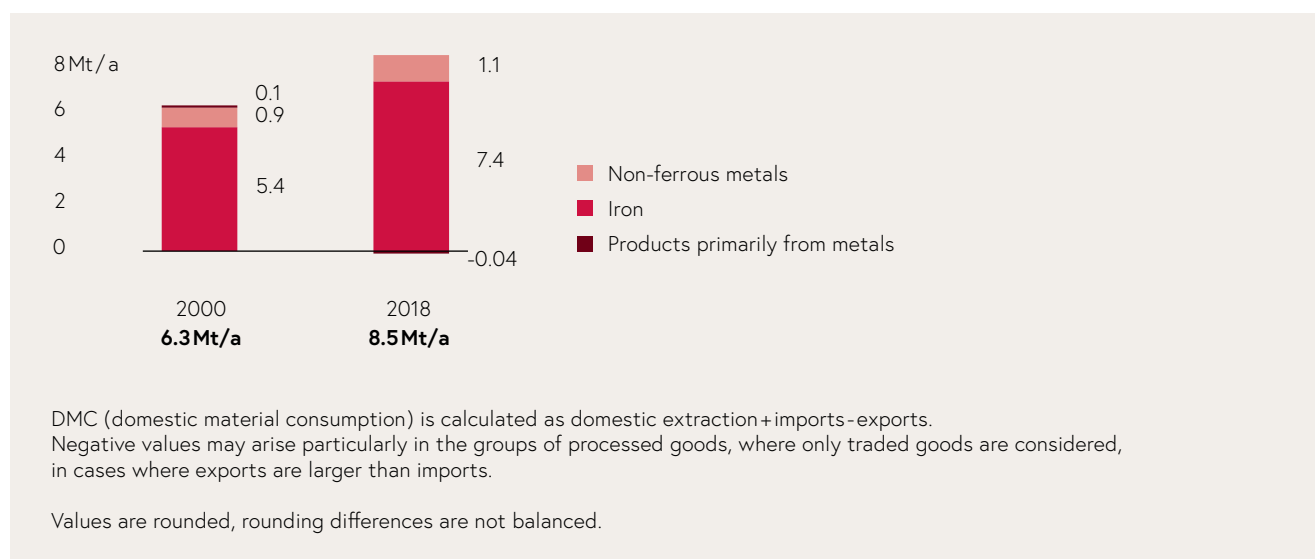


Figure 10: The group of metals by sub-group, 2000 and 2018

Source: Statistik Austria 2019

## Non-metallic minerals

*Non-metallic minerals* include all construction raw materials and industrial minerals, including e.g. sand, salts, phosphates, etc. This group is characterised by large mass flows, particularly of sand, gravel, crushed rock, limestone and clay, which together constitute 97% of total material consumption of *non-metallic minerals*. These large volumes are used for construction and maintenance of our diverse infrastructure and building stocks and remain as stock within these over many decades. Global *societal* stocks are 23 times as large as they were a century ago and amount to almost 800 Gt globally (Krausmann et al. 2017 b). In Austria, we used 95 Mt/a in 2018, slightly less (-3%) than in 2000, when 98 Mt/a were used nationally (see figure 11, page 34). According to an EU study, (Wiedenhofer et al. 2015), about one half of construction raw materials is used for the maintenance of existing buildings and infrastructure, while the other half is used for new construction. This close linkage between flows and stocks particularly for this material group show that we will also need to extract large quantities of *non-metallic minerals* from the natural environment in future to be able to maintain our existing stocks. In other words, if we wish to reduce our resource flows, we will also have to consider adapting our existing buildings and infrastructure.

In comparison to other material categories, the large quantities of construction raw materials are characterised by shorter production chains. Environmental consequences are particularly associated with extraction processes and the high demand for energy to transport these raw materials, as well as with the construction phase and use of buildings (heating, lighting) and roads (fuels for vehicles). Although construction raw materials are

available everywhere, scarcities arise here too. Already in 2014, a UNEP report referred to the increase scarcity of sand (UNEP 2014). Also in terms of the use of available land, the extraction of construction raw materials has to compete with other land use demands, such as agricultural production, leisure activities or the natural areas required to maintain ecosystem processes. Mining activities always represent a temporary intervention in the earth's crust. In Austria, when mining use ends, the affected area is subsequently renatured, recultivated or used in other ways.

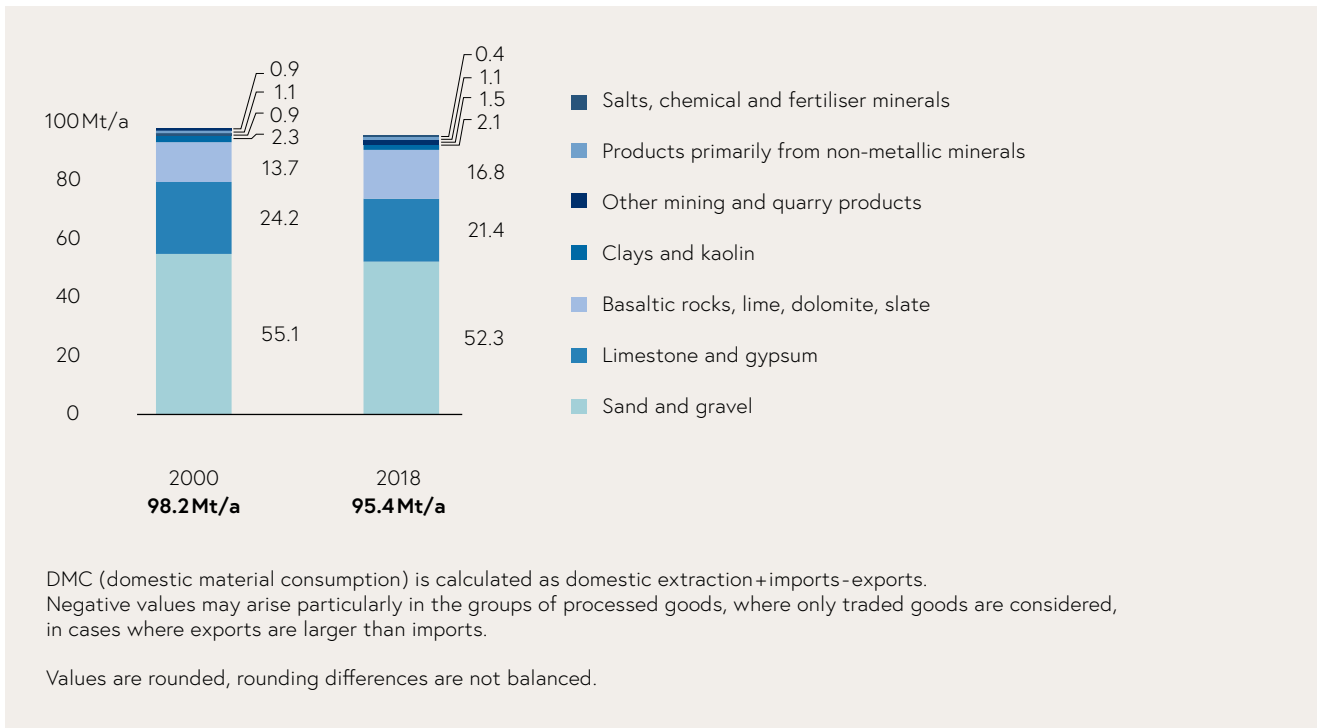


Figure 11: The group of non-metallic minerals by sub-group, 2000 and 2018  
Source: Statistik Austria 2019

## Austria is dependent on resources from other countries

In Austria, over 40% of total *materials* that are used in production or consumption are imported from other countries. In 2000, import dependency, calculated as the share of total material use constituted by *imports* (direct material input, DMI = DE + imports), was still 33%. In particular, *fossil energy carriers* (import dependency 95%) and goods from metallic raw materials (85%) were largely imported (see figure 12, page 35). Both of these are raw materials, which we do not have available to us from domestic sources in sufficient quality and diversity to satisfy demand. Yet in the case of *biomass* input too, over 40% of the total used is imported from abroad. In addition to extraction from cultivated land in Austria, one third of processed field crops and half of all processed wood is imported.

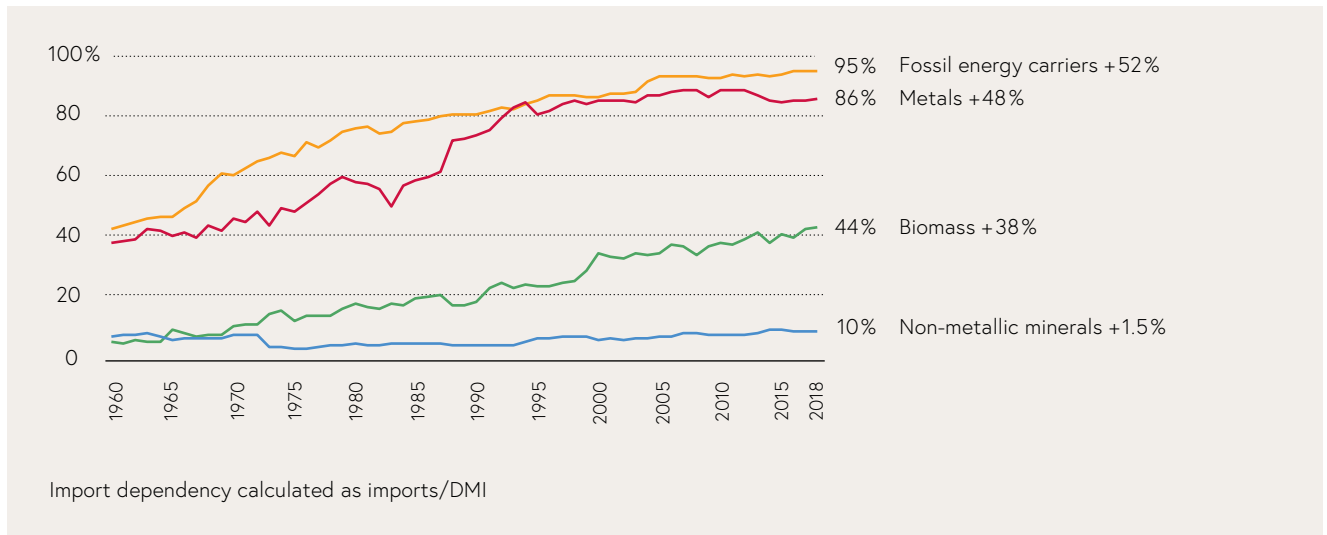


Figure 12: High import dependency on fossil energy carriers and goods from metallic raw materials  
 Source: Statistik Austria 2019

The growing volume of *imports and exports* is the result of the increasing distribution of production processes across the entire globe. Extraction, processing, consumption and waste treatment processes are only very rarely concentrated within a single country. Instead, goods have often been traded multiple times before they arrive at the point of end use. In contrast to the extracted *resources*, traded goods are not raw materials but show varying degrees of processing intensity. Since wastes and emissions occur along the entire production chain, processed goods become “lighter” by precisely these amounts; the more highly processed a product is, the “lighter” it is (Fischer-Kowalski and Amann 2001; UN IRP 2015). Consequently, resource use within a nation state becomes smaller when that country imports consumer goods rather than producing them itself. Conversely, *domestic material consumption* is greater where a country produces many “light” goods for export that require “heavy” upstream processing. In the discussion about sustainable resource use, we therefore need not only a domestic indicator, such as DMC (*domestic material consumption*), but also an indicator that represents the entire raw material consumption induced through domestic final consumption. In recent years, methods have been developed, which can allocate the raw material extraction to final use and thus calculate the *raw material consumption* indicator (RMC; Schaffartzik et al. 2014, 2015 b), also called the *material footprint* (MF; Wiedmann et al. 2015). For a methodology description and discussion see side note 6, page 37, or Eisenmenger et al. 2016.

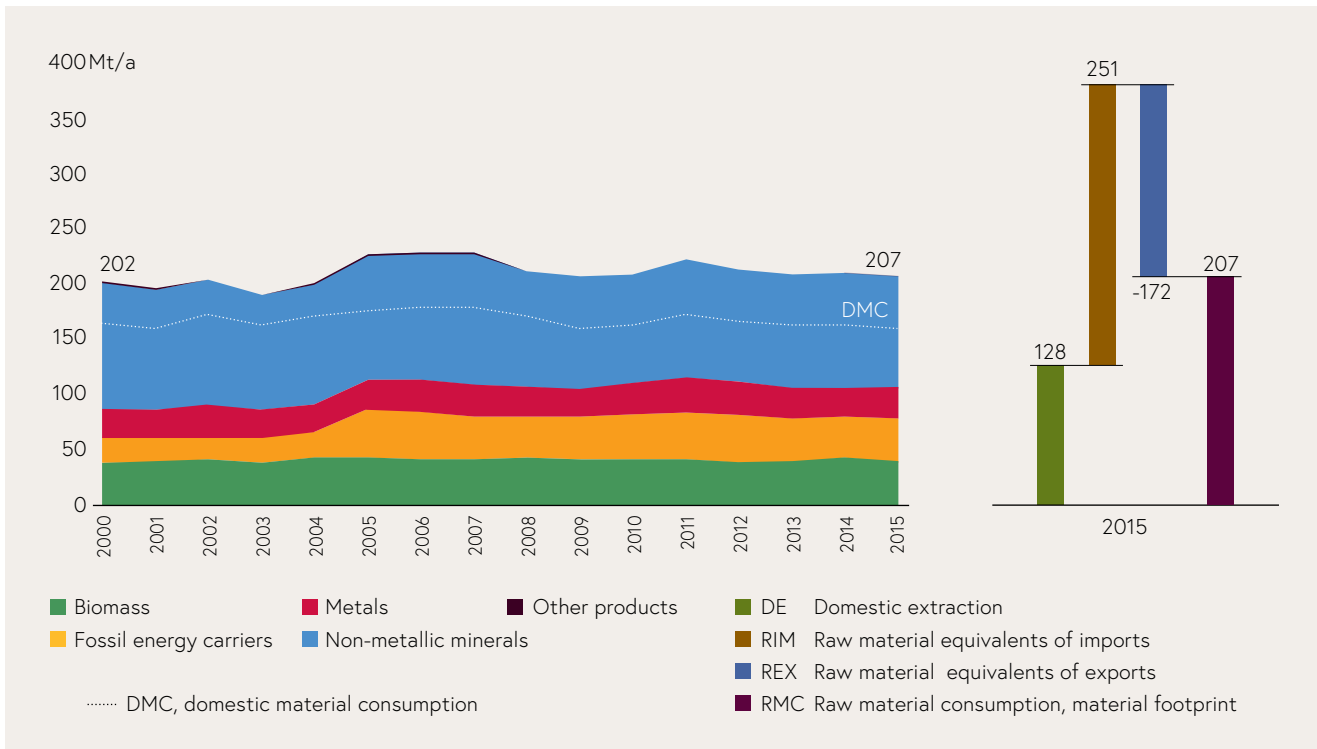


Figure 13: Material footprint of Austria between 2000 and 2015  
 Source: Statistik Austria 2019

Austria imports more than it exports, and is thus a net importer of goods, measured as physical mass. The *material footprint* (MF) is higher than *domestic material consumption* and was approx 202Mt in 2000 and approx 207Mt in 2015 (see figure 13). In 2015 the MF was approx. 40% higher than DMC. The higher *material footprint* was evident particularly in the categories of *metals* (+240%) and *fossil energy* (+77%). Up until the financial crisis of 2008 the trend of MF and DMC was very similar. After this, DMC fell while MF stabilised again after a brief fall during 2008–2010 at the same level as before the financial crisis. This means that the Austrian economy’s material intensity has fallen, yet we continue to use (increasingly abroad) the same amount of *resources*.

Half of Austria’s *material footprint* is caused by consumption in private households, followed by investments in capital stocks (30%). The remaining 20% are the result of spending by governmental and non-governmental organisations. Among the economic sectors which supply to final demand, goods from the manufacturing sector have the largest *material footprint* (38% of the MF), followed by services (23%), mining and construction industries (each 14%) and agriculture (7%) (see figure 14, page37).

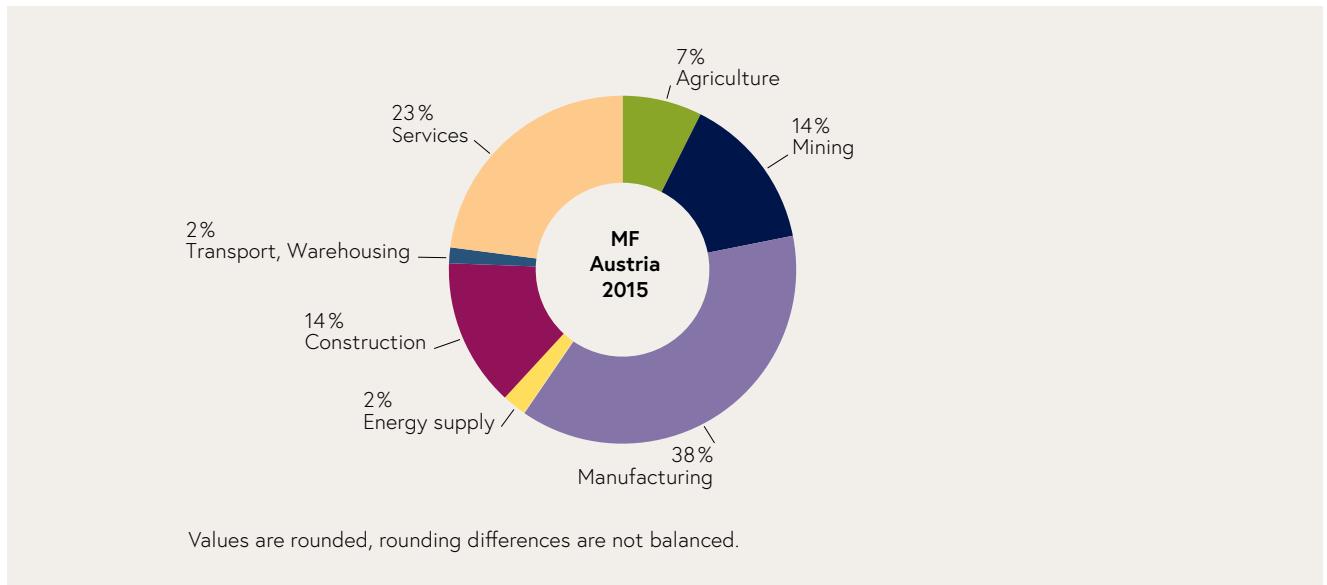


Figure 14: Material footprint by economic sector, 2015

Source: Authors' own calculations using the EE-MRIO exiobase v.3.6, Stadler et al. 2018



### Side note 6: The consumption perspective of footprint indicators and their calculation

In contrast to the usual domestic perspective on environmental impacts contained in the *environmental accounts*, a consumption perspective allows us to take account of the environmental impacts of Austrian demand beyond national borders. In the footprint indicators, resource use and environmental impacts along the entire production and supply chains are allocated to the countries in which end use occurs. Based on multi-regional input-output models, which encompass the entire global economic system and all supplies of goods between sectors and to end users, footprint indicators for *materials*, water, energy, greenhouse gas emissions, pollutants and even land area are calculated (Inomata and Owen 2014; Wiedmann et al. 2011; Wiedmann and Barrett 2013)<sup>3</sup>.

Footprint indicators are best understood by means of an example: When an Austrian man or woman buys a pair of jeans, Austria “receives the bill” for the total *resources* used to produce these jeans along the entire production chain. This ranges from water used to produce the cotton through to chemicals used in the dyeing process, to the CO<sub>2</sub> emissions from the transportation to Austria. If the denim fabric is produced in China, for example, the water use is not assigned to China but to Austria.

<sup>3</sup> This concept should however not be confused with that of the ecological footprint, which translates domestic CO<sub>2</sub> emissions into land use and contrasts this with available land area (Wackernagel and Rees 1996).

In our highly globalised world, including global value chains and thus accounting for our responsibilities in other parts of the world, has become unavoidable. Austria is among those industrialised countries that import more than they export and simultaneously outsource an increasing proportion of their goods production to other countries. The footprint perspective thus represents an important complement to the perspective on Austria as a manufacturing location.

## Resource productivity shows a decoupling of economic growth and resource use

An increase in *resource productivity* (see side note 7, page 40) means a *decoupling* of economic growth and resource use and thus a relative reduction in environmental impacts through economic activities. A *decoupling* of this kind is the goal of political programmes focused on resource efficiency, such as the flagship initiative of the EU (European Commission 2011 a, 2011 b), and is the subject of research analyses (Haberl et al. 2017; Schandl et al. 2016; Steger and Bleischwitz 2009; Steinberger et al. 2013; Steinberger and Krausmann 2011; UN IRP 2011 a, 2016,).

Between 2000 and 2018, Austria's *resource productivity* rose (see side note 7, page 40) from 1,731 Euro/t to 2,211 Euro/t (in 2015 the figure was 2,193 Euro/t). Domestic resource use stabilised, while economic growth increased (see figure 15). Economic performance and *resource productivity* rose by approx. 31% and 28% respectively, while resource consumption remained almost unchanged (+3%).

The explanatory notes on footprint indicators (see side note 5, page 31) have pointed to Austria's growing resource use beyond the country's borders. If one calculates *resource productivity* using the *material footprint* (GDP/MF), then *resource productivity* in Austria increases significantly more slowly, from 1,138 Euro/t in 2000 to 1,665 Euro/t in 2015 (+20%; see figure 15, page 39).

In both cases, increasing *resource productivity* can be determined, due to a stabilising of resource consumption (DMC) or low growth of the *material footprint* (MF), which is lower than economic growth. This is defined as *relative decoupling* (see side note 7, page 40; Krausmann et al. 2017 a). We may only speak of *absolute decoupling* where an actual reduction in resource use is achieved.

Empirical analyses for numerous countries and time periods (see UN IRP 2016 for a summary) have identified hardly any cases of *absolute decoupling*. And even these few examples return to *relative decoupling* when a consumption-based perspective (GDP/MF) is used instead (Wiedmann et al. 2015). Economic growth is therefore still closely coupled with resource use.



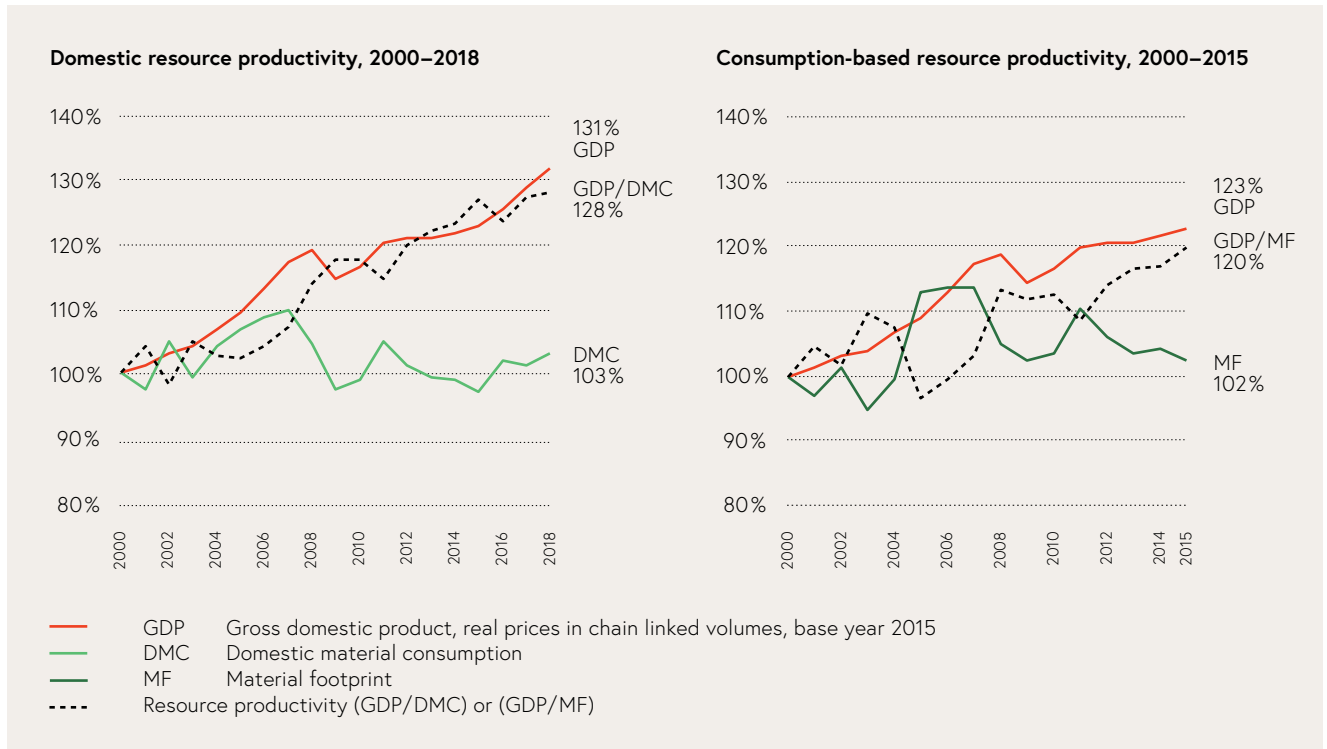
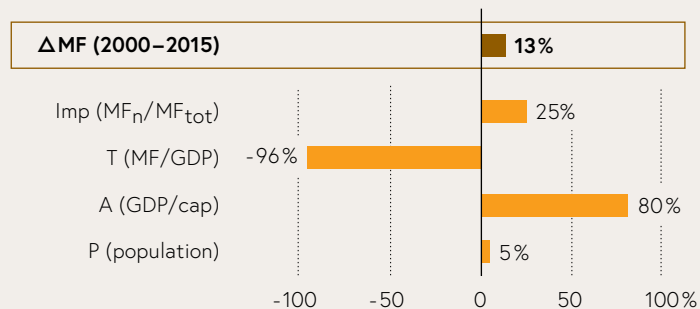


Figure 15: Development of resource productivity between 2000 and 2018 (2015)

Source: Statistik Austria 2019

To achieve sustainable resource use and in particular a reduction of resource consumption, we need to obtain a better understanding of which socioeconomic activities drive resource use. With this in mind, a decomposition analysis (see side note 8, page 41) divided the MF for Austria into the following factors: population growth, affluence, technology, and import structure. Alongside the commonly defined drivers of population, affluence and technology, the contribution made by changes in Austrian import structure were included, since these can have a significant impact upon the size of the footprint. For example, if Austria decides to import more from a country with less efficient production structures and technologies, and therefore imports a smaller proportion from more efficient countries or produces less itself, the Austrian *material footprint* will increase, even where there is no increase in consumption.

For the decomposition analysis the EE-MRIO model exiobase v.3.6. (Stadler et al. 2018) was used. The MF calculated in it deviates slightly from the calculations of Statistik Austria and increases by 13% between 2000 and 2015, shown in the uppermost bar ( $\Delta$ MF) of figure 16, page 40. The lower bars in the chart show how much the four factors have contributed to this change. The four rates of change together add up to the 13%  $\Delta$ MF. The only effect that led to a reduction in material consumption comprised changes in material efficiency of the sectors (-96%). This effect can be attributed on one hand to improvements due to technological advances, and on the other, to transitions made to consumption of goods that are less material intensive. This effect may be the only one that reduces the *material footprint*, yet it is also the one with the greatest impact.



MF Material footprint, representing environmental impacts  
P Population  
A Affluence, economic development = GDP/cap  
Imp Import structure =  $MF_n/MF_{ges}$   
T Technology =  $MF_n/GDP$   
 $MF_n$  MF of the individual countries of origin, i.e. the countries Austria imports from.  
 $MF_{tot}$  total MF

Values are rounded, rounding differences are not balanced.

Figure 16: Decomposition analysis of the Austrian material footprint by population trend, economic growth, changes in import structure and technology effect

Source: Authors' own calculations (Plank et al. 2020) using the EE-MRIO exiobase v.3.6, Stadler et al. 2018

The biggest contribution to increases in the *material footprint* comes from growth in economic output (+80%), measured here as GDP per capita. Greater economic performance, synonymous with greater economic growth, therefore leads to greater material consumption. Even if individual economic activities become more efficient, this reducing effect is cancelled out by ever greater economic production. Furthermore, our trading relationships (import structure) also contribute to an increase in the *material footprint* (+25%). A trend towards division of labour between countries unfortunately leads to increases rather than reductions of the MF. According to Plank et al. (2018), this effect is also evident at global level. Population growth plays only a negligible role in the case of Austria.



### Side note 7: Resource productivity and decoupling

*Resource productivity* is the relationship between material consumption and economic growth measured as GDP/DMC or GDP/MF and describes how many Euros of GDP can be produced with one average tonne of material consumption. Since *resource productivity* is a relative measure, no conclusions can be drawn about the development of material consumption or GDP (Krausmann et al. 2017 a).

An increase in *resource productivity* occurs when economic growth is higher than the growth in resource use. Two examples of *decoupling* are differentiated: *Decoupling* combined with increasing resource use (*relative decoupling*), where *resource productivity* increases more slowly than the rate of economic growth; and *decoupling* combined with decreasing resource use (*absolute decoupling*), where *resource productivity* grows faster than the economy.

*Resource productivity* is defined in the EU as resource efficiency. In the SDGs, resource efficiency is understood as the reciprocal (DMC/GDP or MF/GDP), which is also defined as resource intensity. Resource intensity describes the amount of resource use occurring due to GDP. In this report, the terms “*resource productivity*” and “resource efficiency” are used synonymously.



### **Side note 8: Decomposition analysis or component analysis of the Austrian material footprint**

Decomposition analysis can be used to identify the effect of different drivers on changes to particular indicators, e.g. *material footprint*, over a specific time period. Decomposition analysis has a long tradition of use within economic research, and is increasingly being employed in the analysis of environmental indicators and their drivers (Dietzenbacher and Los 1998; Hoekstra and van den Bergh 2002).

Decomposition analysis or component analysis allows for the quantitative determination of the contributions of different factors to changes in a factor-dependent variable (in this case *material footprint* or MF). The factors being considered are set out in a decomposition equation; it is assumed that a specific functional correlation exists between the factors and the dependent variable. The most prominent form of decomposition equation is the IPAT formula, which divides the environmental impact (I) into three drivers, population (P), affluence (A) and technology (T) (York et al. 2003). The contributions of the different factors contained in the equation to changes in the dependent variable can be distinguished by means of differential calculus; the sum of all these contributions is equal to the actual change observed in the dependent variable. The scale of a factor's contribution is interpreted in line with the logic of *ceteris paribus* i.e. by how much would the dependent variable have changed if that factor alone were to have changed while all others remained unchanged.

Decomposition analysis can be used to differentiate the relevant factors contributing to changes in the *material footprint* during the period 2000–2015:

- Population ( $\Delta$ MFP):  
This factor shows the effect of population growth on RMC,
- Economic development ( $\Delta$ MFA):  
Impact of the actual changes in average per capita income (GDP/cap),

- Import structure effect ( $\Delta MF_{Imp}$ ):  
The effect of a change in the shares of RMC from different countries of origin (in this case, Austria is also a country of origin),
- Technology effect ( $\Delta MF_T$ ):  
Impact of changes in material consumption per economic output of a sector in the respective country of origin (RMC per economic output; gross value added, GVA).

The sum of the effects of each factor create the actual change in the *material footprint*, as the decomposition equation set out here shows:

$$\Delta MF = \Delta MF_P + \Delta MF_A + \Delta MF_{Imp} + \Delta MF_T$$

## In EU-wide comparison, Austria is in 11th place for resource use

When all countries in the EU are compared (see figure 17, page 43) Austria's high level of resource use is clear. Resource use in Austria in 2018 amounted to 19 t/cap/a and thus approx. 5 t/cap/a or 36 % above the EU-28 average (14 t/cap/a). The highest level of resource use is recorded for Finland (35 t/cap/a), while Italy shows the lowest level of resource use (8 t/cap/a). Austria occupies 11th place among the EU-28 countries. If we move to a consumption-based perspective, (see information about the footprint indicators in side note 6, page 37), then Austria lay in 2017 in 5th place, with 33 t/cap/a, and thus approx. 10 t/cap/a higher than the EU-28 average (23 t/cap/a). The highest *material footprint* is found in Cyprus ( 38 t/cap/a )<sup>4</sup>, and the lowest in Bulgaria (13 t/cap/a).

Austria's high level of resource use is due in particular to the large quantities of *non-metallic minerals*. Among the EU-28 countries, Austria lies in 10th place, if one only accounts for the use of *non-metallic minerals* (11 t/cap/a). Finland (17 t/cap/a), Estonia (16 t/cap/a) and Romania (15 t/cap/a) require greater quantities of construction raw materials. Another 9 countries use similar quantities as compared to Austria (between 10 and 13 t/cap/a). This high figure is due to a combination of different causes, including climate and morphology (influenced strongly by the Alps), low population density and relatively few urban agglomerations and thus a higher per capita requirement in terms of infrastructure. In addition, Austria uses a more detailed survey methodology, which results in higher per capita consumption (for details see BMLFUW and BMWFJ 2011).

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4 The *material footprint* for Luxembourg, as reported in the IRP database (UN IRP 2019 b), is not represented in the graphic, because it is regarded as unreliable.

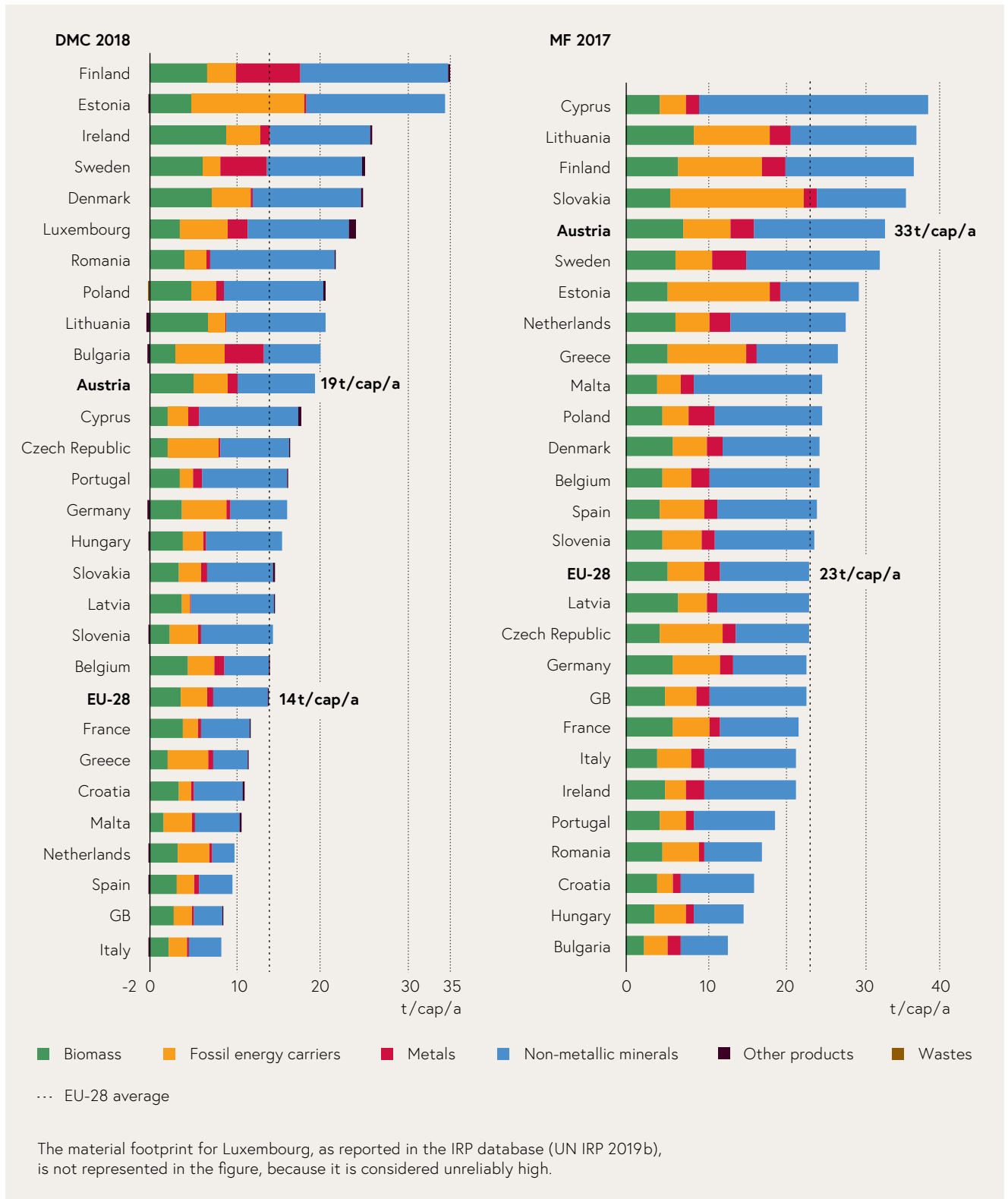


Figure 17: Austria's material consumption (DMC) and material footprint (MF) in EU comparison

Source: DMC: Eurostat MFA Database, Eurostat 2017; MF: UN IRP 2019b

The maps in figure 18 depict the rates of change between 2000 and 2015 in the cases of four indicators: DMC, MF, DPO (*domestic processed outputs*, i.e. all wastes and emissions (see side note 15, page 67, and the chapter on “The circular economy from a macroeconomic perspective”, see page 62), and *resource productivity* (RP = GDP/DMC).

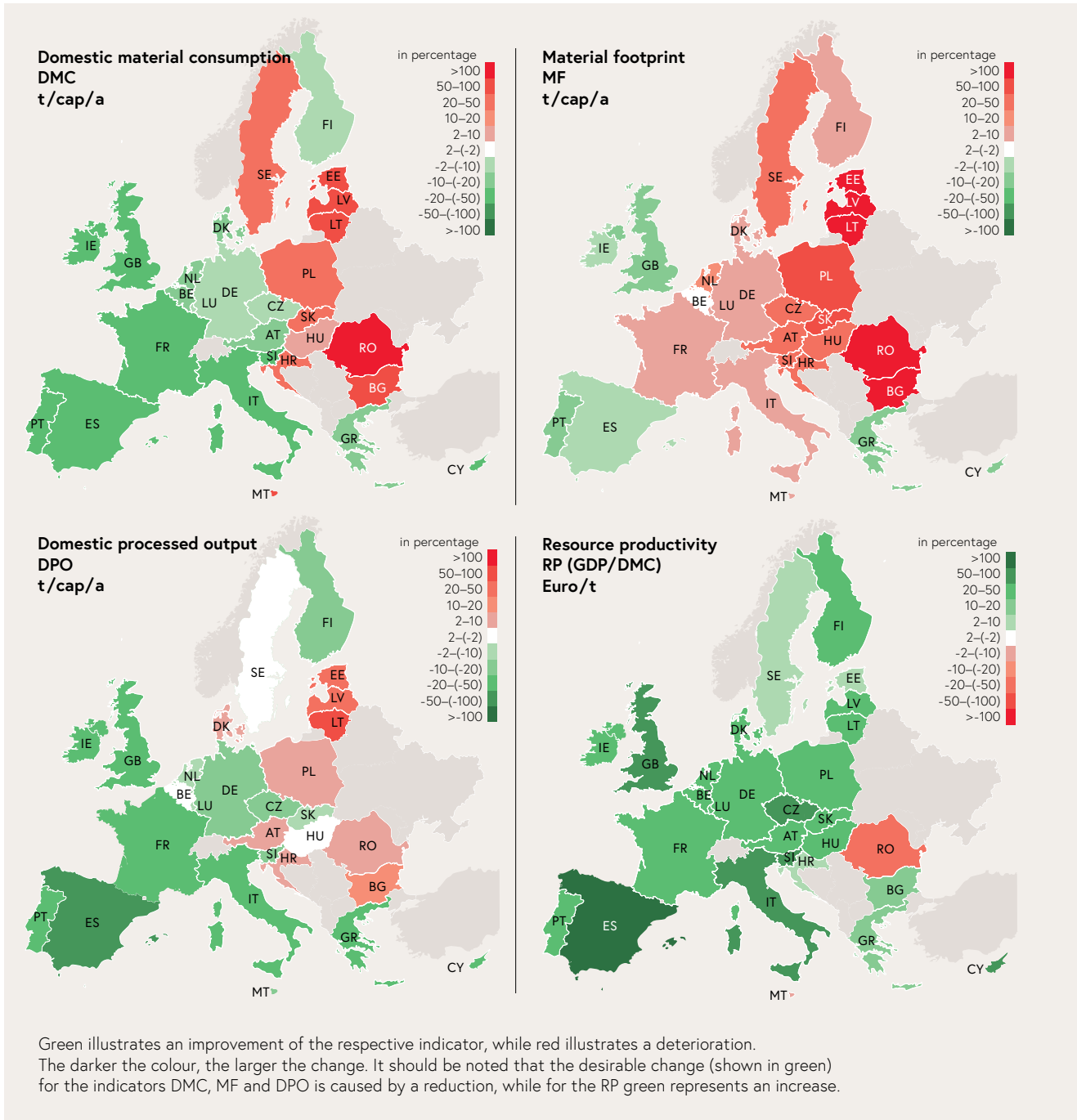


Figure 18: Changes in material consumption (DMC and MF), domestic processed output (DPO) and resource productivity (RP) for the EU between 2000 and 2015

Source: DMC and DPO: Eurostat MFA database, Eurostat 2017, MF: UN IRP 2019 b

The goal would be a reduction in DMC, MF and DPO, in order to achieve a reduction in environmental impact. An increase would be a positive and desired outcome only in the case of RP. We see a reduction in environmental impact primarily for those countries with a higher economic output, including Austria, for DMC (17 countries) and DPO (18 countries). If we change to the consumption perspective (MF), then only 6 countries achieved a reduction. *Resource productivity* increased in all countries, apart from Malta and Romania. When comparing EU countries, Austria lies in the middle, having reduced per capita DMC by 7% (11th place), while RP rose by 31% (14th place), and MF rose by 32% (18th place). DPO increased by 5%, putting Austria in 23rd place among the EU-28 countries.

Resource consumption beyond EU borders is even more widely dispersed. In 2015 the US had a DMC per capita of 21 t/cap/a, while India's resource consumption was only 5 t/cap/a (UN IRP 2019 b, see figure 19). China, which still had a relatively low level of resource consumption in 2000 (9 t/cap/a), actually overtook the US in 2015, with an average of 24 t/cap/a. The close interlinkage between economic growth and resource consumption is particularly evident during phases of rapid economic development in emerging countries.

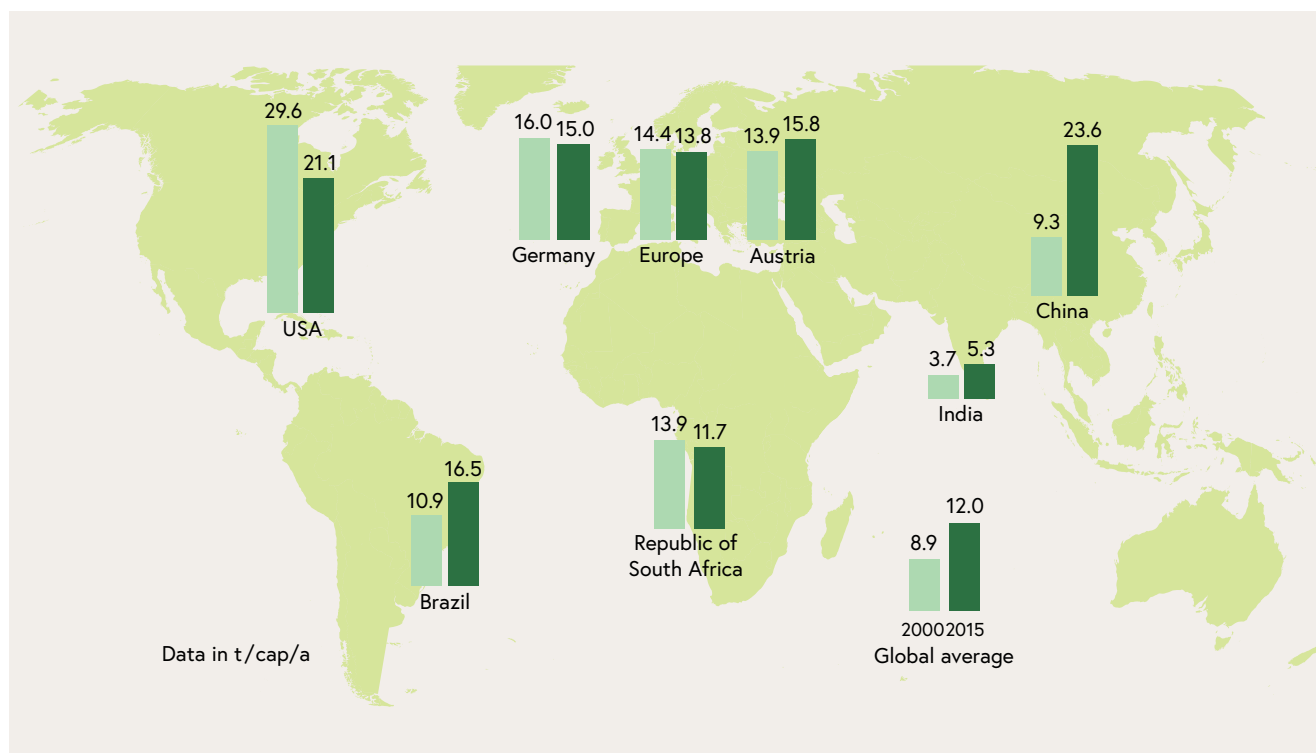


Figure 19: Per capita material consumption in global comparison, 2000 and 2015

Source: UN IRP 2019 b

If we consider that there are still many countries that may expect and hope to experience economic upswings in the coming years and decades, then we have reason to fear that a further, rapid growth in global resource use will occur. The most recent reports from

the International Resource Panel (UN IRP 2019 a) and the OECD (2018) have published projections for resource use up to 2050 or 2060 respectively. Both reports conclude that global resource use between 2015 and 2050 (UN IRP 2019 a) or between 2017 and 2060 (OECD 2018) will more than double (UN IRP 2019 a), with a growth rate of factor 1 or 2 for OECD countries, resource use more than doubling in the BRICS countries (Brazil, Russia, India, China, South Africa), and the largest growth rate (factor 2–3) observed in the remaining countries, including large parts of Africa and Asia (OECD 2018).





Resource  
conservation and  
climate protection  
go hand in hand





Two of the *planetary boundaries*, climate change and biodiversity loss are seen as particularly significant because of their fundamental importance for the earth system (Steffen et al. 2015). Programmes aimed at mitigating climate change are therefore of critical importance for the transformation to a sustainable economic and social system. In the IPCC report from 2018 (IPCC 2018), the Intergovernmental Panel on Climate Change very clearly set out that an increase in global warming of 2°C will set processes in motion that will lead to irreversible changes in biogeochemical cycles. Global warming should therefore not be allowed to exceed 1.5°C, which requires an even greater reduction in global CO<sub>2</sub> emissions. In accordance with the Paris Climate Agreement (UN 2016), the Austrian government set itself the target of reducing national CO<sub>2</sub> emissions by 2030 by 36% (from 2005 levels) (BMNT and BMVIT 2018). The Austrian report on climate protection (Anderl et al. 2018) showed the national target for greenhouse gas emissions of -16% by 2020 in relation to 2005 levels was reached through additional measures; the targets for 2030 (-36%) and 2050 will however only be achievable if far greater efforts are made. In response, Austria is developing a national energy and climate plan<sup>5</sup>, to determine targeted measures across a whole range of activities. Achieving these ambitious goals will require the concerted efforts of many different actors across diverse (policy) sectors.

In recent years, resource efficiency has emerged as one of the central themes of environmental policy (European Commission 2011 a, 2019 c; UN 2015). Thus on one hand, resource efficiency is being discussed and evaluated in closer connection to *materials* and their material and energetic use (see economy-wide material flow accounts, EW-MFA; Eurostat 2018; Fischer-Kowalski et al. 2011; Krausmann et al. 2017 a). On the other hand, resource use is employed in a broader sense as a proxy indicator for *societal resource* use and environmental impacts. Because all resource inputs eventually become wastes or emissions, we need to reduce our inputs if we wish to decrease the outputs ( see side note 2, page 15; or Haberl et al. 2019; Krausmann et al. 2017 a ).

Thus in order to reduce the CO<sub>2</sub> emissions, we must first and foremost reduce the input of *fossil energy carriers*. These are currently used to operate our *societal* stocks, as energy for heating and lighting spaces and buildings or as fuel to operate our many vehicles. It follows, therefore, that input-oriented strategies, such as resource efficiency, can also play an important part in reducing outputs – and in so doing, mitigating climate change.

The interface between resource efficiency and climate protection is increasingly the subject of research studies (Allwood et al. 2011; Barrett and Scott 2012; Hatfield-Dodds et al. 2017; Scott et al. 2018), and is also addressed in the most recent reports published by the UN International Resource Panel (UN IRP 2018, 2019 a, 2020). To reduce greenhouse gas emissions, we must decrease fossil energy use. This is closely coupled

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5 National energy and climate plan, see BMK [bmk.gv.at/themen/innovation/publikationen/energieumwelttechnologie/energie\\_klimaplan.html](https://bmk.gv.at/themen/innovation/publikationen/energieumwelttechnologie/energie_klimaplan.html)

with industrial processes, such as e.g. the production of steel, cement, plastic, paper and aluminium, in which 36% of all global greenhouse gas emissions occur (Allwood et al. 2011). If *material* resource use were indeed to double by the middle of the 21st century (Krausmann et al. 2018; OECD 2018; UN IRP 2019 a), this would be linked to an increase in energy consumption and emissions. The technical possibilities for processing more *material* while using less energy are limited. UN scenarios (UN IRP 2019 a) show that a combination of measures to protect the climate and to increase resource efficiency are capable of producing the greatest reduction in environmental impacts both in terms of emissions and also of material use.



### Side note 9: UN IRP: “Resource efficiency can contribute significantly to climate protection”

The International Resource Panel (IRP) of the UN focuses increasingly on the relationship between resource efficiency and climate change. As early as 2017, the IRP highlighted the important contribution made by resource efficiency (RE) to various policy goals (UN IRP 2017, 2018):

- SDGs: RE can reduce resource use by 28% and thus help to achieve the SDGs.
- Climate protection: RE can reduce global greenhouse gas emissions by 63%.
- Economic growth and job creation: RE is able to more than compensate for the economic costs associated with an ambitious climate strategy and to create economic gains worth 2 billion USD.

The IRP also calculates that integrated policy measures can achieve a greater reduction in resource use and greenhouse gas emissions than individual sets of measures implemented separately.

In 2020 the IRP published a more detailed and precise picture of the role played by resource efficiency in reducing greenhouse gas emissions in a further report “Resource Efficiency and Climate Change. Material Efficiency Strategies for a Low-Carbon Future” (UN IRP 2020). The extraction and processing of *materials* is responsible for 23% of total greenhouse gas emissions, primarily associated with construction activities to provide housing and automobile production. The processing of only a few *materials* plays a significant role here: Iron and steel, cement, gypsum and lime, rubber and plastic, and other *non-metallic minerals*. Changing how and for what purposes we use these *materials* in buildings and vehicles can reduce the greenhouse gas emissions associated with these by 30–70%. Necessary measures address both the production process (reduction through changes in product design, substituting *materials*, efficiency, recycling, re-use and remanufacturing, extending product lifetime) and the demand side through changes in intensity or type of use.



### Side note 10: “Resource-Efficient Pathways to Greenhouse Gas Neutrality – RESCUE” a study by the German Environment Agency, November 2019

The RESCUE study undertaken by the German Environment Agency presents six scenarios that demonstrate potential solutions and steps creating resource-efficient pathways to greenhouse gas neutrality in Germany by 2050. In recognition of the clear interdependencies between climate protection and resource conservation, six different scenarios were explored that set out the options for taking action to create a resource efficient and GHG-neutral Germany.

The scenarios show transformation pathways, which Germany could adopt to achieve greenhouse gas neutrality. The study does not look at Germany in isolation but rather as embedded within the European Union and the world, as an industrial producer country in the context of global trade, with a modern, efficient *society*. Climate protection, decarbonisation, energy saving and collective support for greater resource conservation all characterise the *societal* and industrial transformation that is required.

All the scenarios share a common assumption that Germany will achieve a greenhouse gas reduction by 2050 of at least 95% and by 2030 of at least 55% compared to 1990. To achieve this, the strategies to reduce greenhouse gas emissions involve a combination of avoidance, substitution and the use of natural carbon sinks. Further information about the project and the report can be found here: [umweltbundesamt.de/rescue](http://umweltbundesamt.de/rescue)

### Austria is decoupling domestic resource use and CO<sub>2</sub> emissions, but outsources material consumption to other countries

Between 2000 and 2005, CO<sub>2</sub> emissions in Austria grew continually, and by a total of 20%. In 2005 a change of course is evident, and CO<sub>2</sub> emissions decreased year on year, with a total reduction of 11% by 2014. Due to the strong growth that occurred in the years to 2005, emissions in 2014 were still higher than the level recorded for 2000 (see figure 20, page 53). A raft of climate protection measures played a part in the decrease recorded for this period, including the expansion of renewable energy and retrofitting of buildings (Anderl et al. 2018). From 2014 to 2015 a renewed increase in emissions was recorded (+4%). Further developments will have to be monitored closely. The CO<sub>2</sub> footprint, i.e. all CO<sub>2</sub> emissions in the country and abroad that are caused by Austrian final demand (further information about footprint indicators can be found in side note 6, page 37), is higher than domestic CO<sub>2</sub> emissions. Between 2000 and 2015 the CO<sub>2</sub> footprint shows a slightly smaller increase (3%) than domestic emissions (6%). However, the outsourcing of CO<sub>2</sub>-intensive production to other countries is still continuing.

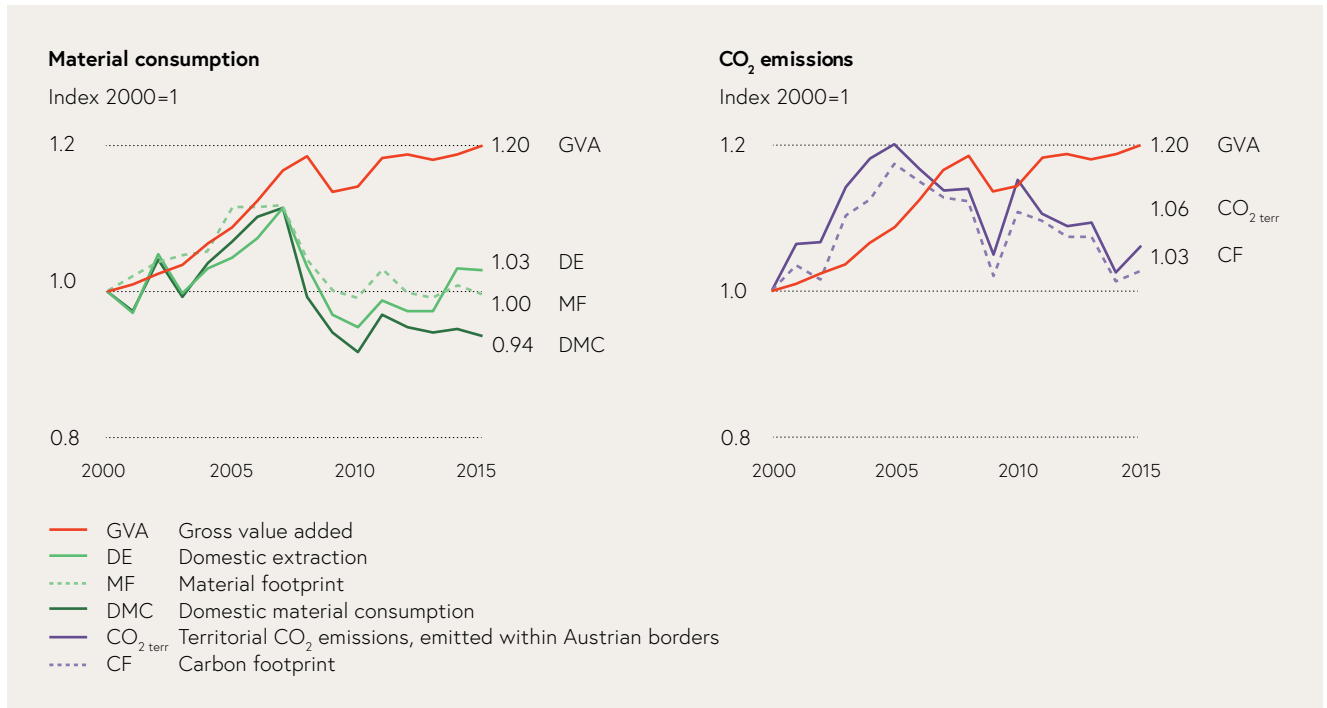


Figure 20: Resource consumption in Austria: material consumption and CO<sub>2</sub> emissions from a domestic and a consumption-based perspective, 2000–2015

Source: GDP, population, material consumption: Statistik Austria 2019, CO<sub>2</sub> emissions: Umweltbundesamt 2019; Footprint indicators on material (material footprint) and CO<sub>2</sub> emissions (CO<sub>2</sub> footprint): EE-MRIO modell exiobase v.3.6, Stadler et al. 2018

Material consumption (measured as DMC) increases by 2007, i.e. until the financial crisis, by a total of 11 %. Since then, it has fallen by 16 % and in 2015 even falls below the figure for 2000 (see figure 20). From a consumption-based perspective, the picture changes very little: the *material footprint* in 2015 is almost the same as it was in 2000; over a period of 15 years, from a consumption perspective, no reduction in resource use has taken place.



### Side note 11: A best practice example: The EU flagship project H2FUTURE

Producing a secure supply of sufficient full-scale “green” hydrogen on a competitive basis is a fundamental precondition for the development and long-term application of hydrogen-based technologies for CO<sub>2</sub>-minimised steel production.

The flagship project H2FUTURE, a joint project of VERBUND, voestalpine, Siemens, Austrian Power Grid (APG) and research partners K1-MET and TNO, explores central research questions concerning the technological and economic conditions for the production and application of green hydrogen at industrial scales. The pilot facility,

which began operation at the end of 2019 and is located at the voestalpine steel plant in Linz has a capacity of 6 MW and production rate of 1,200 m<sup>3</sup> hydrogen per hour, and is currently the largest worldwide in terms of production and application of green hydrogen using PEM (Proton Exchange Membrane) electrolysis technology.

Whereas hydrogen is still largely produced using fossil fuels, primarily natural gas, and thus involves significant CO<sub>2</sub> emissions, H2FUTURE uses 100% renewable electricity to split water into hydrogen and oxygen. This practically emission-free process is used to produce green hydrogen. Project website: [h2future-project.eu](https://h2future-project.eu)



### Side note 12: Gathering data on air emissions

Data records on air emissions have gained in significance in the context of climate change. Consequently, to estimate greenhouse gas emissions numerous statistical data sources for emissions are available, which differ both in terms of the form of reporting and the presentation of data. Where data collection on Austrian air emissions is concerned, three reporting systems are available: The air pollutant and greenhouse gas inventory, which records greenhouse gas emissions on Austria's territorial area, in line with the National Greenhouse Gas Inventories as defined in the IPCC guidelines. Further to this, there is the CORINAIR (Core Inventory of Air Emissions) system based on the UNECE Convention on Long Range Transboundary Air Pollutants (LRTAP). Finally, there are the Air Emissions Accounts, which record the emissions caused by individuals or businesses in Austria. These emissions are assigned to economic activities and private household consumption in line with the ÖNACE classification, which is also used for the economic activities in the *national accounts* (see glossary, page 111).

For explanatory information and data on air emissions, see Statistics Austria: [statistik.gv.at/web\\_de/statistiken/energie\\_umwelt\\_innovation\\_mobilitaet/energie\\_und\\_umwelt/umwelt/luftemissionsrechnung/index.html](https://statistik.gv.at/web_de/statistiken/energie_umwelt_innovation_mobilitaet/energie_und_umwelt/umwelt/luftemissionsrechnung/index.html) or the Environment Agency Austria: [umweltbundesamt.at/klima/emissionsinventur](https://umweltbundesamt.at/klima/emissionsinventur)

## Resource consumption is primarily linked to food production, construction sector and health sector

To enable more precise analysis, we will now take a look at the sectoral level. This involves relating the Austrian *material* or CO<sub>2</sub> *footprints* to the sectors that supply final consumption. These are in large part, although not exclusively, the higher manufacturing levels of the secondary (e.g. manufacturing industry) and tertiary sectors (services sectors). 50% of the *material footprint* (MF) may be assigned to the production of



six sectors<sup>6</sup> (see figure 21): the construction sector (14% of MF), mining (13%), food production (9%), agriculture (5%), the health sector (5%) and public administration and defense (4%). In the case of the CO<sub>2</sub> footprint (CF), 60% of total emissions are attributable to 10 sectors. The largest five are: energy production (10% of CF), the construction sector (8%), the health sector (6%), processing of coal and oil (4%) and food production (4%). Alongside the emissions from production processes, emissions are also produced directly through energy use by final consumption (19% of CF), i.e. emissions through e.g. heating or automotive transport.

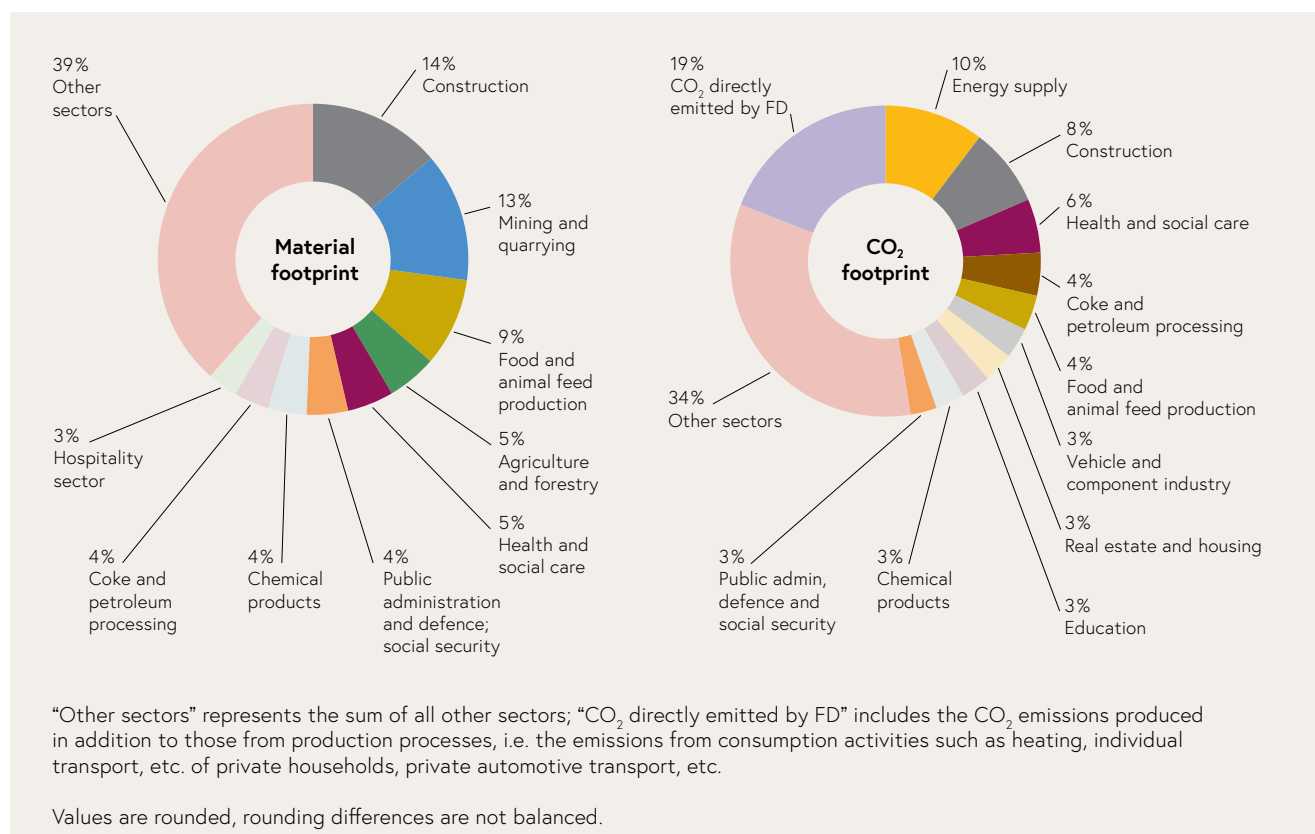


Figure 21: Material footprint (MF) and CO<sub>2</sub> footprint (CF) by sector, 2015

Source: Authors’ own diagram based on Plank et al. 2020

In the context of the climate debate, sectoral hotspots are not a new concept (see for example Anderl et al. 2018; Steininger et al. 2018). Of interest nonetheless is the high degree of correlation between the two perspectives i.e. between *material* and CO<sub>2</sub> footprints. Among the top 5 sectors, three are found in both approaches: the construction, food production and health sectors. Among the top 10 sectors, there are seven correlations: in addition to the three named above, the processing of coal and oil, public administration, vehicle manufacturing, and the processing of chemicals.

<sup>6</sup> Sectors follow the ÖNACE classification (Statistik Austria 2008).

It is clear when looking at the CO<sub>2</sub> intensity (CF/MF), which sectors demonstrate high emissions per tonne of *material* consumed. High CO<sub>2</sub> intensity is in the first instance evident for those sectors, which require little *material* e.g. water or air transport or retail activities. In fifth place are electricity production, gas and hot water supply (1.8 tonnes of CO<sub>2</sub> emissions per tonne of *material* consumed). The processing of coal and oil (place 14, 0.5 t/t) is similarly CO<sub>2</sub>-intensive to the health sector (place 24, 0.5 t/t).

## The major part of resource consumption by manufacturing industry occurs abroad

The analysis of consumption-based indicators (see side note 6, page 37) takes into account the entire supply chain of the goods produced, both within the country and elsewhere. In this way, it is possible to identify whether measures to reduce CO<sub>2</sub> emissions or material consumption would primarily alter the resource flows within Austria or abroad. Figure 22 shows the CO<sub>2</sub> footprint and the *material footprint* in terms of the location at which they occur.

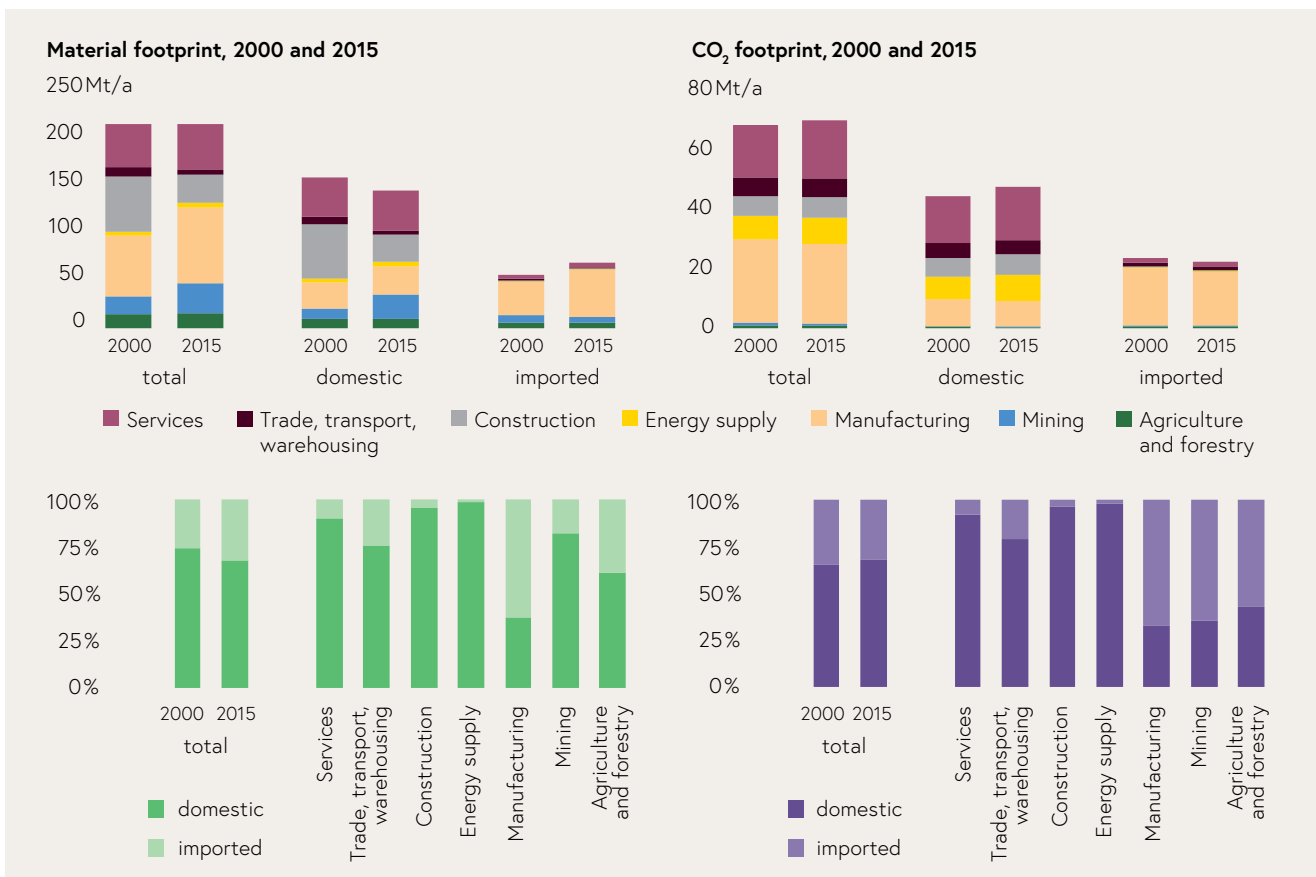


Figure 22: Material footprint (MF) and CO<sub>2</sub> footprint (CF) total by sector and sub-divided into their domestic and foreign component shares

Source: Authors' own diagram based on Plank et al. 2020

The major share of resource consumption (75%) and most CO<sub>2</sub> emissions (65%) take place within Austria. The same is true for most sectors, with the exception of manufacturing industry, in which case the relationship is reversed: 63% of the *material footprint* and 68% of the CO<sub>2</sub> footprint are environmental impacts that occur outside Austria. Changes in consumption patterns would therefore lead primarily to a reduction in resource flows and greenhouse gas emissions abroad.

The changes between 2000 and 2015 show that a reduction in CO<sub>2</sub> emissions occurred exclusively in the production steps abroad and in manufacturing industry. In contrast, the service sectors contributed most to the increase in the CO<sub>2</sub> footprint, through emissions occurring within Austria. A reduction in the *material footprint* is only recorded for the Austrian construction sector. These figures appear, however, to be the result of a transfer from the construction sector to the mining sector and manufacturing industry. A reduction in the *material footprint* within Austria was achieved, yet resource pressures in other countries, particularly in manufacturing industry, increased..

## Ever greater economic output drives resource consumption and CO<sub>2</sub> emissions upwards

Analysis of the hotspots shows us in which areas environmental impacts primarily occur. Yet what drives the activity in these areas?

The decomposition analysis shows (see figure 23, page 58), that Austrian economic growth contributes significantly to the rise in CO<sub>2</sub> emissions. Were all other factors during the 15 years analysed here to have remained unchanged, then CO<sub>2</sub> emissions would even have risen by a far greater amount than they did in practice. The second factor that contributed to the increase in CO<sub>2</sub> emissions was material intensity (*material footprint* per unit of value added in each sector; see side note 6, page 37; for a description of the footprint indicators, see side note 5, page 31). The contribution of material intensity is less than that of economic growth, yet it remains considerable nonetheless. The fact that material intensity has contributed to an increase in the CO<sub>2</sub> footprint shows us the potential for material efficiency measures to contribute to reducing CO<sub>2</sub> emissions. The other two factors, changes in economic structure and the CO<sub>2</sub> emissions per tonne of resource consumption, have contributed to a similar extent to the reduction of the CO<sub>2</sub> footprint. Their reductive role has partly compensated for the effects of economic growth and material intensity. Material intensity (MF/GVA) and emissions intensity (CF/MF) added together give the CO<sub>2</sub> intensity of economic performance (CF/GVA). In the case of Austria, changes in the CO<sub>2</sub> intensity of the economy contributed to the reduction of the CO<sub>2</sub> footprint over the period observed.

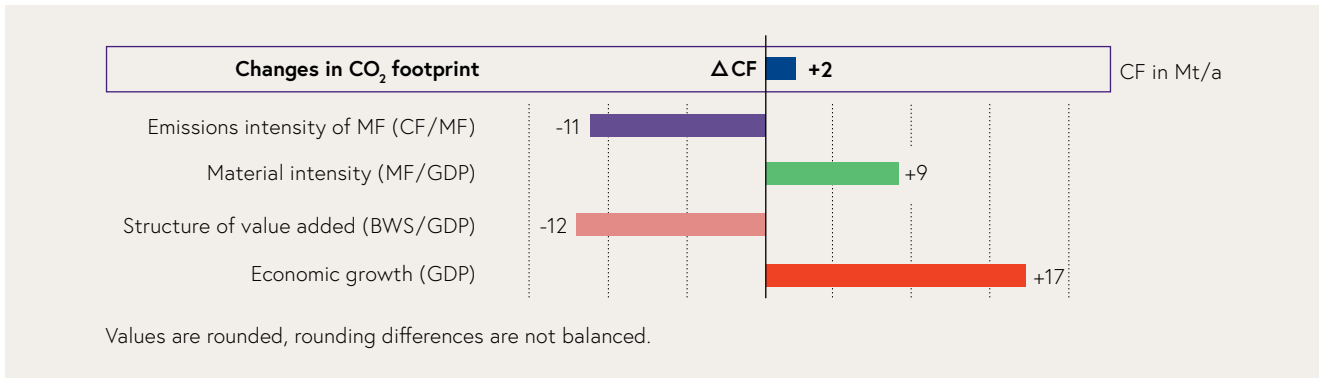


Figure 23: Investigation of which factors drive the Austrian CO<sub>2</sub> footprint, 2000–2015

Source: Plank et al. 2020

The significant contribution shown here of economic growth as a driving force behind increasing resource use and CO<sub>2</sub> emissions confirms many other studies, which also identify economic growth as the most significant driver, overriding other effects (e.g. efficiency improvements) (siehe z.B. Anderl et al. 2018; UN IRP 2019a; Wenzlik et al. 2015).

In figure 24 the same four factors for the domestic and foreign shares of the CO<sub>2</sub> footprint are shown as drivers. The contribution to a reduction of the CO<sub>2</sub> footprint over the emissions intensity per consumed *material* is almost exclusively valid for other countries. In Austria, barely any change in the relation between CO<sub>2</sub> emissions and resource consumption is observed. At the same time, the reductive effect of an altered economic structure is primarily valid within Austria itself; in other countries, there appear to be no positive effects created through any shift between production sectors.

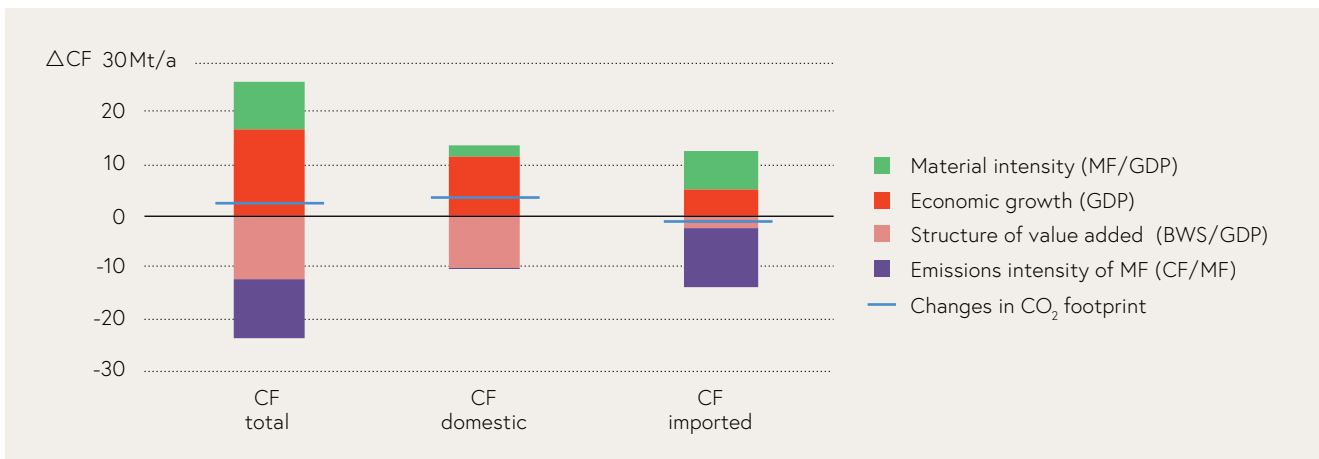


Figure 24: Decomposition of the CO<sub>2</sub> footprint divided into domestic and foreign shares, 2000–2015

Source: Plank et al. 2020



### Side note 13: Decomposition analysis of the Austrian CO<sub>2</sub> footprint

A decomposition analysis (for a description of the methodology see side note 8, page 41; or Dietzenbacher and Los, 1998; Hoekstra and van den Bergh, 2002) is a common statistical method used to identify the driving forces at work. To analyse the factors that lead to an increase or a reduction in the Austrian CO<sub>2</sub> footprint, the analysis presented here distinguishes between the following factors:

CF: CO<sub>2</sub> footprint of Austrian final demand; the changes in CF between 2000 and 2015 are divided using decomposition analysis into individual factors, listed as follows:

- GDP: total economic output of Austria; this shows the effects of economic growth on CO<sub>2</sub> emissions.
- VA: changes in Austrian economic structure, that is, the value added of individual sectors (Gross Value Added GVA) in relation to total GDP (GVA/GDP). The economic structure indicates how large the output of a sector is in comparison to total Austrian economic output. If these proportions change, then production structure in Austria shifts accordingly. Example: The output of Austrian agriculture is increasing. However, production in other sectors is increasing at a greater rate, for which reason the share of agricultural production in comparison with other sectors is decreasing.
- MI: material intensity (MF/GVA) of individual sectors.
- mEI: material-related emissions intensity of each individual sector (CF/MF); mEI indicates the quantity of emissions produced by the processing of a tonne of *material*.

MI and mEI together add up to the “carbon intensity” of sectoral production.

The calculation formula for decomposition analysis is:

$$\Delta CF = \Delta CFBIP + \Delta CFWS + \Delta CFMI + \Delta CFEI$$

and defines the changes in CF between two points in time (in this case, between 2000 and 2015) as the sum of the contributions of the individual factors listed above. Decomposition analysis indicates the annual changes for each individual sub-factor, while the respective other factors remain constant. This means that the effect of a particular factor can then be observed in isolation. A decomposition analysis or component analysis for Austrian CO<sub>2</sub> emissions has already been published in the Austrian Climate Protection Report (Anderl et al. 2018). The analysis presented here includes two aspects that expand on studies to date: firstly, the analysis for domestic and foreign resource consumption has been conducted separately, and secondly, the interlinkage between CO<sub>2</sub> emissions and resource consumption has been explicitly integrated.

## Using synergies – high impact on resource conservation and climate protection

Resource efficiency and climate protection reveal important synergies. Measures promoting sustainable use of natural *resources* and aiming at the limited use of primary *resources* therefore also have a positive impact on the development of CO<sub>2</sub> emissions. Three economic activities have emerged as hotspots both in relation to resource use and to CO<sub>2</sub> emissions: construction activities, agriculture and food production, as well as health services and social care. The health sector in particular is characterised not only by high absolute resource consumption but also by high CO<sub>2</sub> emissions per tonne of *material* used. A German-Austrian research study (Pichler et al. 2019) analysed the health sector in more detail. The study identified that the CO<sub>2</sub> footprint of the health sector is primarily determined by the energy supply system. CO<sub>2</sub> emissions are only to a minor extent determined by healthcare expenditure, e. g. through hospitals, pharmacies, medical practices, etc. These three hotspots are not surprising, since previous analyses on climate protection have already identified that these are areas of activity with key relevance for climate policy (Anderl et al. 2018; Steininger et al. 2018). However, it is interesting that these activities are also responsible for a high level of resource use. The case for coordination and the use of synergies between measures to reduce resource use and those for climate protection is thus clear.

Synergies between resource efficiency and climate protection also exist in great measure in the field of infrastructure. Existing infrastructure, such as buildings, roads or lighting, plays a significant role through prolonged use and maintenance in determining future material and energy consumption and the greenhouse gas emissions associated with this. The choice of *materials* and energy sources as well as the reduction in energy consumption across the entire period of use are thus important mechanisms for producing a resource conserving economy. The reduction of resource consumption and emissions can most effectively be achieved through strategic decision making that favours a low-maintenance and long-lived infrastructure that is not subject to growth. This means: an optimisation of material construction, a reduction in stocks that provide few or no services to *society*, and a regional optimisation that relies on reduced stocks (e. g. increasing density of built areas and shorter routes for travel).

Austria is a net importer of *resources* and causes resource use and environmental impacts abroad through these imports. 30% of the Austrian CO<sub>2</sub> footprint occurs in other countries. In addition, the environmental impacts produced by manufacturing industry occur mainly outside Austria. If we want to take on global responsibility for our way of life, we must take account of the consequences of our consumption beyond Austria's borders too. Along with changes to our patterns of consumption, international policy measures are of particular importance here.

Economic growth is the most important driver leading to increases in resource use and in CO<sub>2</sub> emissions. Improvements through changes in economic structure (changes aimed at less CO<sub>2</sub>-intensive economic activities) or through improvements

in resource intensity are unfortunately more than compensated by the strong growth of economic output. Moving away from prioritising economic growth as an indicator of prosperity and towards a stronger focus on *societal* wellbeing and an absolute reduction in environmental impact (resource consumption and CO<sub>2</sub> emissions) is thus urgently needed.

# The circular economy from a macroeconomic perspective







As an alternative to the current resource and energy-intensive economic framework, which follows the “extraction-consumption-disposal” principle, the aims of a circular economy (CE) both internationally (European Commission 2014, 2015, 2020) and also in Austria (BMNT 2019 c) have gained significantly in relevance. In a circular economy, *resources* are retained in the social system for as long as possible, with the aim of reducing the extraction of primary *resources* from nature. The entire *material* throughput of a *society* should thus be adapted to operate within ecologically sustainable limits and so that ecological cycles are only used within the bounds of their reproductive capacities (Korhonen et al. 2018). The circular economy relies upon, for example, sustainable product design, product service models or the reprocessing of secondary raw materials for production and consumption. By these means, waste products should be greatly reduced, natural *resources* preserved, and the resilience of socioeconomic systems strengthened. The concept of the circular economy aims to contribute not only to resource efficiency but also to sustainable resource use and may be conceived as complementary to but not removing the need for an absolute reduction in resource consumption.

The EU has taken significant steps in recent years to set European development on the path towards a circular economy. These programmes, such as the Circular Economy Package (European Commission 2014), the Circular Economy Action Plan (European Commission 2015) or the Monitoring Framework for the Circular Economy, adopted in January 2018 by the European Commission (European Commission 2018 a), also provide an important framework for implementation in Austria (see side note 15, page 67).

For a long time, the focus of *material flow accounting* lay with input flows, i. e. resource extraction, *imports and exports*. In recent years, this perspective has been broadened to include output flows, i. e. *society's* emissions and disposed wastes, which have not yet found further use within our *society*. Since every output flow corresponds to a flow on the input side, a macroeconomic approach produces new opportunities for analysis. Expanding MFA to include the output side can enable, for example, the circularity potential of an economy to be analysed and demonstrated in detail, showing which share of *resources* are used in a closed cycle and in the extent to which these secondary flows relieve pressure on primary resource inputs and on outputs.

From the consideration of *society* as a whole, the circular economy thus forms an important building block for sustainable resource use. In this section, this macroeconomic approach is examined in greater detail in the context of *material flow accounting* and contributions to the discussion about the circular economy.



## Side note 14: The Circular Economy in the EU

In March 2020, the European Commission adopted a new Circular Economy Action Plan (European Commission 2020). This forms a part of the European Green Deal (European Commission 2019c), Europe's new agenda for sustainable growth. Based on the work undertaken since 2015 in the context of the European Commission's published "Circular Economy Action Plan" (European Commission 2015), the new Circular Economy Action Plan focuses more strongly on a circularity-oriented European economic framework, which aims to retain the value of products, *materials* and *resources* within the economy for as long as possible and in the process to produce as little waste as possible ([ec.europa.eu/environment/circular-economy/index\\_en.htm](http://ec.europa.eu/environment/circular-economy/index_en.htm)). The action plan focuses on sustainable products, strengthening the position of consumers and avoiding the generation of waste along the entire value chain as well as in a very specific sense within branches that have a high circular economy potential such as the construction sector, or textiles.

Further to this, the European Commission has published other strategies with concrete measures and objectives; these include the strategy for plastics, which envisages all plastic packaging being either reusable or recyclable by 2030. Further information is available on the European Commission's page on green growth and the circular economy: [ec.europa.eu/environment/green-growth/index\\_en.htm](http://ec.europa.eu/environment/green-growth/index_en.htm)

### Wastes and emissions from a macroeconomic perspective

All of *society's* wastes and emissions are recorded in the material flow accounts as *domestic processed outputs* (DPO; Eurostat 2018) and have been calculated by Statistics Austria as a consistent time series since 2000. The data are based on various public statistical sources, such as the agricultural statistics, the emissions statistics, the energy balance, other supply balances and the Federal Waste Management Plan, together with estimates (see methods described in Eurostat 2018). DPO encompasses all material flows that pass from our *society* into nature and functions as a proxy for environmental pressures and resulting impacts.

The DPO comprises total emissions in air and water, uncontrolled deposited wastes, the dissipative use of products (e.g. fertilisers, gritting salt) and dissipative losses (e.g. tyre abrasion) within our *society* (see also side note 15, page 67). Air emissions comprise the overwhelming share (95%) of DPO, among them primarily CO<sub>2</sub> emissions (see figure 25, page 66). A further 5% occur through dissipative use of products. All other categories are negligible in terms of their size. In 2000 total DPO in Austria was 83 Mt/a, rising by 2017 to 94 Mt/a (see figure 25, page 66).

A calculation for DPO consistent with the input-side MFA conventions is also a control value for *societal* input, since in accordance with the principle of mass conversion,

all inputs are converted into outputs, where natural *resources* are not bound into *societal* stocks, such as infrastructures, for example. *Biomass*, which we take in through our food, must be found again, for example, in the CO<sub>2</sub> emissions from breathing, in potential food wastes or in sewage sludge. In contrast to the waste statistics, which consider the entire process of waste treatment, in a macroeconomic MFA-approach, wastes and emissions are only accounted for as *material* once, at the point of transfer from *society* back to the natural environment.

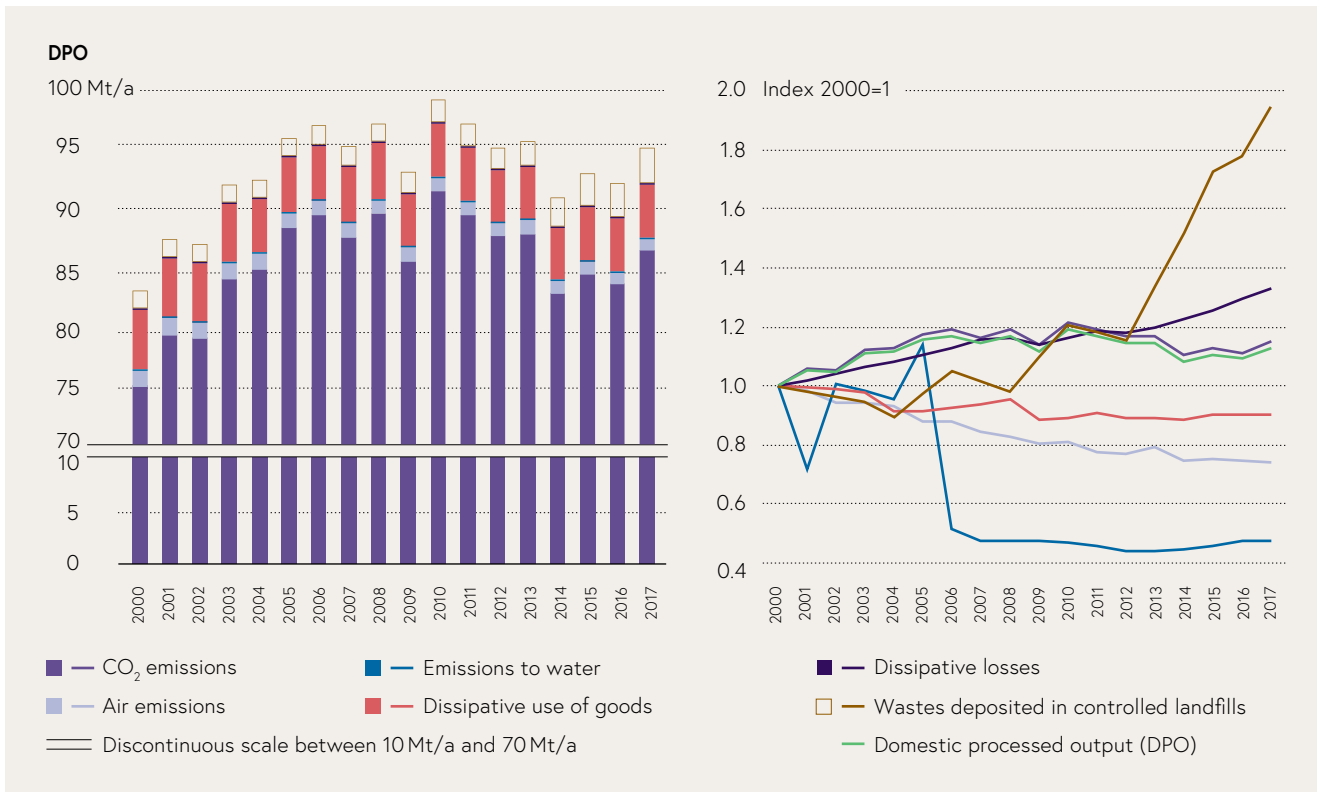


Figure 25: Domestic process outputs (DPO) in Austria, 2000–2017

Source: Statistik Austria 2019

Furthermore, by employing a macroeconomic perspective, waste generation and greenhouse gas emissions can also be related to energy input and material use. In so doing, shifts from one DPO category to another become visible. Thus, for example, a reduction in waste deposited as landfill can be achieved through increased incineration of wastes; by this means, the quantities of deposited wastes are reduced, yet the *domestic processed output* to nature (DPO) remains the same, because air emissions have increased.

Consistency in the recording of DPO flows is thus a fundamental precondition for any empirical discussion of the circular economy. The following section therefore contains a brief description of the individual components of DPO prior to a discussion of the circular economy based on the data, from the perspective of *material flow analysis*.



## Side note 15: Societal wastes and emissions (DPO) in MFA

The sum of domestic emissions and uncontrolled deposited wastes is defined as *domestic processed output* (DPO; Eurostat, 2018). This includes the total quantities of *materials* that are transferred to the natural environment as gaseous, liquid or solid outputs after their use in the socioeconomic system.

According to Eurostat (2018), this very heterogeneous group is divided into the following sub-categories. The outputs are grouped according to the medium in which they are transferred, that is emissions to air and to water, and uncontrolled deposits as landfill. Further to this, a distinction is made between the dissipative use of products and dissipative losses. The former concern targeted outputs, which occur through the use of a product, and are therefore consciously and for a specific purpose released into soil, air or water. These include, for example, organic and mineral fertilisers, sewage sludge, compost, pesticides, seeds, spreading grit and solvents, nitrous oxide, etc. Dissipative losses are unplanned outputs, which occur through the use of goods; this includes material losses through tyre and brake abrasion, losses through leaks in gas pipelines, losses in the form of lubricants or through wear and tear in infrastructure and buildings.

As with *domestic extraction*, the system boundary between *society* and natural environment must be very precisely defined for DPO. Output to the environment is defined as the point at which the respective material flow is no longer subject to *societal* control (Eurostat 2018). According to this definition, for example fertilisers are to be accounted for at the point of their application on cultivated land. In contrast, wastes that are stored in controlled landfills are not included in DPO, but only when *materials* leave the landfill site and thus *societal* control (e.g. emissions or leakages into soil). However, deposited wastes are, according to Eurostat convention, recorded as memorandum items i.e. the quantities are reported, but are not included in DPO. Estimation methods can thus make reference to these figures from the waste statistics. On the other hand, uncontrolled depositing of wastes is included in DPO.

### **Air emissions, particularly CO<sub>2</sub> emissions, form the major part of societal outputs**

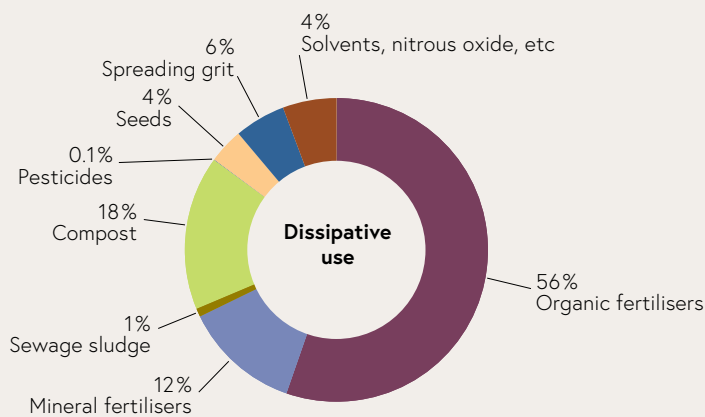
Air emissions form by far the largest share (95%) of *domestic processed outputs* (DPO; see figure 25, page 66). This refers to all gases or particulate matter. In statistical reporting, 14 air emissions are separately defined: carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), nitrogen oxides (NO<sub>x</sub>), hydrofluorocarbon (HFCs), perfluorocarbon (PFCs), sulphur hexafluoride (SF<sub>6</sub>), carbon monoxide (CO), non-methane volatile organic compounds (NMVOC), sulphur dioxide (SO<sub>2</sub>), ammonia (NH<sub>3</sub>), heavy *metals*, persistent organic pollutants (POPs) and particulate matter. These emissions, among these particularly CO<sub>2</sub> emissions, occur in almost every economic sector and are principally attributable to combustion processes, primarily involving fossil energy but

also *biomass*. Between 2005 and 2014 CO<sub>2</sub> emissions exhibited a downward trend, but in 2015, emissions rose once again. The share of CO<sub>2</sub> emissions from the combustion of *biomass* has increased continually (from 17% to 28%), as a result of the increasing use of *biomass* to generate energy.

Other air emissions occur due to agriculture and livestock farming in particular, although these are harder to record, since their “entry point” into the environment is often not precisely defined and the quantities emitted cannot be very accurately captured either. A more precise record of different air emissions, their sources and trends can, for example, be found in the current climate protection report from the Environment Agency Austria (Anderl et al. 2018).

### Further outputs involve dissipative use of products, emissions into water and dissipative losses

The second largest share of DPO (5%) concerns targeted applications, which are recorded under the category dissipative use of products (see side note 14, page 65). These include, for example, fertilisers, compost, pesticides or spreading grit. In Austria, the total quantity of these applied products between 2000 and 2017 decreased slightly, from 5 to 4.5 million tonnes per year. More than half of these concern the application of organic fertilisers, followed by compost (18%) and the use of mineral fertilisers (12%; see figure 26).



Values are rounded, rounding differences are not balanced.

Figure 26: Dissipative use of products in Austria, 2017

Source: Statistik Austria 2019

Alongside the deliberate use of products, other *materials* are released into the environment without knowledge or deliberate intent; these outputs are recorded in DPO as dissipative losses and include e.g. tyre and brake abrasion from vehicles, losses through gas pipelines or wear and tear of infrastructure and buildings (see also side note 14, page 65). Although many of these flows have significant health and environmental impacts, there is a lack of both data and suitable estimation methods (see Eurostat 2018). These losses are therefore often not accounted for statistically or are greatly underestimated (for more information see Eurostat 2018).

Emissions into water are in quantitative terms a very small category (less than 1% of total DPO). Water emissions had already shown a significant decrease by the early 1990s, due to the large-scale expansion of sewage systems and wastewater treatment plants, and are today mainly comprised of controlled discharges from municipal and industrial wastewater treatment plants.

Solid wastes amounting to 3.1 million tonnes were deposited in 2017 in Austria (excluding excavated soil); by comparison, in 2000 the equivalent amount was 1.4 million tonnes. The upward trend in the amount of deposited wastes can be observed particularly since 2012. Further information on how these data are recorded can be found in the Eurostat Handbook (Eurostat 2018) or in the Federal Waste Management Plan (BMNT 2017, 2019 d). Uncontrolled depositing of wastes into the environment has been forbidden by law in Austria since 1990, for which reason this category contains no values.

### **With regard to DPO, Austria is in 12th place in the EU comparison**

As already discussed in the above chapter “EU-wide comparison, Austria is in 11th place for resource use” (see page 43), Austria has shown itself to be a country with a high level of resource use in 2018. In figure 27 (see page 70) comparison between DMC and DPO in 2016 for the 28 EU Member States shows that Austria is in 8th place for material consumption (DMC), and is in 12th place in the case of DPO compared with other EU Member States (Eurostat 2019 c).

With regard to air emissions, which form the major share of DPO, Austria is in 11th place among EU countries in 2016. The second largest flow within DPO results from dissipative use of products (see chapter „Wastes and emissions from a macroeconomic perspective“, page 65). In this respect, Austria is in 9th place.

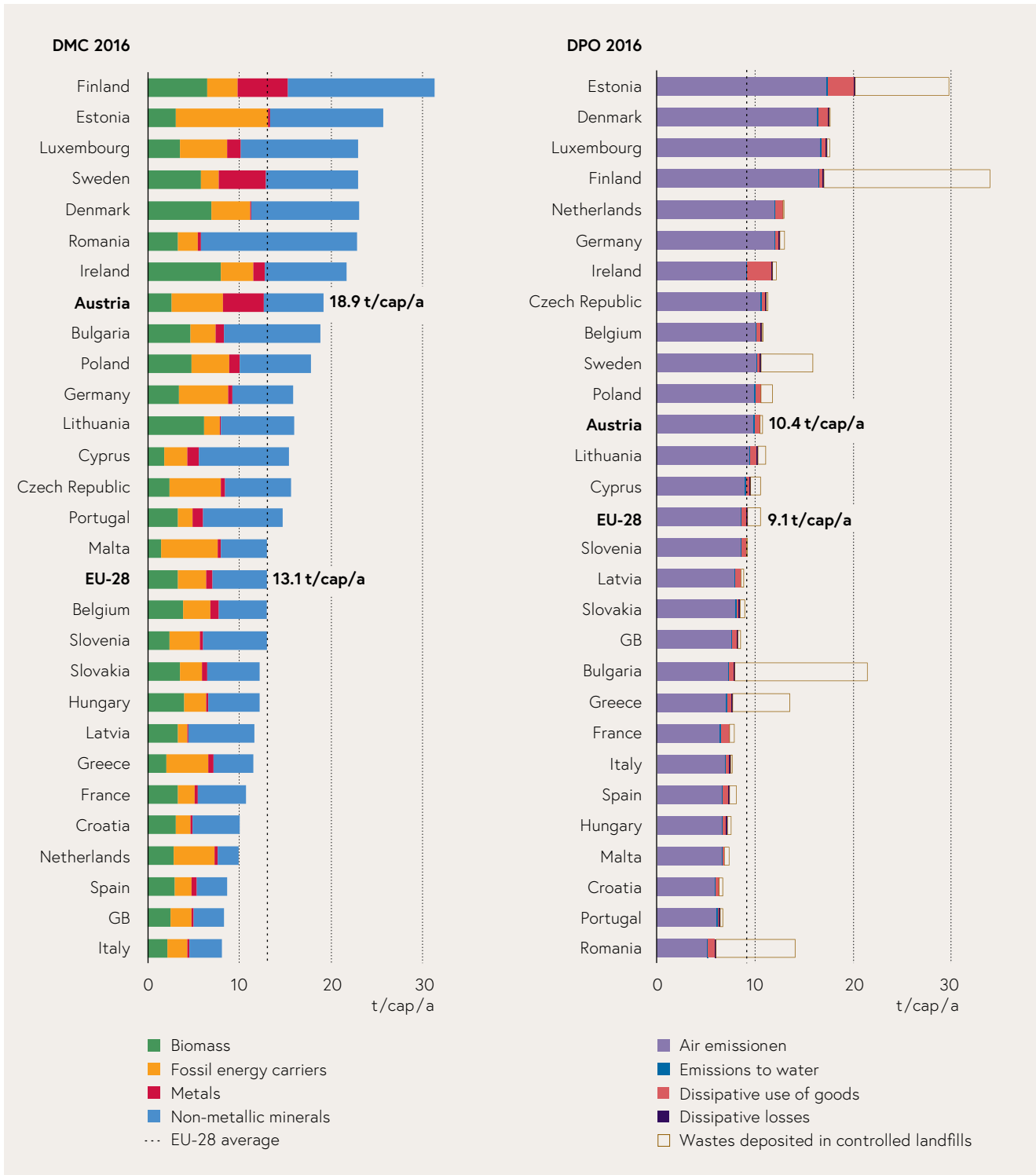


Figure 27: Austria in comparison with the EU-28 Member States; DMC and DPO in 2016

Source: Eurostat 2019 b



## At least half of resource inputs are accumulated in stocks

If one compares the *societal* outputs (DPO, *exports*) with inputs (DE, *imports*), the difference provides an indication of changes to overall *societal* stocks. If the inputs are greater than the outputs, this suggests that *societal* stocks are increasing<sup>7</sup> (further information about material stocks may be found in side note 15, page 67; or in Krausmann et al. 2018 ). In Austria, as in most other industrialised countries, the inputs into a *society* significantly exceed the outputs ( see figure 28 ). Alongside the expansion and new additions to our *society's* stocks, Austria also requires great quantities of *material* in order to maintain and renovate existing stocks ( Wiedenhofer et al. 2015 ).

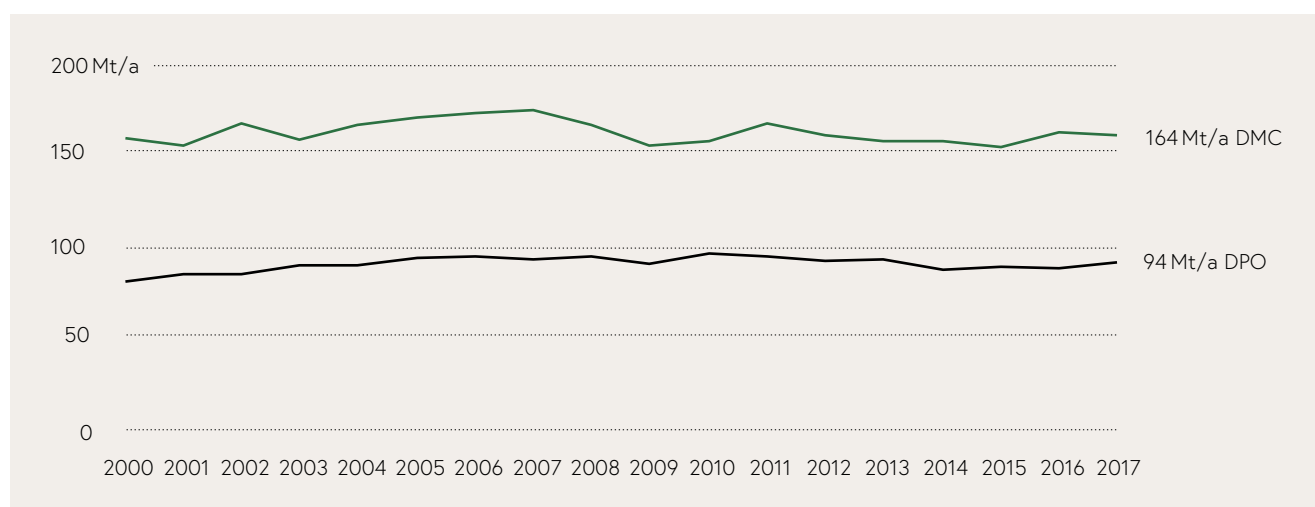


Figure 28: Material use in comparison with wastes and emissions in Austria, 2000–2017

Source: Statistik Austria 2019



### Side note 16: Material flows vs. material stocks

*Material flow accounting* (MFA) measures all material flows that are required to build up, operate and maintain the biophysical structures of a *society* i.e. its material stocks. A flow is always bound to a specific time period, and all flows are calculated in MFA as tonnes per year. Stocks, in contrast, are measured at a particular point in time. In MFA *societal* stocks comprise the artefacts of a socioeconomic system and the livestock within

<sup>7</sup> To actually close the material balance, additional balancing items (BI; for further information see Eurostat 2018, page 88) are also required. These include e.g. on the input side, oxygen from the air that is bound into CO<sub>2</sub> emissions through respiration or combustion processes. Or on the output side, the water vapour that is produced from water during combustion processes or respiration.

it as well as the human population itself. Artefacts include all infrastructure, buildings and vehicles, together with all machinery and durable consumer goods.

All *materials* from stocks flow back into the natural environment sooner or later as wastes or emissions. The average retention time spent within the social system differs according to material category and is dependent both on the lifetime of respective products and also on recycling and reprocessing rates. In this context it is thus particularly important to distinguish which flows accumulate in *societal* stocks, which *materials* are recycled and re-used (flows within the system) and which *materials* actually flow back into nature. The latter flows, i. e. wastes and emissions, are calculated together in MFA as domestic outputs to nature (*domestic processed output*, DPO, see also side note 15, page 67).

## Austria's macroeconomic recycling rate was 9% in 2014

From a macroeconomic perspective, a circular economy becomes reality when on one hand all material wastes from mineral or fossil raw materials are reintroduced back into the *societal* system of production through recycling or re-use. On the other hand, *societal biomass* use must not exceed the bioproductivity of land areas nor may outputs overload ecosystem cycles.

Alongside the material consumption of *resources* a circular economy requires that issues relating to energetic resource use are also considered: Energy is required for resource extraction, processing, marketing, operation and disposal of material goods. In energy supply, fossil energy still play an important role. Combustion of these creates emissions, waste materials and also residual heat. To achieve sustainable resource management, this cycle needs to be closed as well as far as it is possible to do so, by reducing fossil energy use to zero, furthermore through the use of renewable energy sources together with cascading energy use (using energy across multiple phases).

A research study at the Institute for Social Ecology (Jacobi et al. 2018) compiled the macroeconomic flows from the inputs to outputs and including exchange of stocks for Austria in 2014 for the first time using *material flow analysis*. The study provides a differentiated picture of the circular economy in Austria and is summarised in figure 29, page 73. Three main findings may be derived from this:

- In Austria in 2014, of the wastes that flow into waste processing at the end of their lifecycle, 30% were actually recycled. This recycling rate is defined as output recycling rate.
- In relation to the entire resource input, the share of recycled materials was only 9% in 2014. This rate is defined as input recycling rate.
- CO<sub>2</sub> emissions from the combustion of fossil energy cannot be integrated in a circular economy and must be reduced to zero. In Austria, the share of CO<sub>2</sub> emissions that came from *fossil energy carriers* is 45%.

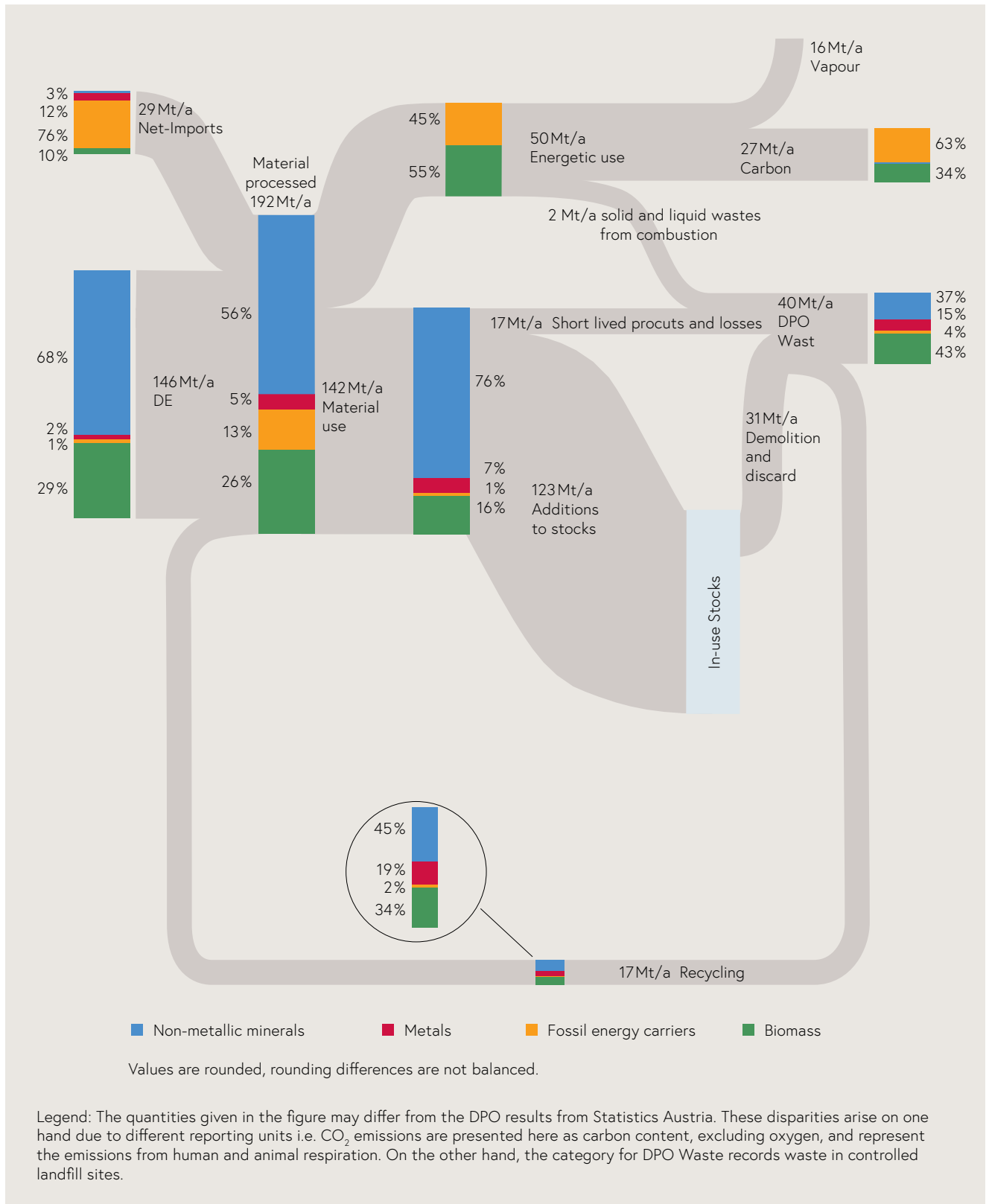


Figure 29: Austria and the circular economy in 2014

Source: Jacobi et al. 2018

For the three main findings regarding the macroeconomic circular economy described above, a differentiated presentation of material flows in and through Austrian society is required. To understand this better, the key flows are therefore briefly described below.

In the case of Austria, the input from secondary raw materials in 2014 amounted to 17Mt or 9% of the total processed *materials* (PM = DE + imports + secondary resources; Jacobi et al. 2018). These total processed material inputs are sub-divided in relation to their use into material use (74%) and energetic use (26%). *Materials* that are used materially are largely *non-metallic minerals*, which are used for construction activities. These *materials* flow into *societal* stocks and remain there for a number of years or decades.

The emissions related to energetically used *materials* (*fossil energy carriers* and *biomass*), i.e. C-emissions<sup>8</sup> and water vapour, are located on the output side. Material use generally creates wastes (end of life waste, EoL). Emissions and EoL together are defined here as Interim Outputs (Int-Out), since these are measured before any eventual recycling or waste treatment processes. The total Interim Outputs amount to 42% of processed material inputs and of these, 9% are recycled or reprocessed.

## Challenges for a circular economy: societal stocks and fundamental laws of physics

The Circularity Gap Report Austria (Circle Economy and ARA 2019) has addressed the empirical analysis presented here for Austria (Jacobi et al., 2018) and derives four recommendations for action from this:

- Supply all energy requirements using renewable resources.
- Increase the reprocessing of potentially recyclable wastes.
- Stabilise the material stocks (built infrastructure); Renovation or replacement of existing infrastructure must be covered by recycling continually accruing demolition wastes.
- Increase the share of secondary raw materials in imported goods.

The Circularity Gap Report Austria calculates that the measures recommended above can increase the circularity of the Austrian economy to 37.4% (Circle Economy and ARA 2019).

Societal stocks play an important role in the discussion around a circular economy. On one hand, this is because construction raw materials (that is, *non-metallic minerals*) comprise more than half of all material consumption, and on the other hand, because

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8 Discrepancies in the case of emissions with the DPO figures from Statistics Austria arise because Jacobi and colleagues (2018) present emissions as carbon (without oxygen).

extraction, construction and operation of infrastructures requires a considerable amount of energy. At the same time, a circular economy related to construction raw materials is not easy to implement. Lifespans of more than a year, often of multiple decades, lead to a situation in which outputs are available in far smaller quantities and much later (Jacobi et al. 2018) than the existing requirement for resource inputs. Further to this, because of their long lifespans, *societal* stocks develop long-term dependencies upon specific *resources*, to ensure their operation and maintenance. Demolition materials available today often exhibit a material composition that adheres to technical standards from decades earlier and which, because of their composition, often cannot be introduced into reprocessing processes. At the same time, many decisions that are being made today in the areas of regional development, product design or waste management will have a significant impact on the potential structure of a future circular economy (Krausmann et al. 2017 b).

Studies contributing to critical debate on recycling and the circular economy also point out that a distinction must be made between “closed-loop recycling” and “open-loop recycling” (Haupt et al. 2017). In the case of closed-loop recycling, secondary raw materials are recycled to the same quality as the original starting *material*. In contrast, where open-loop recycling is concerned, secondary raw materials do not have the same material quality after recycling as the original starting *materials* (also termed downcycling) and can therefore only be used for other purposes. Secondary raw materials from “open-loop recycling” cannot therefore replace primary raw materials but become available for other additional uses.

In the discussion on the circular economy, it must also be acknowledged that the material and energetic uses of *resources* are subject to the basic laws of physics (thermodynamics) and the limits contained therein. For example, dissipation, that is the distribution of previously concentrated *materials* (e.g. through material losses in production processes, dissipative losses during use or the application of very small quantities in end products), hinders closed loop circulation, because a disproportionate energy expenditure would be required in order to collect these *materials* together for further use.

Finally, the utilisation of energy is essential for many circular processes. Energy cannot itself form a circular process but at best can be used in a cascading way. As an alternative to *fossil energy carriers*, climate friendly renewable energy sources are accorded high priority. The competing use of *biomass* for food production for humans and animals, for energetic use, and increasingly also for material use in the context of the bioeconomy strategy (see side note 5, page 31) present significant challenges.

## Outlook


The macroeconomic approach to the circular economy – as facilitated by MFA – shows that looking in isolation at the waste side, at the input side, at technical recycling quotas,

or at climate-impacting emissions only illuminates a small part of the whole picture. A consistent macroeconomic framework is also needed – as provided through MFA – through which the output side can be examined in relation to the input side and to stocks. In this way, interactions and limits in the substitution between wastes, emissions, stocks and between different resource inputs can be rendered visible. Effects – synergies but also conflicting aims – between measures and programmes addressing greenhouse gas emissions, waste generation, resource input and growth of stocks become visible for the first time and deliver important insights for sustainable resource use.

For this reason, this section expands upon the input-oriented focal points of MFA to date to take account of the macroeconomic perspective and also introduces the MFA indicator DPO. Along with resource efficiency, the concept of the circular economy is thus an important building block towards achieving sustainable resource use. As pointed out above, circular economy measures can only be understood as complementary to and not as substitutes for an absolute reduction in resource use.

The circular economy encompasses a wide range of measures and strategies that address the entire production chain as well as consumption. These include measures on recycling, changes to the lifespan of products and product components (re-use, repair, renovation, remanufacturing, redesign) or changes to the ways in which products and services are used or produced (changes of use, sharing/leasing/shared use, reducing material input in production) (Moraga et al. 2019; Morsetto 2020).





Critical raw materials  
play a keyrole for  
future technologies





There are a wide range of different *metals* (iron and steel additives, non-ferrous metals, precious metals) that represent key *resources* for our industrialised production and consumption patterns. At the same time, the group of *metals* is the smallest of the four material categories (only 2% of Austrian DMC). The role of *metals* in *social metabolism* is a diverse one: a very small number contribute in large quantities to our stocks. The three most important *metals* in quantitative terms are: iron, which as steel forms the construction basis of our buildings and roads, or gives form to the bodywork of our vehicles; copper, which because of its effectiveness as an electrical conductor is used in all types of cables, as well as for roof construction and pipework; aluminium, as the most widely-used metal, is used for lightweight vehicle bodywork, drinks cans, window frames, etc. On the other hand, many *metals* are only used in very small quantities, yet as such these have critical significance for strategically important technologies. These include, for example, lithium and cobalt in batteries, indium and germanium for photovoltaics, tantalum, palladium and platinum in electronic equipment, catalytic converters and the chemicals industry, or *metals* from the rare earth group in catalytic converters and wind turbines.

In recent years, supply shortages for key raw materials have become noticeable and have made themselves felt particularly through high price increases. The EU has responded to these insecurities and has begun to monitor and analyse raw material inputs and supply through *imports* (European Commission 2011c). In 2011 the EU published a list of 14 critical raw materials (European Commission 2011c), for which supply security was judged particularly critical. In 2014, the list was expanded to 20 critical raw materials (European Commission 2011c) and then to 27 in 2017 (European Commission 2017a).

## **Metallic raw materials – the smallest group in social metabolism**

Iron ores constitute the largest quantities of metallic raw materials that are extracted worldwide and used in socioeconomic processes; in 2017, 4Gt were extracted globally (UN IRP 2019b), which is almost half the global extraction of ores, but only 4% of the total global extraction of biotic and abiotic raw materials. In Austria, only a small quantity of metallic raw materials is still being extracted – in 2017, 3.5Mt of ores were extracted, or almost 3% of total Austrian DE or 0.04% of global DE. Austrian primary metal extraction is currently limited to iron ores (85%) and tungsten ores (5%); apart from this, Austria produces secondary metallic raw materials (e.g. copper and aluminium).

### **Demand for metals grows in close correlation with the economy and accumulates large anthropogenic stocks**

*Metals* fulfill a very diverse range of purposes in our *society*; they are used in buildings, transport, electrical and electronic equipment, and for jewellery (Graedel 2010). The use of *metals* is closely correlated with economic output (GDP) as well as prosperity

indicators such as the Human Development Index, HDI (Graedel and Cao 2010). When a country uses more *metals* due to accelerating economic growth, it is not the case that individual *metals* are used more but rather that the demand for the entire spectrum of *metals* rises (Graedel and Cao 2010). With the expected high rate of economic development in the countries of the global South, a strong growth in demand for the entire palette of *metals* is also anticipated. Graedel and Cao (2010) calculate that demand can be expected to increase by 2050 by a factor of 5–10.

Since *metals* involve *materials* that we accumulate in our *societal* stocks, the strong increase in their use means that the anthropogenic stocks of *metals* are subject to continual expansion. Calculations of the anthropogenic stocks estimate that in 2000 these equated to approx. 500 Mt of aluminium, 300 Mt of copper, 14.8 Gt of iron, and 200 Mt of zinc (Rauch 2009). Since the figures are strongly correlated with GDP (Graedel and Cao 2010), the values vary between countries as well as between regions and cities. Calculated metal stocks per capita range from 2–4 t/cap of iron, 0.5–2 t/cap of copper, and 0.1 t/cap for aluminium (Gerst and Graedel 2008; Krausmann et al. 2017 b). 25 % of the anthropogenic stocks of aluminium, copper, iron and zinc, according to Rauch (2009), are found in the eastern United States, in western Europe, South Korea and Japan.

### **From deposits to metal**

Ores are found in varying concentrations in deposits in the lithosphere and are distributed unevenly around the globe. *Metals* are – with the exception of placer deposits – generally enclosed in surrounding rock. Just how much of the metal is contained in the rock may vary greatly and differs from one deposit to another. For copper deposits to be worth mining, for example, these have an average metal content of less than 1% copper in crude ore, varying however between 0.4% and 3%. During subsequent processing of the mined ores, the metal content is enriched to approx. 24% copper in a commercially viable concentrated form. A further specificity of *metals* is that they are often mined as polymetallic ores, and the metallic components are only separated as single concentrates during subsequent processing. For example, in the large-scale South American copper deposits, molybdenum, gold and silver are also extracted as byproducts. Technologically important *metals* such as indium, gallium and germanium, which are concentrated in lead and zinc ores, are exclusively extracted as co-products during extraction of the main metal using metallurgic-chemical processes. Where the main *metals* are no longer mined, the so-called “spice metals”, which are not (currently) of primary economic interest, can no longer be obtained.

In accordance with the MFA conventions, metallic raw materials are recorded as crude ores. The quantity of ore thus recorded in the DE is therefore considerably higher than the pure metal contained within and produced from it.

## **Growing demand, decreasing metal content, rising energy use – recycling as a counter measure**

Over recent decades, the metal content of productive mines has fallen continually, i.e. there is less metal contained in the extracted ores. Multiple factors play a role in this reduction of metal content (UN IRP 2013): High grade ores have been extracted first and are now largely depleted. At the same time, technological advances mean that it is economically viable to extract ores from less concentrated deposits, which produce metallic secondary components in addition as they can also be obtained there (e.g. molybdenum, selenium, tellurium in porphyry copper deposits). Most recently, increasing demand has led to a situation in which there is a commercial basis for mining even from low-grade ore deposits. The world market price for *metals* is very dynamic and the result of interaction between several factors. These include among others the changes to the contents of exploitable deposits and their metal content. Equal influence upon prices is exerted by increasing energy use, since where metal content decreases, greater quantities of ore must be extracted and because a smaller grain size is required during subsequent processing (separation of the raw materials from the surrounding rock) (UN IRP 2013).

Alongside the altered circumstances for commercial mining, there are growing anthropogenic stocks (especially urban mines), which are gaining in importance as reserves for the future (UN IRP 2011 b). Recycling and re-use are thus core strategies for supplying the growing demand for *metals*. The potential for reprocessing *metals* from our urban mines or anthropogenic stocks at the end of their lifespan is seen as very high (ibid.).

All steps along the production chain for metal goods are closely coupled with energy consumption, and approx. 8% of global energy consumption relates to metal production (UN IRP 2013). Dependent on the metal being processed, the energy demand ranges from 20 MJ/kg of metal for steel to 200,000 MJ/kg for platinum (UN IRP 2013). The initial processing phases, which involve moving large volumes, require a very great amount of energy. In comparison, reprocessing of secondary raw materials is often less energy intensive, because less processing steps are required and the *metals* in the product at the end of its lifespan are available in higher concentrations. A report from the International Resource Panel (UN IRP 2013) calculates energy savings of up to 75% for steel or 90% for aluminium and platinum. Recycling complex metal alloys needed for hi-tech applications represent a future challenge, since separating the different components is both energy-intensive and costly.

## **Critical raw materials caught between supply risks and growing demand for future technologies**

*Metals* play a central role in industrialised economies, for which reason they are particularly sensitive to shortages or bottlenecks in supply. In relation to a range of *mineral raw materials* that are characterised by high import dependencies, price

fluctuations and monopoly positions of producer countries, including some that play a strategically important role in future technologies, there have been increasing supply problems in recent years. The EU therefore decided to more closely monitor, analyse and find solutions to supply shortages for critical raw materials (CRM) (European Commission 2011 c). Critical *metals* are those that play an irreplaceable role in high-tech products as well as in product innovations, including solar panels, wind turbines, electric vehicles, etc., i. e. technologies of key importance within a decarbonisation strategy (European Commission 2018 b, see also side note 17).

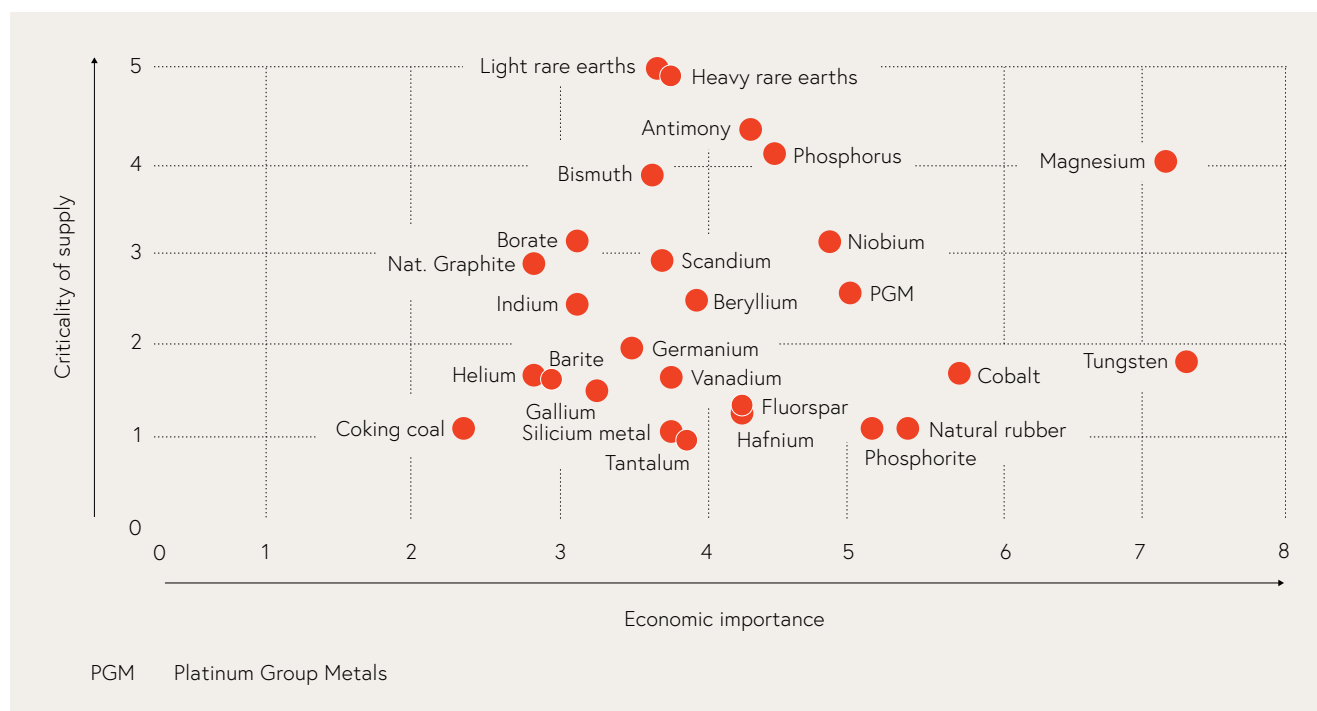


Figure 30: The 27 critical raw materials

Source: Author's own diagram based European Commission, DG JRC 2019

The definition of critical raw materials combines multiple factors. These include on one hand, the economic importance of the raw material, and on the other, the risk to supply ( for details see EC 2017 or JRC Report 2017 or side note 17). The current list of critical raw materials encompasses 27 raw materials, represented here in figure 30.



**Side note 17:**  
**Critical raw materials (CRM)**

Critical raw materials are *materials* that are closely linked to many industrial processes, which are largely involved in the production of modern technologies, and which are irreplaceable in the case of future technologies e.g. wind turbines, and electric vehicles (European Commission, DG JRC 2017). The EU published an updated list of 27 critical raw materials in 2017 (updating lists published in 2011 and 2014). The definition (European

Commission, DG JRC 2017) of which raw materials should be defined as critical is based on two factors:

- High economic importance
- High risk level for continuity of supply

The economic importance is based on the *material* in relation to added value of the manufacturing sector and the substitution potential of the raw material. The supply risk takes account of the concentration of production in the countries, the political stability of the countries and trade relationships. Supply risk level relies heavily on the *Herfindahl-Hirschman Index* (HHI), which provides a way of measuring market concentration (BMNT 2019 a).

The list is intended to stimulate measures to secure supply of the raw material. These include, for example, efficient use of the raw materials and increasing recycling rates, the exploration, expansion and inception or resumption of mining activities, diversification of supply channels and boosting research and development.

### The EU has to import critical raw materials

The EU is an importer of critical raw materials on an increasingly large scale. Between 2000 and 2017 primary production of *mineral raw materials* in Europe fell by 16.7% (excluding construction raw materials, see figure 31). In all other regions of the world, however, production activities increased. European demand thus has to be met by other countries; 18 of the critical raw materials come primarily from China, while the US, Russia and Mexico are also important producer countries.

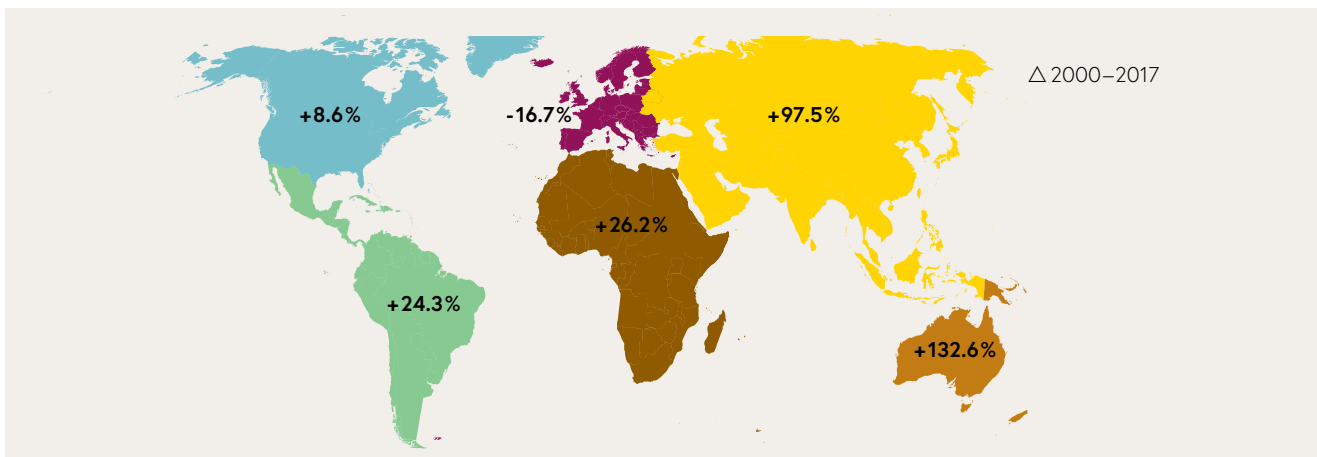


Figure 31: Mining production declines since 2000 only in Europe

Source: World Mining Data, BMNT 2019a

The concentration of production in a small number of countries is measured using the *Herfindahl-Hirschman Index* (HHI; BMNT 2019 a ; see also side note 17, page 83 ). In the case of most critical raw materials, the HHI is higher than the upper limit from 2000,

which means that the major share of these imported *materials* come from a very small number of countries. Along with concentration, the political stability of such countries is accounted for. A high concentration in politically unstable countries translates into a high risk to supply security.

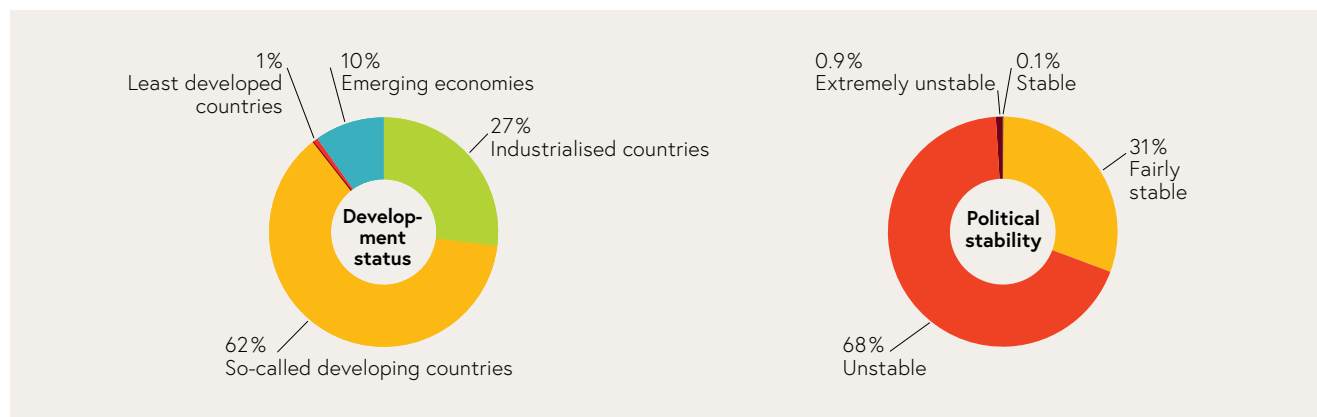


Figure 32: All producer countries for critical raw materials grouped by development status and by political stability, 2017

Source: World Mining Data, BMNT 2019a

The global production of critical raw materials is concentrated in a very small number of countries, and the majority of these are in so-called developing countries (62%) and emerging economies (10%; see figure 32). At the same time, most of the countries in which critical raw materials are produced are classified as relatively unstable politically (68 %, see figure 32; BMNT 2019 a).

### Critical raw materials are important raw materials for use in future technologies – the example of cobalt

Critical raw materials are important components in future technologies and are seen as enabling “sustainability” and an “electronic revolution”, both of which make important contributions to the decarbonisation and energy transition that is needed (UN IRP 2013; European Commission 2018b). The term future sustainability technologies (UNEP et al. 2009) is applied to those that enable an increase in energy efficiency and a reduction in emissions, and particularly those that replace older technologies in these areas with more innovative ones. These include economic activities relating to electronic products, batteries, renewable energies and catalytic converters (UNEP et al. 2009; European Commission 2018b).

In the case of electromobility, the raw materials lithium, cobalt, manganese and graphite are currently of particular strategic importance due to their use in batteries. Cobalt is among the *metals* classified as critical and is generally produced as a byproduct of nickel or copper. 42% of the cobalt produced is used in the production of batteries, and a further 23% of global production is used in the manufacture of super alloys (European Commission, DG JRC 2019). Global demand for cobalt has risen from 3% in 1995 to 23%

in 2006 (UNEP et al. 2009), to a similar extent as the increase in its application in super alloys (+21%). Estimates produced by UNEP for future demand suggest an increase of approximately +2.8% per year. The European Commission has calculated that anticipated increases in demand for electric vehicles will require cobalt production to increase by more than 2000% by 2030 (European Commission 2018b).

The largest producer of cobalt worldwide is the Democratic Republic of the Congo (approx. 60% of global production in 2017; BMNT 2019a), which is categorised as an unstable democracy with high potential for conflict. Most of the cobalt ore is exported from the Democratic Republic of the Congo for further processing in other countries, principally China, where approx. 40% of refined cobalt is produced (European Commission 2017b).

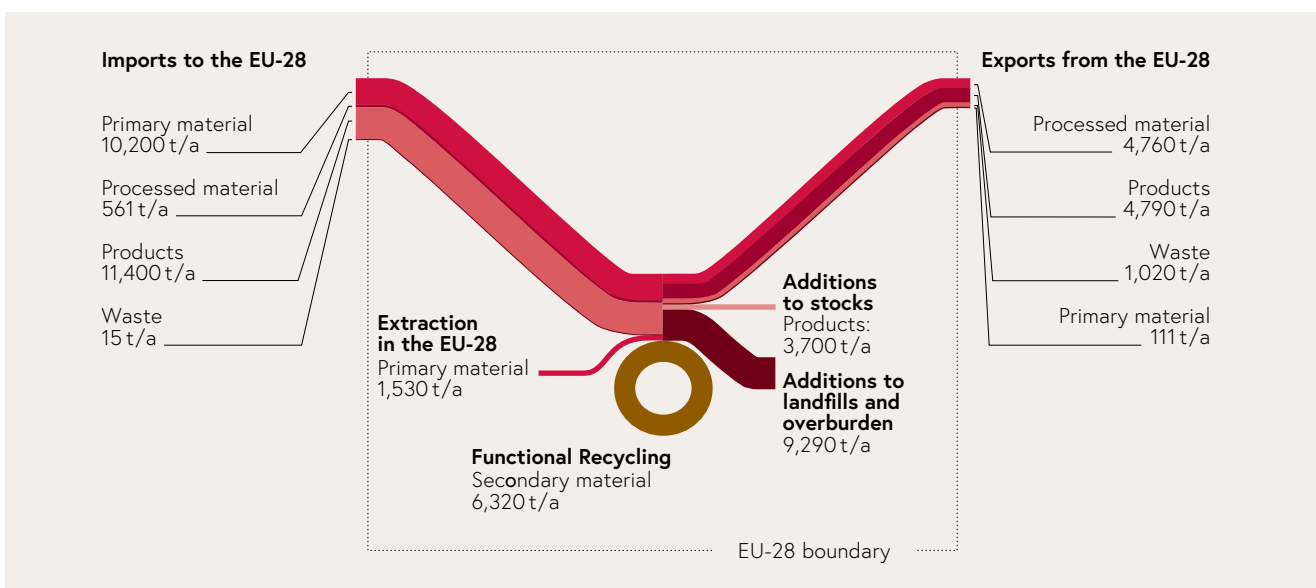


Figure 33: Flow diagram for cobalt, 2012

Source: Authors' own diagram, based on European Commission 2018b; European Commission, DG JRC 2019

Almost the entire EU requirement for cobalt is imported from other countries, 90% from Russia (European Commission, DG JRC 2019). In Finland, Belgium and France, cobalt concentrate undergoes further processing, 36% of which is exported again, and 12% of which enters *societal* stocks in the EU. 31% ends up in wastes in landfill sites and 21% is recycled (European Commission 2018b). The share of cobalt currently in landfill sites is estimated by the European Commissions (European Commission, DG JRC 2019) to be 100,000 t, with an annual increase of 10,000 t/a.

21% of the total cobalt used is recycled in the EU (European Commission 2018b). Nine EU Member States have currently achieved the goal of 45% for collecting, and exploiting further recycling options will be an important step forward. Apart from helping conserve primary *resources*, increasing the use of secondary cobalt *resources* also has positive impacts on energy and water consumption: the European Commission states



that energy use during extraction of primary cobalt is 140–2100 MJ/kg, whereas only 20–140 MJ/kg are required to process secondary *resources*. Similarly, water consumption declines from 40–2,000 m<sup>3</sup>/t to 20–100 m<sup>3</sup>/t (European Commission 2018b).

The EU published a strategic action plan in 2018, followed by an implementation plan (European Commission 2019a, 2019b), to establish a value chain for batteries. The core of this initiative is primarily to develop and expand the currently small sector involved in the production, collection and re-use of batteries, to close the gap to other economies (primarily China), and to establish the EU in future markets concerning sustainable battery production. The aim is to increase the sourcing of component *materials* from the EU and with this to increase resilience in relation to supply shortages.

### **Critical raw materials from a macro-metabolic perspective**

Purely from the perspective of biophysical quantities, critical raw materials hold little significance (less than 1% of total DMC). However, from the point of view of a future energy transition, their strategic role and steering function are far more important. In this context, it is not the tonnes of CRM transported and used that are significant but rather the impacts on other physical flows associated with them. For example, CRMs are mainly extracted in combination with other *metals* (copper, nickel, zinc, etc.). Increasing production therefore has impacts upon other resource flows and their subsequent processing. Equally, there may be relevant quantities of CRMs to be found in production wastes from other *metals* (e.g. cobalt in copper mining residues; European Commission 2017b). Unexploited potentials should be explored and taken advantage of. Extraction and processing in the case of primary raw materials, or collection, disassembling and processing in the case of secondary raw materials are all closely linked to energy consumption. Any increase in production is therefore also linked to an increase in future energy use. Therefore, an increase in the production of alternative forms of energy, which is in most cases associated with the use of batteries, retrospectively implies an increase in energy consumption. This feedback effect shows that efforts must be made to achieve a simultaneous reduction in overall energy demand.

# Future challenges

A photograph of a city street scene, viewed from a low angle looking up. On the left, a modern, multi-story apartment building with a light-colored facade and many windows is visible. On the right, a traditional, multi-story building with a darker facade and smaller windows is visible. A large, leafy green tree stands in the middle ground, partially obscuring the buildings. The sky is a pale, overcast grey. The entire image is overlaid with a semi-transparent green filter. The text 'Future challenges' is written in a white, sans-serif font in the upper left quadrant.



The global sustainability goals of the UN (2015) provide the framework for a future development path that addresses all three pillars of sustainability (social, economic and environmental sustainability) ( see side note 1, page 10). Eurostat regularly publishes reports on progress in implementing the Agenda 2030 of the EU and its Member States. Figure 34 summarises Austria's progress in achieving the targets of SDG 12, based on the most recent Eurostat report (Eurostat 2019a).



Figure 34: Austria's progress in achieving the targets of SDG 12

Source: Author's own image, based on Eurostat 2019a

In the period from 2004 to 2016, Austria shows some progress in the area of sustainable resource use: *resource productivity* is increasing both from a domestic (DMC) and consumption-based (RMC or *material footprint*) perspective. Nonetheless, no significant reduction in absolute resource consumption has been achieved to date. In EU comparison, resource efficiency in Austria is growing more slowly and even declined in 2015. The further trend will need to be monitored closely.

We also see improvements (increasing rates of recycling, falling volumes of wastes generated) in the case of waste reduction. However, the explanations contained in the chapter on the circular economy demonstrate that looking purely at the waste side can only shed light on a small area of the whole picture. A macroeconomic perspective must look at four areas: greenhouse gas emissions, waste generation, resource input, and the accumulation of stocks ( see chapter on “The circular economy from a macroeconomic perspective”, page 62 ). From this perspective, we can see, for example, that there is a positive trend in CO<sub>2</sub> emissions, which declined for more than ten years between 2005 and 2014. Nonetheless, these reductions were too small to contribute enough to achieving the global climate goals. Furthermore, the emissions between 2014 and 2015 rose once again and the further trend will have to be carefully monitored.

An analysis of the relationship between resource efficiency and climate protection (see chapter on “Resource conservation and climate protection go hand in hand”, page 36) reveals great synergies and consequently that activities aimed at increasing resource efficiency can have positive impacts on CO<sub>2</sub> emissions. Hotspots include economic activities related to the construction industry, food production and healthcare.

SDG 12 also addresses the energy consumption of a country. Although Austria lies above the EU average in this respect because of its high share of energy from renewable sources, its energy consumption is increasing somewhat. Transforming the energy system and reducing fossil energy use in favour of renewable energies brings with it new challenges, which have received relatively little attention up to now: renewable energy sources are very closely linked to the increasing demand for critical raw materials (see chapter on “Critical mineral raw materials play a keyrole for future technologies“, page 58). Pressures due to rising prices, supply shortages and increasing energy use in the production of infrastructure are factors that potentially could lead to an increase in both resource use and energy consumption.

The thematic chapters in this report have highlighted different approaches to analysing and implementing sustainable resource use. These diverse perspectives reveal elements within the *metabolism of society* as a whole, which, however, do not act in isolation from one another but are connected with one another through *societal* structures of production and consumption. Examples of successful implementation in sub-sections of the overall picture must therefore be analysed in terms of their impacts on the system as a whole. To mitigate potential conflicts of interest, these sub-sections must work towards an overarching goal. Reducing the overall resource use of *society* as a whole is the overarching goal in the case of sustainable resource use. We need to extract less *resources* from nature and release less wastes and emissions into natural ecosystems. We will only achieve a change of course through the long-term absolute reduction in resource use.

## Austria's resource use is still too high – what should happen next?

The challenges of sustainable resource use are clear – we need to achieve a reduction in the resource use of *society* as a whole. Substantial measures are required, which go far beyond the efforts made so far. To better estimate the scale at which such measures will be needed, the following section highlights trend projections showing how implementing certain targets would impact resource use in Austria between 2030 and 2050.

Developments over the last 15 years were characterised by *relative decoupling*: the economy has grown by an average of 1.4% per year, while resource use has shown a very slight reduction (average -0.2% per year). If we were to follow a similar path in the years ahead and continue the developments of the past on into the future, resource use would remain relatively stable, with a minimal reduction by 2030 of 152 million tonnes or 16 t/cap/a in 2030 and 146 million tonnes or 15 t/cap/a in 2050. If economic growth occurs, this would involve the production of 2,511 Euros per tonne in 2030. This means that resource efficiency would grow by a factor of 1.3 or by 30%. By 2050, resource efficiency would increase further to 3,505 Euros per tonne, equating to an increase of 80%.

To actually reduce resource use and with this the environmental impact, there needs to be an absolute reduction in resource consumption. We have seen from the analyses in this report that in the European context, Austria is characterised by a relatively high level of resource use. In 2018, Austria used 19 tonnes per capita, in contrast to the EU average of just under 14 t/cap/a. For Austria to reduce its consumption levels to the European average by 2030, material consumption would have to fall to 126 Mt/a (-19%). If we only reduce consumption to the EU average by 2050, then the reduction of resource use would be less marked, at -15%. Material consumption in 2050 would then be 133 Mt/a .

It is difficult to determine sustainable resource use in terms of a specific value for tonnes of *resources* consumed per year when it comes to pressure indicators (pressure indicators; see UN IRP 2019a), because they do not reveal direct environmental impacts. Reduction targets are therefore specified in accordance with a precautionary principle. In the literature, we may find, for example, a specification of 7 t/cap/a as an acceptable figure for resource use (Bringezu 2015; UN IRP 2014). If we were to adopt this target value of 7 t/cap/a for Austria to achieve by 2050, we would have to reduce resource use to 69 Mt/a ; this would equate to half of the resource use seen in 2015 (-56%). If we wished to achieve this target of 7 t/cap/a by 2030, then we would have to reduce resource use by then by almost 60% to 66 Mt/a .

## Which measures will enable us to achieve a change of course?

The projections show that ambitious measures are required; all the options identified so far must be fully exploited. Almost half of all resource use relates to *non-metallic minerals*, which are required to expand and maintain our stocks. What is more, although sand, gravel and stone have been freely available until now, they are becoming scarce commodities through the huge scale of demand, shrinking availability of land and the quality of grain structure. If we were to make changes to our stocks, we could also reduce consumption of *non-metallic minerals*. At the same time, we would be able to achieve a reduction in metallic raw materials, which are also fixed in stocks, albeit in smaller quantities. And finally, reducing these stocks would also have an indirect and multiplying impact, particularly through reduced energy consumption in both the production and the operation of our stocks. A change of course thus requires the conversion of our *societal* stocks in the direction of non-growing, low-maintenance and durable infrastructures. . What is needed here are innovative ideas from planning to optimal land use, as well as from construction technologies to optimising the material composition of building materials.

Along with a focus on stocks, we also need to transform energy use, to reduce greenhouse gases further and at a greater rate. A transformation of energy use requires an end to the use of fossil fuels and a transition to renewable energy sources. Reducing *societal* stocks would also support a reduction in greenhouse gases, since our built infrastructure is closely linked to energy consumption and subsequently to emissions.

Finally, we must acknowledge that our *society* cannot be sustained without the use of *resources*. We require energetic supply for our *metabolism* (beginning with food for humans and animals) and base our everyday lives on material consumer goods. Thus, to achieve sustainable resource use we will have to exploit the potential of recycling to the maximum level that is environmentally and socially tolerable. Doing this requires measures such as changes in product design (to promote repair and the enable objects to be disassembled into their component parts), extending the lifetimes of legal guarantees, mandatory requirements for product lifespans, management measures to support repair services, to prolong the useful life of products, optimising recycling processes through technology development and processing anthropogenic stocks (waste disposal sites and redundant infrastructure). And finally, we must develop ways of living and social models that require less *resources*. Despite all the efficiency measures and optimised technology, the high material standard of living enjoyed in today's industrialised countries is not transferable throughout the world.

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## Glossary

**Biomass** encompasses all organic matter: live plants, animals, micro-organisms, and also dead organic matter (dead wood, leaf litter, straw, etc.) Biomass is frequently referred to as renewable raw material. Material flow accounting does not include the fossil energy carriers that have their origin in biomass.

**Decoupling** of economic output and resource consumption occurs when economic growth is higher than the growth of resource consumption (in other words, resource productivity increases). A distinction is made between two types of decoupling: decoupling with increasing resource consumption (relative decoupling) in which resource productivity increases more slowly than economic growth; and decoupling with decreasing resource consumption (absolute decoupling), in which resource productivity increases at a faster rate than economic growth.

**Domestic extraction** (DE) encompasses all domestically extracted materials. These include the agricultural harvest, felled timber and the products of mining.

**Domestic material consumption** (DMC) describes the share of materials remaining in a national economy. The DMC therefore equals domestic material extraction plus imports minus exports. In this report, DMC is often referred to in shortened form as material consumption.

**Domestic processed output** (DPO) includes all materials, which following their use in socio-economic systems are emitted into the natural environment as gaseous, liquid or material outputs. This is the sum of domestic emissions into the air and water together with uncontrolled deposited wastes.

**Environmental accounts** are accounts in monetary and physical units, which supplement the national accounts to provide a comprehensive picture of the interconnections between the economy and the environment. For this purpose physical data concerning raw material, energy, water or land use, waste and waste water disposal as well as atmospheric emissions, are set against monetary data, including gross domestic product, income, consumption, investments, etc. Environmental accounts are structured according to the EU guidelines on environmental indicators and a green national accounting system.

**Fossil energy carriers** are non-metallic mineral raw materials, which have been produced in the Earth's crust over millions of years from plant or animal remains and are primarily used for energy production.

The indicator **HANPP** (human appropriation of net primary production) quantifies the amount of biomass extracted for use by society as a proportion of the total biomass

existing in ecosystems, measured in net primary production (Erb 2011; Haberl 2012; Haberl et al. 2007), and functions to some degree as an indicator for land use intensity. Analogous to material footprint, the consumption-based indicator eHANPP (Erb et al. 2009) can be calculated.

The **Herfindahl-Hirschman Index (HHI)** is a measure for (market) concentration in a common market, enabling a potentially dominant position by one or more firms within the market to be made visible. The HHI is calculated as the sum of the square of the market shares of firms within a common market. The higher the HHI, the smaller the number of firms upon which a relatively larger share of production is concentrated. In the EU a market is defined as concentrated when the HHI lies above 2000. In this report the HHI is used as in the World Mining Data as an indicator for the concentration of raw materials by country.

Physical **imports and exports** comprise all goods traded at the mass they exhibit at the point of crossing national borders. The goods include products from widely varying stages of production, ranging from simple products to semi-finished and finished products. In the MFA, the products traded are allocated to one of the four material categories, depending on their main components. There are products which cannot be assigned to any of the four material categories: these are subsumed under the category “Other products” and include e.g. plant facilities, antiques, and optical elements.

The term **material** is used for the material aspect of resources. Material flows are expressed in metric tonnes and according to four main groups: biomass, fossil energy carriers, metals and non-metallic minerals. Material flows, as recorded in material flow accounting, can also comprise materials that have been processed into products.

**Material flow analysis or Material flow accounting (MFA)** is an accounting tool for the material inputs and outputs of a socioeconomic system. The MFA is complementary to economic national accounts and forms part of the environmental accounts. It records all material extractions in the country, imports and exports together with changes in stocks and outputs to nature. The socioeconomic system studied is defined analogously to the System of National Accounts (SNA) and the boundaries to the natural environment and to other economies are set accordingly. From the natural environment resources extracted from the domestic territory (domestic extraction, DE) enter the system as inputs and flow back into it as emissions and wastes (DPO, domestic processed output). Imports enter the system from other economies and exports leave the system to flow into other economies.

**Material footprint (MF)** reflects the domestic material consumption in raw material equivalents. This means, that it comprises domestic extraction plus the imports measured in RME minus the exports measured in RME. The MF thus describes the entire requirement

for raw materials, both nationally and globally, which a country makes use of through its final consumption. Another synonymous term for material footprint is raw material consumption (RMC), which was used in previous reports.

**Metals** include mineral materials ranging from ores to processed metals. Raw material sciences define ores as mineral materials from which metals can be extracted with economic benefit. In material flow analysis, metals are subdivided into ferrous and non-ferrous ores.

Fossil energy carriers, metallic and non-metallic minerals together are also defined as **mineral raw materials**. Mineral raw materials are anorganic and organic mineral substances in a solid, liquid or gaseous state, which developed through geological processes by natural means, were enriched in deposits and, due to their utility value, can be exploited economically.

The group of **non-metallic minerals** comprises construction minerals and industrial minerals. Construction minerals are non-metallic mineral raw materials, such as sand and gravel, of which great amounts are needed for construction purposes. Industrial minerals are mineral raw materials, which, due to their chemical or physical properties, can be directly used in production processes. Industrial minerals do not include ores, construction minerals and raw materials for energy.

The **physical trade balance** (PTB) is calculated by subtracting exports from imports. It is defined conversely to the monetary trade balance (which is calculated by subtracting imports from exports). This reflects the fact that money and material flow in opposite directions in economies (imports mean that money flows abroad, while material enters the country in the form of products). A positive PTB (imports exceed exports) means that the country is a net importer of materials and thus depends on the supply of materials from abroad, whereas a negative PTB characterises countries which offer materials on the global market for use in other countries.

The concept of **planetary boundaries** (Rockström et al. 2009; Steffen et al. 2015) defines the Earth's biophysical boundaries, and the severe impacts on the stability of ecosystems and the basis for sustaining human life that will occur when these thresholds are exceeded. Scientists have defined nine of these planetary boundaries: climate change, acidification of oceans, stratospheric ozone depletion, biogeochemical cycles of nitrogen and phosphorus, freshwater consumption, land use changes, biodiversity loss, chemical pollution and introduction of novel substances, and atmospheric aerosol pollution.

**Raw material equivalents** (RME) of imports (RIM) and exports (REX) are composed of the entire raw material inputs that were required in the production of the traded goods (intermediate inputs of material), plus the mass of the imports and exports

themselves. RME correspond to the entire raw materials from which an import or export is constituted, regardless of where (i. e. in which economy) the raw materials were used during production.

**Resource productivity** (from a perspective of material flows as GDP/DMC) describes the relationship between monetary output and resource input: How many Euros of GDP can be generated by means of the materials used? Resource productivity is a relative value. An increase can thus be achieved through rising GDP or through diminishing material consumption. Resource productivity is also defined in the EU as resource efficiency. In the SDGs, resource efficiency is understood as its reciprocal (DMC/GDP or MF/GDP), which is also referred to as resource intensity. Resource intensity describes how much resource consumption is caused by GDP. In this report, the terms resource productivity and resource efficiency are used synonymously.

**Resources** include all physical raw materials and stocks that are intentionally extracted or transformed in nature and used by society. The physical resources themselves are not lost when used, but are transformed instead. The specific quality, which makes them useful for society is usually consumed and lost in this process. In the empirical analysis, this report focuses on material resources, i. e. on biomass, fossil energy carriers, and metallic and non-metallic minerals.

The **System of National Accounts (SNA)** is, in principle, a closed system of accounts in which significant macroeconomic variables are reported as transactions or balances (e. g. gross domestic product (GDP) gross national income, available household income, net lending/borrowing by the state, private consumption, investments), based on the notion of an economic cycle. The System of National Accounts is internationally harmonised. A variant specifically tailored to European conditions is the European System of National Accounts (ESNA). Whereas the SNA is a recommendation, the ESNA is legally binding (EU Regulation).

The term **society** as used in this publication is complementary to nature (or the “natural system”). Society is a communication system that is coupled with the natural system via biophysical structures. The communication system of society comprises subsystems like the economy, law, politics and education. Biophysical elements of society include the human population, its infrastructures and artefacts, as well as, by definition, productive livestock. Society must reproduce itself both in respect of culture and communication and also biophysically. Resources are used for the purposes of biophysical reproduction i. e. the establishment and maintenance of the physical structures of society.

The concept of **social metabolism** assumes that society, analogous to a biological organism, operates through “metabolism” (or exchange) with its natural environment. During this process, inputs (e. g. material, energy, water, air) from nature are used,

transformed, and partly integrated into its stocks. Sooner or later, all these inputs (following one-time or multiple periods of use) become outputs again, which society discharges into its environment in the form of wastes or emissions. Physical accounts can be used to record this metabolism.

## Abbreviations

CF	carbon footprint
CRM	critical raw materials
DE	domestic extraction
DMC	domestic material consumption
DMI	direct material input
DPO	domestic processed output
EE-MRIO	environmentally-extended multi-region input-output models
EU-28	the 28 Member States of the European Union (as of 2019)
GDP	gross domestic product
GVA	gross value added
HANPP	human appropriation of net primary production
HDI	human development index
HHI	Herfindahl-Hirschman Index
LCA	life cycle analysis
MF	material footprint
MFA	material flow accounting
PTB	physical trade balance
RMC	raw material consumption
RME	raw material equivalents
RP	resource productivity
SNA	System of National Accounts

## Units

/a	per annum
/cap	per capita
GJ	gigajoule (billion joules)
Gt	gigatonne (billion metric tonnes)
ha	hectare
kg	kilogramme
kt	kilotonne (thousand metric tonnes)
MJ	megajoule (million joules)
Mt	megatonne (million metric tonnes)
t	metric tonnes

## Countries

AT	Austria
BE	Belgium
BG	Bulgaria
CY	Cyprus
CZ	Czech Republic
DE	Germany
DK	Denmark
EE	Estonia
ES	Spain
FI	Finland
FR	France
GB	Great Britain
GR	Greece
HR	Croatia
HU	Hungary
IE	Ireland
IT	Italy
LT	Latvia
LU	Luxembourg
LV	Lithuania
MT	Malta
NL	Netherlands
PL	Poland
PT	Portugal
RO	Romania
SE	Sweden
SI	Slovenia
SK	Slovakia

## Data tables

**Table 1:**  
Austrian material flows in million tonnes per year, growth of flows between 2000 and 2018, and composition of flows by material category

Values are rounded, rounding differences are not balanced.

	Material flows (Mt/a)		Growth (factor)	Share of total flow	
	2000	2018	2000–2018	2000	2018
<b>Domestic extraction (DE)</b>	<b>136</b>	<b>135</b>	<b>1.0</b>		
Biomass	32	35	1.1	23%	26%
Fossil energy carriers	4	2	0.4	3%	1%
Metals	2	3	1.5	2%	2%
Non-metallic minerals	98	95	1.0	72%	71%
<b>Imports</b>	<b>67</b>	<b>99</b>	<b>1.5</b>		
Biomass	17	27	1.6	26%	27%
Fossil energy carriers	25	34	1.4	38%	35%
Metals	14	21	1.6	20%	22%
Non-metallic minerals	7	10	1.4	11%	10%
Other products	3	6	1.8	5%	6%
<b>Exports</b>	<b>40</b>	<b>67</b>	<b>1.7</b>		
Biomass	16	24	1.5	39%	36%
Fossil energy carriers	6	12	2.1	14%	18%
Metals	10	16	1.7	24%	24%
Non-metallic minerals	7	10	1.4	17%	14%
Other products	3	5	1.8	7%	7%
<b>Domestic material consumption (DMC)</b>	<b>162</b>	<b>167</b>	<b>1.0</b>		
Biomass	34	38	1.1	21%	23%
Fossil energy carriers	23	24	1.0	14%	15%
Metals	6	8	1.3	4%	5%
Non-metallic minerals	98	95	1.0	61%	57%
Other products	1	1	1.7	0%	1%



**Table 2:**  
**Austrian domestic material consumption (DMC) in tonnes per capita**  
**and year by material category and growth of flows between 2000**  
**and 2018**

*Values are rounded, rounding differences are not balanced.*

	Material flows (t/cap/a)		Material flows (factor)	Share of total flow	
	2000	2018	2000–2018	2000	2018
<b>Domestic material consumption per cap (DMC/cap/a)</b>	<b>20</b>	<b>19</b>	<b>0.9</b>		
Biomass	4	4	1.0	21%	23%
Fossil energy carriers	3	3	0.9	14%	15%
Metals	1	1	1.2	4%	5%
Non-metallic minerals	12	11	0.9	61%	57%
Other products	0	0	1.5	0%	1%

**Table 3:**  
**Resource productivity (RP) in Euros per kilogramme, as well as its components domestic material consumption (DMC) in million tonnes per year and GDP in billion Euros per year, 2000 and 2018; growth of flows between 2000 and 2018**

*Values are rounded, rounding differences are not balanced.*

	2000	2018	Growth (factor)
Resource productivity, RP (€/t)	1,731	2,211	1.3
Domestic material consumption, DMC (Mt/a)	162	167	1.0
Gross domestic product, GDP* (M€/a)	280,579	368,712	1.3

\* GDP in chained volumes (Base year 2015)

**Table 4:**  
**Austrian material flows by material category in million tonnes per**  
**year, 2000–2018**

*Values are rounded, rounding differences are not balanced.*

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
<b>Domestic extraction (DE)</b>	<b>136</b>	<b>132</b>	<b>145</b>	<b>135</b>	<b>142</b>	<b>144</b>	<b>144</b>	<b>148</b>	<b>142</b>	<b>131</b>	<b>130</b>	<b>137</b>	<b>130</b>	<b>129</b>	<b>132</b>	<b>128</b>	<b>134</b>	<b>132</b>	<b>135</b>
Biomass	32	33	34	33	37	38	37	37	41	36	36	38	35	35	38	35	38	35	35
Fossil energy carriers	4	4	4	4	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Metals	2	2	2	3	2	3	2	3	2	2	2	3	3	3	3	3	3	3	3
Non-metallic minerals	98	93	104	95	100	102	102	105	97	90	89	94	90	89	89	88	92	92	95
<b>Imports</b>	<b>67</b>	<b>69</b>	<b>72</b>	<b>75</b>	<b>79</b>	<b>83</b>	<b>89</b>	<b>92</b>	<b>89</b>	<b>81</b>	<b>89</b>	<b>93</b>	<b>93</b>	<b>90</b>	<b>88</b>	<b>90</b>	<b>94</b>	<b>97</b>	<b>99</b>
Biomass	17	17	17	18	20	20	23	23	22	22	23	24	23	25	24	25	26	27	27
Fossil energy carriers	25	27	29	31	31	33	33	33	33	31	33	34	34	31	30	31	33	34	34
Metals	14	14	14	15	16	17	19	21	21	15	20	22	21	19	18	19	19	21	21
Non-metallic minerals	7	7	7	7	8	8	9	10	9	8	8	9	8	9	10	10	9	10	10
Other products	3	4	4	4	4	4	5	5	5	5	5	6	6	6	6	6	6	6	6
<b>Exports</b>	<b>40</b>	<b>43</b>	<b>46</b>	<b>48</b>	<b>52</b>	<b>54</b>	<b>57</b>	<b>63</b>	<b>63</b>	<b>54</b>	<b>59</b>	<b>60</b>	<b>59</b>	<b>59</b>	<b>60</b>	<b>61</b>	<b>63</b>	<b>65</b>	<b>67</b>
Biomass	16	16	17	18	19	20	21	22	22	20	21	22	21	21	21	22	23	23	24
Fossil energy carriers	6	7	8	8	9	9	10	12	12	10	11	12	11	10	10	11	11	11	12
Metals	10	10	10	11	12	12	13	14	15	11	13	14	14	14	15	14	15	16	16
Non-metallic minerals	7	7	8	8	8	8	9	10	10	8	9	9	8	8	9	9	9	9	10
Other products	3	3	3	3	4	4	4	4	5	4	4	4	4	5	5	5	5	5	5
<b>DMC</b>	<b>162</b>	<b>158</b>	<b>170</b>	<b>161</b>	<b>169</b>	<b>173</b>	<b>176</b>	<b>177</b>	<b>169</b>	<b>158</b>	<b>161</b>	<b>170</b>	<b>164</b>	<b>161</b>	<b>160</b>	<b>157</b>	<b>165</b>	<b>164</b>	<b>167</b>
Biomass	34	34	34	33	38	37	39	38	40	38	38	40	37	38	41	37	41	38	38
Fossil energy carriers	23	24	25	27	25	26	26	24	23	23	24	24	26	23	22	23	24	24	24
Metals	6	6	6	7	6	8	9	10	8	7	9	10	10	8	6	8	8	9	8
Non-metallic minerals	98	93	103	95	99	102	102	105	97	89	88	94	90	90	90	89	92	92	95
Other products	1	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1

**Table 5:**  
**Austrian domestic material consumption (DMC) by material category**  
**in tonnes per cap and year, 2000–2018**

*Values are rounded, rounding differences are not balanced.*

	Material flows (Mt/a)		Growth (factor)	Share of total flow	
	2000	2018	2000–2018	2000	2018
<b>Domestic extraction (DE)</b>	<b>136</b>	<b>135</b>	<b>1.0</b>		
Biomass	32	35	1.1	23 %	26 %
Fossil energy carriers	4	2	0.4	3 %	1 %
Metals	2	3	1.5	2 %	2 %
Non-metallic minerals	98	95	1.0	72 %	71 %
<b>Imports</b>	<b>67</b>	<b>99</b>	<b>1.5</b>		
Biomass	17	27	1.6	26 %	27 %
Fossil energy carriers	25	34	1.4	38 %	35 %
Metals	14	21	1.6	20 %	22 %
Non-metallic minerals	7	10	1.4	11 %	10 %
Other products	3	6	1.8	5 %	6 %
<b>Exports</b>	<b>40</b>	<b>67</b>	<b>1.7</b>		
Biomass	16	24	1.5	39 %	36 %
Fossil energy carriers	6	12	2.1	14 %	18 %
Metals	10	16	1.7	24 %	24 %
Non-metallic minerals	7	10	1.4	17 %	14 %
Other products	3	5	1.8	7 %	7 %
<b>Domestic material consumption (DMC)</b>	<b>162</b>	<b>167</b>	<b>1.0</b>		
Biomass	34	38	1.1	21 %	23 %
Fossil energy carriers	23	24	1.0	14 %	15 %
Metals	6	8	1.3	4 %	5 %
Non-metallic minerals	98	95	1.0	61 %	57 %
Other products	1	1	1.7	0 %	1 %

**Table 6:**  
**Austrian resource productivity (RP) in Euros per kilogramme, and its components domestic material consumption (DMC) in million tonnes per year and GDP in billion Euros per year, 2000–2018**

*Values are rounded, rounding differences are not balanced.*

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
<b>Domestic material consumption per capita(DMC/cap/a)</b>	20	20	21	20	21	21	21	21	20	19	19	20	19	19	19	18	19	19	19
Biomass	4	4	4	4	5	5	5	5	5	5	5	5	4	5	5	4	5	4	4
Fossil energy carriers	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Metals	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Non-metallic minerals	12	12	13	12	12	12	12	13	12	11	11	11	11	11	11	10	11	11	11
Other products	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

**Table 7:**  
**Austrian material footprint (MF) in million tonnes per year and tonnes per cap and year, 2000–2015**

*Values are rounded, rounding differences are not balanced.*

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Material footprint (Mt/a)	202	196	204	192	201	228	229	230	212	207	209	223	214	209	210	207
Material footprint (t/cap/a)	25	24	25	24	25	28	28	28	26	25	25	27	25	25	25	24

**Table 8:**  
**Austrian domestic processed output (DPO) by sub-category in million tonnes per year, 2000–2017**

*Values are rounded, rounding differences are not balanced.*

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
<b>Domestic processed outputs (DPO)(Mt/a)</b>	83	87	87	92	92	96	97	95	97	93	99	97	95	95	90	92	91	94
Air emissions	78	82	82	87	88	91	92	90	92	88	94	92	90	91	85	87	86	89
of these, CO <sub>2</sub> emissions	76	81	81	86	86	90	91	89	91	87	93	91	89	89	84	86	85	88
Emissions to water*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dissipative use of products	5	5	5	5	5	5	5	5	5	4	4	5	4	4	4	5	5	5
Dissipative losses*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wastes deposited to controlled landfills	2	2	2	1	1	2	2	2	2	2	2	2	2	2	2	3	3	3

\* zero values indicate values smaller than 1Mt; in the case of emissions to water between 77,055 t (2000) and 32,163 t (2017), in the case of dissipative losses between 2,987 t (2000) and 3,593 t (2017).







