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

Federal Ministry
Republic of Austria
Finance

Resource Use in Austria 2024

Volume 4.

Resource Use in Austria 2024

Vienna, 2024

Imprint

Media owner, publisher and editor: Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK)
Radetzkystraße 2, 1030 Vienna
Tel: +43 (0) 800 21 53 59
bmk.gv.at

In cooperation with the Federal Ministry of Finance, Directorate VI/5 Mineral Resources Policy
Johannesgasse 5, 1010 Vienna
Tel: +43 1 514 33-0
bmf.gv.at

Overall realization: BMK, Directorate General V Environment and Circular Economy

Authors:
Nina Eisenmenger, André Baumgart, Fridolin Krausmann, Hanspeter Wieland, Willi Haas
(Institute of Social Ecology, Universität für Bodenkultur Wien)
Milla Neubauer, Sylvia Gierlinger
(Statistics Austria)

Expert coordination:
Erna Etlinger Van Der Veeren, Andreas Tschulik
(Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology)
Magdalena Pupp, Susanne Strobl, Robert Holnsteiner
(Federal Ministry of Finance, Directorate General Telecommunications, Post and Mining)

Design: COPE Content Performance Group
Illustrations: Leonard Schwieger
Photography credits: BKA/Andy Wenzel (Portrait Magnus Brunner), BMK/Cajetan Perwein (Portrait Leonore Gewessler)
English Translation: Ursula Lindenberg

Vienna, 2024

Foreword Magnus Brunner

Federal Minister of Finance
Magnus Brunner

An entire spectrum of measures and new technologies are required to secure the foundations for our existence and to progress towards climate neutrality. Developing these transformative technologies requires a significant increase in the use of mineral raw materials. Currently, 34 raw materials are designated as critical raw materials by the European Union, due to the high level of risk associated with their supply. Of these, 17 are categorised as having particular strategic importance. The Critical Raw Materials Act (CRMA), which entered into force as an EU Regulation in May 2024, is intended to minimise the supply risks relating to these raw materials, through support for the domestic mining industry, accelerating the transition to a circular economy, and the diversification of supply chains.

Supply security also involves sustainable and efficient resource management. This requires detailed analysis of supply and demand and of the entire lifecycle, from extraction through use to recycling. This report, the fourth in a series titled "Resource Use in Austria", focuses on these themes and seeks to identify pathways towards a climate-neutral future for Austria.

Foreword Leonore Gewessler

Bundesministerin
Leonore Gewessler

Our society's use of resources plays a central role in the transformation to a sustainable, climate-neutral, circular and resilient economy. Global resource use has more than tripled over the last 50 years and, unless preventive action is taken, is expected, according to the current Global Resource Outlook, to be 60 per cent higher by 2060 than it is today. Reducing the use of our valuable natural resources also significantly reduces greenhouse gas emissions and the pressures on our environment.

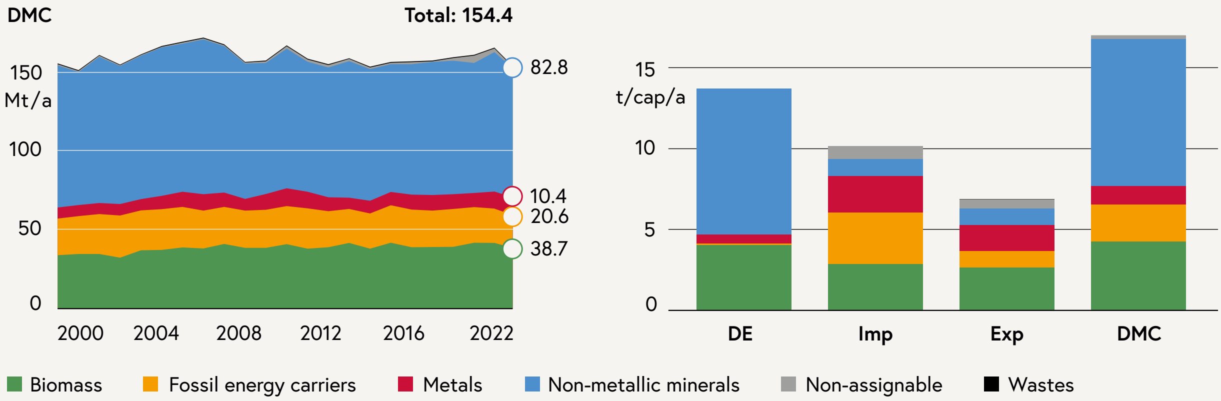
Conserving resources is synonymous with climate protection. The Circular Economy Strategy, adopted by the Austrian federal government in 2022, represents a key building block for the transition to a circular economy. This aims to transform the Austrian economy and society into a climate-neutral and sustainable circular economy by 2050. Within a circular economy, resources are used efficiently, products are circulating and in use for as long as possible, reused, repaired and at the end of their life reprocessed or recycled as material resources. A more sustainable and future-oriented approach to our material resources allows us and succeeding generations the opportunity to create a just and climate-neutral future. The preparation of reliable data is an essential basis for political decision making. This report makes use of the most recent data in its analysis of Austria's resource use and thereby provides an evidence-based foundation for policy approaches that centre resource sustainability and the circular economy. I hope this will prove an enjoyable and interesting read for all!

Table of Contents

With a circular economy towards sustainable resource use? The essentials in brief

Resource use in Austria

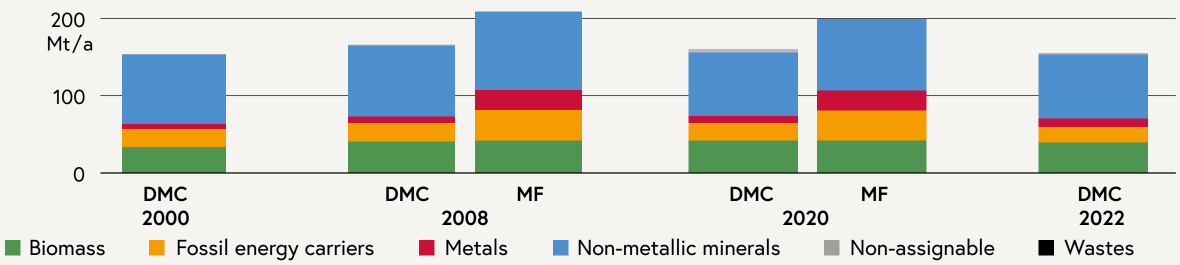
Resource use in Austria increased steadily since 1960 and amounted to 154 million tonnes in 2000. Since then and up to 2022 domestic material consumption remained at more or less the same, high level. With a per capita material consumption of 17 t/cap/yr in 2022 we are transgressing planetary boundaries.



The category “Waste” includes net imports of waste for final treatment and landfill. “Waste” therefore does not show the total amount of waste treated or landfilled in Austria. The category “unclassifiable” includes, on the one hand, finished goods made from a mix of materials that cannot be assigned to any of the four material groups and, on the other hand, raw materials or goods that cannot be specified in more detail in the statistics for reasons of confidentiality.
Source: Statistics Austria 2024

Material footprint in Austria

The material footprint (MF) of Austria is larger than the DMC, which indicates that the global raw material demand associated with final demand in Austria is larger than the domestic material consumption within Austrian administrative boundaries. The development of MF is similar to the one of DMC, between 2008 and 2020 the material footprint decreased from 209 Mt/a to 199 Mt/a by 5 %.

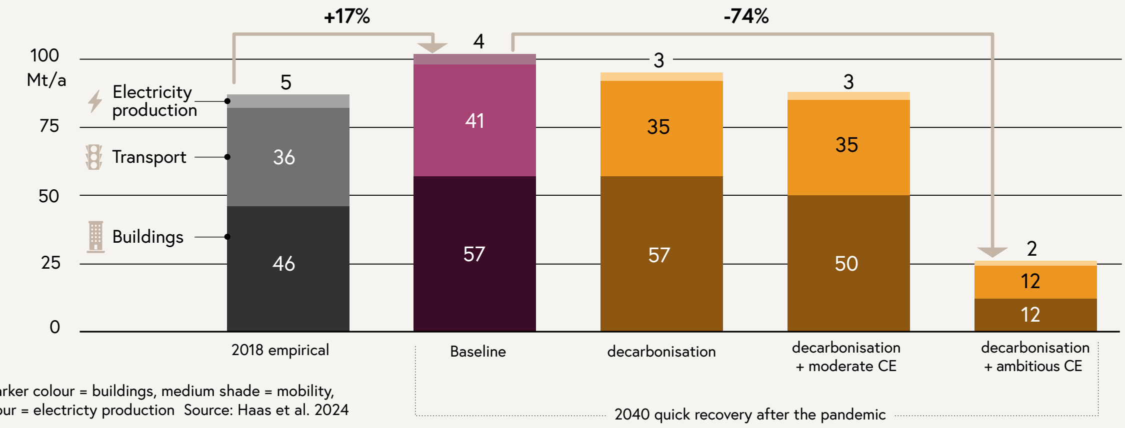


Explanatory note: The category “non-assignable” comprises on one hand manufactured products containing a mix of materials, which prevents their allocation to one of the four material categories, and on the other hand goods not further specified in the statistics for reasons of confidentiality.
Source: Statistics Austria 2024

Impact of circular economy measures

Ambitious circular economy measures could lead to a significant reduction in material consumption to 26 Mt/a in 2040 (-37 %). The most important measures are far-reaching, sufficiency-based measures such as a halt to construction on undeveloped land, extending the lifespan of buildings, and a shift in the modal split towards active mobility and car sharing.

PROCESSED MATERIALS

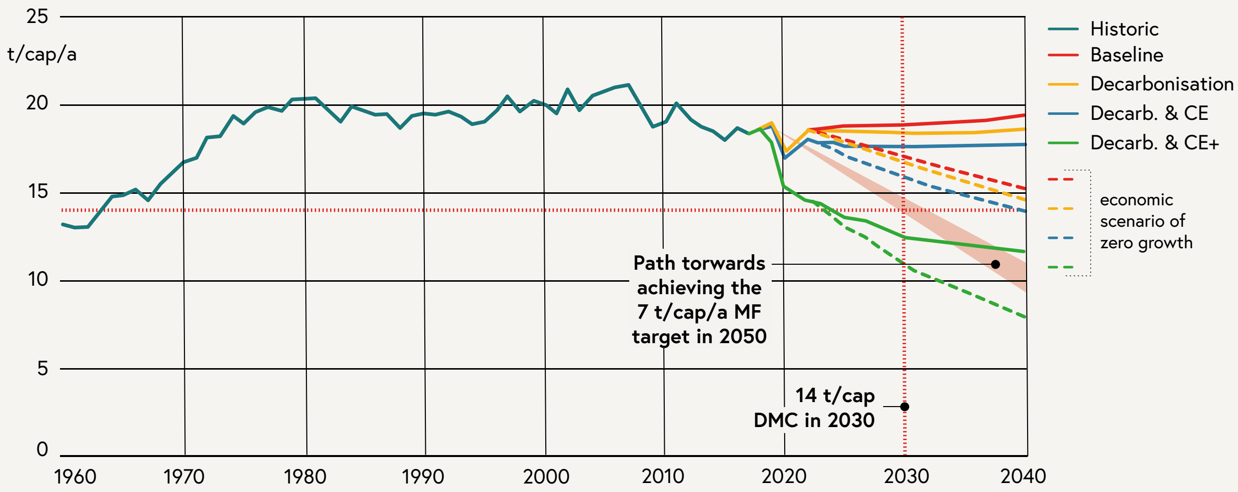


notes: darker colour = buildings, medium shade = mobility, light colour = electricty production Source: Haas et al. 2024

Achievement of the goals of the circular economy strategy

In order to achieve the goals of the circular economy strategy, a significant shift away from current trends is necessary. Reduction strategies (narrowing) have the greatest impact, as they can reduce material consumption by up to 70 %.

DMC



Notes: Decarb. = Decarbonisation, CE = moderate circular economy measures, CE+ = ambitious circular economy measures.

1 Planetary boundaries are frequently exceeded

Our current way of life, particularly in the industrialised world, is not sustainable. In fact, the opposite is true: our societal and economic activities are creating environmental pressures, which exceed the planetary boundaries of our world (Rockström et al. 2009b; Steffen et al. 2015; Fanning et al. 2022). The most recent publication from Richardson et al. (2023) argues that globally six of the nine planetary boundaries have been exceeded; three to four of these being in the high-risk zone (biosphere integrity, climate change, biogeochemical flows and novel entities). Furthermore, the authors show that the degree by which these boundaries are being exceeded has increased since the first assessments were made (Rockström et al. 2009b; Steffen et al. 2015). Because of this, environmental pressures are increasing rapidly; an effect that is referred to in the scientific literature as the "great acceleration" (Steffen et al. 2015).

All the environmental impacts of societal activities are the consequence of socioeconomic resource use (further details are contained in the following chapter) and are closely linked to economic activities and societal consumption (Brand-Correa et al. 2020). This makes rethinking, transforming and reducing resource use very challenging for us all. Nonetheless, the ever more visible and tangible environmental crises, such as the climate crisis or the biodiversity crisis, call for urgent action to be taken: we must reduce both environmental pressures and resource use. Unfortunately, studies to date reveal very few stories of success (see, for example, the systematic literature review by Haberl et al. 2020). Empirical analysis shows that significant changes or even reversals in current trends can only be observed during phases of economic crisis.

In the last decade, diverse social, economic and ecological crises have occurred in rapid succession; these appear to have become characteristic aspects of our globalised world. The last five years alone were marked by signs of a deepening climate crisis, with an abundance of heatwaves and extreme weather events. This situation is being driven by societal use of fossil energy carriers and large-scale changes in land use, while the impacts of the climate crisis are causing enormous damage to infrastructure as well as to the agriculture and forestry sectors. Phasing out the use of fossil energy carriers in the next few years is absolutely essential. The COVID pandemic unleashed a health crisis that was without parallel in recent decades, and which can at least in part be attributed to the increasing land use demands of agricultural resource consumption. The continuous pressure on and exploitation of habitats makes the transmission of pathogens from animals in the wild to livestock and domestic animals and subsequently to humans (zoonosis) ever more likely (Dobson et al. 2020; White and Razgour 2020; Bernstein et al. 2022). The COVID pandemic also repeatedly interrupted supply chains and consequently also the supply of resources to societies (Chowdhury et al. 2021). Following on from this, the Russian invasion of Ukraine had profound and unanticipated political and economic impacts in Europe. The Ukraine war itself has a close link to the issues of resource use, both in terms of the cause of conflict (Ukraine has significant deposits of raw materials required for future technologies; Zeit Online 2022) and of the consequences of the war. The latter was evident particularly through interruptions in supply chains for fossil energy carriers and cereals (Behnassi and El Haiba 2022; Zhou et al. 2023).

Together with the evident problems, every crisis has great potential for transformation. Familiar pathways are at least temporarily abandoned, and new ones are trialled and can be experienced in practice. Thus, for example, a widespread transition to home working by a large portion of the population would have been unthinkable before the pandemic. New ways of working were very rapidly developed and implemented during the COVID pandemic and became established practice in many sectors even after the pandemic had ended. Similarly, avoidance of or reduction in air travel (whether for private or business purposes) had seemed unthinkable before this. Although some of these changes were initially only temporary, they did at least reveal options that a large proportion of the population have now experienced and which could be employed again in future. Current evidence indicates to what extent a transition to renewable energy and a reduction in energy use, driven by the significant increases in energy prices as a consequence of the Ukraine war, can be accelerated.

With a necessary transformation of resource use in mind, questions arise of how resource flows have developed through these turbulent years, what can be learned from these years of crisis, which levers look to be particularly effective in producing change, and whether these can be translated into new measures. At the same time, we must consider that the current problems we face are also creating new concerns around regional, national and global inequalities. Monitoring is needed to understand who is benefiting from resource use and who is suffering the negative ecological and social consequences of extraction, processing and excessive use of these resources.

In order to identify the opportunities to take action and to develop effective measures, we require firstly an overview of socioeconomic extraction, distribution, use and disposal/recycling of natural resources (biomass, fossil energy carriers, metals and non-metallic minerals, water, land and ecosystem services) and secondly an analysis of socioeconomic interlinkages and drivers, which stimulate resource use and determine its quality and quantity. The empirical data for this is provided by material flow accounts and analysis (MFA; Eurostat 2018; Krausmann et al. 2017) as part of the environmental accounts (see the following section and the methodology summary in the Appendix: "Material flow accounting"). On the basis of these data, interlinkages can be identified between resource extraction, trade and final demand on one hand, and between economic development and resource use as well as between policy measures and their impact on biophysical indicators on the other.

The current resource use report, published by the Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK) and the Federal Ministry of Finance (BMF), is part of a series that now comprises four volumes. These reports summarise current research on Austrian resource use and discuss development and trends in materials use over the last two to three decades. Alongside this, each report focuses on a particular theme that is currently relevant. The first report (BMLFUW and BMWFJ 2011) takes the theme of construction materials, which together comprise more than half of all resource use in Austria, as its focus, while the second report (BMLFUW and BMWFW 2015) focuses on biomass materials as the foundation of a bioeconomy and the third report (BMK and BMLRT 2020) looks at sustainable resource use as the intersection of resource efficiency, climate protection and raw materials for future technologies.

This report, the fourth volume in the series, takes the circular economy as its focus and with this, the empirical basis for two very recent political strategies: the national Austrian Circular Economy Strategy (BMK 2022), adopted by the Austrian Council of Ministers in December 2022, which aims to transform the Austrian economy and society into a climate-neutral and sustainable circular economy by 2050; and the Master Plan Raw Materials 2030 (BMLRT 2021), to ensure an ecologically and socially responsible supply of mineral raw materials to Austria from domestic and international sources.

The contents of this report are organised within two main chapters: Chapter 2 details the current figures and trends regarding Austrian resource use from 2000 to 2022, with reference to four material categories (biomass, fossil energy carriers, metals, and non-metallic minerals), the material outputs, the integration within global supply chains, a comparison between EU Member States, and the connection with economic development (resource productivity and decoupling). Chapter 3 focuses on the circular economy and discusses the aims of the national Circular Economy Strategy in the context of current material flow accounts data. This forms the basis for a look ahead at the future, building on the results of the research project "Circular economy and decarbonisation: synergies and Trade-Offs"[1]. This explores models for the development of the circular economy in Austria by 2040 along four different future pathways. This potential future perspective shows what a climate-neutral and resource efficient way of life could look like in 2040.

1 forschung.boku.ac.at/de/projects/13725

Material flow accounts provide the evidence base for discussing sustainable resource use

> Statement 1 – Austria as an international leader in systematic reporting on resource use: Austria may justifiably be regarded as a global leader in the field of systematic reporting on resource use. Although Japan had already presented a proposal in 2004 at a G8 meeting for the development of a "sound material cycle society: reduce, reuse, recycle", environmental reporting in Europe and the US was dominated by a confusing plethora of emissions-related impacts (forest dieback, air pollution, noise pollution, water quality concerns, etc.). Focusing on resources was based on the insight that everything causing environmental impacts as emissions and wastes was ultimately determined by inputs - and could be systematically recorded by analysing socio-economic statistics. This approach was positively received in Austria, both by the Environment Ministry and Statistics Austria. They supported the development of corresponding material flow statistics. This formed the model for the subsequent development by Eurostat of a similar Europe-wide database (EW-MFA) from 2011 onwards. UNEP (the UN Environment Programme) took the important step of establishing an International Resource Panel (2007), which resulted in an initial report in 2011, "Decoupling Natural Resource Use and Environmental Impacts from Economic Growth" (UN IRP 2011), and led thereafter (2016) to the development of the Global Material Flows Database in time series.
> – Univ.Prof.emeritus Dr. Marina Fischer-Kowalski, Institute of Social Ecology (SEC), BOKU University

Our way of life as a society, with all our activities in terms of production and consumption, is directly linked to the use of natural resources. We require resources particularly for the construction and maintenance of built material stocks (e.g., buildings, roads, other infrastructure such as sewerage systems, energy infrastructure, bridges, etc.), providing food for humans as well as livestock and domestic pets, and manufactured consumer goods (e.g., clothing, furniture and equipment). Due to population increases and the changing needs and demands of our society, material stocks are continually growing, i.e., we build new houses, vehicles and roads, we buy ever more items of equipment and consumer goods, and must also feed a growing population and increasing numbers of livestock. However, only one Earth, with its limited quantities of materials, is available to this growing society. This conflict lies at the root of the environmental problems that are becoming increasingly evident, for example in the form of ever more frequent and more serious heatwaves and other extreme weather events, and biodiversity loss. In the case of some raw materials and goods, the increasingly global interconnection of both our production and our consumption activities is also leading to further supply uncertainties and shortages.

In order to understand socioeconomic resource use and develop appropriate measures, we need a scientifically proven theoretical basis and consistent analyses of both patterns and trends. The scientific concept which provides the framework for this report's analysis of socioeconomic resource use is that of social metabolism (Haberl et al. 2016; Haberl et al. 2019) (see Figure 1).

In this context, societies are seen as analogous to an organism that requires an input of nutrients to have a supply of energy and to be able to grow and carry out activities. Within identified system limits, resources are extracted from nature or traded between socioeconomic systems and are finally returned to nature as wastes and emissions (see Figure 1). Following the fundamental laws of physics on thermodynamics, all material inputs (raw materials) are transformed at the end of their utilisation phase into outputs (air and water emissions as well as solid wastes). Raw materials remain in circulation within society for longer where resources are utilised in the form of material stocks (buildings, roads, consumer goods, etc.) with a particular service life. Inputs and outputs, translated into material stocks, are thus directly correlated. It therefore follows, that if we wish to reduce emissions, we will also need to decrease our input of raw materials and thus also reconsider and adapt our material stocks accordingly.

To better understand the ways in which we are using a whole spectrum of diverse resources, we must track their journey all the way from extraction, through socioeconomic production to consumption. Following a consolidation of methods, data and analyses relating to socioeconomic inputs (UN 2017; Eurostat 2018), MFA has undergone further development in this direction. Current research focuses on calculating societal stocks (Krausmann et al. 2017, 2020; Wiedenhofer et al. 2021; Haberl et al. 2023), and taking a mass balance approach to the interlinkage between material inputs and material outputs with regard to these stocks. This mass-balanced accounting of inputs, stocks, and outputs enables empirical analysis of the circular economy at a macroeconomic level (Haas et al. 2015; Mayer et al. 2018; Haas et al. 2020). Similarly, global trade relationships are analysed and the environmental impacts of e.g., Austrian consumption activities on other continents are identified (Lenzen et al. 2012; Schaffartzik et al. 2014; Wiedmann et al. 2015; UN IRP 2019a; Dorninger et al. 2021; Lenzen et al. 2021). Environmental impacts resulting from the use and extraction of materials are increasingly being recorded and analysed, particularly the impacts upon biodiversity (Lenzen et al. 2012; Marques et al. 2019; Luckeneder et al. 2021; Giljum et al. 2022). Ultimately, MFA data are also addressed in large-scale framework concepts regarding wellbeing, doughnut economics and planetary boundaries (O'Neill et al. 2018; Fanning et al. 2022).

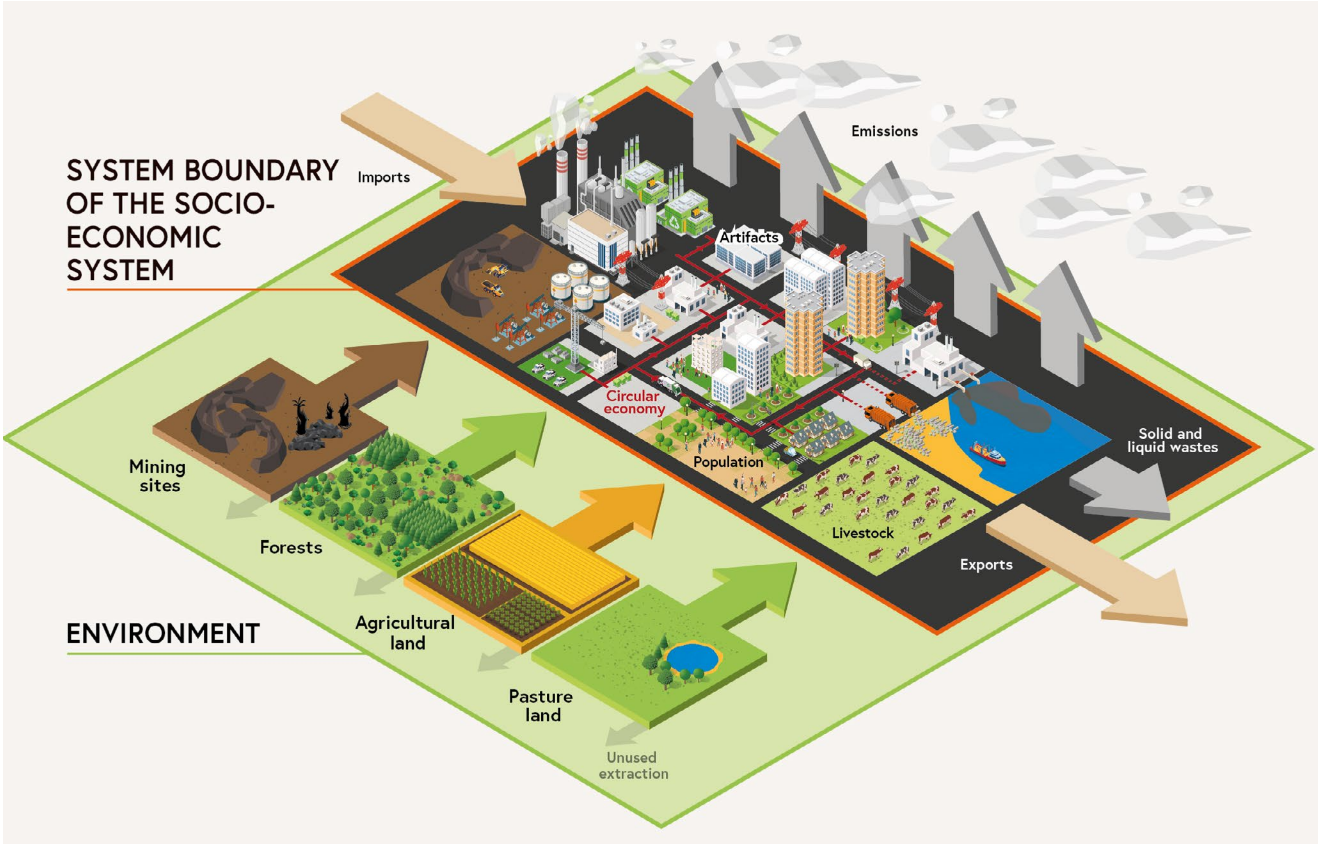


Figure 1: Social metabolism.

Environmental accounts (BMK 2021) and within these, the MFA (Krausmann et al. 2017; Eurostat 2018), both provide us with the data basis for analysing societal resource use and for developing and evaluating political strategies. Resource use includes many different materials with very diverse biophysical characteristics and forms of utilisation by society. To aid analysis, data in the MFA are divided into four major categories: biomass, fossil energy carriers, metals and non-metallic minerals. Each of these major categories can be further divided into subcategories (e.g., crops, non-ferrous metals, igneous rock) and finally broken down into individual materials (e.g., wheat, hardwood, coal, nickel ore, limestone, phosphates).

In the MFA and in this report, further categories are designated in addition to the four major material groups: the "not assignable" category comprises two different groups: on one hand, finished products composed of a mix of materials, which does not allow their categorisation according to one of the four material groups (e.g., artworks, measuring instruments, etc.) - this material group is referred to in other reports as "other commodities" or "other products"; and on the other hand, goods are included that for reasons of confidentiality cannot be more precisely recorded in the statistical data. Results can be seen in Figure 7. The category of "Waste for final treatment or landfill" comprises imports and exports of wastes composed of various materials, which are sent to the destination country for final treatment.

Water[2] is not accounted for in the MFA, which does not signify lesser importance but rather the large quantities, which exceed those of other materials by a factor of 50 (Krausmann et al.2018; UN IRP 2019a). Hence, water use is recorded in dedicated water balances (Eurostat 2015; UN 2023). Only brief mention is made in this resource report of details regarding Austrian water requirements and water use (see following chapter).

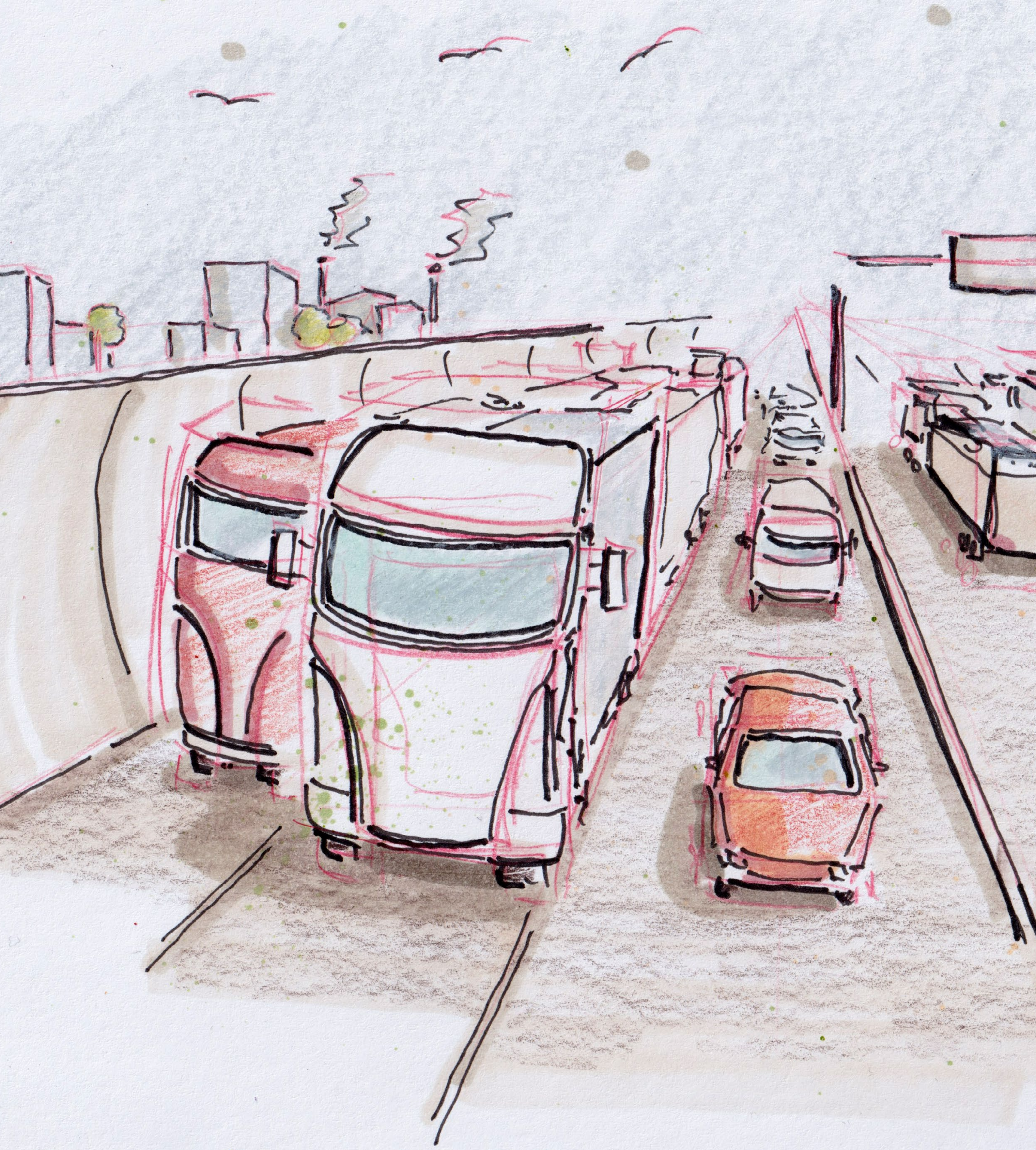
The MFA includes all material and energy use of raw materials (biomass, fossil energy carriers, metals and non-metallic minerals) in metric tonnes (methodologies and data sources are detailed in "Material flow accounting" in the Appendix). The most important specific terminology used in the MFA is listed and explained in the Glossary (see "Glossary" in the Appendix).

In the four resource use reports produced to date (BMLFUW and BMWFJ 2011; BMLFUW and BMWFW 2015; BMK and BMLRT 2020), the contemporary data of the MFA, i.e., the type and quantity of the raw materials that are processed in the Austrian economy and which satisfy domestic consumption, are presented and discussed. The data within the MFA are also presented in various publications by Statistics Austria (Statistics Austria 2024).

A concluding note: All the data presented here are rounded values. Possible rounding differences have not been balanced.

2 With the exception of water that is contained in different materials, e.g., in agricultural produce, wood, fossil energy carriers, etc. See Appendix "Material flow accounting".

2 Resource Use in Austria



Statement 2 – A reduction in demand for materials is technically feasible and would make an important contribution to climate protection and nature conservation: Austria uses natural resources from around the world; metals, fossil energy carriers, fertiliser and feedstuff, as this report so impressively demonstrates. Material production is responsible for a quarter of all global greenhouse gas emissions. A reduction in the demand for materials, replacing single family homes with apartment blocks, car-sharing or avoiding using cars, purchasing good quality products rather than disposable goods, is technically feasible and would make an important contribution to climate protection and nature conservation. Policy making should focus on providing incentives for this. – Univ.Prof. Dr. Edgar Hertwich, Professor of Industrial Ecology, NTNU Norway, and member of the European Scientific Advisory Board on Climate Change of the European Commission

In Austria each year, in order to carry out our social activities and economic processes, large quantities of natural resources are used and consumed. In 2022, domestic material consumption (DMC) in Austria stood at 17 tonnes per capita and year, while energy use was calculated to be around 150 MJ per capita and year. Of the materials consumed, 25 % comprised biomass materials, which were used as food and feedstuff as well as sources of energy; metallic and non-metallic minerals (60 %) were used for construction and civil engineering projects or the production of consumer goods, while fossil energy carriers (13 %) were used to heat residential homes and workspaces and to power the entire range of machines and items of equipment that we use. However, we not only use the materials already mentioned, but additionally water, for example to drink, or in cooling processes and in many industrial processes (e.g., as solvents and binding agents). Austria is a country with plentiful supplies of water, yet we are also impacted by regional droughts and extreme precipitation events, which can cause flooding[3]. The rapid progression of climate change will make sustainable water use ever more important in the future.

3 umweltbundesamt.at/wasser

Statement 3 – Austria is rich in water - yet water use will increase significantly in the future: Austria's water resources will remain abundant in future, however the proportion of usable groundwater resources could shrink by up to one-fifth of its current volume of 5.1 billion m3 per year by 2050, due to impacts such as those associated with climate change. Regional differences will also become more marked, particularly in low precipitation regions in the eastern part of Austria. The share of available water resources that are used will increase in future (with an increase in intensity of groundwater usage from 16 % to 26 %). Groundwater use comprises 40 % of total water consumption in Austria. The greatest increase in usage, involving almost a doubling of demand, is projected for agricultural irrigation purposes by 2050. Groundwater resources will be increasingly required in the future for cooling processes and energy generation. Intensive use of watercourses and associated containment measures are responsible for very significant impacts on their ecological status due to detrimental hydromorphological changes, and more than half of all water bodies currently fail to meet the standards set by the EU Water Framework Directive. Approximately 60 % of all fish species in Austria are at risk as a result. – Univ.Prof. Dr. Thomas Hein, Institute of Hydrobiology and Aquatic Ecosystem Management (IHG), BOKU University

Austria's resource use increased from 100 million tonnes to 154 million tonnes in 60 years and exceeds planetary boundaries

In the course of an economic boom following the Second World War, many of today's industrialised states experienced a continuous improvement in living standards. Both this economic development pathway and a tripling of the global population since 1950 led to an increase in global resource use from 15 billion tonnes in 1950 to 89 billion tonnes in 2015 (Krausmann et al. 2018), in other words, a sixfold increase. This rapid increase in material and energy use, which is also defined as the "Great Acceleration" (Will Steffen et al. 2015), also increases the environmental pressures caused by this level of consumption, such as greenhouse gas emissions, industrial or agricultural encroachment into natural habitats, biodiversity loss and the exploitation of natural resources, for example in the form of deforestation, overfishing or soil sealing. Shortages of critical raw materials occur as a result of the unevenness of their geological distribution, geopolitical conflicts and the outsourcing of mining and further processing activities to locations outside Europe

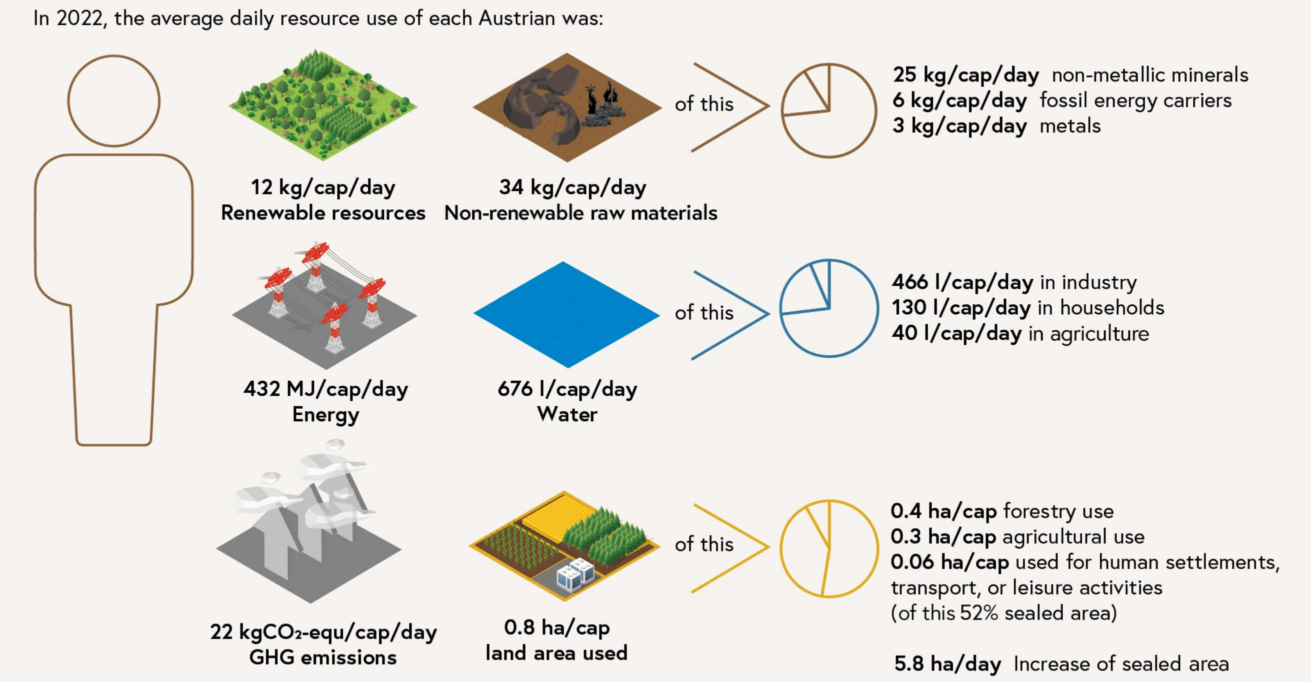
Statement 4 – Materials extraction and accumulation of stocks drive the sealing and fragmentation of landscapes and cause biodiversity loss: Natural ecosystems need more space, or more area. This is critical for conserving and restoring biodiversity and for securing the multiplicity of ecosystem services upon which society depends, e.g., supporting food security, maintaining water supplies, climate protection and adaptation to climate change through greater natural buffer capacities. To ensure this is possible, there needs to be a trend reversal in the dynamics of increasing land use, such as agricultural extensification, and a reduction in the fragmentation of habitats. What does this have to do with resource use? A great deal, since resource extraction within the mining, agricultural and forestry sectors and resource use for roads, buildings and infrastructure projects are drivers of land take. This leads to soil sealing and fragmentation of landscapes. The degree to which we are successful in changing direction to create a low-resource economy will determine the future of biodiversity in Austria. – Assoc.Prof. Mag. Dr. Franz Essl, Department of Botany and Biodiversity Research, University of Vienna

There has been a simultaneous intensification of trade interlinkages within an increasingly globalised world economy. Products used by consumers in one country are being produced in another, with the raw materials required for their production have often been extracted in a third country. At the same time, the material composition of products is becoming ever more complex and there is a growing dependency upon a large number of regions from which sought-after raw materials are extracted.

In Austria too, material resource consumption rose from approximately 100 million tonnes per annum in 1960 to reach a high point in 2007 of 170 million tonnes, i.e., by a factor of 1.7. In comparison, the population in Austria rose in the same period (1960-2007) by a factor of 1.2 (Eurostat 2023a). A slight reduction in domestic material consumption is observable since 2007, falling to 154 million tonnes in 2022. This represents the daily use per person of 12 kg renewable raw materials, 3 kg of metals, 25 kg of non-metallic minerals and 6 kg of fossil energy carriers (see Figure 2). Additionally, 676 litres of water (466 litres in industry, 130 litres in households and 40 litres in agriculture[4]) and 432 MJ of energy (gross domestic consumption, territoriality principle; Statistics Austria 2023a) were required per person per day. The consumption of fossil energy carriers resulted in daily levels of greenhouse gas (GHG) emissions of 22 kg CO_2-equivalent per capita (Austrian Federal Environment Agency, 2023a). Austria's territorial land area comprises 8.39 million ha, which represents approximately 0.8 hectares per capita (Statistics Austria 2023b); 0.3 ha/cap of which is used for agriculture and 0.4 ha/cap for forestry. Land area utilised for human settlements, transport,

4 trinkwasserinfo.at

recreational and leisure activities etc. amounted in 2021 to 630 m^2/cap (ÖROK 2024), and 52 % of these areas are sealed. According to the Austrian Federal Environment Agency (2024a), an average of 11.3 ha of land is converted to settlement areas in Austria every day, 5.8 ha (52 %) of which is sealed.



Sources: Material consumption as DMC by material category (Statistics Austria 2024), water consumption (ÖVGW 2019; BM LFRW 2023), energy consumption as gross domestic consumption according to the territoriality principle (Statistics Austria 2023a). Increase in land use as 3-year average 2019-2021 (Federal Environment Agency 2024a). Greenhouse gases (Federal Environment Agency 2024b).
Note: Values are rounded. Possible rounding differences have not been balanced.

Figure 2: Resource Use in Austria 2022.

In 2022, individual Austrian residents consumed on average 17 tonnes of materials per capita, of which 14 tonnes were extracted domestically. The major share of materials extracted in Austria comprised biomass for food production together with wood and non-metallic minerals, which were used primarily in construction and the maintenance of buildings, roads and other infrastructure. On the other hand, this included the import of 10 tonnes and export of 7 tonnes of materials per capita and year. Since 2000, a gradual reduction in domestic extraction (DE) of 8 % can be observed alongside a simultaneous and significant increase in international trade activities of 35 % in the case of imports and 47 % in the case of exports.

Statement 5 – Land continues to be regarded as a disposable product: It is universally acknowledged that land take in Austria is very high. Approximately 11 hectares per day or 40 km^2 per year are built upon each year. We are thus very far away from the levels we need to see. We have already built upon so much land area that, in statistical terms, each Austrian could inhabit a detached family home, each car would have more than enough room to park and there would be well beyond the requisite space available for offices and business parks - yet unfortunately these are never located where they are actually needed. Starting points for change include placing limits on the designation of land for building development and more appropriately calculating the cost of soil degradation. Reduced land take would ultimately lead also to a significant reduction in Austria's high levels of resource use. – Gundula Prokop, Senior expert on land take and soil sealing at the Austrian Federal Environment Agency

Resource use in Austria has global impacts

Our individual resource consumption, i.e., the quantities of materials that we actually utilise and consume directly through our activities, is nonetheless lower in most cases than the per capita consumption for Austria as a whole. This is because natural resources are not only utilised for individual private consumption but are to a significant degree used in the production and supply of public services and goods, for example in transport infrastructure, and in health, education, sports and leisure institutions, etc. It therefore follows that social metabolism is greater than the sum of all resources used by individuals.

Furthermore, the extraction, processing and transportation of materials in themselves require the consumption of materials and energy, for example in the form of agricultural irrigation and fuels for freight transport. Since Austria's demand for resources cannot be satisfied entirely through domestic production, a share of these materials is imported from other countries. This international trade is itself ultimately linked to an expenditure of resources in terms of transport and energy. Austria's participation in global markets also means that Austrian material consumption inclusive of the entire global supply chain is larger than the quantity of resources consumed within Austria's national borders (domestic material consumption). The material consumption of Austrian consumer goods inclusive of upstream consumption of materials along the entire production chains for imported goods, which takes place outside Austria, is defined as the 'material footprint'. Thus, Austria's consumption also has an impact on the resource consumption of other countries.

Global material consumption in 2022 comprised an average of 13 t/cap/a or 36 kg per capita and day (UN IRP 2024). Austria's material footprint in 2020 was 61 kg/day (Statistics Austria 2024). Thus, if one takes the entire production chain including upstream resource consumption into account, 15 kg or 30 % more material per capita and day is consumed than is consumed directly within the country. This is particularly relevant for metals and fossil energy carriers, which in contrast to biomass and non-metallic minerals is largely imported, since the extraction of deposits existing within the country is not (any longer) economically viable, mining is currently not taking place, or these raw materials are not available within Austria. In the case of metals, it is also the case that a large share of the materials are imported into the country in the form of highly processed products, for example automotive vehicles or machinery, the production of which has involved material consumption in other countries. Thus, taking a consumption perspective means the use of metals is tripled and the use of fossil energy carriers doubled.

The water footprint in 2022 was 4,377 l/cap/day (Neunteufel et al. 2021), which is more than 6 times the figure for direct water consumption. The energy footprint (644 MJ/cap/day) and the land footprint (1.2 ha/cap) (both UN Environment 2024) were around 50 % higher than domestic consumption, while the carbon footprint (28 kg CO_2equ/cap/day; UN Environment 2024) exceeded the figure for domestic emissions by 28 %.

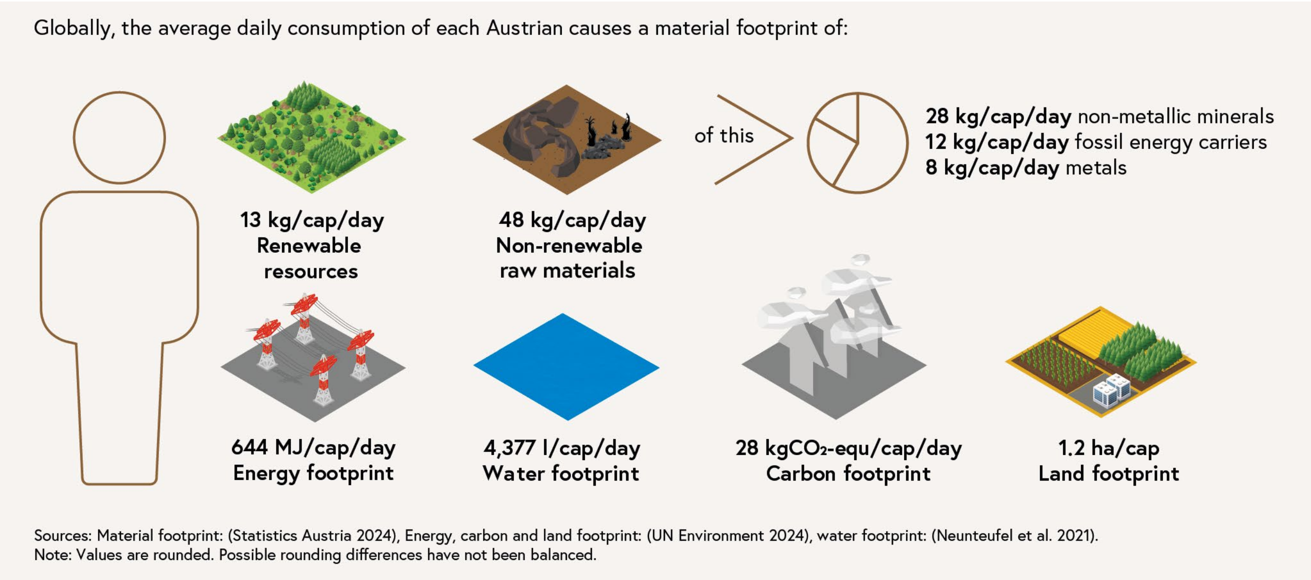


Figure 3: Material footprint: the resource needs of Austrian final consumption, 2022.

A sustainable lifestyle must not exceed ecological limits and must at the same time guarantee minimum social standards

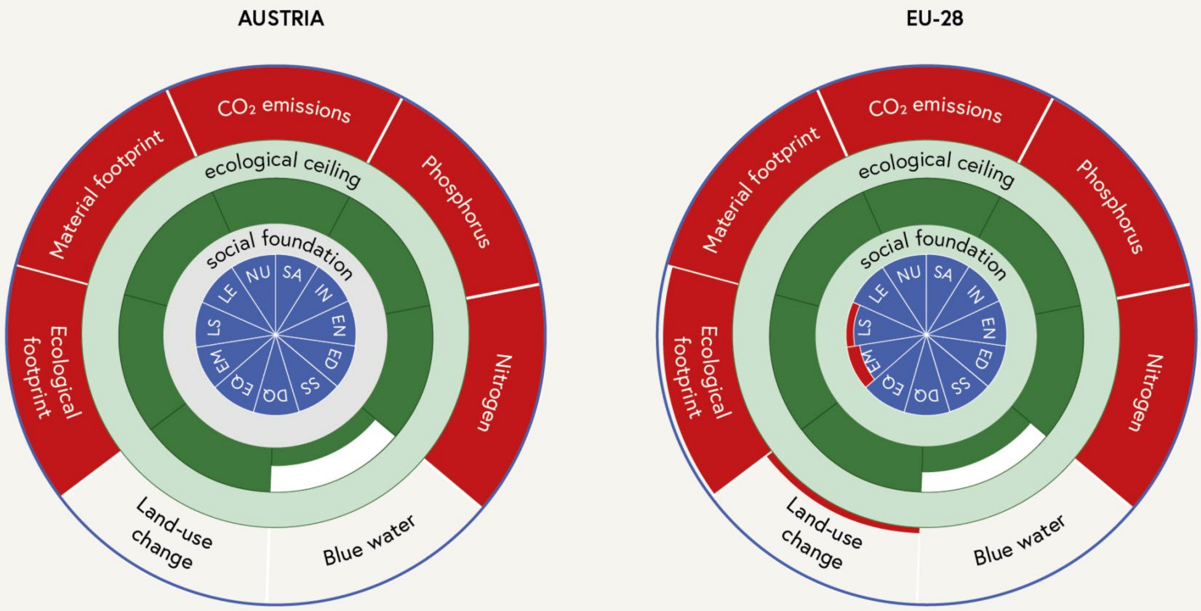
In recent decades, we have seen a significant increase in many social, economic and biophysical indicators, a phenomenon described in the literature as 'the great acceleration' (Will Steffen et al. 2015). The exponential growth in ecological indicators has exceeded planetary boundaries in many areas. As early as 2009, Rockström and colleagues (2009b) defined planetary boundaries for nine resources or ecosystem services, updated six years later by Steffen and colleagues (2015):

1. Climate change
2. Ocean acidification
3. Stratospheric ozone depletion
4. Atmospheric aerosol loading
5. Biogeochemical flows: interference with P and N cycles
6. Global freshwater use
7. Land-system change
8. Biodiversity loss
9. Chemical pollution

Studies have shown how the economic and social development of a country is always accompanied by increasing resource consumption (Raworth 2017; OECD 2018; UN IRP 2019a; Brand-Correa et al. 2020; Haberl et al. 2020). Beyond a certain level of income, however, the consumption picture flattens out; greater resource or energy consumption (or emissions) then lead only to insignificant increases in GDP, in human development (measured as HDI, Human Development Index), or other social indicators (Steinberger and Roberts 2010; O'Neill et al. 2018; UNDP 2019; Chancel 2022).

Kate Raworth (2017) subsequently combined the planetary boundaries with social boundaries to create the Doughnut concept (see Figure 4). This demonstrates that a sustainability transformation must give consideration to all the dimensions of sustainability and ensure that environmental impacts remain within planetary boundaries, while social (minimum) boundaries must also be met. The same intention underpins the UN Sustainable Development Goals (SDG; UN 2015). Unfortunately, recent studies have shown that no single country has (thus far) achieved these definitions of sustainability (O'Neill et al. 2018; Fanning et al. 2022). Countries (above all industrialised countries) that have achieved all the social standards have simultaneously exceeded one or, usually, several planetary boundaries. Conversely, countries (often referred to as developing countries) that are living within the planetary boundaries often fail to achieve the minimum standards defined for social life. Observed over time, it is evident that the planetary boundaries are being exceeded more rapidly than social standards are being achieved. Richardson et al. (2023) shows that meanwhile six of the nine planetary boundaries have been exceeded and that the degree to which they are being exceeded has increased since the earlier studies (Rockström et al. 2009b; W. Steffen et al. 2015).

Too little attention has been paid to date to the analysis by Lade et al. (2019), according to which the expected feedbacks between planetary boundaries are producing an acceleration in the environmental impacts caused by human activities to the Earth's systems. Combating these ecological crises requires actions that go beyond the measures seen thus far. A social transformation is needed (Görg et al. 2017; Brand et al. 2020; Haas et al. 2023), so that societal resource use can return to levels that lie within the planetary boundaries.



LS	Life Satisfaction	IN	Income	DQ	Democratic Quality
LE	Healthy Life Expectancy	EN	Access to Energy	EQ	Equality
NU	Nutrition	ED	Education	EM	Employment
SA	Sanitation	SS	Social Support		

- resource use in relation to a biophysical sustainability boundary
- social performance in relation to the basic needs threshold
- shortfall below social threshold or overshoot beyond biophysical boundary

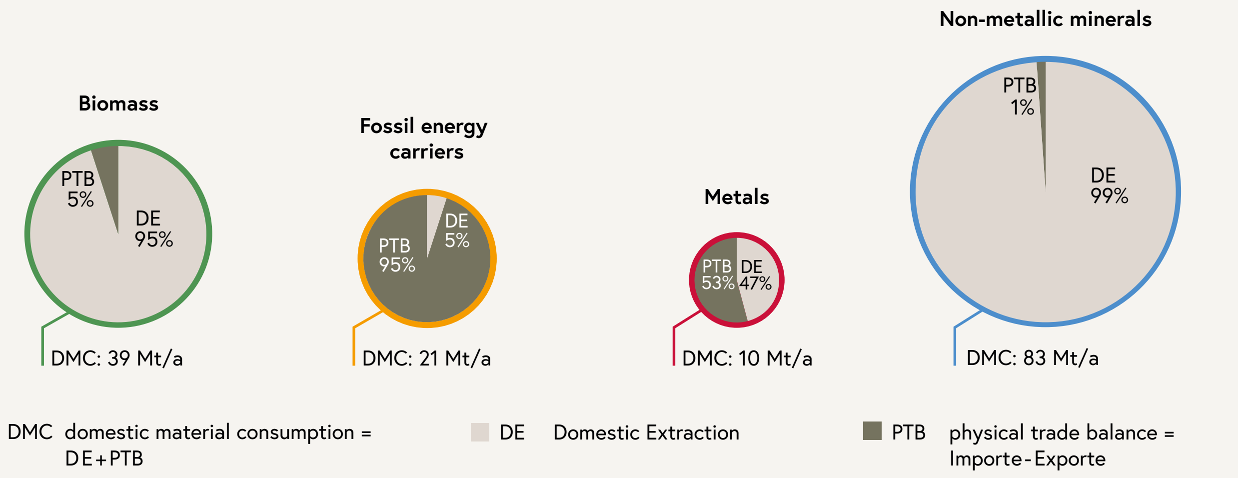
Note: Most indicators are for 2011.
Source: Fanning et al. 2020, goodlife.leeds.ac.uk/national-snapshots/countries/#Austria

Figure 4: Is Austria within the "safe operating space"?

Resource consumption is a combination of local material extraction and international trade - Austrian trends from 2000 to 2022

The overview presented in summary in the previous chapter clearly indicates that we must reduce our resource consumption. This understanding is increasingly reflected in political programmes, most recently in the Austrian Circular Economy Strategy (BMK 2022): The Austrian federal government committed itself therein to the goal of reducing resource consumption (measured as material footprint) to 7 tonnes per capita and year by 2050, and reducing domestic material consumption (DMC) to 14 tonnes per capita and year by 2030. In the following chapter, the current data on resource consumption in Austria, based on the data provided by Statistics Austria in its Material Flow Accounts (Statistics Austria 2024) is presented.

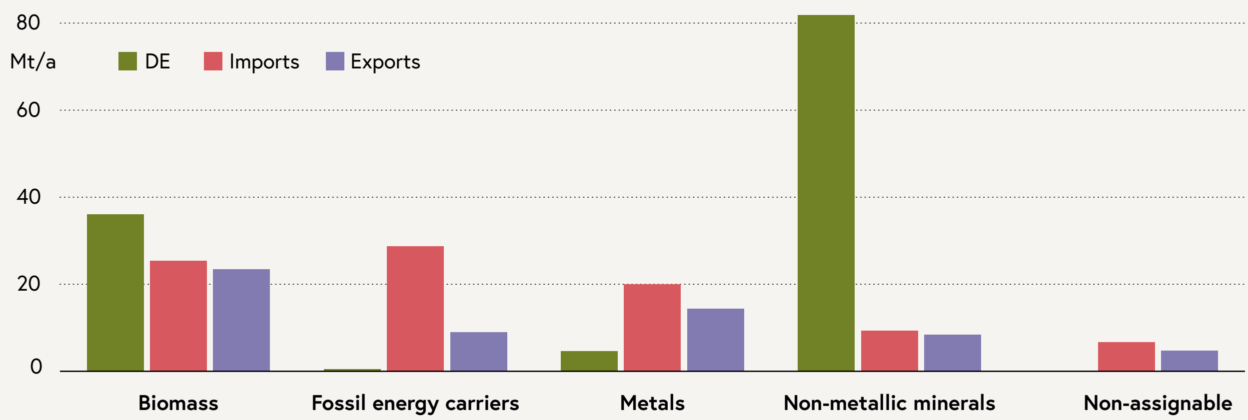
The resources required in Austria may be either extracted from the environment as raw materials within Austria's national boundaries (domestic extraction, DE) or imported from other countries. Of the entire domestic material consumption (DMC) for 2022, 81 % could be supplied in the form of materials extracted domestically (DE). In terms of biomass products from agriculture and forestry and non-metallic minerals, Austria is well supplied with domestic resources. A large share of domestic consumption of these materials is supplied by domestic extraction (91 % in the case of biomass, and 99 % in the case of non-metallic minerals) (see Figure 5). In the case of fossil energy carriers and metals, the major share of domestic consumption requirements is supplied through imports. The proportion of net imports (physical trade balance, PTB; calculated as imports minus exports) in Austria in 2022 was 54 % for metals and 95 % for fossil energy carriers (see Figure 5).



Source: Statistics Austria 2024, Values are rounded, rounding differences are not balanced.

Figure 5: Share of Austrian domestic extraction (DE) and net imports (PTB) in domestic material consumption (DMC) for four material categories in 2022.

Austria exports a share of the materials that are processed within the country in the form of manufactured products and provides these for final consumption in other countries. As Figure 6 shows, the quantities of imports (26 million tonnes/year or Mt/a) and exports (24 Mt/a) of biomass products in 2022 were similar in scale to the quantities of materials that are extracted in Austria (DE of 37 Mt/a in 2022). In the case of metals, only 5 Mt/a were extracted in Austria while a further 20 Mt/a were imported. A significant share of these imports was further processed in Austria and then exported again (15 Mt/a). Where fossil energy carriers and non-metallic minerals are concerned, the proportions look rather different: the domestic extraction (DE) of about one million tonnes of fossil energy carriers in 2022 contrasts with imports of 30 Mt/a. Exports consist mainly of processed products, which comprise about 9 Mt/a. Contrastingly, in the case of non-metallic minerals, domestic extraction is predominant (82 Mt/a in 2022). Imports and exports (10 Mt/a and 9 Mt/a) were relatively minor proportions for this category of materials. Figure 6 also shows the category “non assignable”, which contains materials that for reasons of confidentiality cannot be identified, or because they are products with an unknown material composition. Please see the following chapter for further details.



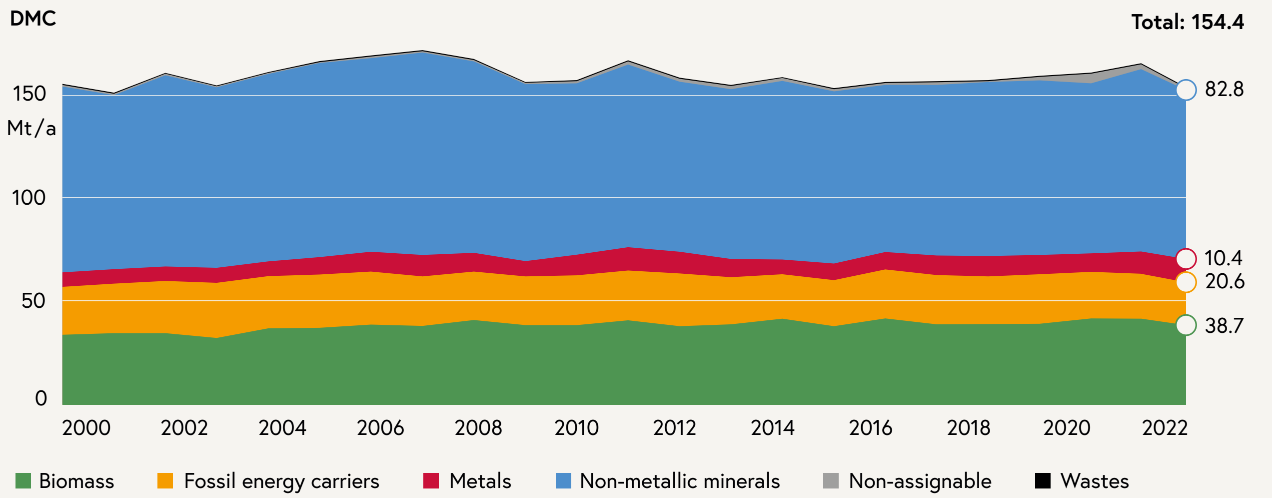
Explanatory note: The category “non-assignable” comprises on the one hand manufactured products containing an unknown mix of materials, which prevents their allocation to one of the four material categories, and on the other hand raw materials or goods not specified in the statistics for reasons of confidentiality.

Source: Statistics Austria 2024

Figure 6: Austria’s domestic extraction (DE), imports and exports for four material categories, 2022.

Material consumption has increased - even during the COVID pandemic

Domestic material consumption (DMC) (see Eurostat 2018 and the methodology section in the Appendix) amounted to 154 million tonnes in 2022, and was predominantly made up of non-metallic minerals (83 Mt/a in 2022, which is 54 % of DMC) (see Figure 7). Biotic materials constituted the second largest category which 39 Mt/a in 2022, 25 % of overall DMC. Further to this, 21 Mt/a of fossil energy carriers (13 % of DMC) and 10 Mt/a of metals (7 % of DMC) were consumed.



Explanatory note: The category "Waste" includes net imports of waste for final treatment and landfill. "Waste" therefore does not show the total amount of waste treated or landfilled in Austria. The category "non-assignable" includes, on the one hand, finished goods made from a mix of materials that cannot be assigned to any of the four material groups and, on the other hand, raw materials or goods that cannot be specified in more detail in the statistics for reasons of confidentiality.

Source: Statistics Austria 2024

Figure 7: Austria's domestic material consumption (DMC) in four material categories, together with non-assignable materials and wastes in Austria, 2000 to 2022.

Between 2000 and 2022, domestic material consumption remained at more or less the same level (154.1 Mt/a in 2000 and 154.4 Mt/a in 2022). Within each of the four material categories some changes were evident: the largest changes were observed in the case of metals and biomass: material consumption of metals rose by 49 %, and of biomass by 15 % (for further details, see the chapter "Our resource consumption is comprised of four material categories: biomass, fossil energy carriers, metals and non-metallic minerals"). Consumption of non-metallic minerals decreased by 7 %. Since 99 % of this consumption is based on materials from domestic extraction, this development mirrors changes in domestic extraction. Fossil energy carriers saw the greatest reduction in consumption, from 23 Mt/a (2000) to 21 Mt/a (2022), decreasing by 11 %. A significant increase is evident for "non-assignable" materials in 2020, although this is largely attributable to measures introduced to ensure confidentiality of the primary data in the statistical sources. Statistics Austria created this collective material category designation because of cases in which detailed information is covered by data protection regulations. Alongside the raw materials or goods that are subject to confidentiality regulations, the "non-assignable" materials also include finished products composed of an unknown mix of materials, which therefore cannot be allocated to one of the four material categories ("other products"). Discussion or interpretation of the "non-assignable" category therefore serves no useful purpose.

The most significant fluctuations in domestic material consumption were observed during the years of major economic crisis. The financial and economic crisis of 2008/09 led to a reduction in DMC of 3 % in 2008 and of 7 % in 2009 – the largest such decrease of the last 20 years. The economy recovered in 2011, which led to a renewed increase in DMC (+6 %). The slump was seen in all four material categories, to the same extent as in the case of the renewed increase in 2011. The country's economic development followed a similar trend, with GDP falling from 2008 to 2009 by 4 % before rising in the following two years (-2 % and +3 %).

In contrast to the 2008/09 economic crisis, during the COVID pandemic no reduction in material consumption was recorded. Instead, material consumption increased from 2020 to 2021 by 4 %. At the level of the four material categories, a differentiated picture emerges. Consumption of fossil energy carriers fell by 1 % from 2020 to 2021, while consumption of metals and non-metallic minerals rose by 21 % and 7 % respectively. Economic data on gross value added in the different sectors also shows a difference between the economic crisis of 2008/09 and the COVID pandemic of 2020/21. The economic crisis led to a slump primarily in manufacturing industry and a little less marked in the construction industry, although in the case of the latter, this lasted longer through subsequent years. In contrast, the COVID pandemic shows impacts across almost all sectors, although barely at all in the construction industry. Gross domestic product fell from 2019 to 2020 by 7 % followed by renewed growth in 2021 of 4 %.

With the beginning of the Russian war against Ukraine in February 2022, material consumption decreased significantly in comparison with the previous year, by a total of 7 %. This decrease occurred in all main material categories. Thus, the war against Ukraine seems to have had a similar impact on material consumption to that caused by other economic crises. A different picture emerged here with the development of the economy, which in terms of GDP showed no slump from 2021 to 2022, rising instead by 5 %. The trend that followed through the subsequent energy crisis and the impacts on resource consumption have yet to be identified.

In Austria, we extract primarily biomass and non-metallic minerals from the natural environment

81 % of domestic material consumption is accounted for by raw materials extraction in Austria itself. Domestic extraction (DE) is accordingly large in scale and amounted to 125 million tonnes in 2022. The largest share was accounted for by non-metallic minerals (82 Mt/a in 2022), followed by biomass materials (37 Mt/a) (see Figure 8). Deposits of fossil energy carriers and metals are very limited in Austria, for which reason these raw materials are not (any longer) extracted in large quantities; in 2022, domestic extraction of fossil energy carriers amounted to about one million tonnes and 5 million tonnes of metal ores (for details, see the chapter "Our resource consumption is comprised of four material categories: biomass, fossil energy carriers, metals and non-metallic minerals").

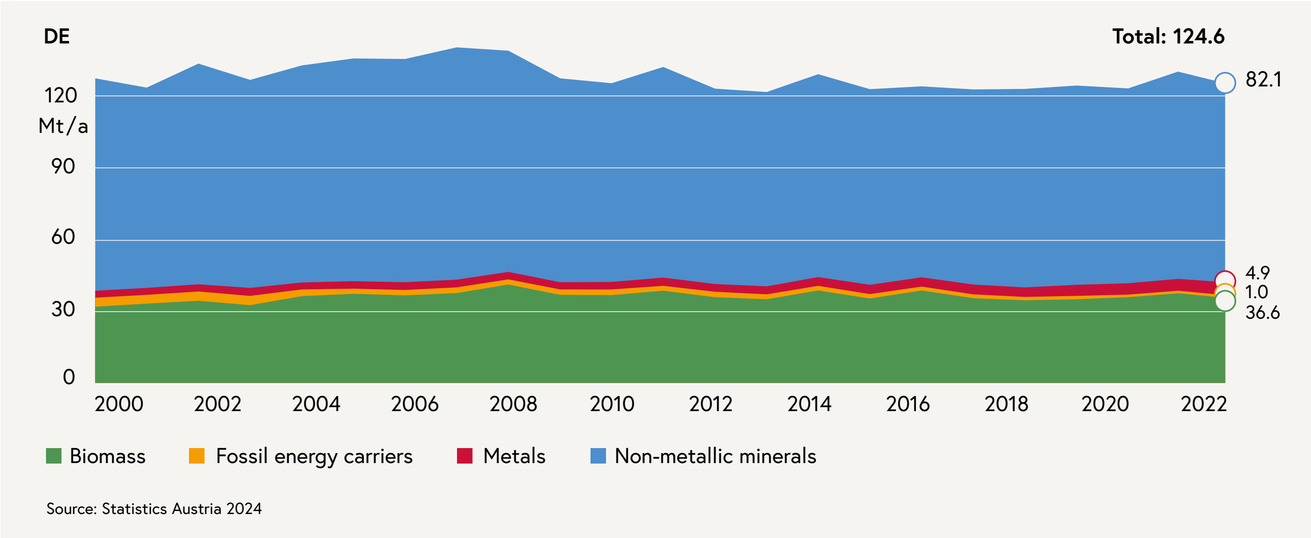


Figure 8: Austria's domestic extraction (DE) in four material categories, 2000-2022.

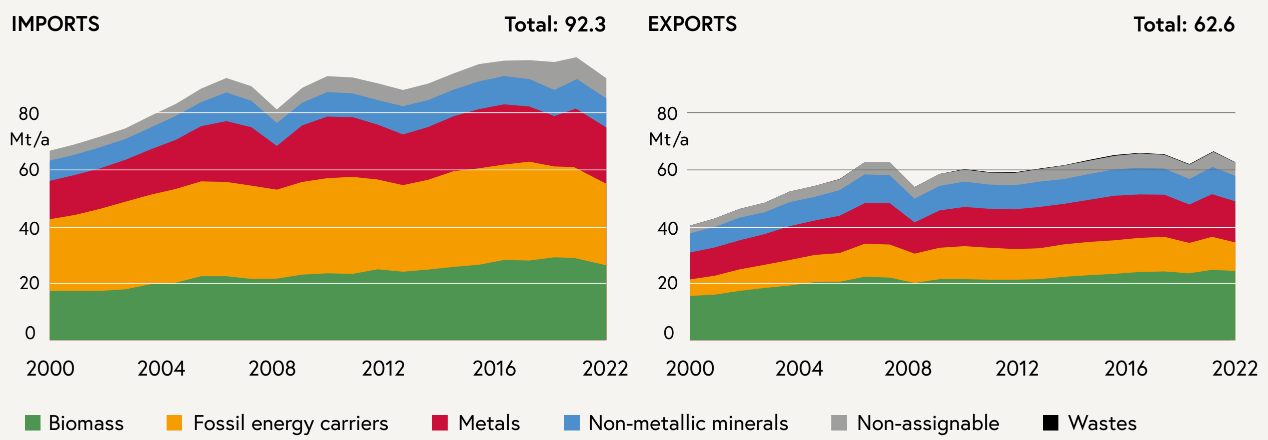
In the period from 2000 to 2022, the quantity of extracted materials fell by 2 %. The annual fluctuations during this 22-year period in most cases (in 15 of the 22 years) amounted to less than -5 %. If we examine the four material categories separately, we can nonetheless identify different trends. The material extraction for biomass shows an overall increase of 15 % and that of metals an increase of 69 %. The extraction of fossil energy carriers, in contrast, shows a reduction of 74 % from 3.8 Mt/a (2000) to one million tonnes (2022). Over the 22-year period, the DE for non-metallic minerals fell by 8 %, however with strong annual fluctuations evident throughout the period, which are closely related to the economic crises already noted in the context of material consumption. Since non-metallic minerals represent the largest material category, fluctuations in this group are mirrored also in the overall development trends for domestic extraction.

Economic crises have a major impact on international trade

In 2000, Austria imported 67 Mt/a, that is, roughly half as much quantity of materials as were extracted within the country (Figure 9a). In 2022, imports comprised 92 Mt/a, which corresponds to 74 % of extracted materials. In the two decades being analysed, imports therefore showed an increase of 38 %, while domestic extraction remained at roughly the same level (-2 %). In 2022, exports amounted to 63 Mt/a, compared with 2000, when Austria exported 40 Mt/a (Figure 9b). Accordingly, exports, with an increase of 55 %, increased more rapidly than imports.

The material composition of trade flows differed strongly from that of material extraction and material consumption. In 2022, fossil energy carriers were the most important category, comprising 31 % of total imports, followed closely by biomass materials (28 %). Metals also represented a significant category in quantitative terms (22 %) while non-metallic minerals played a relatively minor role, comprising only 11 % of imports. It should be noted at this point that allocating highly processed products to one of the four material categories is not always possible. Traded goods are almost entirely semi-finished or finished products, i.e., not raw materials as in the case of domestic extraction. In accordance with MFA convention, products that are composed of a mix of materials are allocated to the material group which represents the primary share of materials within the product. Products for which information on material composition is not available or for which the composition cannot be more precisely described for reasons of confidentiality are allocated to the category "non-assignable". In the case of highly processed goods, this convention can only provide a rough approximation, however the largest flows in quantitative terms comprise semi-finished products, which can be clearly allocated to one of the material categories.

The annual rates of change for imports and exports have shown a stronger dynamic than in the case of extraction and consumption. For example, during the years of the 2008/09 economic crisis, a sharp fall in the import of metals of 25 % could be observed, followed by an increase in the following year of 30 %. The import of manufactured goods decreased by 10 %, followed by an increase in the following year of 13 %. In the cases of some other material categories, some individual years and periods also recorded annual rates of change of 10 % or more. In contrast to material consumption, the impact of the 2020/21 COVID pandemic is more clearly seen in physical imports and exports. In 2020, imports fell across almost all categories; however, an increase was observed in the case of biomass (4 %) and for non-assignable materials (47 %).



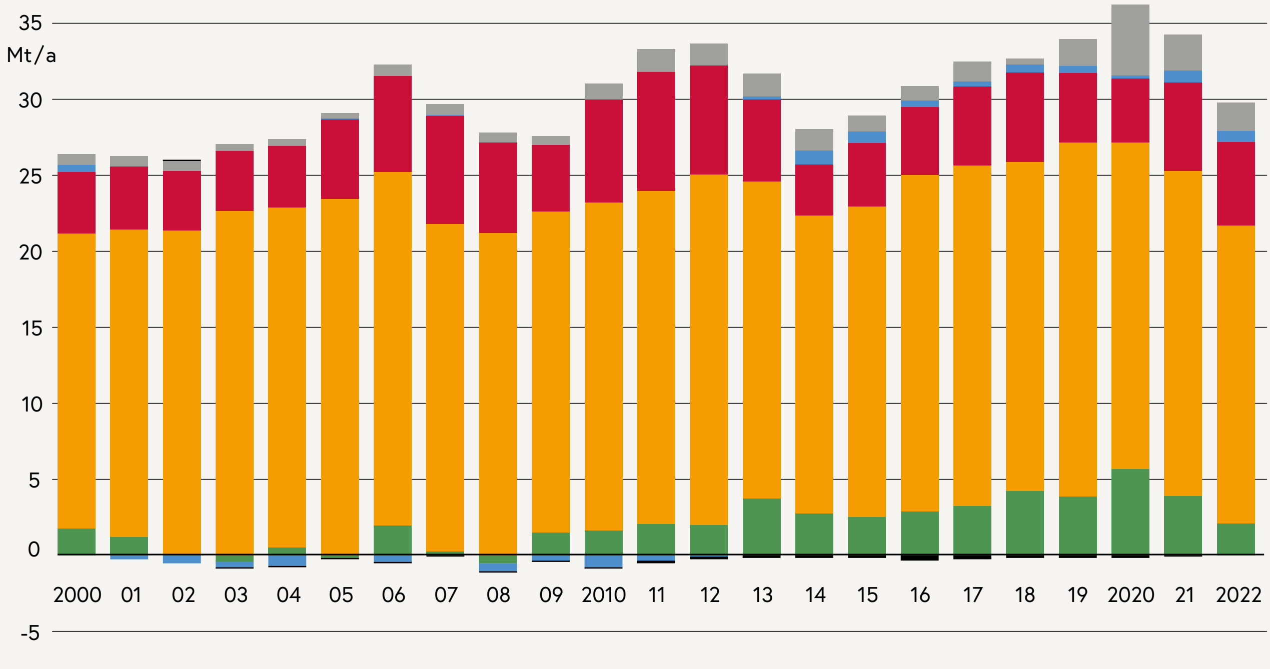
Explanatory note: "Waste" include traded wastes for final processing and landfill (note that the quantity is too small to be visible in the graph). The category "non-assignable" comprises on the one hand manufactured products containing a mix of materials, which prevents their allocation to one of the four material categories, and on the other hand goods not further specified in the statistics for reasons of confidentiality.

Source: Statistics Austria 2024

Figure 9: Material imports to and exports from Austria for the four material categories and for non-assignable materials and wastes, 2000-2022.

In 2022, imports were roughly one-third higher than exports. Austria's physical trade balance (PTB; calculated as imports minus exports) was therefore positive. Austria was a net importer of material goods. In 2000, net imports amounted to 26 Mt/a. By 2022, the physical trade balance had risen by 13 % to 30 Mt/a (Figure 10). During an intervening peak in 2020, net imports comprised 36 Mt/a, strongly influenced by the fact that there was a significant reduction in exports during that year (-5 %), while imports had only slightly decreased (-1 %). In 2021, imports and exports rose strongly again

(2 % and 7 %), but nonetheless the PTB still fell by 5 %, primarily due to the trend for the biomass category and that for non-assignable materials. In 2022 too, this trend continued, with the PTB falling by a further 13 %. This reduction was reflected most strongly in the net imports of biomass and fossil energy carriers.



Explanatory note: "Wastes" include traded wastes for final processing and landfill (note that the quantity is too small to be visible in the graph). The category "non-assignable" comprises on the one hand manufactured products containing a mix of materials, which prevents their allocation to one of the four material categories, and on the other hand goods not further specified in the statistics for reasons of confidentiality.

Source: Statistics Austria 2024

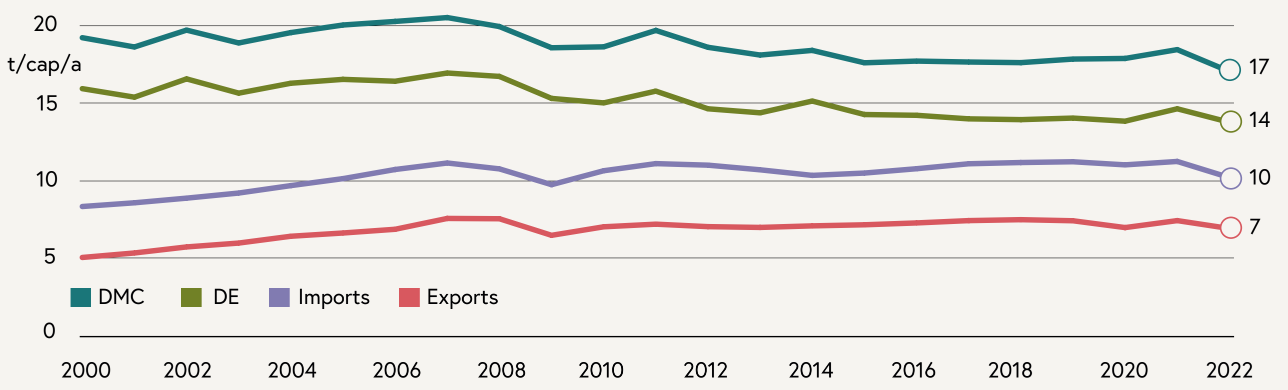
Figure 10: Austria's physical trade balance (PTB) for the four material categories and for non-assignable materials and wastes, 2000-2022.

Technical Support Instrument Project of the European Commission: "Roadmap for a Future Comprehensive Raw Material Balance"

The development of technologies to enable the documentation and analysis of raw material flows is one of the key measures within the Master Plan Raw Materials 2030. Knowledge about the raw materials value chain and raw material flows are indispensable for the development of an effective and strategic raw materials policy. Ensuring the supply security of raw materials depends upon a comprehensive evidence base, which provides data on the national production of primary and secondary raw materials and additionally the import and export of raw materials from both qualitative and quantitative perspectives. The purpose of such a raw material balance is to provide the evidence base for decision-making and thus optimise long-term resource management in Austria, to strengthen a sustainable circular economy and to achieve both national and international climate and energy goals. For this reason, the Federal Ministry of Finance is in the process of creating a roadmap for the development of a comprehensive raw material balance. The project is financed by the European Union's Technical Support Instrument and is being implemented in collaboration with AARC, Vienna University of Technology, Repuco Unternehmensberatung GmbH in cooperation with the European Commission (DG REFORM).

Material consumption comprised 17 tonnes per capita and year in 2022

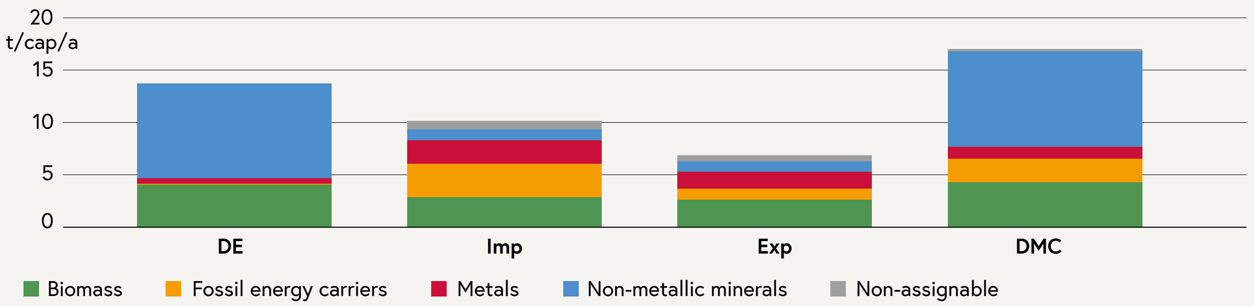
Material consumption comprises domestic extraction plus imports minus exports and amounted to 17 tonnes per capita and year (t/cap/a) in 2022. In Austria, 81 % of material consumption is accounted for by domestic raw materials (the major share of biomass and non-metallic minerals), for which reason DE at 14 t/cap/a is only 3t/cap/yr than DMC (see Figure 11). Imports in 2022 amounted to 10 t/cap/a and exports to 7 t/cap/a. DMC and DE show a slight downward trend in per-capita terms (-4 % and -8 % respectively), while trade flows are increasing (imports 35 %, exports 47 %).



Source: Statistics Austria 2024

Figure 11: Austria's domestic extraction (DE), imports, exports, and domestic material consumption (DMC), 2000-2022.

In 2022, 9 t/cap/a of non-metallic minerals were extracted in Austria, while imports and exports within this material category were significantly lower (1.1 t/cap/a for imports and 1.0 t/cap/a for exports) (see Figure 12). The biomass category is the only category in which extraction, imports and exports are recorded in similar quantities: 4 t/cap/a for extraction, 2.9 t/cap/a for imports and 2.7 t/cap/a for exports; the PTB (imports minus exports) accordingly amounted to 0.2 t/cap/a. Only small quantities of fossil energy carriers and metals are extracted in Austria (0.1 t/cap/a and 0.5 t/cap/a respectively), however in both categories, imports and exports are significantly larger: the imports of fossil energy carriers amounted to 3.2 t/cap/a, and the exports to 1.0 t/cap/a. In the case of metals, imports amounted to 2.2 t/cap/a, and exports to 1.6 t/cap/a. DMC per capita is (as in the case of DMC in absolute quantities) also dominated by biomass and non-metallic minerals (54 % and 25 %). The remaining materials together comprise a total of 21 % of per-capita DMC.



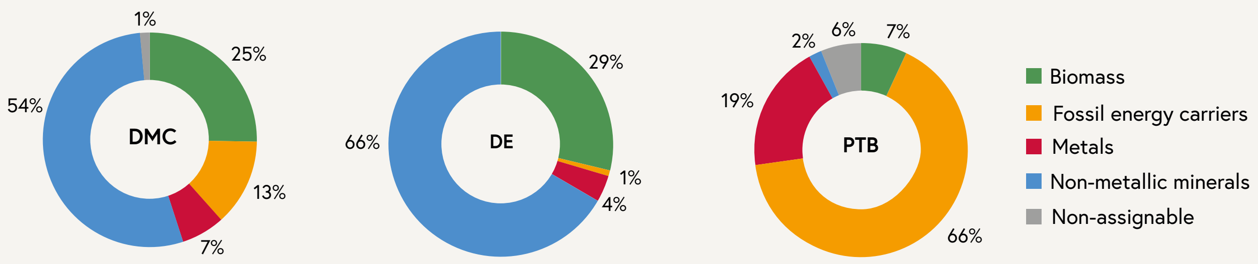
Explanatory note: "Wastes" include traded wastes for final processing and landfill (note that the quantity is too small to be visible in the graph). The category "non-assignable" comprises on the one hand manufactured products containing a mix of materials, which prevents their allocation to one of the four material categories, and on the other hand goods not further specified in the statistics for reasons of confidentiality.

Source: Statistics Austria 2024

Figure 12: Austria's domestic extraction (DE), imports, exports, domestic material consumption (DMC) for four material categories, non-assignable materials and wastes, 2022.

Austria's resource consumption is comprised of four material categories: biomass, fossil energy carriers, metals and non-metallic minerals

DMC and DE are primarily comprised of non-metallic minerals (54 % and 66 % respectively in 2022) and biomass (25 % and 29 % respectively in 2022) (Figure 13), while the PTB is dominated by fossil energy carriers and metals. These differences arise from the domestic availability of resources, the economic viability of extracting those resources, and associated transport costs. The latter mandates that a longer transportation option for e.g., non-metallic minerals, which are available in almost all regions and are characterised by large volumes but also low prices, simply is not economically viable.



Explanatory note: "wastes" include traded wastes for final processing and landfill (note that the quantity is too small to be visible in the graph). The category "non-assignable" comprises on the one hand manufactured products containing a mix of materials, which prevents their allocation to one of the four material categories, and on the other hand goods not further specified in the statistics for reasons of confidentiality.

Source: Statistics Austria 2024, Values are rounded, rounding differences are not balanced.

Figure 13: Share of the four material categories in Austrian domestic consumption (DMC), in domestic extraction (DE) and in net imports (PTB), 2022.

The following chapter provides a more detailed analysis of the four material groups in terms of material composition and trends in DE, DMC and trade, as well as the challenges for society in terms of their utilisation.

Biomass – Food, energy source, construction material

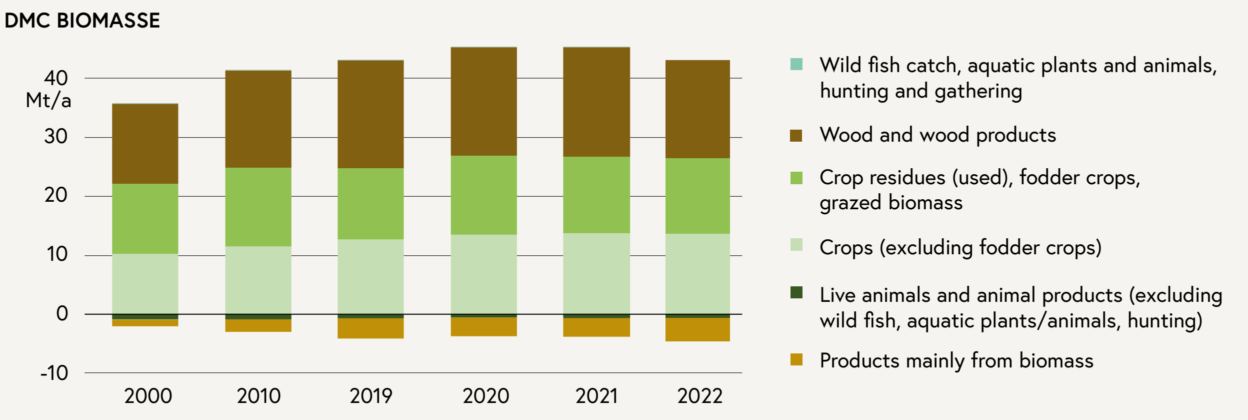
> Statement 6 – Sustainable biomass production cannot be reconciled with the dominant patterns of production and consumption: Biomass provides vital raw materials, including foodstuffs and is classified as renewable, because it regrows again each year. Nonetheless, productive areas of land and their potential for sustainable biomass production are limited: intensive forms of agriculture and forestry significantly contribute to greenhouse gas emissions and biodiversity loss. At the same time, biomass production is impacted negatively by the climate and biodiversity crisis (weather extremes, the decline in pollinating insects). Agriculture and forestry therefore currently face the challenge of reducing their environmental impacts while simultaneously adapting to changing environmental conditions. To be able to provide for society's basic needs while taking account of sustainable biomass options, we need both to make changes in production (greening agriculture and forestry) and to adopt new, less biomass intensive patterns of consumption (e.g., reducing the consumption of animal based foods and of energy used for heating, increasing the useful lifespan of wood products). – Assoc.Prof. Dr. Simone Gingrich, Institute of Social Ecology (SEC), BOKU University

Biomass denotes all biogenic materials of plant and animal origin, which are produced from agriculture, fisheries and forestry. Biomass materials are organic in substance and are therefore categorised as renewable raw materials. They are used as food and feed, serve as renewable energy sources in the form of firewood, pellets or biofuels, and are used as industrial materials in construction, for the production of goods such as furniture, paper or musical instruments or as raw materials in the chemical-technical industry (sugar, starch, oils).

Agriculture and forestry make use of fertile land to supply the biogenic raw materials vital for humans (food) and economic processes. The availability and productivity of land areas thus plays a central role in the domestic production of biomass. In Austria in 2022, 1.3 million hectares of cultivated land (Statistics Austria 2023b) was used to produce 11 Mt/a of crops and 13 Mt/a of harvest byproducts. In addition, 1.2 million hectares of grasslands (meadows, pastures and alpine pastures) were used for livestock farming. Some 48% of Austria's total landmass is covered by forest, of which 3.4 million hectares are used for forestry (Statistics Austria 2023b). In 2022, 13 million tonnes of timber were extracted from this area.

The domestic material consumption (DMC) of biomass has risen by 15 % since 2000 (see Figure 14). Whereas 34 million tonnes of biomass were used in 2000, 22 years later this figure had risen to 39 million tonnes. In per capita terms, this represents a slight increase from 4.2 to 4.3 t/cap/a. The major share of biomass consumption, at 17 million tonnes annually, comprises timber and wood products. The increased use of a variety of timber species in the construction industry together with the use wood byproducts for energy, for example in the form of pellets for biomass boilers, are also reflected in the significant increase in wood consumption of 23 % between 2000 and 2022. Alongside wood products, in 2022 13 million tonnes of crops and almost 13 million tonnes of harvest byproducts (e.g. straw) from agricultural production were used. The latter were used largely in livestock farming (e.g. as bedding material) but also as industrial raw materials and for energy production. Agricultural crops showed a larger increase between 2000 and 2022 of 31 %, consequently exceeding the quantity of harvest byproducts from 2017 onwards (byproducts showed an increase of 8 % in the same period).

Domestic extraction of biomass in 2022 comprised 37 % timber and wood, 35 % harvest byproducts and 29 % crops, with a total of 37 Mt/a. In addition to domestic extraction, 26 million tonnes of biomass were imported into Austria (28 % of all biophysical imports) and 24 million tonnes were exported (38 % of all exports). Austria imported primarily timber and wood products (45 % of the biomass imports in 2022, or 12 Mt/a), crops (24 %, or 6 Mt/a) and other products primarily consisting of biomass (25 %, or 6 Mt/a). In quantitative terms, the most significant export goods also comprise the same three categories: timber and wood products (36 % of total biomass exports), crops (14 %) and other products consisting primarily of biomass (42 %).



Source: Statistics Austria 2024

Figure 14: Austria's domestic material consumption (DMC) of biomass, 2000, 2010, 2019, 2020, 2021 and 2022.

In accordance with MFA conventions (see methodology summary in Appendix and Eurostat 2018), livestock is seen as a part of the socioeconomic system. The extraction from the environment that is required for keeping livestock, i.e. the harvested or grazed plant biomass, is thus a primary input into the socioeconomic system. Domestic animal products are therefore not accounted for as primary extraction, but constitute secondary products, which are produced within the socioeconomic system from the extracted plant-based materials. Animal products are only recorded in imports and exports as material inputs or outputs. In Austria, more animal products are exported than imported, which is why the negative DMC (-0.6 million tonnes), in this case only reflects the net export volumes for this category in 2022.

Austria is equipped with extensive forested and agricultural land with a high level of biological productivity, from which high volumes of biomass are harvested. The average cereal yield (harvest per unit of area) in Austria is around 28 % above the EU average, for example (FAO 2023). In the case of most agricultural and forestry products, Austria demonstrates a high level of self-sufficiency, consequently the share of DE within DMC for biomass is 95 % (for crops: 78 %; harvest byproducts: 100 %; timber and wood products: 80 %; fish, aquatic animals and game: 12 %[5]). Overall, net imports contribute only 5% to DMC of biomass (see Figure 5). Nonetheless, the data on international trade flows also show that, despite the high degree of self-sufficiency, Austria both imports and exports large quantities of timber and agricultural products. Across all material categories, imports of wood products constitute the third-largest product group in terms of quantity (with imports of 11.8 Mt/a), only exceeded by mineral oil (12.9 Mt/a) and iron (12.7 Mt/a) (see data tables in Appendix). A large amount of byproducts from the timber industry (which uses a large amount of imported roundwood) is used as energy carriers, thus the calculations show a large share (roughly 39 %) of the wood biomass used for energy in Austria coming from imports (Jandl et al 2024). Despite the high levels of domestic biomass availability and harvest, Austria is firmly integrated within European and global biomass supply chains and markets and consequently also dependent upon these.

Land – a limited resource

National and global demand for biomass is growing and sustainable production of this biomass requirement presents a significant challenge, while agricultural activities contribute significantly to greenhouse gas emissions (10.6 % of Austrian emissions in 2021; Federal Environment Agency 2023a). Land use trajectories in Austria are also characterised by long-term soil sealing and fragmentation of land areas. According to the Federal Environment Agency, soil sealing leads to the long-term loss of approximately 4100 ha/a or 11.3 ha/day of productive agricultural land each year (Federal Environment Agency 2024a). The increasing demand for biogenic materials is intensifying the pressure on land as a limited resource: the energy transition, the measures contained in the Bioeconomy Strategy (BMNT et al 2019), increased use of timber in the construction industry, etc. are driving a demand for biomass materials. Yet the available land area is limited and the intensity of utilisation is already very high, while at the same time the trend is

5 The categories of animal products and products primarily consisting of biomass comprise almost no raw materials (apart from wild catch from fishing and hunting); thus these categories primarily appear in imports and exports.

heading towards more extensive land use. Accordingly, competition for available land areas and biomass harvested from them is increasing (Gingrich et al 2015; Schirpke et al 2023). Due to this and the high degree to which the calculation of potential benefits is depending on the choice of reporting procedure, the APCC Special Report on Land Use and Climate Change (Jandl et al. 2024) concludes that no realistic potential for reducing emissions can be assigned to bioenergy.

Levers for reducing biomass consumption

Various levers exist to mitigate the growth in demand and to produce biomass more sustainably. A much-discussed option involves the avoidance of waste generation along the production chains, particularly of food waste: food waste in Austria amounts to about 1.2 million tonnes annually, the major share of which is produced by private households (61 %), 17 % by the hospitality industry and care services providers, and 14 % through the processing and production of foodstuffs (BMK 2023). It is estimated that roughly 50 % of these wastes generated in Austria are essentially avoidable (Pladerer und Hietler 2019). Even greater importance is given to the transition to a diet that is both more sustainable and healthier, containing a reduced share of products of animal origin (Willett et al. 2019; Jandl et al. 2024). A very large share of agricultural biomass (produced within Austria and imported) is used to provide feed for livestock. Reducing the consumption of animal products is therefore regarded as an important opportunity to reduce both the demand for land and primary biomass, and the greenhouse gas emissions created by the food system (Schlatzer and Lindenthal 2020; Lauk et al. 2022).

Fossil Energy carriers – an obsolete model?

> Statement 7 – Limiting global heating to 1.5°C implies reaching net zero CO_2 emissions globally by 2050: The use of fossil energy carriers is not only a driver of dangerous climate change, but also a cause of air pollution, and of the increasing challenges for energy security and the high costs associated with this. For these reasons, and above all to limit global heating to 1.5°C, net zero emissions must be achieved globally by the middle of this century. This is the "carbon law", which means that Europe, including Austria, needs to phase out fossil energy use and transition to carbon-free sources such as renewable energies. Decarbonisation requires comprehensive electrification and is not only a question of finding technological and economic solutions but above all, of demand side and human behaviour changes. – Univ.Prof.i.R. MA PhD. Nebojsa Nakicenovic. Member of the European Scientific Advisory Board on Climate Change of the European Commission

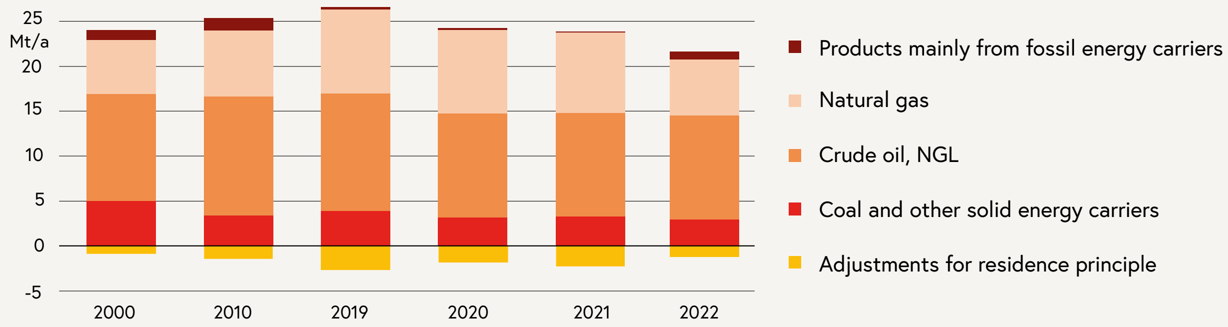
Fossil energy carriers are non-renewable mineral raw materials, created from organic materials in the Earth's crust over the course of millions of years as a result of biogeochemical processes. They are primarily used to provide energy through combustion. Thus, even today, the majority of buildings are heated using oil or gas, vehicles are largely propelled by diesel or gasoline and many industrial processes are powered by fossil energy. Fossil energy carriers are additionally used as industrial materials, for example in the petrochemical industry to manufacture products such as asphalt and plastics, as coke for the reduction of iron in the steel industry, or natural gas for the synthesis of ammonia for nitrogen fertilisers.

Only very small quantities of fossil energy carriers are extracted in Austria. Coal is no longer mined, since the closure of the last mining areas in 2006 (BMF 2022). The extraction of oil and gas has fallen from 1.1 million tonnes and 1.4 million tonnes respectively in 2000 to half a million tonnes in each case in 2022. More than 95 % of the Austrian demand for fossil energy carriers is therefore met through imports. In 2022, total imports of fossil energy carriers amounted to 29 Mt/a, of which 13 Mt/a were oil, 7 Mt/a were natural gas and 3 Mt/a were coal, as well as products primarily comprised of fossil energy carriers (4 Mt/a) and 2 Mt/a from refuelling for Austrian vehicles, ships or airlines outside Austria[6]. Since 2000, coal imports have fallen by 21 %, oil imports have risen slightly by 5 %, while annual imports of natural gas have risen sharply since 2000 (up by 51 %). In 2022, however, Austria also exported 9 million tonnes of fossil energy carriers primarily in the form of manufactured products (e.g., plastics and products from the chemical industry, 3.6 Mt/a in total).

Austria's consumption of fossil energy carriers fell by 11 % over the period under review, 2000-2022. The DMC of 21 million tonnes of fossil energy carriers in 2022 contrasts with a figure of 23 million tonnes for 2000 (see Figure 15). This represents a per capita use of 2.3 tonnes in 2022 and a reduction of 13 %. Nonetheless, significant fluctuations in consumption are evident within these 22 years: The peak years of consumption were in 2003 (26.6 Mt/a), 2005 (25.6 Mt/a) and 2012 (25.3 Mt/a). The lowest consumption figures were observed for 2014 (21.6 Mt/a) and 2022 (20.6 Mt/a). Since 2019 (24.6 Mt/a), there has been a continuous fall year on year in the consumption of fossil energy carriers (see Figure 15). Coal consumption decreased continuously from 2002, with oil following the same decreasing trend from 2004. The upward trend in gas consumption reversed from 2016, since which year consumption reduced slightly.

6 This last category is denoted as "adjustments for residence principle" in material flow accounts and includes fuels obtained abroad by Austrian residents for transportation, and those obtained within Austria by residents of other countries. These flows are not recorded in the external trade data and are therefore, similarly to air emissions calculations, recorded and accounted for in accordance with the principle of national treatment within the MFA. For further details, see the Statistics Austria project report (Neubauer & Gierlinger 2023).

DMC FOSSIL ENERGY CARRIERS



Notes: NGL = natural gas liquids; The category "Adjustments for residence principle" includes fuels purchased abroad by Austrian residents for transportation (as inflow), and those purchased within Austria by residents of other countries (as outflow). These flows are not recorded in the external trade data and are therefore, similarly to air emissions calculations, recorded and accounted for in accordance with the principle of national treatment within the MFA. For further details, see the Statistics Austria project report (Neubauer & Gierlinger 2023).

Source: Statistics Austria 2024

Figure 15: Austria's domestic material consumption (DMC) of fossil energy carriers, 2000, 2010, 2019, 2020, 2021 and 2022.

There are high levels of import dependencies from a few fossil energy carrier exporting countries

More than 80% of the global extraction of fossil energy carriers takes place in only four countries: China, India, Indonesia and the USA (BMF 2023). These, together with four further countries (Russia, Australia, South Africa and Kazakhstan), account for 96% of global production. The continuing high demand for fossil raw materials thus creates pronounced import dependencies for many states and leads to volatile prices on the global markets. Austria also obtained about 96% of its oil imports during the last 10 years from only 12 countries, some of which are categorised as "politically unstable" (BMF 2023). Russia's war against Ukraine made these dependencies visible in the case of natural gas in particular, as well as for oil, and the negative consequences (shortages and supply problems or pauses as well as the drastic price increases unleashed as a consequence) became tangible.

Renewable forms of energy are alternatives to fossil energy - however, a simultaneous reduction in energy demand is required

Along with the management of acute shortages in the supply chain, it will also be necessary to abandon the use of fossil fuels in the medium term. The use of fossil energy carriers is a cause of CO_2 emissions and is consequently the major driver of climate change. There is a prevailing consensus that abandoning the use of fossil energy in the next few decades is unavoidable, if we are to mitigate climate change and prevent an impending climate catastrophe (IPCC 2023). The Austrian federal government has set itself the goal of achieving climate neutrality by 2040[7]. The options for energy supply comprise renewable forms of energy, including solar energy, hydropower, wind energy,

7 bmluk.gv.at/themen/klima-und-umwelt/klima/nationale-klimapolitik/klimaschutzgesetz.html

geothermal energy and ambient heat, as well as energy from biomass (wood, biogas, biogenic waste). When one considers the limited availability of biogenic raw materials mentioned in the previous chapter on Biomass, together with the shortage of particularly critical raw materials detailed in the following chapter on Metals, it becomes clear that a comprehensive concept of energy transition is required. In other words, a substantial reduction in energy demand is needed alongside the substitution of fossil energy carriers with renewable energies (Creutzig et al. 2022).

Metals – small quantities, yet great strategic importance

> Statement 8 – Sustainability criteria need to be implemented in mining and further processing including through international cooperation: The global demand for primary mineral raw materials will continue to increase in the coming decades despite the commitment to a circular economy, due to the energy and digital transformation currently underway. In the context of planetary limits, this means that not only mining itself, but also the further processing and use of extracted products must become sustainable. CO_2 neutrality, decreased land and water use, the improvement rather than minimisation of biodiversity, and social acceptance of mining, are just some of the aspects that are relevant in this respect. Since Austria and the EU cannot meet their own requirements for metals domestically, we also need to pursue international cooperation in accordance with the same principles, if we are to avoid resource shortages and conflicts.
> – Univ.Prof. Dr. Michael Tost, Professor for Sustainable Mining Technology, Montanuniversität Leoben

The group of metals comprises ores, ore concentrates and more highly processed metallic materials and products. Ores include the rock extracted through mining activities and the metal contained within it with varying degrees of metal concentration. Pure metal is extracted from ores and ore concentrates by means of smelting[8] and chemical processes. Metals are subdivided in material flow accounts into two groups; the quantitatively predominant ferrous metals, and non-ferrous metals. Further to these, manufactured products made from metallic raw materials that are imported and exported are assigned to the group of products primarily consisting of metals.

The individual metals that form part of this very diverse group are very clearly distinguished from one another in respect of their physical characteristics, use and economic value. Ferrous metals form the largest share of this material category in quan-

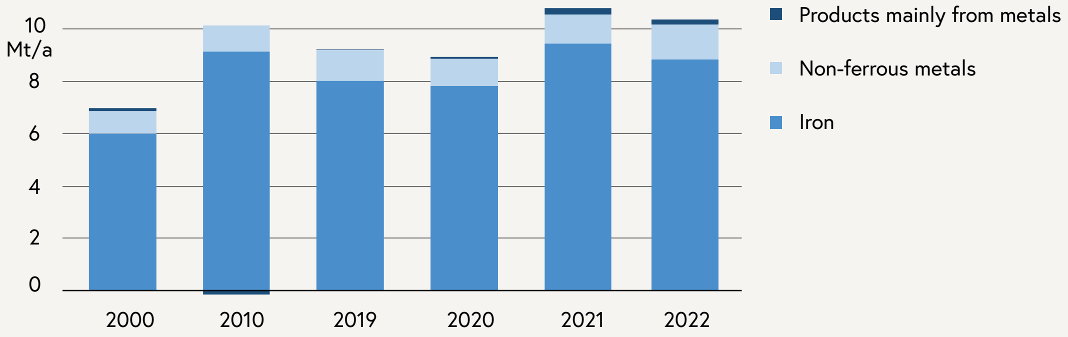
8 Smelting refers to the thermal process by which a metal or reusable material is extracted from an ore.

titative terms (85 % of DMC of metals) and are used particularly in the form of a broad variety of steel types in many products (e.g. machines, vehicles, household equipment) and in the built environment (buildings, transport infrastructure). Non-ferrous metals in contrast are a very diverse group ranging from, for example, aluminium, copper, zinc, tin and magnesium to rare earths and so called spice metals used in very small quantities. Some of these materials can be found in countless products used for daily life (e.g. aluminium in cars, window frames, tennis rackets, sanitary items, and tableware, or copper in the form of cables for electronic goods and machines). Other metals are used in complex combinations and alloys within high-tech instruments and devices, which also play a critically important role in the energy transition or new technologies. Rare earth metals, for example, are required, for the permanent magnets in wind turbines or electric vehicles (neodymium), for batteries (lithium and cobalt) and in electronic devices for digitisation (tantalum, gallium and indium). In summary, metals are stock-forming materials that accumulate in a huge variety of long-life goods, buildings and infrastructures.

Extraction of metal ores in Austria is very limited in comparison to the other material categories (the extraction of metals comprises only 7 % of total DMC), however it has gradually increased in the past two decades from 3 Mt/a in 2000 to almost 5 Mt/a in 2022, of which 4.3 Mt/a comprised ferrous metals. In the same year, 20 Mt/a of metal ores and metallic products were imported and 15 Mt/a were exported.

Austrian consumption of metals increased by 49 % from 2000. Nonetheless, significant decreases due to reductions in imports were observed during the financial crisis of 2008 and again in 2012. In 2021 iron and ferrous products comprised more than 85 % of the total domestic material consumption of metals.

DMC METALS



Source: Statistics Austria 2024

Figure 16: Austria's domestic material consumption (DMC) of metals in 2000, 2010, 2019, 2020, 2021 and 2022.

Metals, like fossil energy carriers, are not available ubiquitously and are instead concentrated in deposits in the lithosphere. Alongside the extraction of primary metals from naturally occurring deposits, the use of secondary metallic resources through recycling processes has acquired great importance. Metal recycling not only conserves primary raw materials but also energy, since no energy-intensive extraction of the metals from ores is required.

Socioeconomic metal stocks are urban mines for secondary use

Metals are primarily used in long-life goods or buildings and infrastructures that have a lifespan of several decades, and by this accumulate within society. In this context, reference is made to “anthropogenic deposits”, since the metals can theoretically become available as secondary raw materials at the end of the lifespan of these products and structures. The increasing use of metals has resulted in considerable accumulation of anthropogenic metal stocks during the 20th century (Graedel 2010). In the context of the circular economy, efficient recovery of metals (and other secondary raw materials) from anthropogenic stocks at the end of their lifespan has therefore come into focus as “urban mining”.

The demand for metals will soon exceed the supply

Metals are primarily utilised in long-life goods such as buildings, vehicles or machines. Since naturally occurring deposits of metals are finite and new mining areas are not immediately available or in sufficient quantities in Europe, the economic importance of accumulated anthropogenic stocks is continually increasing. However, current recycling technologies do not allow all metals to be recovered for reuse with the same degree of efficiency. In 2020, the Austrian recycling rate for metals was 93 % and 66 % for metal packaging (BMK 2023). The demand for metallic raw materials will soon exceed the supply. The Austrian Master Plan Raw Materials 2030 (BMLRT 2021) responds to these challenges and aims to enhance the supply from domestic sources as well as to secure supply from abroad.

Master Plan Raw Materials 2030

Since the publication of the Master Plan Raw Materials 2030 in December 2021, the geopolitical situation has changed and the related supply of raw materials have worsened. As a consequence of the energy transition, the electrification of mobility, the decarbonisation of industry and digitalisation, the demand for often “new” raw materials is growing strongly and patterns of usage are undergoing changes. At the same time, the situation within the international raw materials markets is becoming particularly fraught. The approach of the Master Plan Raw Materials 2030 has three pillars – supply from domestic sources; supply from international sources; smart production, circular economy, and new technologies and products – and addresses cross-cutting themes of acceptance and sustainability, digitalisation and automation, research and development, education and training, and dialogue and foresight policy, offers solutions-based approaches to the current challenges of raw materials supply. The measures contained within the Master Plan and their implementation were evaluated by the Monitoring Committee in 2023 and a set of recommendations were formulated.[9]

9 For more information (in German), see: bmf.gv.at/themen/bergbau/mineralrohstoffpolitik/oesterreich/masterplan-rohstoffe-2030.html

Key raw materials of the future are classified as critical raw materials, and plans to increase their production within the EU

In the case of metals, a particular importance is assigned to critical raw materials, i.e., mineral raw materials that are characterised as having strategic economic importance and a high degree of supply risk[10]. The EU published a first list of 14 critical raw materials in 2011. In the fifth such list, published in 2023, 34 raw materials are classified as critical (European Commission 2023c). The list includes bauxite (the raw material for aluminium), copper, nickel, and metals that are used albeit in small quantities but in particularly important future technologies (solar panels, wind turbines, EVs, etc.), such as cobalt, the rare earths, platinum group metals or lithium. In the case of rare earths, for example, almost 62 % of the quantities utilised worldwide are extracted in China (BMF 2023). Critical raw materials are faced with a very fast-growing global demand, for which reason there is a strong impetus to extract secondary raw materials from the large anthropogenic stocks that already exist. Therefore, EU strategy aims to stimulate production within Europe, to strengthen recycling activities and to increase the efficiency of utilisation. In 2023, the EU published the Critical Raw Materials Act and the Net Zero Industry Act. Both documents are intended to achieve raw materials supply security and to ensure and enhance the competitiveness of net-zero technologies.

Critical Raw Materials Act

The Critical Raw Materials Act (CRMA) provides a strategic framework for European raw materials supply. This new EU regulation aims to achieve long-term supply security of critical and strategic raw materials and to minimise any supply dependencies. Both the transformation leading to climate neutrality and the simultaneous enhancement of European competitiveness help to ensure secure and responsible raw materials supply. The key aspects of this package focus on strengthening European supply chains, diversifying EU imports, enhancing the monitoring of critical raw materials supply chains, and sustainability and circular economy development. Achieving these aims of the CRMA depends on strengthening processing and recycling capacities and increasing the share of raw materials extraction within the EU, further developing strategic partnerships and ensuring stress tests are carried out by the Commission. In addition, decision-making processes on permit allocation will be streamlined, while still adhering to high ESG standards (Environment, Social, Governance).

Net Zero Industry Act

The European Commission intends that the Net Zero Industry Act (NZIA) together with the Critical Raw Materials Act provides a clear strategic framework within which to strengthen the competitiveness of the European net zero greenhouse gas emissions industry. Accordingly, the strategy aims to create a conducive environment for the pro-

---

10 bmf.gv.at/themen/bergbau/mineralrohstoffpolitik/europaeische-union/kritische-rohstoffe.html

duction of and investment in clean, emissions-free technologies within Europe, which will drive the transition to climate neutrality. The aim is to ensure that production capacity for the most strategically important net zero technologies reaches at least 40 % of EU requirements by 2030. Permit-granting processes for strategically important value chains are to be made easier, State aid rules made simpler and the use of EU funds made more flexible. Net zero technologies include those technologies that play an important role in the transition towards decarbonisation, such as photovoltaics, wind energy, batteries, geothermal energy, CCS (carbon capture and storage) and CCU (carbon capture and utilisation).

Non-metallic minerals – the largest mass flow

> Statement 9 – Sustainable use of mineral materials requires a different approach within the construction sector: The construction and operational use of buildings is responsible for approximately 30-60 % (depending on the parameters defined) of all greenhouse gas emissions in Austria and also consumes a similar share of total energy and primary materials used. The influence of the building sector and also the potential for optimisation are therefore huge. Although technological advances, particularly during the last 120 years, have led to an improvement in the functionality of buildings, the material and energy consumption associated with construction has risen sharply and involves combinations of a large number of diverse materials, which can only be separated again with difficulty at the end of their lifespan. – Univ.Prof. Dr. Benjamin Kromoser, Institute of Green Civil Engineering, BOKU University

The course of industrialisation has seen a marked reduction in the costs of materials and machinery in relation to the cost of human resources, so that the most resource-efficient solution in terms of material and energy consumption is generally no longer the most economically attractive solution. Current construction engineering technologies are materials-intensive, particularly in the case of load-bearing structures, and in real terms have only very limited potential for recycling and reuse.

Minimising both the grey energy and the operating energy used in the construction of new building projects and the maintenance of existing buildings, taking account of the entire lifecycle is essential, without favouring particular materials or construction techniques. In future, an objective ecological optimisation, which aims to achieve optimal expenditure of materials and energy, will have to play a central role alongside high-quality functional and structural design. Awareness within society about the influence and potential of the construction sector needs to be fostered, and mechanisms need to be created to ensure that ecological approaches to construction and civil engineering can also become more economically attractive. Further to this, we need to establish green building methods that are suitable for large-scale application.

In terms of the total quantities available, non-metallic minerals are the largest material category. In material flow accounts, this group is sometimes divided into construction raw materials and industrial minerals. Construction raw materials include a diverse range of rock types such as limestone, dolomite, sand or gravel, which are used primarily for the construction of buildings, roads and other infrastructures. Limestone is an important raw material, as it is the source material for cement production. In terms of industrial applications, quartz sand is used in glass manufacturing, diamond in mechanical engineering because of its hardness, kaolin and calcite as fillers for paper production and phosphate rock for the production of fertiliser. However, a clear dividing line between construction and industrial minerals cannot be easily drawn, because the forms of utilisation partially overlap. The type of material, by contrast, can be clearly distinguished, for which reason the material groups within the MFA are organised according to this scheme. As in the case of metals, non-metallic minerals are primarily stock-building materials that accumulate in socioeconomic systems.

With only a few exceptions (particularly the special mineral materials used for industrial applications), the major share of non-metallic minerals used in Austria is extracted domestically. In 2022, 82 Mt/a of non-metallic minerals were extracted in Austria. Since 2000, however, the extraction of non-metallic minerals has decreased by 8 % in total.

The largest share (95 %) of extracted non-metallic minerals come from only three categories: sand and gravel (DE of 39 Mt/a in 2022), limestone and gypsum (22 Mt/a) and basaltic rock, chalk, dolomite and shale (17 Mt/a). Further mineral materials such as clays, kaolin, salts, chemical minerals, minerals for fertiliser production (phosphate, potassium) and other mining and quarrying products amounting to 4 Mt/a in total were extracted within Austria.

Trading activities relating to this material category are very limited in relation to DE; in 2022, 10 Mt/a were imported and 9 Mt/a exported. In terms of imports, the group of products composed of non-metallic minerals comprised the largest quantities (3.3 Mt/a) followed by sand and gravel (3.1 Mt/a). In the case of exports, the largest items were in the categories of sand and gravel (3 Mt/a), salt and chemical and fertiliser minerals as well as products composed of non-metallic minerals (both groups 2 Mt/a).

Domestic consumption of non-metallic minerals has remained relatively stable since 2009, at between 80 and 87 Mt/a (see Figure 17). In recent years, a slight reduction during the COVID crisis in 2020 was observed, but DMC increased again in the following year to 89 Mt/a, i.e., almost three times the rate of the previous year's decrease. The three years of 2011, 2014 and 2021 recorded the highest figures in consumption of non-metallic minerals since 2009. Per capita consumption of non-metallic minerals in 2021 in Austria was approximately 10 t/a. Roughly half of total consumption can be attributed to sand and gravel. In 2022, consumption fell once again to 83 Mt/a or 9 t/cap/a. gen.

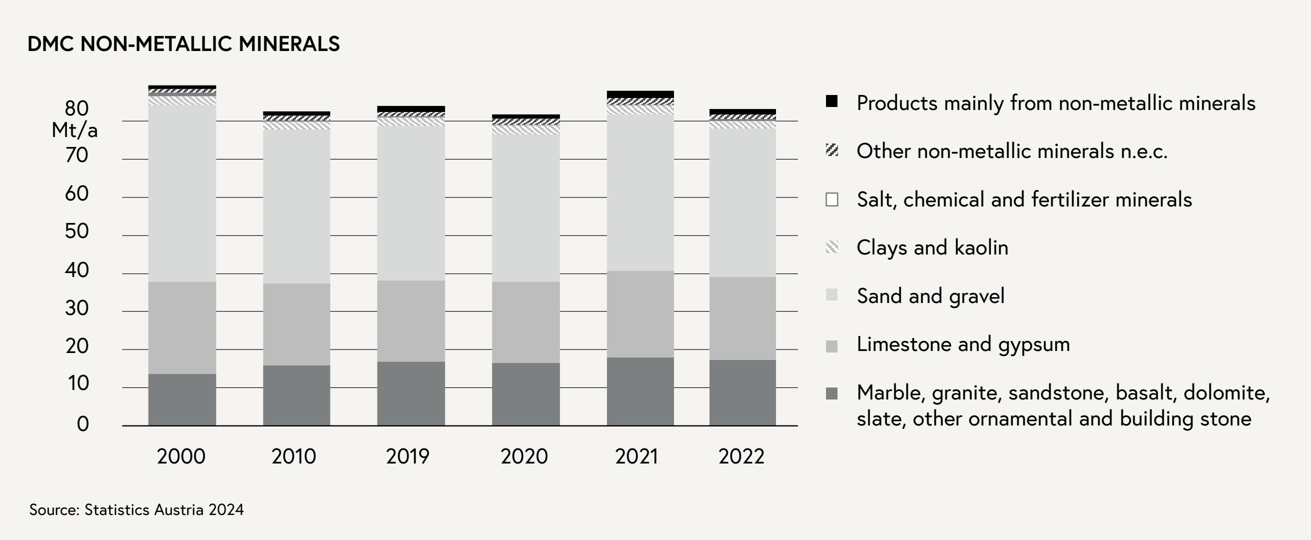


Figure 17: Austria's domestic material consumption (DMC) of non-metallic minerals, 2000, 2010, 2019, 2020, 2021 and 2022.

Our building and infrastructure stocks are the drivers of future resource flows

Non-metallic minerals are primarily used for the construction and maintenance of socioeconomic stocks (e.g., roads, residential buildings, hospitals, sewerage systems, etc.). Large volumes of concrete, bricks, and sand and crushed rock for foundations are used each year for the construction of buildings, roads and civil infrastructure projects. Although these materials are generally not toxic or particularly dangerous, environmental impacts are involved as a result, among other factors, of the large quantities being extracted. Every form of resource extraction, regardless of the materials involved, causes environmental impacts, e.g., vegetation and soil loss, groundwater degradation, changes and damage to the structure and functioning of ecosystems and subsequently of ecosystem services for local populations (UN IRP 2019b). By far the most significant environmental consequences arise, however, from the use of these materials in the form of huge socioeconomic stocks. Firstly, these stocks in the form of buildings and infrastructure determine the material flows of the future, since each house and each road must be maintained and repaired at regular intervals. Wiedenhofer and others (Wiedenhofer et al. 2015; Haberl et al. 2021) have calculated that approximately half of all the construction raw materials used are required for maintenance and repair of existing stocks, while half are used for new construction and infrastructure projects. Secondly, stocks are a cause of energy consumption, since each house is heated, illuminated and equipped with a variety of electronic devices and equipment. Roads and related infrastructures (e.g., underground garages) require illumination and are utilised by vehicles being powered by fuels. Thirdly, the expansion of stocks is currently linked to an expansion in soil sealing, which has already reached an alarming extent in Austria (Federal Environment Agency 2024a). In this context, it is important on one hand to recycle existing construction materials as fully as possible, and by this means to reduce the extraction of primary raw materials. On the other hand, structures that already exist should be more efficiently and more intensively utilised, so as to limit the further expansion of stocks and the soil sealing that accompanies such projects.

For construction raw materials too, secondary use of anthropogenic deposits is increasingly important for combatting shortages associated with regional planning

Construction raw materials are used in large volumes and are also available in great quantities in deposits within Austria. Shortages ensue less as a result of dwindling natural resources but rather through the limited availability of suitable land. Available raw materials can often not be mined or quarried due to regional planning disputes (Weber 2008). The use of anthropogenic deposits will therefore become increasingly important for these materials too. This is, however, hindered by the difficulties of processing construction waste, of separating composite materials, and because large quantities end up in downcycling processes; the material cannot be recovered in the same quality as before its original use, and instead becomes available as a material of lower quality for use in other, low-grade applications. Thus, foundations for buildings are generally filled using crushed and recycled concrete and other construction waste materials.

Biophysical stocks determine resource flows – Stock-Flow-Service-Nexus

Statement 10 – Density and spatial organisation of settlements and infrastructures influence the resource use and the emissions of cities: Globally, societal material stocks already weigh approximately as much as all living beings, i.e., one trillion (1015) tonnes and this figure is rising exponentially (Elhacham et al. 2020). By far the largest share of these stocks consist of buildings and transport infrastructures, followed by machinery and consumer goods as well as humans, livestock and domestic animals. It has long been known that density and spatial organisation of settlements and infrastructures influence the resource use of cities, particularly the emissions from transport. This is also true at the national level. A recent statistical research report has shown that land and spatial organisation of buildings and infrastructures in a country have roughly as strong an influence on per capita energy use and CO_2 emissions as economic performance, i.e., gross domestic product (GDP). This effect occurs separately and in addition to GDP, i.e., among countries in which GDP is at the same level, those with larger and more diffusely distributed infrastructures consume and emit at a higher rate (Haberl et al. 2023). The most influential factor concerns sealed area per capita. Therefore, halting soil sealing would not only be an important contributor to conservation of soils, biodiversity and water resources, but would also help reduce resource use; on one hand, because less construction materials have

to be produced and above all, because their maintenance and use is linked with long-term high levels of energy and material inputs.
– Univ.Prof. Mag. Dr. Helmut Haberl, Institute of Social Ecology (SEC), BOKU University

When we observe a system, we see that inflows and outflows determine the stock levels of that system. This can be illustrated in comparison with the example of the water levels in a bathtub (Forrester 1994; Sweeney and Sterman 2000) or the population of a country (with births, deaths and migration as inputs and outputs). This connection between inputs, outputs and stocks also exists for societal resource flows. Thus, the material stocks are a determining factor for the current high level of resource flows and emissions (Haberl et al. 2017; Krausmann et al. 2017).

At the beginning of the previous century, material consumption was still characterised by the dissipative use of resources: by far the largest share of materials consumed were used for the provision of energy. In other words, they were consumed as food and feed or as technical sources of energy within a relatively short time period after their extraction, and subsequently exited the socioeconomic system as outputs (excrements, emissions). The socioeconomic stocks were comparatively small. One hundred years later, social metabolism had changed to such a degree that the largest share of materials was used to create stocks, i.e., the materials were largely used for the construction and maintenance of buildings, infrastructures and durable goods, and thereby accumulated in socioeconomic systems (Krausmann et al. 2018).

Contemporary societies are organised in such a way that we require and use a vast range of stocks in our working and private lives (see Figure 18). These stocks include artefacts that are large-scale (e.g. buildings, roads, bridges, underground infrastructure, machinery, vehicles) and smaller-scale products (e.g. clothing items, leisure and hobby equipment, furniture, tools and communications devices). In the material flow accounts, stocks comprise all "things" that remain in socioeconomic use for longer than one year. Along with the built and manufactured stocks, humans themselves, domestic animals and livestock are also included in the calculations of socioeconomic stocks, which require resource inputs such as food and feedstuff to maintain their existence (Krausmann et al. 2017; Eurostat 2018).

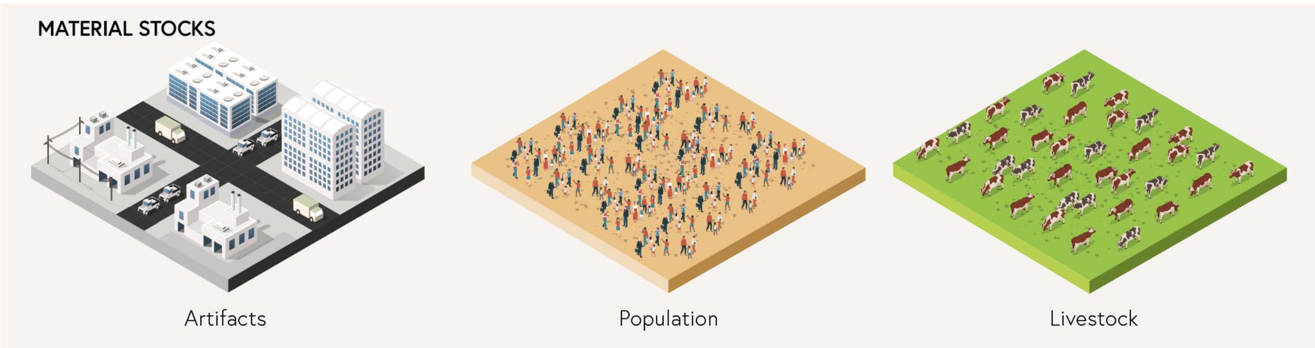


Figure 18: Material stocks.

Stocks create resource flows. Material and energy are required on one hand to construct and maintain buildings and roads, for example, and on the other hand to operate these, i.e., to provide services such as shelter and mobility from them (Haberl et al. 2017; Krausmann et al. 2017). A significant share of the resources that we use in production, but also above all in the operation phase, is energy. A reduction in resource flows would therefore also result in a transformation of the structure, quality and use of stocks, and in some circumstances the reduction of stocks themselves. However, we need to analyse our stocks in even greater detail. Let us take the example of an apartment within a house: we have an apartment because we want to have protection from cold or heat, rain or snow and because we want to create a comfortable home, in which we feel safe and sheltered; these criteria represent key aspects of quality of life (Görg et al. 2023). Precisely what material lies hidden within the walls is comparatively far less relevant. To take another example: we own a car because we use it to travel to work. In this respect, it is generally less about car ownership or the materials from which the car is built, than it is about getting from A to B. The mode of transport that is associated subjectively as being the most accessible, the nearest, the quickest and the most comfortable will be preferred for the service requirement "get me from A to B". A third example would be infrastructures such as sanitation or electricity supply networks. Here too, I enjoy the advantages as a private person of being able to use this infrastructure without having any direct influence on their material composition or by consuming an actual product. The available infrastructure, i.e. how the public space is organised and structured, provides the framework within which individual (consumer) decisions are made. In urban regions, it is far easier to avoid using a car due to a more densely structured public transport system and shorter journeys, whereas in rural areas the conditions and opportunities for travel look very different. In other words, when it comes to stocks and the flows associated with their construction, maintenance and utilisation, we are less concerned with the materials in themselves and far more interested in the function, the service that they provide for us (Krausmann et al. 2017; Haberl et al. 2021; Carmona et al. 2022). Societal wellbeing is not defined by the quantity of cement, steel and other materials from which our apartment is constructed but rather by the quality of the various functions (security, warmth, communications space, access to green space, access to shops and healthcare services), which the living space offers. These functions can be provided in more or less resource-efficient ways. Pauliuk and colleagues (Pauliuk et al. 2021; Pauliuk and Heeren 2021) have, for example, calculated that material efficiency measures in the sphere of residential buildings and private vehicles can make a decisive contribution (alongside energy efficiency and low-carbon energy supply) to reducing greenhouse gas emissions. In other words, if we use existing living space more efficiently and give more priority to material and energy efficiency in new construction projects, we could conserve resources without losing quality of life. It is not the quantity and ownership of goods and stocks that should be of central importance, but rather the quality of services and functions, which contribute to a higher quality of life (Jackson 2014; O'Neill et al. 2018; Millward-Hopkins et al. 2020).

In terms of built infrastructure, final consumers generally have little immediate decision-making power regarding their construction and design. These are rather determined in political planning processes. Infrastructures are collectively created and usually are not at the service of any individual person. Infrastructures are also not products but rather they integrate production, distribution and consumption (Jonas et al. 2023, 27). It is precisely when it comes to questions of resource use that it is important to look in more detail at provisioning systems, since these mediate "between human well-being and biophysical processes" (O'Neill et al. 2018).

The stocks, which we build today, create a resource input not only in the present time but also in the future. Every house that is built today needs material for construction and further material to fill it with furniture, equipment and other products. In the future, an already built house will have to be continually maintained and repaired through the use of further material inputs, while energy inputs are required to illuminate and heat the house and to operate the many devices and pieces of equipment contained within it. This means that a reduction in resource flows cannot be achieved at the same time as a further build-up and growth of social stocks.

When a stock item is demolished at the end of its lifespan, the demolition materials should be re-used for planned new construction in accordance with a circular economy. Yet stocks often remain for many years, decades and even centuries in our society; thus, the demolition material will have a material composition that reflects the technical conditions of prior decades. In current times, other materials are generally used for construction, therefore only a small share of the material remaining from the demolition of a 19th century building can be used in the construction of new buildings. In the case of products expected to accumulate over long periods in society, it is increasingly important to consider smart, sustainable and recyclable product design (eco-design), to avoid path dependencies[11]. Durable goods need to be easy to dismantle into components and materials, and easy to reuse and recycle so that they can indeed be deployed in production. This is the only way to avoid stocks becoming legacy burdens.

11 Path dependencies are existing structures (infrastructures, technology, or institutions and power relationships), that determine a particular development path and that hinder any deviation from this path (WBGU 2011; Grafström and Aasma 2021).

Statement 11 – Predetermined: Contaminants as a future problem. A path leads from the demand for soda ash in the textile industry of the 19th century to carbon tetrachloride, a solvent used in laundry services until the middle of the 20th century, which now forms part of contaminant problems globally as a toxic, water-polluting and all too long-lasting substance. Railway sleepers, impregnated with creosote-containing wood preservative, continue to release carcinogenic, low-volatility aromatic hydrocarbons for many decades after their installation. Asbestos, integrated in buildings due to its fire-retardant qualities, creates the need for expensive removal processes decades later. In Austria, contaminated materials are recorded in a register, and in the case of building projects, their regulated disposal is a costly obligation. Yet new contaminants will very likely continue to be produced that will create a burden for future generations to dispose of, for as long as the precautionary principle is not applied. – Univ.Prof. (i.R.) Ing. Dr. phil. Dr. h.c. Verena Winiwarter, Austrian Academy of Sciences

Austria's material stocks have grown to 540 tons per capita

In recent years, a number of research teams have focused upon the quantification and analysis of socioeconomic stocks (Tanikawa et al. 2012; Pauliuk and Müller 2014; Fishman et al. 2015; Krausmann et al. 2017; Krausmann et al. 2020; Haberl, Schmid, et al. 2021; Tanikawa et al. 2021; Wiedenhofer et al. 2021; Soonsawad et al. 2022). In a global study, Krausmann et al. (2017) found that total socioeconomic stocks had increased over the previous century by a factor of 23. This increase was more than twice as fast as the growth of global material consumption (factor of 10). Global population grew in the same period far more slowly (by a factor of 4) while the global economy grew at a rate (factor of 27) similar to the increase in socioeconomic stocks (Krausmann et al. 2017). Accordingly, there is no evidence of decoupling between stock accumulation and economic growth.

In 2010, global stocks amounted to 780 billion tonnes (Gt) or 110 t/cap (Krausmann et al. 2017). As expected, the material stocks accumulated in industrialised countries are significantly higher and in 2010 amounted to 335 t/cap (Krausmann et al. 2017). The exponential growth of stocks was also reflected in changes in resource flows. Whereas in 1900, 81 % of materials consumed were used for feeding humans and animals (51 %), technical energy from fossil energy carriers (19 %) and a variety of dissipative uses (11 %), and only 19 % of material consumption was used to produce stocks, this picture has been entirely transformed. In 2015, only 17 % of materials consumed were used for the provision of foodstuff, 17 % comprised fossil energy carriers and 7 % were for dissipative uses. However, 59 % of all material consumption was used for the creation of socioeconomic stocks (Krausmann et al. 2018).

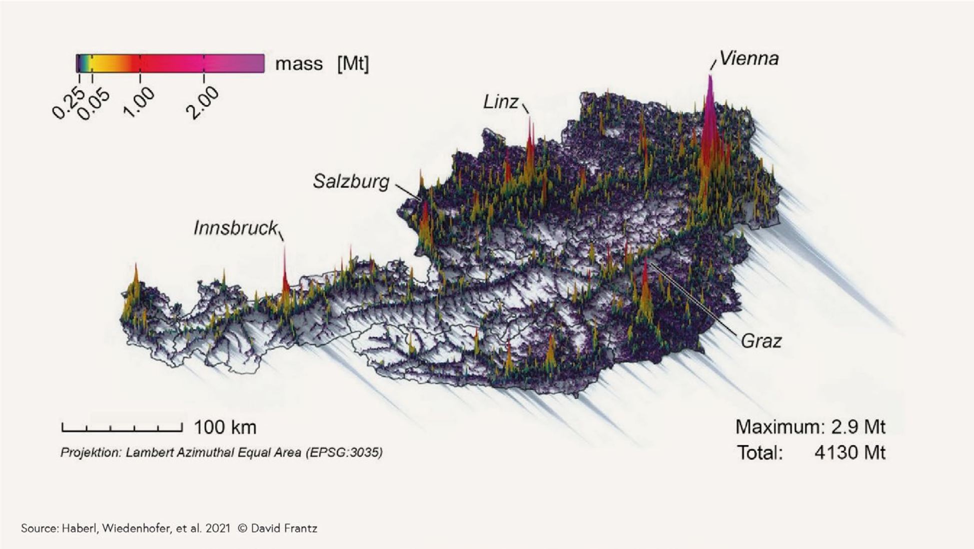


Figure 19: Material stocks in Austria, 2019.

Figure 19 shows the spatial distribution of material stocks in the form of buildings and mobility infrastructure in Austria in 2019. Haberl et al. (2021) have calculated a total amount of material stocks for Austria of approximately 540 t/cap, while the stocks for Germany amount to 450 t/cap. In addition, it was estimated that the material input required to maintain and renovate existing buildings and transport infrastructure is approximately the same amount as would be required for completely rebuilding these stocks anew (Wiedenhofer et al. 2021).

The studies referred to here have reached the following conclusion: Since a predominant share of materials are accumulating in stocks and these stocks are continuing to grow, far more material inputs are required than material outputs accrue. Accordingly, increasing stocks represent an obstacle to material loop closing though recycling and an overall reduction of material consumption (Wiedenhofer et al. 2021).

All material inputs will become outputs – wastes and emissions

> Statement 12 – Involvement of the waste management industry is an important pillar of a comprehensive approach to the circular economy: "Classic waste management" and the "modern circular economy" are often regarded as diametrically opposed. This is not the case, however. Even the first version of the European Waste Framework Directive from 1975 already called alongside the technical circularity (recycling of waste materials) 'the reduction of waste generation', i.e. waste prevention, as the highest priority in waste management, which still applies today. Measures to achieve this overarching goal are now specified in the Circular Economy Strategy in the first three of the "10 Rs": "Refuse, Rethink, Reduce". The fact that these priority measures have not yet been comprehensively implemented in daily life within our society, but the focus is primarily limited to "recycling", represents a challenge for us all. – Univ.Prof. Dr. Marion Huber-Humer, Institute of Waste Management and Circularity, BOKU University

From the systemic perspective of social metabolism, every material input into society eventually becomes an output, which is returned to the natural environment (law of conservation of mass). In their approach to socioeconomic outputs, statistical accounting, scientific research and policymaking have for a long time focused on wastes and emissions separately from one another and not in relation to resource inputs. In the early phase of its development, material flow accounting has for its part focused on resource inputs, albeit in recent years it has expanded this view towards outputs and EUROSTAT included these as a voluntary addition within the annual statistical MFA reporting framework. The material flow accounts record as outputs all materials and substances that are released into nature (air, water or soil) following their use by society and define these altogether as domestic processed outputs, or DPO (Eurostat 2018).

The domestic processed outputs to nature (DPO) are reported in material flow accounts within European Statistics (Eurostat 2018) in accordance with the following sub-groups:

1. **Emissions to air**, i . e. CO_2, CH_4, N_2O, NO_x, HFCs, PFCs, SF_6, CO, NMVOC, SO_2, NH_3, heavy metals, POPs, particulate matter e.g. PM_{10}, dust, etc.
2. **Waste deposited in uncontrolled landfills** refers to direct discharge of waste into the natural environment, which is forbidden in Austria, however. In contrast, **deposited waste**, i.e., those wastes that are deposited in controlled landfills, are according to MFA convention not regarded as outputs to nature but rather as remaining within the socio-economic system. Only discharges to nature from landfills (leachate, vapour, etc.) must be accounted for in MFA accounts. Within

the data provided by Statistics Austria, emissions to air from landfills are recorded but possible leaching is not. Although the quantity of deposited waste is not an output, it does however represent important information (e.g., for possible secondary use) about the quantity of materials at the end of socioeconomic use. They are therefore not considered in the MFA indicators but are nonetheless reported on in the form of a memorandum item as additional information.

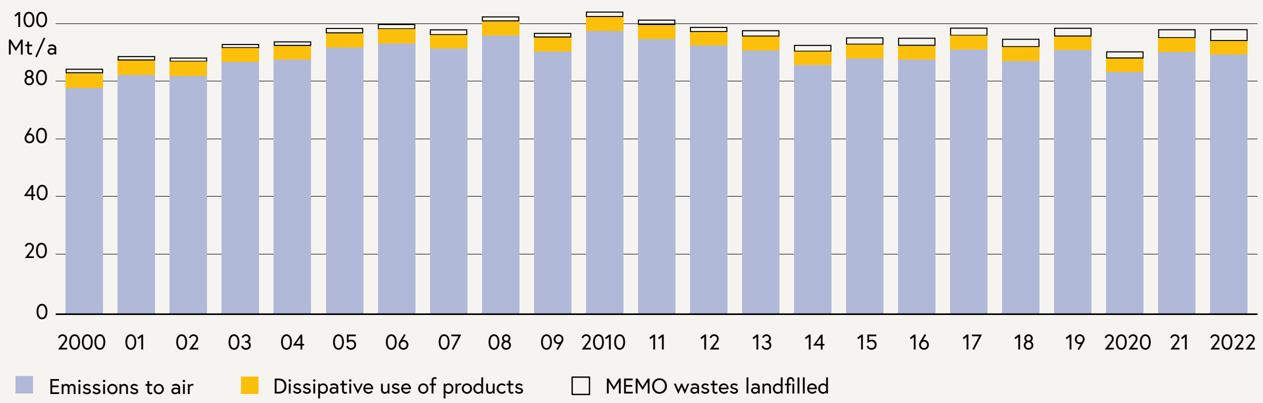
3. **Emissions to water** include all substances that - whether processed or not - are released to natural water bodies. This largely concerns nitrogen and phosphorus compounds, heavy metals (at permitted concentrations), organic materials, and dumping of food at sea.
4. **Dissipative use of products** includes all materials that are deliberately dissipated into nature; e.g., industrial fertilisers, compost, manure, sewage sludge, pesticides, seeds, salt and other thawing products spread on roads, solvents, etc.
5. **Dissipative losses** are unintentional outputs to the environment caused by wear and tear, e.g. (tyre) abrasion, corrosion, erosion, leakages or accidental losses during the transport of goods. These flows are barely recorded at all in MFA data, and only tyre and brake abrasion (according to the air pollution inventory) are reported under this category in the Austrian MFA.

MFA distinguishes among the outputs on one hand according to the environmental medium into which outputs are released (1-3) and on the other, according to the type of release, as deliberate or unintended (4-5).

The total domestic processed outputs to nature (DPO, Figure 20) amounted in 2022 to 94 Mt/a or 10 t/cap/a. In 2000, DPO was 83 Mt/a, thus socioeconomic outputs increased by 15 % between 2000 and 2022. By far the largest share of DPO is caused by emissions to air (95 % of DPO), which amounted to 89 Mt/a in 2022 and increased from 2000 (78 Mt/a) by 15 %. Almost all the emissions to air were CO_2 emissions (in accordance with MFA convention, including the share of oxygen; Eurostat 2018). The next largest categories are carbon monoxide (CO, 0.58 %), methane (CH4, 0.24 %), and nitrous oxides (NOx, 0.12 %) (Statistics Austria 2024, 2023c).

Regarding dissipative use of products in 2022, materials amounting to 4.6 Mt/a were output into the Austrian environment, of which 63 % was organic fertiliser in the form of manure. Further material flows in this category were compost (13 %), mineral fertilisers (9 %), salt or other thawing materials spread on roads (6 %), solvents (4 %), seeds (4 %) and sewage sludge (1 %). In 2000, dissipative use amounted to 5 Mt/a, i.e., 8 % more than in 2022. The reduction in dissipative use was due to a reduction in the larger categories i.e., manure (-11 %) and mineral fertilizers (-36 %). During the same period, the use of compost increased by 43 %, as did the use of pesticides (+72 %), salt and other thawing materials (+18 %) and sewage sludge (+35 %).

Discharges into nature from dissipative losses and emissions to water bodies comprise very small amounts (5 Mt/a and 50 kt/a respectively), but are particularly difficult to record and therefore fraught with uncertainty.



Notes: there are no available data for "waste disposals in nature" and "dissipative losses". These output categories are therefore not included in this Figure. The Figure also depicts the memorandum item "deposited waste". This waste is regarded in accordance with MFA conventions (Eurostat 2018) as forming part of socioeconomic stocks; waste that is deposited in controlled landfills is therefore not accounted for as DPO. Despite this, these waste quantities constitute important information about the quantity of materials at the end of socioeconomic use and are therefore presented as a memorandum item.

Source: Statistics Austria (2024)

Figure 20: Austria's material outputs: domestic processed outputs to nature and deposited waste, 2000-2022.

Balancing items are required on the input and output side to produce a mass balance

The material flow accounts are based on the principle of mass conservation (inputs = outputs +/- stock changes, see also the chapter "Biophysical stocks determine resource flows - Stock-Flow-Service-Nexus"); all material inputs must therefore be counterbalanced on the output side, taking stock changes into account. In some production processes, gaseous substances (oxygen or nitrogen from the air) or water are taken up or are released. Although the MFA does not account for air and water as resource flows, these quantities of air or water must be included in the MFA to satisfy the mass balance principle. According to Eurostat conventions (Eurostat 2018), these flows are reported as balancing items on the input and output sides. In the MFA indicators, however, the balancing items are not included.

Balancing items on the input side are the following: Oxygen (O), which is bound through combustion processes in CO_2, oxygen that is converted into CO_2 through respiration of humans and livestock, nitrogen that is extracted from the air for ammonia production (Haber-Bosch process), and water that, for example, is required for the production of beverages. In 2022, the balancing items on the input side for Austria amounted to approximately 12 t/cap/a.

On the output side, the following materials and substances are accounted for as balancing items: water vapour from combustion and drying processes, CO_2 and water vapour from the respiration of humans and animals, etc. Since the carbon or water on the input side forms a part of extracted materials, this amount must also be accounted for on the output side, so that the thermodynamic mass balance can be completed. The output balancing items for Austria in 2022 amounted to 9 t/cap/a.

Material footprint – Austria's resource use extends beyond its national borders

> Statement 13 – The true scale of material consumption is obscured by supply chains: Current events, such as the war in Ukraine or the closure of Chinese ports due to the COVID pandemic, have clearly demonstrated Europe's economic vulnerability to supply chain disruptions. This is because a large share of, for example, the metallic raw materials that the continent requires for production and consumption are extracted in other parts of the world. Alongside the risk of limited supply security, the complex integration of global supply chains also often has the effect of rendering social and ecological impacts of resource extraction and processing invisible. Policy measures for sustainable and responsible resource use therefore need to take account of the consumption perspective together with the connections between raw materials extraction and the consequences of these activities. The EU's Corporate Sustainability Due Diligence Directive could provide an important basis for changes in this direction. – Univ.Doz. Dr. Stefan Giljum and Dr. MMSc Stephan Lutter, Institute for Ecological Economics, Vienna University of Economics and Business

Austria's production and consumption structures are embedded within a global economy, in which global production and supply chains are becoming ever longer and more complex. Austria would not be able to provide either the quantity or the types of products that end consumers demand purely from domestic resource supplies. Thus, imports are required to close this gap in supply. At the same time, Austria's economy has specialised in the production of specific products, which are supplied to a global market via exports. The trade balance for goods resulting from this is largely balanced in monetary terms. However, in biophysical terms, Austria is a net importer of material products; the physical trade balance is therefore strongly positive (see Figure 10), and imports exceed exports by a factor of 1.4 to 1.7 (Statistics Austria 2024).

Imports are recorded by weight in the MFA, as they are in the external trade statistics. The imports (and to the same extent, the exports) are, unlike domestic extraction (DE), not raw materials that we have extracted from nature, but processed materials, semi-finished products or finished products, which have passed through one or more production processes. In the course of the production process, the mass of products decreases at almost every stage, because waste and emissions are removed from them and remain in the respective producer country (see Figure 21). If Austria imports highly processed products instead of producing them within the country, the production-based material consumption (as recorded in the DMC) is lower than the quantity of raw materials that are extracted outside Austria, converted into processed goods and imported into Austria. This makes the country's economy appear more resource-efficient than it is in fact. Increasing globalisation and rapidly growing import and export volumes strengthen the effect of spatial decoupling of raw materials extraction, production and the place of consumption, while there is a growing disparity between direct import quantities and upstream material requirements.

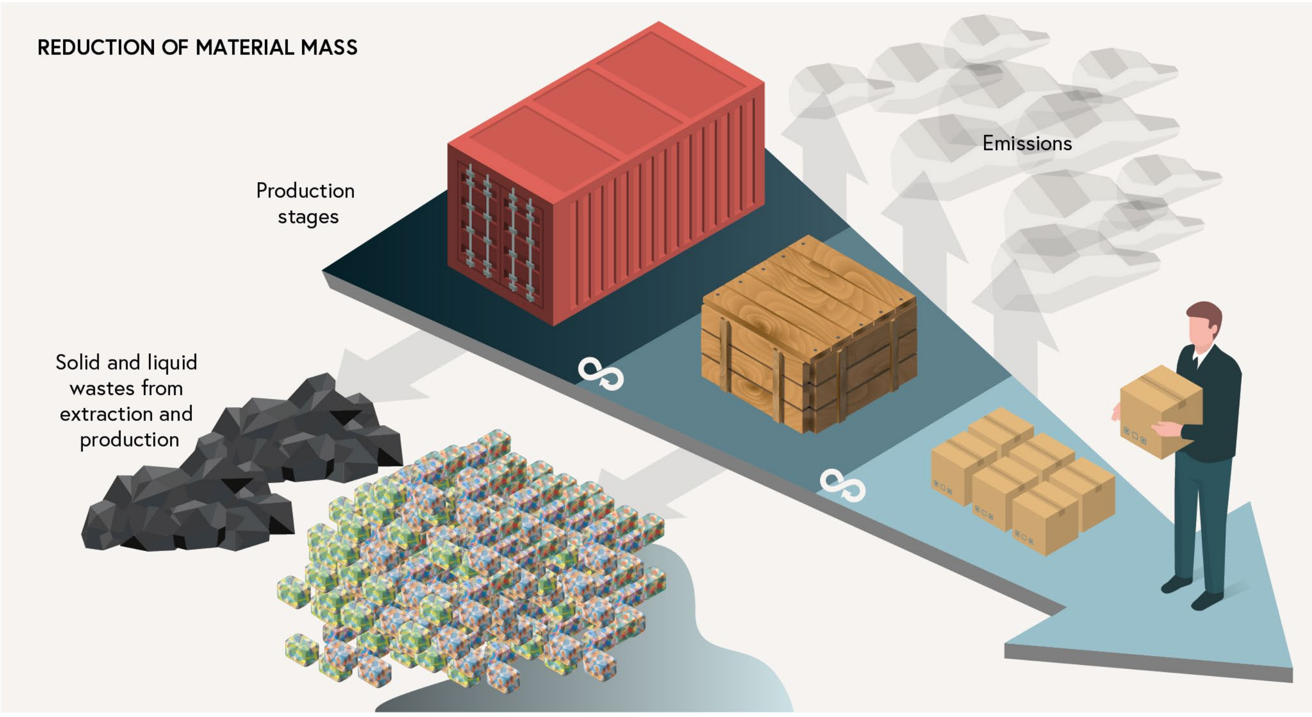
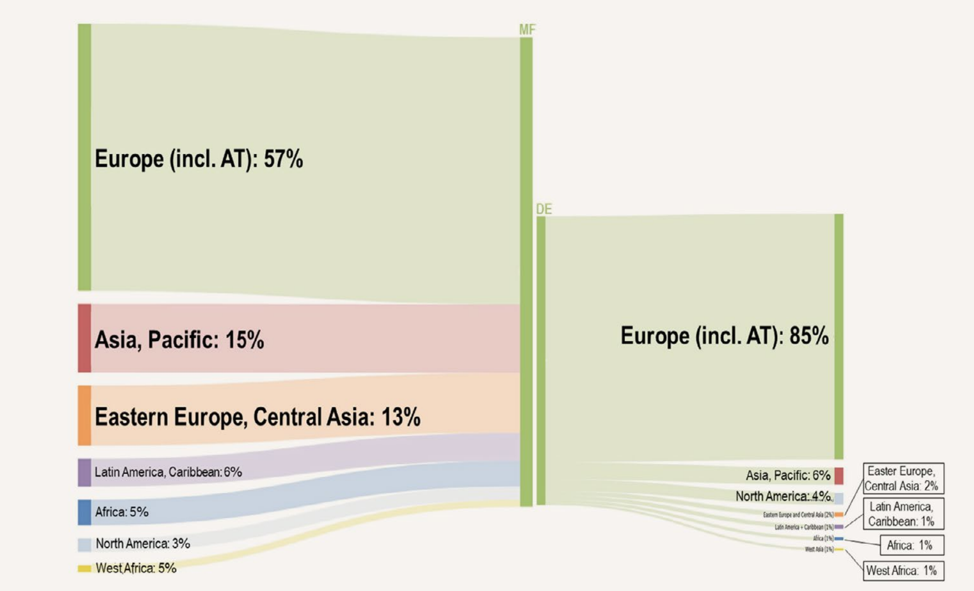


Figure 21: The mass of a product continually decreases along a production chain, as waste and emissions remain behind. Schematic drawing.

When evaluating environmental impacts, therefore, the production-based MFA indicators (DE, DMC) are complemented by consumption-based indicators. The consumption-based perspective illuminates the global raw materials extraction that is caused, for example, by Austrian final demand. Consumption-based indicators (like the material footprint) account for the raw materials, regardless of where in the world they are extracted and used for the production of goods, and assign them to the country in which the end use of these products takes place. At the same time, taking a consumption-based perspective means that the material consumption and emissions associated with goods that are produced in Austria and then exported will be assigned to the countries in which final demand for these products is located.

The Visualisation Centre on the material flow analysis portal materialflows.net (Vienna University of Economics and Business, 2023) makes the global interlinkages due to international trade visible, and Figure 22 depicts these in the case of Austria. The left-hand part of the graphic shows the regions in which material extraction has occurred that can be linked to Austria's material footprint in 2021. (Austrian domestic consumption of materials extracted in Austria is included in the Europe region within this graphic.) Austria obtains the major share of the material footprint from its own domestic extraction and from other EU countries. The next largest import partners are in the Asia-Pacific region and in Eastern Europe and Central Asia. The right-hand side of the graphic shows the material extraction in Austria and in which countries these raw materials are used to satisfy final demand. (Here too, Austria's domestic consumption of domestic extraction (DE) is included in Europe.) After Europe, the second most important trade partner is the region of Asia followed by North America.



Source: materialflows.net

Figure 22: Austria's material footprint and the regions in which raw materials are extracted, together with material extraction in Austria and the regions in which final consumption occurs, 2021.

The consumption-based material footprint of Austria thus includes all raw materials that are extracted and used outside Austria's borders to create the products for Austrian final demand. The material footprint is also denoted as raw material consumption (RMC; Statistics Austria 2024).

The material footprint is an important supplement to domestic material consumption but should not be regarded as a substitute for DMC. Both perspectives have their own focal points, advantages and disadvantages and should be used in combination with one another. Thus, the DMC focuses on all those materials that are transported and processed within Austria, are sooner or later converted into waste and emissions, and thereby cause environmental pressures within Austria. These include those resulting from the Austrian production of export goods. The material footprint, by contrast, focuses on issues of global distribution of resources and allows to address issues of equity of distribution. Globally, costs and benefits of material consumption and the impacts caused by the production of raw materials and goods are very unevenly distributed (Infante-Amate and Krausmann 2019; UN IRP 2019a; Dorninger et al. 2021; Lenzen et al. 2021; Schaffartzik and Krausmann 2021). From the footprint perspective, Austrian production of exports is not assigned to Austria but rather the global resource consumption due to the country's final consumption.

Statement 14 – Resource-intensive patterns of production and consumption create poverty and environmental damage in other countries: The rapid increase in global resource use in recent decades is caused by fundamentally different developments at national and sub-national level. The resource- and emissions-intensive production and consumption patterns of the world's wealthiest countries, including Austria, cannot be maintained without poverty and environmental damage "elsewhere". At the same time, the people in these rich countries are discovering that their options for intervening in global interlinkages, and to change them for the better, are limited. Environmental justice therefore takes account not only of the differences in the relationship with natural resources and in relation to this, the degree to which humans are exposed to environmental impacts, but also of the profound differences in political and social agency and participation.
– Asst.Prof. Dr. Anke Schaffartzik, Department of Environmental Sciences and Policy, Central European University (CEU)

Austria's material footprint in 2020 was 22 tonnes per capita, which is 24 % larger than domestic material consumption

Austria's material footprint (MF) in 2020 was approximately 199 million tonnes (Figure 23). In 2008, the material footprint was about 5 % higher, at 209 million tonnes. At the level of the four material categories, the MF of three material categories has fallen (fossil energy carriers -3 %, metals -1 %, non-metallic minerals -9 %), and has remained unchanged in the case of biomass materials.

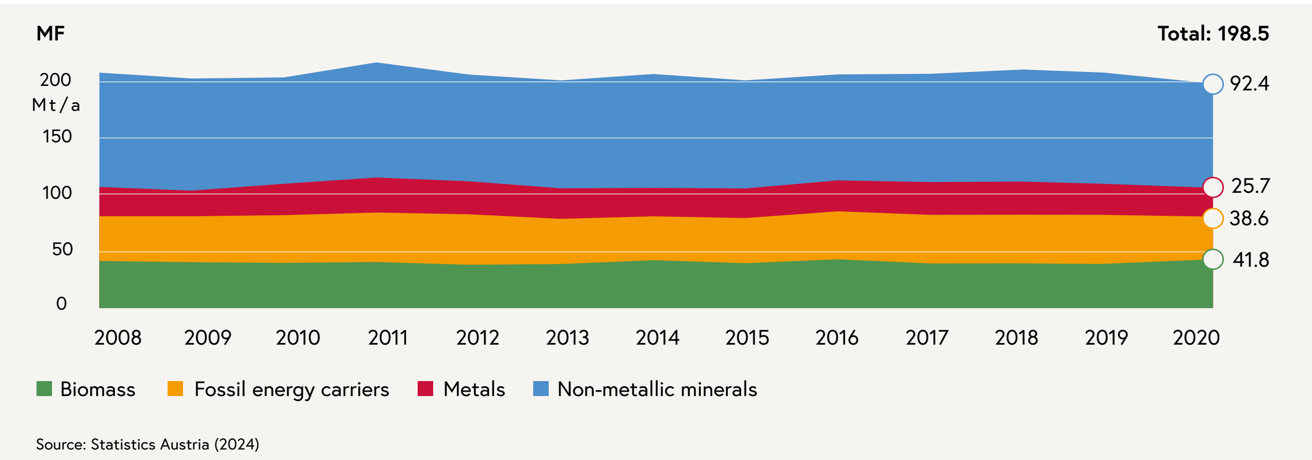


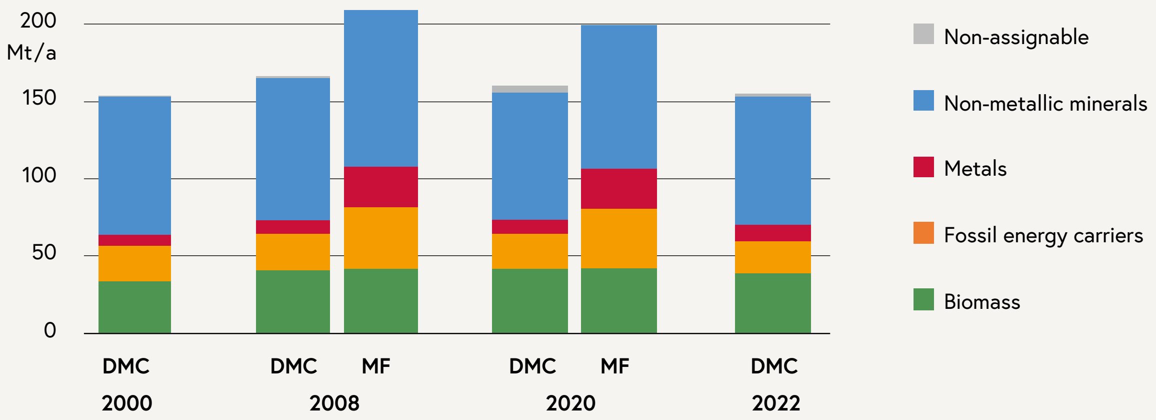
Figure 23: Austria's material footprint (MF), 2008-2020.

Two methodological approaches are available for calculating the material footprint. One of these involves the use of global multi-regional input-output models (MRIO), which depict inter-industry sectors' deliveries between all countries (or groups of countries). This enables all raw materials extraction to be organised along sectoral supply chains (via economic input-output matrices) and tracked to the point of final consumption. Among the MRIOs, two models are most commonly used in a variety of research contexts: EXIOBASE (Stadler et al. 2018) is an EU-focused MRIO, which was developed with the involvement of Austrian researchers in the context of three EU-funded research projects. The second is GLORIA (Lenzen et al. 2017, 2021; UNSW Sydney 2023) and its predecessor Eora (Lenzen et al. 2013; Eora 2014), which both use algorithms to enable data adjustments when producing MRIO models. The MF data of the GLORIA MRIO form part of the UNEP global material flow database (UN IRP 2023).

MRIO models are very intensive in data and computational terms and updates of the models to most recent years often lags behind. Statistical authorities and national states often require a simpler calculation model and more transparent access to the individual stages of calculations, which - as far as possible - are supplied with data available within statistical offices. For this reason, these institutions often employ coefficient-based methods, in which the material inputs associated with imports (and equally for exports) are calculated with the help of product- or industrial sector-specific material intensities (or coefficients derived from life cycle analysis (LCA)). The direct imports including upstream material consumption are defined in MFA as raw material equivalents (RME). RME represent the entire raw materials that are associated with a particular import or export, independently of where - in which economy - the raw materials were used for production.

In a coefficient—based approach, LCA coefficients are often combined with national input-output (IO) models as well (also referred to as a hybrid approach), such as in the calculation of Austrian MF (Schaffartzik et al. 2014; Neubauer and Gierlinger 2022) or in the Eurostat calculations (Schoer et al. 2012; Eurostat 2023b). This hybrid approach involves calculating the upstream inputs using coefficients, which are then allocated to final demand via input-output tables. In recent years, numerous discussions have taken place about the various methodologies and comparisons of results stemming from the different models, which have made essential contributions to the further development of calculation methodologies (Owen et al. 2014; de Koning et al. 2015; de Koning et al. 2015; Eisenmenger et al. 2016; Giljum et al. 2019).

Depending on the calculation method, further development therein, as well as data revisions, very different results for the MF for a particular country may be found over time. Within the 2020 Report Resource Use in Austria (BMK and BMLRT 2020), for example, Statistics Austria calculated an MF of 24 t/cap/a for 2015, whereas the UN IRP MFA Database, calculated using the MRIO Eora (Lenzen et al. 2013; Eora 2014), produced a figure of 33 t/cap/a for 2017. The figures for 2020 show a smaller difference between the two data sources: Statistics Austria reported an MF of 22 t/cap for 2020, and UN IRP calculated MF at 25 t/cap for the same year. A similar data variance and consolidation over time was also observable for DMC, particularly in the early years of MFA implementation. In the case of MF, the development of methodologies is still in process and therefore produces successive updates to findings.



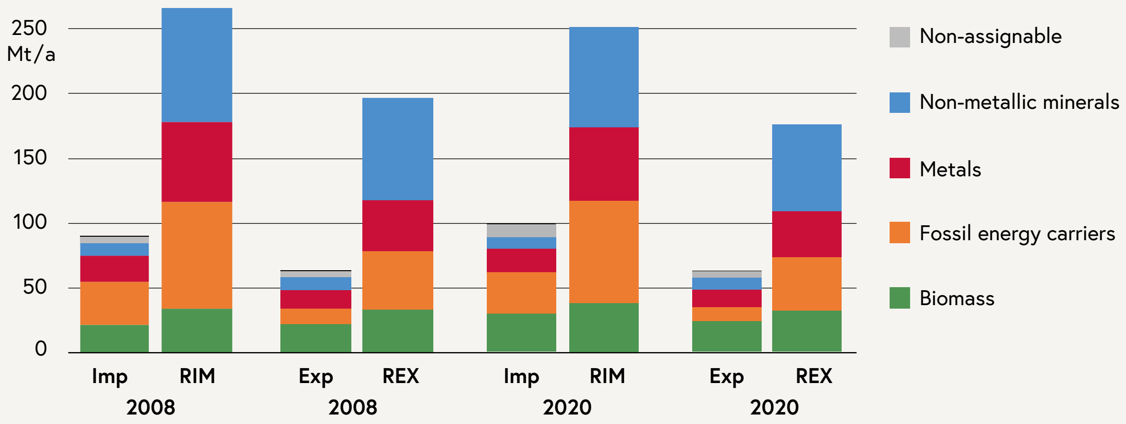
Notes: The category "non-assignable" comprises on the one hand manufactured products containing a mix of materials, which prevents their allocation to one of the four material categories, and on the other hand goods not further specified in the statistics for reasons of confidentiality.

Source: Statistik Austria 2024

Figure 24: Austria's domestic material consumption (DMC) and material footprint (MF), 2000, 2008, 2019 and 2022.

DMC and MF show a very similar development over time (see Figure 24). DMC fell by 4 % from 166 Mt/a in 2008 to 160 Mt/a in 2020. The MF fell during the same period by 5 % from 209 Mt/a to 199 Mt/a. Direct imports rose during the same period by 10 % (due to an increase in the categories of biomass and "non-assignable") while direct exports fell by 1 %. The physical trade balance correspondingly grew significantly by 35 %. In contrast, the RME of imports decreased by 6 % and the RME of exports by 11 %. The raw materials balance amounted in 2020 to 75 Mt/a, showing an increase of 8 % since 2008 (see Figure 25).

A more detailed analysis of imports and exports clearly shows the large volume of materials that are required internationally along the production chain (Figure 25). The raw material equivalents of imports (RIM) and exports (REX) are in each case three times as large as the direct imports and exports. At the level of the four material categories, the upstream inputs for non-metallic minerals are the largest, with a factor of 8-10 in the case of imports and 7-8 for exports. The RIM for metals and fossil energy carriers are larger by a factor of 3 and 2.5 respectively than the direct imports. In the case of biomass, the factor is smallest (1.5 to 1.3). Factor scales are similar for exports: for fossil energy carriers, the REX are larger by a factor of 3.5-4.5 than the direct imports, in the case of metals by a factor of 2-3 and in the case of biomass by a factor of 1.5.



Notes: Imp = imports; RIM = raw material equivalents for imports; Exp = exports; REX = raw material equivalents for exports. "Wastes" include traded wastes for final processing and landfill (note that the quantity is too small to be visible in the graph). The category "non-assignable" comprises on the one hand manufactured products containing a mix of materials, which prevents their allocation to one of the four material categories, and on the other hand goods not further specified in the statistics for reasons of confidentiality.

Source: Statistics Austria (2024)

Figure 25: Austria's imports, exports and respective raw material equivalents in comparison, 2008 and 2020.

Since 2008, direct imports rose by 10 %, particularly due to the increase in biomass imports (+35 %) and in the case of imports of the category "non-assignable" (89 %). The direct exports fell by 1 %, yet here too biomass exports grew (7 %) as did the "non-assignable" exports (14 %). The upstream material inputs that are associated with direct imports did however fell slightly between 2008 and 2019 (6 % in the case of RIM, 11 % in the case of REX). RME only increased in the case of biomass imports (10 %), while for all other categories RME were reduced. Thus, material consumption along the entire supply chain showed a reduction not only for imports but particularly clearly in the case of exports.

The raw material trade balance (RTB = RIM-REX) increased between 2008 and 2020 by 8 %, the physical trade balance (PTB = imports-exports) increased far more rapidly by 35 % (a factor of 4).

Resource consumption must be decoupled from economic growth and thereby resource productivity increased

Statement 15 – Structural transformation is required to achieve the decoupling of material consumption from economic growth: Material consumption and economic development remain very closely interlinked. Sustainable development requires that economic development should be decoupled from the demand for materials. This necessitates not only a significant increase in resource efficiency but above all a structural transformation that relies on services as the motor for economic development. In materials-intensive sectors such as the construction industry, moving away from a cycle of demolition and new building and towards renovation, adaptation and the conversion of built structures to other uses can drastically reduce the consumption of raw materials. – Dr. Ina Meyer, Austrian Institute of Economic Research – WIFO, Climate, Environmental and Resource Economics Research Group

As early as the 1970s, Meadows et al. (1972) talked about the limited resources existing in our world, and in den 2000s, the theme became the subject of renewed attention in the discussion of planetary boundaries (Rockström et al. 2009; Steffen et al. 2015; Fanning et al. 2022).

Current political programmes such as the European Green Deal (European Commission 2019), the EU's Circular Economy Action Plan (EU 2020) or the Sustainable Development Goals (UN 2015), "Green Growth" (OECD 2023) or the "Green Economy" (UNEP 2023) work towards the decoupling of economic growth and environmental impacts (UN IRP 2011). Decoupling can be achieved in two different ways: absolute decoupling involves increasing economic growth accompanied by decreasing environmental impacts; relative decoupling is achieved when both the economy and environmental impacts are growing, however the environmental impacts increase more slowly than economic growth.

Decoupling is measured using the indicator of resource productivity (RP), which is generally calculated as gross domestic product divided by material use (GDP/DMC or GDP/MF). Thus, resource productivity describes how much economic output can be produced per unit of resource use. Resource productivity (also defined as resource efficiency; see European Commission 2011) is thus analogous to the definition of labour productivity.

In the case of absolute decoupling, resource productivity increases; the growth rate of resource productivity is greater than that of the economy. In the case of relative decoupling, resource productivity also grows, albeit at a slower rate than the economy.

The resource productivity indicator and an increase in resource productivity as a target value are found in many political programmes, e.g. in the UN sustainable development goals SDG 8 and SDG 12 (UN 2015) or in the Circular Economy monitoring framework (European Commission 2023a). The Austrian Circular Economy Strategy (BMK 2022) also sets out the goal of increasing resource productivity, with a concrete target of +50 % by 2030 in relation to 2015.

Relative decoupling is already happening, but absolute decoupling is barely evident

Numerous empirical studies analysing decoupling have been undertaken, which have recently also been collated and analysed in a systematic literature review (Parrique et al. 2019; Haberl et al. 2020). Almost all empirical results show that relative decoupling can be observed in many cases in industrialised countries but that barely any instances of absolute decoupling are evident (UN IRP 2011; OECD 2018; UN IRP 2019a; Haberl et al. 2020) or that decoupling is taking place far too slowly (Vogel and Hickel 2023).

An absolute reduction in resource use is found primarily in times of crisis, for example as a consequence of the financial crisis in 2008 and 2009. In the absence of economic crises and without the outsourcing of materials-intensive production sectors, hardly any absolute reductions in material consumption can be found at all (Haberl et al. 2020). Because of this, the idea that current measures to achieve decoupling possess sufficient leverage to do so is attracting increasingly critical assessment (Hickel 2019; Hickel and Kallis 2019; Jackson and Victor 2019; Haberl et al. 2020; Vogel and Hickel 2023). This chapter therefore looks in more detail at decoupling and the challenges associated with it.

The many environmental crises of the current time create a clear picture: an absolute reduction in our resource use must be accorded the very highest priority. This concerns not only CO_2 emissions, but also materials, land area (e.g. sealed area) and water consumption, as well as the quantity of wastes produced annually. Reduction of resource consumption must fulfil the following criteria:

- It must involve a significant reduction. In line with current policy goals, CO_2 emissions must be reduced to zero[12] and material consumption must be more than halved in Austria (Circular Economy Strategy; BMK 2022).
- The reductions must be realised within the next 2-3 decades i.e., relatively quickly, so that, above all, exceeding irreversible tipping points can be avoided (Lenton et al. 2019; Ripple et al. 2023). Comprehensive decarbonisation is aimed for by 2040, and halving material consumption by 2050.
- Following on from reduction, resource consumption must be sustained at the new, low level.

Ultimately, the reductions achieved cannot only lessen the environmental impacts within Austria but must include global supply chains. For this reason, the Austrian Circular Economy Strategy not only sets a target for DMC reduction but also sets a target for reduction in the MF.

Resource productivity grew in Austria between 2000 and 2022 by 35 %, albeit as relative decoupling

Domestic material consumption remained constant in Austria between 2000 and 2022, amounting to 154 Mt/a in 2022. Economic growth grew in the same period by 36 %, so that by 2022, gross domestic product (GDP) was 380 billion Euros (chain-linked volumes based on previous year's prices; Statistics Austria 2023d). Thus, resource productivity (GDP/DMC) rose from 1,821 Euro/t in 2000 to 2,464 Euro/t in 2022. This represented a 35 % increase over the 22 years. Although resource productivity increased, it did so at a very slightly slower rate than GDP. Consequently, the data show a relative decoupling between economic growth and resource consumption (Figure 26a).

---

12 oesterreich.gv.at/de/themen/umwelt_und_klima/klima_und_umweltschutz/1/Seite.1000310

Resource productivity can also be represented as the relation between GDP and material footprint. Since data for the material footprint only exist for a shorter time period from 2008 to 2020, we have therefore analysed the resource productivity for both material consumption indicators for this shorter period of time (Table 1).

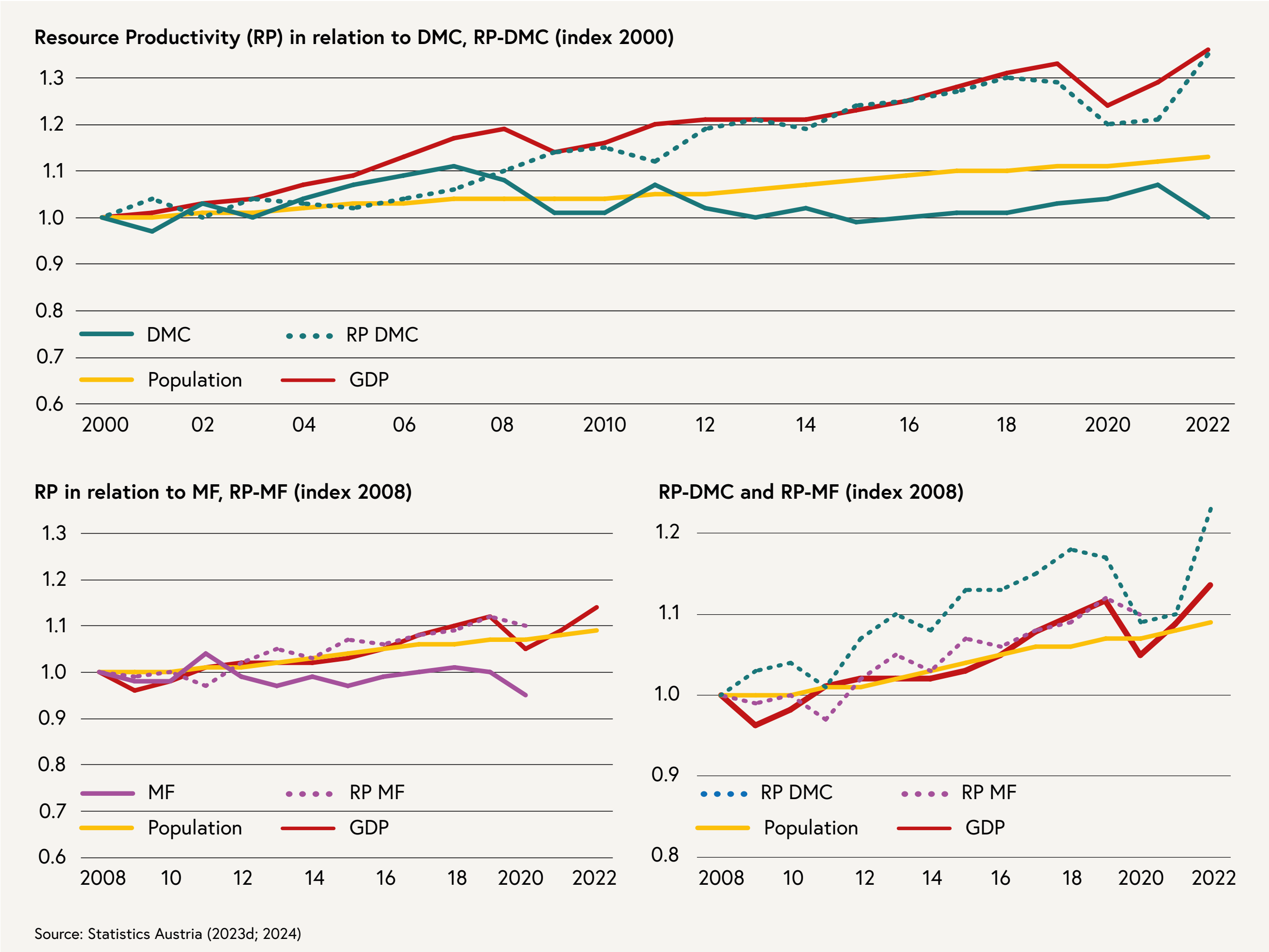
Table 1: Resource productivity based on domestic material consumption and material footprint for Austria in the years 2000, 2008, 2020 and 2022. Notes: GDP = gross domestic product in chain-linked volumes on the basis of the previous year's prices. DMC = domestic material consumption. MF = material footprint. RP-DMC = resource productivity as GDP/DMC. RP-MF = resource productivity as GDP/MF. Source: Statistics Austria (2024)

	2000	2008	2020	2022
BIP (million Euro)	280.579	333.253	348.400	380.417
Population (thousands)	8.012	8.322	8.917	9.053
DMC (Mt/a)	154	166	160	154
MF (Mt/a)	-	209	199	-
RP-DMC (Euro/t)	1.821	2.008	2.184	2.464
RP-MF (Euro/t)	-	1.597	1.755	-

DMC amounted to 154 Mt/a in 2000 and remained at the same level in 2022. For the shorter time period from 2008 to 2020, DMC fell by 4 % from 166 Mt/a to 160 Mt/a. The MF in 2008 was 209 Mt/a, decreasing by 5 % to 199 Mt/a by 2020 (Table 1, Figure 26b). Resource productivity based on DMC, RP-DMC, rose by 9 % from 2,008 Euro/t (2008) to 2,184 Euro/t (2020). This increase was larger than that of GDP (5 %), consequently absolute decoupling was observed for RP-DMC. Resource productivity based on the MF, RP-MF, increased over the same time period from 1,597 Euro/t to 1,755 Euro/t i.e., by 10 % (Figure 26c). Here too, RP-MF increased more rapidly than GDP, so that absolute decoupling was achieved.

The years since 2019 are characterised by significant political, economic and environmental policy challenges. The trends in biophysical indicators often fluctuate annually. Nonetheless, in the development trend for greenhouse gas emissions, we see a reduction in 2022[13], and a similar reduction for material consumption. It remains to be seen whether a more positive trend can be established beyond the crises of this period.

13 umweltbundesamt.at/news240116



The Circular Economy Strategy has defined a goal of a 50 % increase in resource productivity (PR-DMC) by 2030 in relation to 2015. The empirical data show a resource productivity of 2,266 Euro/t in 2015. An increase of 50 % would mean that RP-DMC has to be 3,400 Euro/t by 2030. This would require on average an annual increase in resource productivity of 2.75 %. From 2015 to 2022, the average annual growth rate amounted to 1.3 %. The highest rate of growth was 12 % in 2022, but this was due to the upturn after the Corona years and should be seen as an exception. In the previous years, growth rates of no more than 2 % (2017) and 2.1 % (2018) were observed. During the same period there were also annual growth rates of less than 1 % (2016, 2019, 2021).

Figure 26: Resource productivity in Austria. (a) RP-DMC, 2000-2022, (b) RP-MF, 2008-2020, (c) RP-DMC und RP-MF, 2008-2020.

Why is decoupling so difficult?

A range of factors exist as barriers to decoupling material consumption and economic growth. Some of these factors and their impacts are delineated briefly in the following section (see Parrique et al. 2019):

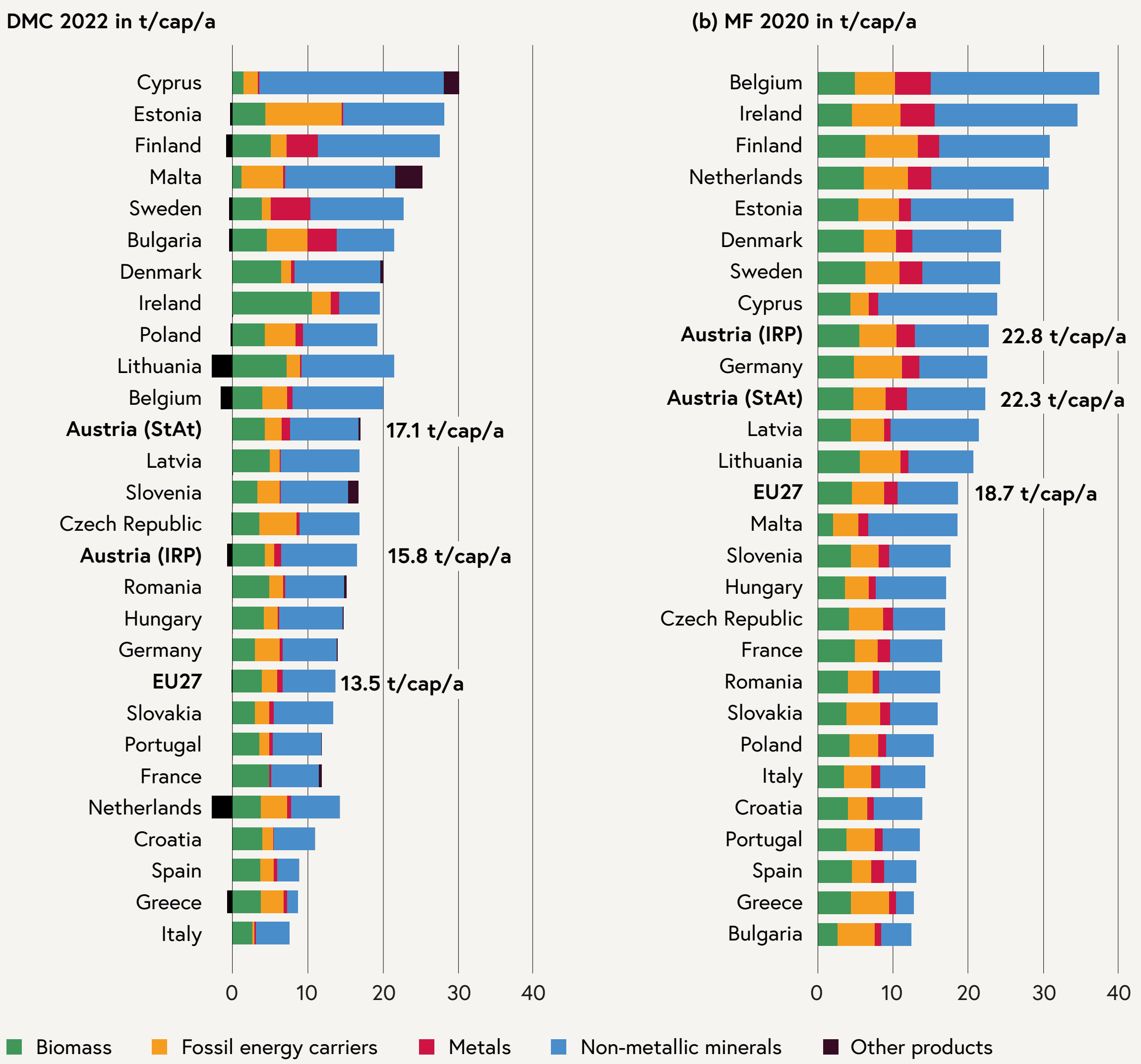
- **Technological development and the rebound effect:** The development of new technologies enables significant increases in resource efficiency across many different sectors or production processes. Yet the simultaneous increase in consumption activities compensates for the progress made in efficiency at economy-wide level (OECD 2018; Parrique et al. 2019; Ottelin et al. 2020; Sorrell et al. 2020; UNEP 2024); this is defined as the rebound effect. The increase in resource consumption then exceeds the resource conservation effects of increased efficiency and compensates for the decoupling effect (OECD 2018; UN IRP 2019a).
- **Shifting the problem elsewhere:** A reduction in environmental impacts involving a resource or environmental medium is often only achieved by shifting the environmental damage to other areas. One example is the replacement of fossil energy carriers by renewable energy sources. Although substituting fossil energy carriers with biomass ostensibly produces a specific saving in terms of CO_2 emissions, the quantity of biomass that is additionally required can nonetheless create other problems, such as conflicts over land areas, further loss of biodiversity, putting CO_2 sinks at risk through increased use of forested areas, extending biomass production to less productive land areas, competition over resource utilisation (biomass for food, fuel, textiles, bioplastics, etc.) among others.
- **Overestimating the importance of service sectors:** To continue along the path of economic growth, a move away from production in primary sectors to sectors that are assumed to be less resource-intensive within the tertiary sector is often promoted. However, the growth in service sectors does not go hand in hand with a reduction of the same order of magnitude in the production activities of the primary and secondary sectors, but often takes place in addition to these (for details, see Parrique et al. 2019). Empirical data also show that although service sectors, seen from a production-based perspective, consume less materials and cause less CO_2 emissions, some are associated with a significant material footprint e.g. through the use of material-intensive products that are required in the service sector, when we examine these from a footprint perspective (see, for example, Pichler et al. 2019 for the health sector).

These challenges show that resource efficiency can be increased in many sub-sectors, thereby leading to relative decoupling. The overarching goal of achieving an absolute reduction in material consumption and thereby absolute decoupling was not possible to achieve by 2021, yet has indeed been achieved in 2022. It remains to be seen whether this trend continues despite the current crises.

Austria sits within the lower middle rank among EU countries

To better understand the resource consumption of Austria in context, this section provides a comparison between the results for Austria with those for other EU Member States as well as with the EU27 average. For this comparison, MFA data of the UN IRP database (UN IRP 2024) was used, because this database contains DMC and material footprint data for all EU Member States and the same calculation methodologies have been applied in the case of all Member States (CSIRO 2022). The data for Austria within the IRP database show a slight variance from those of Statistics Austria: DMC according to Statistics Austria amounted to 154 Mt/a or 17 t/cap/a in 2022 whereas the IRP database has calculated 141 Mt/a or 16 t/cap/a. The reason for this slight variance in these results stems from the data basis used (the IRP uses primary data from international statistics) and also the different methodologies employed for calculating, particularly for international trade flows (see CSIRO 2022). For this reason, Figure 27 presents both sets of results for Austria (Austria according to the calculations of Statistics Austria and according to the calculations of the IRP). MFA data for the EU Member States are also provided by Eurostat (Eurostat 2023c), however the calculation methodologies for material footprint in the individual countries remain very varied and are not available ordered by material category for all countries. Furthermore, Luxembourg is not included in the following discussion, because the data within the IRP database appear implausibly high (DMC of 38 t/cap/a and MF of 44 t/cap/a).

In the case of domestic material consumption, Austria was ranked in 2022 in a comparison between all EU Member States in 15th place for DMC, at 17 tonnes per capita (see Figure 27a) and in the IRP calculations (16 t/cap/a) in 12th place. Italy, Greece and Spain occupy the first three places, with the lowest material consumption (with 7, 8 and 9 t/cap/a, respectively). DMC for these countries was 34-46 % below the EU27 average of 13 tonnes per capita. Austria's consumption is 27 % higher than the EU27 average. Coming last according to this comparison, with the highest material consumption, are Cyprus (30 t/cap/a), Estonia (28 t/cap/a) and Finland (27 t/cap/a). Their material consumption is at least double the size of the EU27 average.



Notes: The DMC and MF for Luxembourg, as reported in the IRP database, are not accounted for in this Figure, because they were assessed as being implausibly high.

Source: UN IRP 2024, Austria (StAt): Statistics Austria 2024

Figure 27: (a) domestic material consumption (DMC), 2022, and (b) material footprint (MF), 2020.

In most EU countries, material consumption in 2020 was dominated by the non-metallic minerals, which constituted between 50 % and 60 % of DMC in almost all countries (in Austria, the figure is 54 %). Only Latvia, Lithuania and Cyprus show a higher figure for the consumption of construction materials, while Greece, Spain, Ireland and Bulgaria used significantly less. The relatively high resource consumption of Austria is primarily attributable to the high level of non-metallic minerals use (9 t/cap/a or 54 % according to the calculations of Statistics Austria, and as much as 64 % according to IRP methodologies). The major share of these flow into anthropogenic stocks (see chapter on "Biophysical stocks determine resource flows - Stock-Flow-Service-Nexus"), in particular, into buildings (Wiedenhofer et al. 2021). The EU27 comparison shows that the countries of Scandinavia (Finland, Denmark, Sweden) and the Baltic states (Estonia, Latvia, Lithuania) lead the list with a high level of material consumption particularly for construction materials (between 11 and 25 t/cap/a)[14]. Since residential buildings as well as roads in colder regions tend to require a higher level of material input (e.g., in the form of thicker wall and frost-resistant materials), the climatic situation also leads to larger material consumption in alpine Austria. Further important reasons for high per-capita resource consumption include population density and economic prosperity. Thus, Germany and the Netherlands exhibit a similar level of economic prosperity in comparison with Austria, yet both countries have a far higher population density. From a per-capita perspective, resource consumption is higher in sparsely populated alpine regions, because small settlements need to be linked with one another through material-intensive structures such as roads, bridges and tunnels and these infrastructures require regular maintenance or rebuilding. Finally, data collection must be considered as an influencing factor for resource consumption. The data available in the case of heavy mass minerals, particularly the domestic extraction of sand and gravel, is usually insufficient. In Austria, therefore, a dedicated and detailed estimation procedure was developed to additionally calculate the non-reported extraction of particularly sand and crushed rock. This concerns (1) extracted raw materials that are not traded but used directly within the extracting company for further processing (own final use), (2) extraction by small companies (with less than 20 employees), for whom no reporting obligation exists, and (3) the extraction of sand and gravel in companies allocated to other sectors than mining (e.g., construction industry, agriculture, trade and transport) (BMLFUW und BMWFJ 2011). These additional calculations produce an increase in the figure for material extraction of non-metallic minerals in 2020 from 30 Mt/a (primary collection) to 38.6 Mt/a, and material consumption for this material category increases from 8 t/cap/a to 9 t/cap/a (2020). Material consumption is thereby higher, but the data quality may be seen as greater (BMLFUW and BMWFJ 2011; Neubauer et al. 2023).

The second largest category for material consumption in EU countries concerns biomass materials or fossil energy carriers. Biomass consumption per capita and year shows a broad degree of variance and in 2022, ranged from one tonne in Malta or two tonnes in Cyprus to 7 tonnes in Lithuania and Denmark or 11 tonnes in Ireland. The countries with the highest level of biomass consumption were characterised by a large forestry or agricultural sector (particularly livestock farming). The consumption of fossil energy carriers also showed a similarly high degree of variance from less than a tonne per capita in Italy and France to 10 t/cap/a in Estonia.

In terms of total mass, the smallest of the four material categories is that of metals. Material consumption amounted to significantly less than one tonne in almost every EU country. Three EU countries stand out in terms of consumption: Finland (4 t/cap/a), Bulgaria (4 t/cap/a) and Sweden (5 t/cap/a). In each of these three countries, mining

14 Other countries that have a high level of consumption of non-metallic minerals include Belgium (12 t/cap/a) and Cyprus (25 t/cap/a). The reasons for this require further research, and missing data cannot be discounted as a factor in this case.

plays an important role. In Finland, selenium, silver, chrome, and nickel in particular but also many different rare earths are extracted. Copper, silver, iron ore, lead, and zinc are mined in Sweden and in Bulgaria, copper, gold, silver and manganese are extracted. According to the measures in the Critical Raw Materials Act (see the chapter on "Key raw materials of the future are classified as critical raw materials, and plans to increase their production within the EU."), which aim to increase production from mining so that import dependency can be reduced, changes in the MFA data are expected to be seen, particularly in the group of metals.

The material consumption represented as per-capita indicator showed that countries in colder climate regions and with lower population density generally display a rather high DMC/cap (we do not go into further detail here regarding possible other factors). An EU comparison using per-capita values is therefore only one possible form of representation or analysis. Available land area could be chosen as the unit of reference rather than population. Even in the early MFA analyses for the EU (Eurostat 2002; Weisz et al. 2006), the indicator DMC/land area (or also DE/land area) was used and discussed as an indicator for land use intensity. If one looks at material consumption in relation to available land, then land use intensity will be low for those countries that are characterised by low population density and a high DMC/cap (see Figure 28). Examples of this are the Baltic states, Finland and Sweden. Contrastingly, countries with high population density (more than 140 people/km^2) are characterised by high land use intensity, as in the cases of Belgium, Cyprus, Denmark, Germany and the Netherlands.

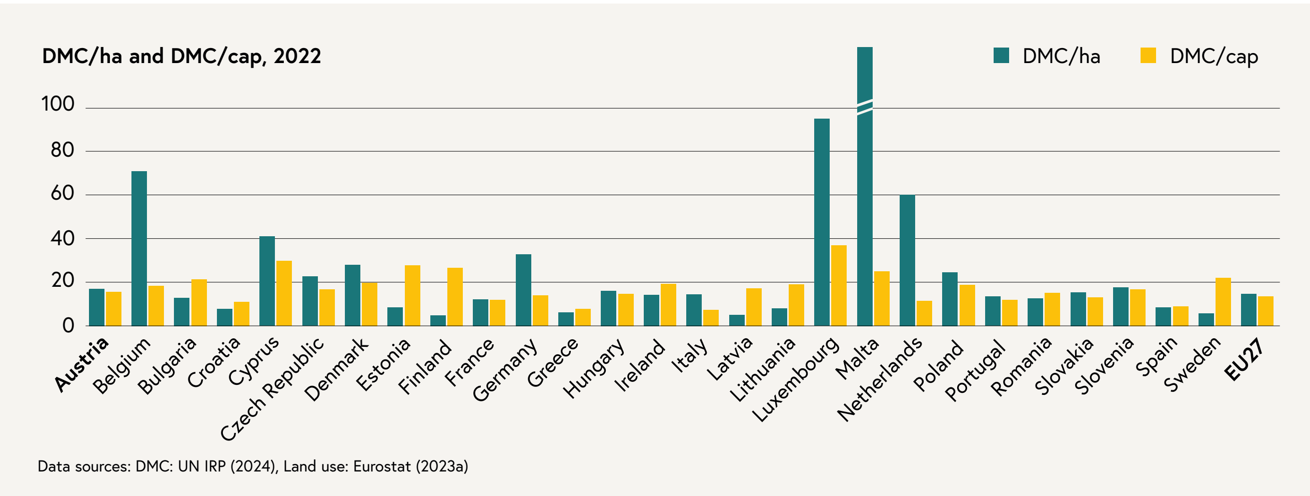


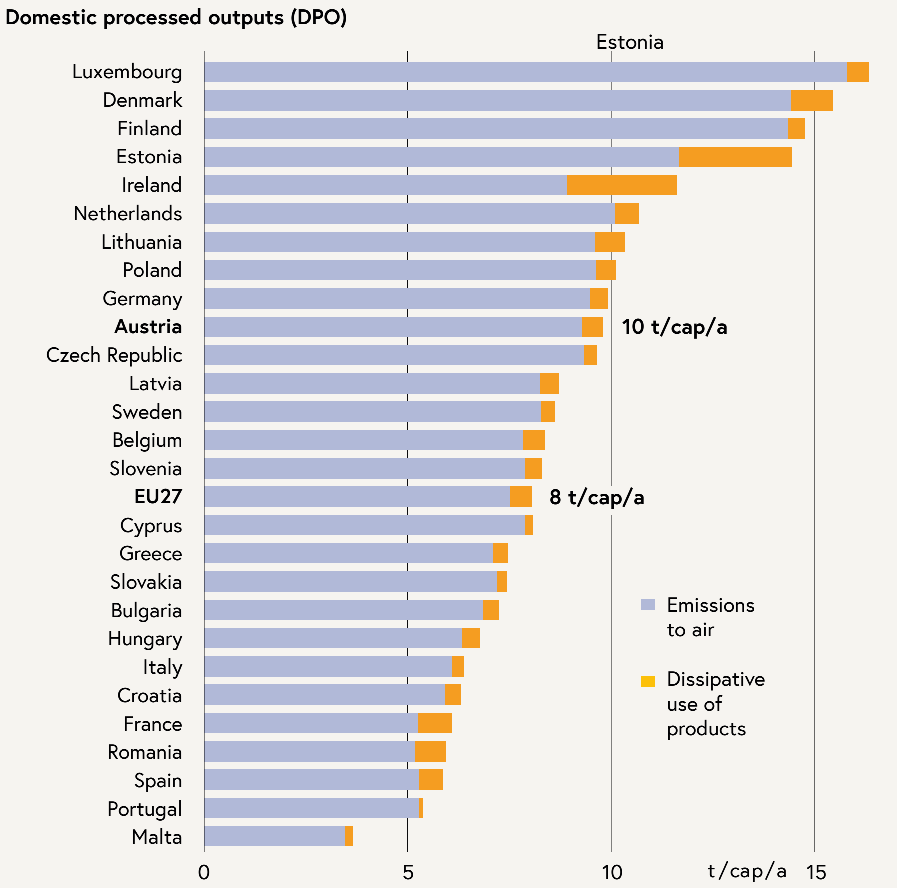
Figure 28: Land use intensity as material consumption per hectare (DMC/ha) in comparison to material consumption per capita (DMC/cap), EU Member States, 2022.

Austria's material footprint, i.e., the material consumption including upstream consumption outside Austria's national borders, amounted in 2020 to 199 Mt/a or 22 t/cap/a. The European comparison for material footprint reveals a similar ranking as for DMC: Finland (31 t/cap/a), Ireland (35 t/cap/a) and Belgium (37 t/cap/a) came last with a relatively high MF/cap/a. The countries with the lowest per capita footprint were Bulgaria (12 t/cap/a), Greece and Spain (each with 13 t/cap/a). The MF for Austria, at 22 t/cap/a, was almost twice as high and even the domestic material consumption (DMC) for Austria

(17 t/cap/a) was about 30 % higher than the MF for these countries. The EU27 average for material footprint amounted to 19 tonnes per capita in 2020, and Austria's footprint was 22 % higher than this. Austria thus ranked in 17th place, with 16 countries showing a lower MF/cap/a.

MFA reporting to Eurostat also includes the output side (DPO; see chapter "All material inputs will become outputs") as a voluntary reporting item with which several countries, including Austria, already comply (Eurostat 2024a). The missing data are compiled by Eurostat itself. The two relevant categories under domestic processed output are, as already described in the chapter "All material inputs will become outputs - waste and emissions", emissions to air and the dissipative use of products (waste deposited in landfills is not part of the domestic processed output but remains part of the socioeconomic system). Emissions comprise the major share of DPO (over 90 % in 22 countries, between 90 % and 85 % in Spain, Romania and France, 81 % in Estonia, and 76 % in Ireland). The EU27 average for DPO in 2020 was 8 t/cap/a. 12 countries were below the EU27 average. Austria belonged, with a DPO of 10 t/cap/a, among the group of countries that cause more outputs than the EU average. Overall, Austria was ranked 18th among EU countries and was thus in the lowest third. The five countries with the largest DPO were Luxembourg (16 t/cap/a), Denmark, Finland (both 15 t/cap/a), Estonia (14 t/cap/a) and Ireland (12 t/cap/a) (Figure 29a). In Malta (4 t/cap/a), Portugal (5 t/cap/a), Spain, Romania, France, Croatia and Italy (each with 6 t/cap/a), the lowest per capita quantities of wastes and emissions can be found.

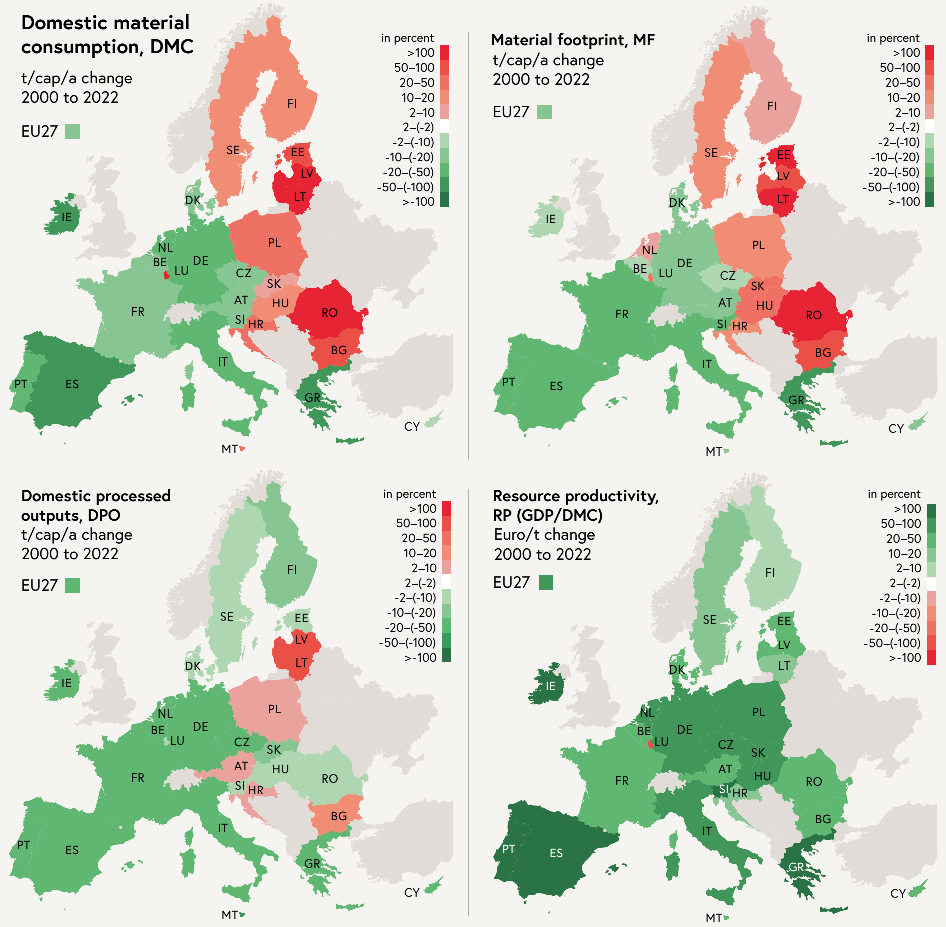
Figure 29: Domestic processed outputs (DPO) in t/cap/a in 2020 for the EU27 countries in comparison.



Notes: In the Figure, only those categories are represented for which values greater than 10 kg/cap/a were reported. Wastes landfilled are no outputs to nature and consequently not part of DPO.

Source: Eurostat 2024a

In the period 2000-2022 (and 2000-2020 for the DPO), it was possible to reduce per-capita material consumption in almost half of all EU countries, including in Austria (see "Material consumption has increased - even during the COVID pandemic"). In Sweden, Finland and in all countries that joined the EU in the context of the EU expansion in 2004 or at a later date, (with the exception of Czechia and Slovenia), material consumption rose in comparison with the year 2000 (UN IRP 2024). Resource productivity, measured as gross domestic product per DMC, increased in the entire EU27, and in Greece, Ireland, Portugal, Slovenia and Spain the RP actually more than doubled (UN IRP 2024). A reduction in MF was achieved in 13 countries (Austria, Czechia, Denmark, France, Germany, Greece, Ireland, Italy, The Netherlands, Portugal, Slovenia, Spain and Sweden) (UN IRP 2024). The spatial pattern of change in DPO (the most recent available year with Eurostat being 2020) resembles that for DMC. Austria is in this case among the 22 countries in which a reduction in DPO was observed (Eurostat 2024a). In 16 countries, the reduction amounted to 10 % or more, with the greatest reduction achieved in Malta (51 %), Belgium (40 %) and Spain and Greece (35 %). In Austria and in three other countries (Hungary, Romania, Estonia), the reductions in DPO were only 5 % or less than this. Having achieved stabilisation of DMC (+/-0 %), a reduction in the MF of 5 %, a reduction in DPO of 5 %, and a 24 % increase in resource productivity, Austria ranks in the middle of the group of European countries.

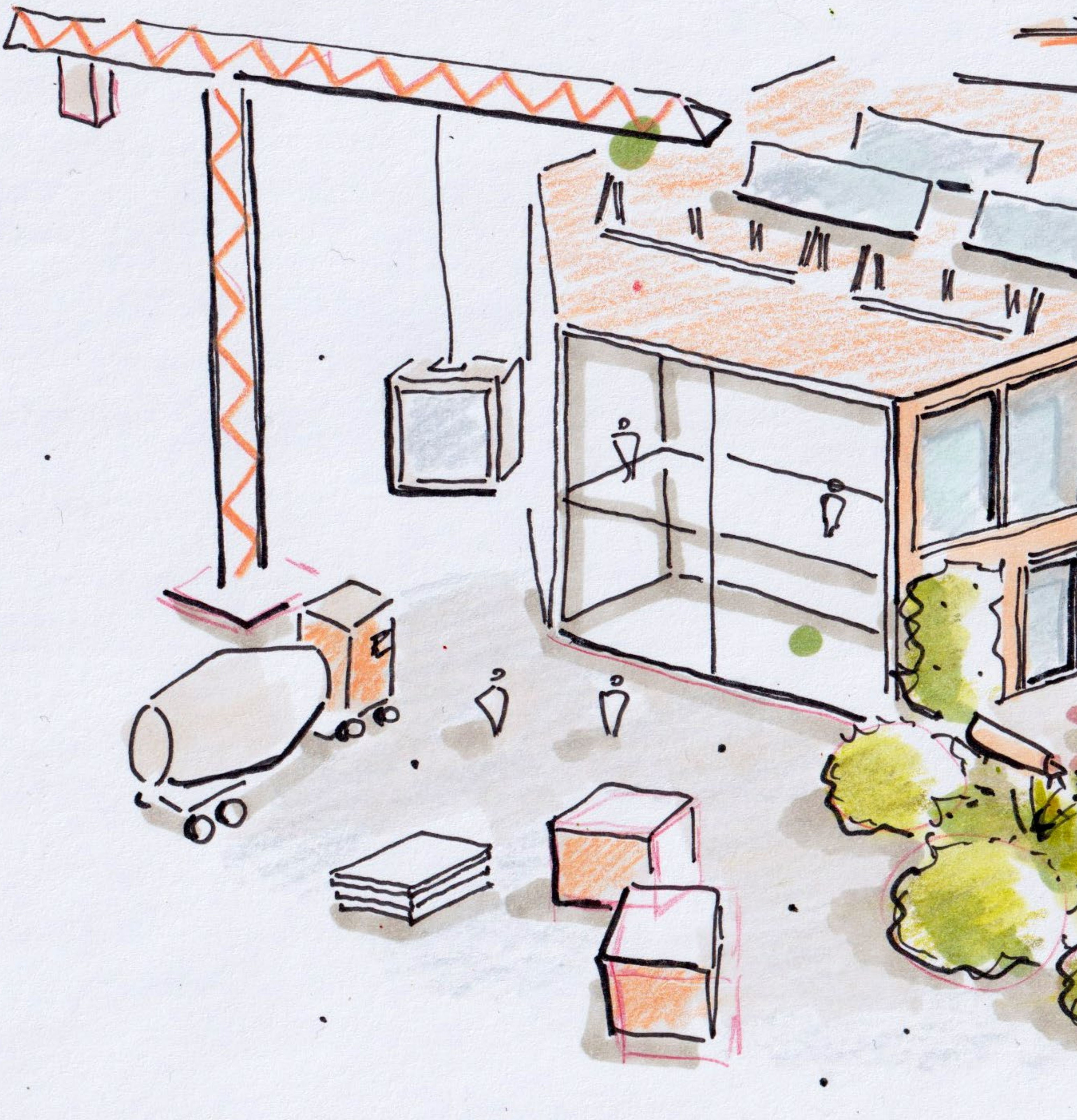


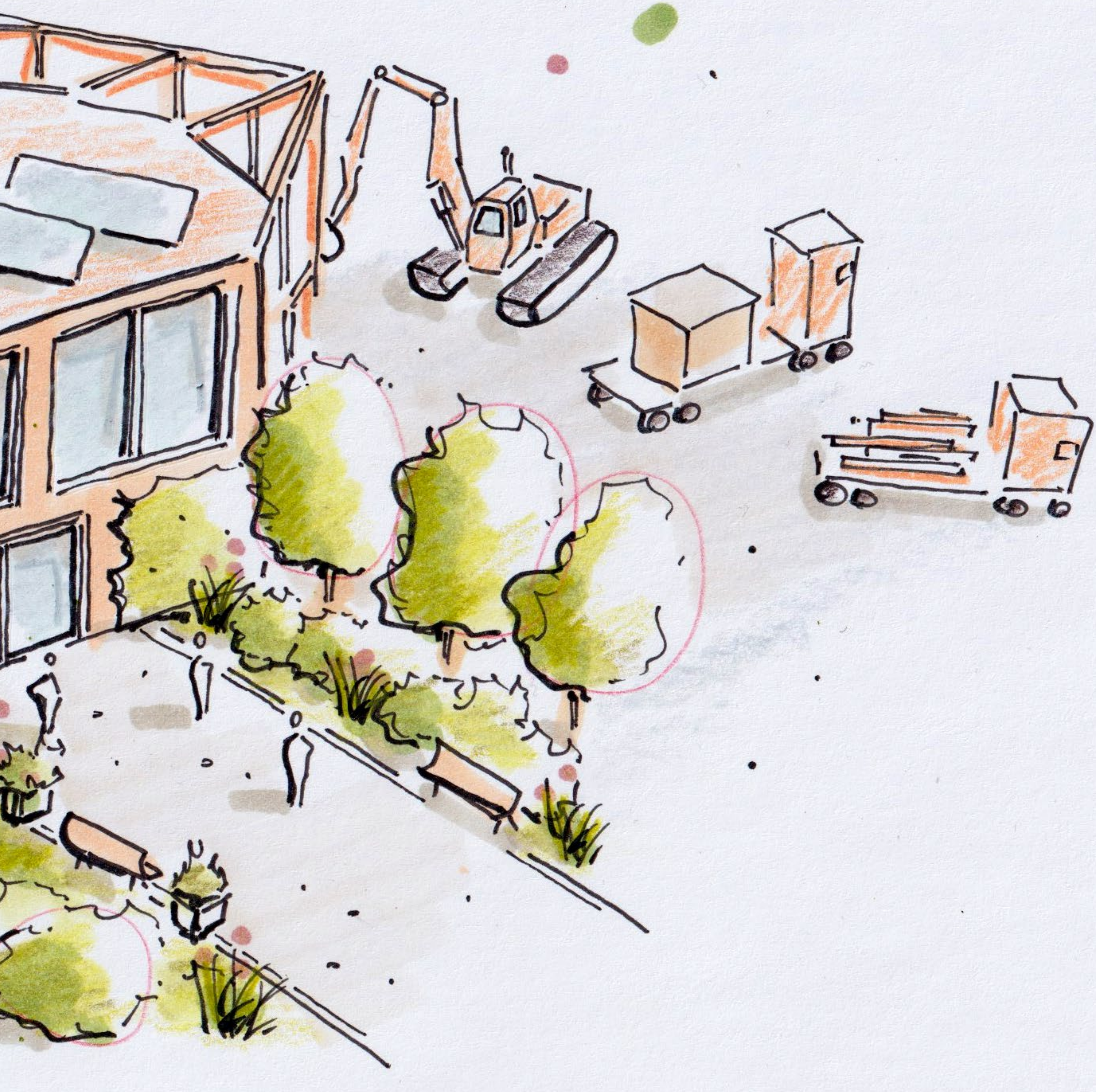
Explanation: In green means an improvement for the respective indicator while red means a detoriation.
Darker colors indicate more change. It should be noted that the desired change (shown in green) are achieved through reductions for the indicators DMC, MF and DPO, and through increases for RP.

Source: DMC, material footprint, resource productivity: UN RP (2024), DPO: Eurostat (2024a)

Figure 30: Changes in material consumption (DMC), material footprint (MF), domestic outputs to nature (domestic processed output, DPO) and resource productivity (RP) in the EU between 2000 and 2022, and between 2000 and 2020 in the case of DPO.

3 Circular Economy





The challenges of transforming a linear economic system into a circular economy

> Statement 16 – Circular economies can contribute to achieving climate and other environmental goals: The provision of raw materials is a key driver of environmental crises including climate change, environmental pollution and biodiversity loss (UNEP 2024). Reducing the requirements for primary raw materials through e.g. circular economy measures can therefore make an important contribution to achieving climate and other environmental goals. An economy-wide approach to material flows and stock dynamics helps to identify options for conserving resources as early as possible and to enable these to inform and shape policy. – Philip Nuss, PhD, Federal Environment Agency Germany

Our economic model remains largely linear in its organisational form. Resources are extracted from nature, processed to create products or infrastructures, used in households or by the state, businesses or other organisations, and finally disposed of as wastes or emitted in dissipative form i.e., dispersed in low concentrations into nature. The useful lifespan of different products varies widely. Thus, a house may have a lifespan of 50 to well over 100 years, while a car produced today is expected to have a service life of up to 20 years. An article of clothing, by contrast, will generally remain in use for no longer than 5 years and most foodstuffs have the likely shortest period of utilisation, of days, weeks or at most, a few months. If a product is no longer required, it becomes waste and as such is sent for waste processing, finally being output to nature as emissions to air or into water. Increasing shortages of raw materials and environmental crises caused by emissions and the processing of wastes and waste water are symptoms of exceeding the absorption capacities of the ecosystem and the finite existence of natural resources (Meadows et al. 1972; Rockström et al. 2009a; Steffen et al. 2015; O'Neill et al. 2018; Persson et al. 2022; Richardson, et al. 2023). Since the 1970s and 1980s, heavily influenced by the oil price shocks of the period, there have been and still are numerous efforts to reduce growing waste flows and emissions, and to see wastes as resources and to include them in recycling. Recycling - particularly of metals - was recognised as the central strategy for valorisation of waste materials.

Similarly, the input-oriented MFA database, which became established at the beginning of the 2000s, soon made clear that progressing from monitoring resource flows to developing courses of action can only be achieved by expanding the area of inquiry beyond society's use of materials to the end of their lifecycle. The scientific MFA community has consequently devoted itself to recording and analysing the entire period in which materials are utilised by society. Both in conceptual and in empirical terms, the systematic approach of social metabolism has proven essential in this context. A clear definition of the system being observed, adherence to the laws of thermodynamics, and a mass balance approach to accounting for all flows in conjunction with the changes to stocks enable the complex modelling of all resource flows. This robust evidence base then also provides the basis for decision making within political programmes, such as the Circular Economy Strategy.

The circular economy (CE) aims to reduce material inputs and outputs of society as far as possible, so that primarily resource inputs are minimised and the resources used continue to be utilised for as long as possible. Only when they reach the end of their utilisation phase will materials finally be fed back into the production process as part of a closed-loop system. Political and economic discourse has contained much talk over recent years and decades about the successes of recycling and high recycling rates. Numerous targets set by the EU (Eurostat 2023e) set out to address the recycling of batteries, electronic equipment, packaging materials, vehicles, household waste and construction waste. Yet although a focus on waste materials and respective rates of recycling is important, it must be expanded to include an understanding of the input side. The narrow focus on recycling therefore needs to be extended to take account of the other strategies within the circular economy, of reducing and slowing, both of which precede recycling. Not until a comprehensive circular economy approach, from resource use to utilisation through to waste management, and the prioritisation of demand reduction strategies at the very start of the usage chain are implemented will resource conservation in the sense of a reduction of economy-wide resource consumption become possible. It is precisely this approach that is taken by the Austrian Circular Economy Strategy.

Energy and material use of resources – two separate flows, which are mutually dependent

From a metabolic perspective, it is useful at this point to highlight a further important difference in socioeconomic resource use. On one hand, we require material resources in order to use these in their material form, for example for the production of stocks or for short-lived products. On the other hand, materials provide us with energy benefits (to date, largely through fossil energy carriers) and also in the form of food for humans, domestic animals and livestock. Materials that contribute to material utilisation become waste materials at the end of the utilisation period, which can be available for recycling or a variety of strategies for reuse. In the case of energy use, material resources are consumed during their utilisation and converted into emissions. These emissions are discharged into the air in dissipative form, i.e., at many locations in very low concentrations. It should be noted that reusing or recycling these 'waste materials' is practically not feasible or is only possible through highly intensive use of energy.

These two forms of use cannot be regarded as being independent of one another. Indeed, the opposite is true: energy is required at all stages in the production of material goods (from resource extraction, processing, manufacturing, through to transportation). Furthermore, energy is also required after the production process, in order to make the produced stocks usable (lighting and heating for buildings, electricity for the many items of equipment produced, fuels for vehicle mobility, etc.).

Recycling rates of 70 % and above contrast with a circularity rate of 14 %. Why is the circular economy so challenging to put into practice?

If only maximising recycling rates was aimed for within a circular economy, we would not achieve a successful outcome. It should be noted that recycling rates for metals of 64 % or 66 % (BMK 2023) are put sharply into perspective when one compares the economy-wide total of all secondary raw materials with total resource consumption. This input-side focused 'recycling' rate or circularity rate (circular material use rate, European Commission 2023b) amounted globally to roughly 6 % in 2015 (Haas et al. 2020) and in Austria to just below 14 % in 2022 (Statistics Austria 2024).

One of the major constraints on the circular use of materials is the accumulation of socioeconomic stocks, such as buildings, roads and products. These require far more in terms of resource inputs than can be made available as waste materials for recycling. Globally in 2015, we required about 70 billion tonnes of non-renewable resources, yet only a little less than 20 million tonnes accrued as waste materials (Krausmann et al. 2018). Even if it were possible to achieve a recycling rate of 100 %, which is impossible according to the second law of thermodynamics, secondary inputs from accrued waste materials would only be able to provide a maximum of 30 % of the resources required, given the current rate of the accumulation of stocks.

Aside from the theoretical planning, when it comes to implementation in practice, yet more challenges exist that further decrease the theoretical recycling rates. These include, for example, the complex process of collecting waste materials across the often very widely dispersed locations of accumulated wastes. Furthermore, modern products are very complex in terms of their production and material composition, consisting of a wide variety of different elements of the periodic table, combined through chemical processes to create composites or alloys. These complex compounds are often impossible to separate into pure forms of their original constituent elements, not least because the high-tech processes involved in manufacturing contrast with the simple processes at use in separation of waste materials, such as screening or sifting, air classifiers, magnetic separation, washing or breaking up. In modern industrial processes, increasing use is also being made of nanomaterials, which can have toxic effects despite the extremely minute quantities employed. The combination of a range of different materials can also result in these diffusing into one another during utilisation or during their disposal. There is currently insufficient knowledge regarding the final disposal of such materials and what their eventual state might be, and about their potential toxicological consequences for humans and the environment.

The circular economy, in the context of an economy-wide approach, has the potential to act as the framework shaping sustainable resource use through all the different processing and utilisation phases involved in production and consumption. A systemic approach, i.e. the accounting of the resource inputs and outputs of the socioeconomic system of production and consumption in accordance with clearly defined system boundaries, is key here. Given that resource flows are inextricably interlinked with our biophysical stocks (see the chapter "Biophysical stocks determine resource flows - Stock-Flow-Service-Nexus"), the monitoring of a circular economy must on one hand follow a mass balance approach, which systematically records the changes to stocks - i.e. their accumulation, maintenance and demolition. Otherwise, environmentally important material flows can remain hidden behind data gaps or inconsistent approaches to recording data (e.g. as a result of divergent system boundaries). Integrating stocks within an economy-wide approach is of particularly high importance in the case of countries such as Austria, in which about 75 % of the extracted and imported material flows accumulate in stocks.

The scientific basis for this rests on the concept of material flow analysis and was further developed initially by Haas et al. (2015) for the circular economy and expanded to create a globally consistent empirical analysis approach (Haas et al. 2020). In collaboration with the European Commission, the concept was also used as the basis for developing a consistent set of indicators (Mayer et al. 2018; de Wit et al. 2019).

The goals of the Austrian Circular Economy Strategy are very ambitious

Circular economy – a strategy for Austria

The circular economy plays a crucial role in the transformation towards a sustainable and resource-conserving society and economy. It allows economic success to be combined with environmental protection and social progress. Reduced resource consumption, the avoidance of pollutants and the minimisation of waste and emissions together reduce the ecological footprint. The circular economy thereby helps tackle the challenges of climate change, biodiversity loss and other ecological concerns.

The national Circular Economy Strategy, "Austria on the Path to a Sustainable and Circular Economy", was developed with the involvement of a broad coalition of stakeholders and experts from the economy, scientific research, political administration and the wider society, and was adopted in December 2022 by the federal government. The national strategy builds upon the European Green Deal and the EU Circular Economy Action Plan and is consistent with European recommendations. The strategy defines the fundamental principles of a circular economy, the vision, strategic and long-term goals and the medium-term operational targets. The central goals of the Circular Economy Strategy are[15]:

- Goal 1: Reduction of resource consumption measured as material footprint (7 t/cap/a by 2050) as well as in terms of domestic material consumption (14 t/cap/a by 2030)
- Goal 2: Increasing domestic resource productivity by 50 % by 2030 in comparison with 2015

15 For more information (in German), see: bmk.gv.at/themen/klima_umwelt/abfall/Kreislaufwirtschaft/strategie.html

- Goal 3: Increasing the circularity rate to 18 % by 2030
- Goal 4: Reduction of the material consumption of private households by 10 % by 2030 compared to 2020

Implementing the circular economy in Austria relies upon a closely harmonised combination of measures; in the case of seven focal points for transformation (construction industry and infrastructure, mobility, plastics and packaging, textile industry, electrical and electronic devices and communication technologies, biomass, waste and secondary resources), packages of measures have already been recommended for implementation.

The goals are accompanied by a set of principles for a circular economy (the 10 R-strategies) and for raw material supply: Sustainable secondary material sources should be used as a priority to meet demand for raw materials in future, then sustainable renewable sources, and only the remainder should come from non-renewable sources. Where new raw materials and substances come into use in future, their sustainable production must also be accorded the highest priority.

The 10 R-strategies of the circular economy from Rethink to Recover

> Statement 17 – Resource management and the boundaries of the circular economy: As the Resource Report shows, the circular economy in Austria has barely been implemented to date. There are two important reasons for this: firstly, resource consumption is high and contributes to rapid accumulation of stocks. During a period of growth such as this, no strong closed-loop circularity can be achieved in practice. A circularity gap of 10 % that is typical for many regions of the country shows this to be the case. Secondly, the use of raw materials is accompanied by a significant increase in entropy, because in material terms we produce very complex products that can subsequently only be recycled (if at all) with the application of great technical effort and (too much) cost. Producing entropy is always easier than reducing it thereafter. Resource management provides the methods and knowledge to describe, analyse and optimise the material economy. – Univ.Prof. DI Dr.techn. Dr.h.c. Helmut Rechberger, Head of Research Unit, Waste and Resource Management, TU Wien (Vienna University of Technology)

The circular economy includes a broad palette of processes and activities, which can be organised in accordance with the 10 R-strategies, and concentrated within three strategic groups: Narrowing, Slowing, and Closing resource loops (Potting et al. 2017; see Morseletto 2020). The Austrian Circular Economy Strategy (BMK 2022) is based upon this grouping, see Figure 31.

Source: BMK 2022

Figure 31: The 10 R-strategies of the circular economy. Infographic from the Austrian Circular Economy Strategy.

The 10 R-strategies cover the entire process from production and consumption to disposal, establishing the design from the outset and expanding upon the purely economic and technical or waste management focus to include a social transformation perspective. The R-strategies are structured in a way that reflects their prioritisation: products, services and systems should be considered from a circularity perspective at the point of their conception and design, before production processes are determined (see also the Austrian Circular Economy Strategy; BMK 2022). Furthermore, with respect to the sources of raw materials, a scheme of prioritisation should be followed: raw materials should in the first instance be derived from secondary sources, secondly from sustainable renewable sources, and only as a last resort, from non-renewable sources (BMK 2022).

Narrowing is intended to reduce the amount of materials used from the very beginning onwards

The first three R-strategies – Refuse, Rethink, Reduce – place socioeconomic requirements for specific services at the centre. Before production or design of a product is even considered, the concepts of Refuse and Rethink involve questioning whether a specific service could be provided by completely different products or through another form of socioeconomic organisation. By way of example: I wish to undertake sports activities in order to increase my fitness level. Instead of taking out an annual membership of a fitness centre (with all its material infrastructure and equipment, including operation and maintenance) and driving there and back by car, I could join a self-organised sports or fitness group meeting in a park that is accessible on foot within my neighbourhood. Or, for example, unused premises could be occupied for multiple uses, as community centres for multi-generational living including childcare, for special events and sports such as table tennis, rather than building numerous dedicated structures at greater distance from one another. Furthermore, the variety of sharing concepts, familiar from the past in the case of public libraries, as well as tool-sharing platforms and places, also have great potential in this context. Sharing concepts, which are applicable not only at the level of products but rather at system level, hold particular relevance. Thus, public transport (which is also a sharing concept), instead of individual motorised transport through car ownership, is far more resource-efficient, particularly where this involves the relocation of mobility from resource-intensive road networks to rail networks, which use far less resources. This can be supplemented by car-sharing opportunities that promote the rethinking of car ownership in favour of community use.

In the context of this strategic group, the term 'sufficiency' is often used (Görg et al. 2023), which refers to the fact that individuals can lead a good life with a high quality of life despite consuming less in terms of goods and services (Millward-Hopkins et al. 2020). Sufficiency in a general sense describes a change to the dominant patterns of consumption, usually including the reduction of consumption. In contrast to this, the term 'efficiency' is concerned with producing and using goods and services with less material, waste and emissions. In this context, the concept of 'consumption corridors' is also used, which sets out a lower and an upper limit for consumption. In economy-focused discussions, sufficiency is also considered in the context of demand-side measures, focussing on how consumption and demand on the part of final consumers can be adapted and changed.

Another component of the Narrowing strategy group is the 'Reduce' principle, in the sense of a reduction in the number of consumed products or the material consumption per product. A clear demarcation between the three Rs – Refuse, Rethink, Reduce – is often hard to achieve. However, what they have in common is that all contribute to a narrowing of resource inputs.

Among the circularity indicators, narrowing the flows becomes evident through the reduced quantities of non-circular flows, i.e., of primary materials. This also leads to a reduction in the total processed materials, in the case of which the circularity rate (recycling as a share of the materials being processed) increases with the same amount of absolute recycling flows.

One aspect is not explicitly considered in the 10 R-strategies; that is the substitution of non-renewable by renewable raw materials, i.e., biomass-based materials. Since even the provision of renewable raw materials requires both material and energy, and the regeneration rates of ecosystems place limits upon their availability, a substitution approach should only be taken when the options to Refuse, Rethink and Reduce have all been exhausted. Thus, a scheme of prioritisation should also be followed when it comes to sources of raw materials: 1. secondary sources, 2. renewable raw materials, 3. non-renewable sources. These raw materials principles are all addressed in the Austrian Circular Economy Strategy (BMK 2022).

Slowing involves materials remaining in use for longer

Five further R-strategies – Reuse, Repair, Refurbish, Remanufacture, Repurpose – are aimed at prolonging the useful lifespan of products, product components or materials in society. These strategies are largely services-based and have been significantly developed and expanded in recent years. Exchange and intermediary platforms, for example, can potentially ensure that products in good condition that are no longer required by their current owner can be either purchased or obtained for free for use by others, rather than disposed of. One example of how the useful lifespan of products can be extended is the campaign by the Federal Ministry for Climate Action promoting the repair of electrical and electronic equipment and devices (involving a nationwide repair bonus scheme). The European Ecodesign Sustainable Products Regulation (ESPR)[16] came into force on July 18, 2024 and addresses the various aspects of prolonging the useful lifespan of products.

In the case of products from renewable biomass, their cascading usage - despite the lack of explicit reference in the 10 R-strategies, nonetheless addressed by them - can also be allocated to the Slowing category. This can refer to the use of clothing items being repurposed as cleaning cloths or the use of shuttering boards or wooden components of demolished houses being used for making furniture. In contrast to recycling, where the material comes back into the production process, in the case of reuse, the product remains intact as a whole or in its component parts. The cascade is

16 commission.europa.eu/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/sustainable-products/ecodesign-sustainable-products-regulation_en

formed by the fact that the secondary use is characterised by a lesser quality of the reused or repurposed product.

In the circularity indicators, Slowing is evident either through the reduced quantity of non-circular flows, since stocks such as buildings or products do not have to be replaced; or through the creation of less waste, because the products or stocks become waste materials at a later stage than they would otherwise.

The prolonged service lives of materials cannot easily be measured at the level of aggregated national accounts. An effective option could be the application of a new indicator: a material turnover rate, i.e., the ratio between waste materials from stocks to the materials that are used as inputs for the production of stocks. This indicator provides an estimate for how long the total of all stocks and products remains in use. So, for example, in the case of an annual material input of 5 t/a (for maintenance and expansion of stocks) and one tonne of waste, the ratio would be 1:5 and the material turnover rate would be 20 %. The ratio 1:5 means that the stocks are entirely renewed every five years.

Statement 18 – Business models and products need to be reconceived: Both products and the business models associated with them need to be fundamentally reconceived, so that long service lives, reduced resource consumption and the implementation of circularity with a high level of value creation can work together in perfect harmony. To this end, many new ideas are emerging for product design in the sense of ecodesign, which directly addresses the actual requirements of users. This goal is achieved when the economic success of an enterprise is decoupled from resource consumption.

– Ao.Univ.Prof. DI Dr. Wolfgang Wimmer, EcoDesign, TU Wien (Vienna University of Technology)

Closing material cycles is aimed at transforming waste into secondary raw materials

The final two R-strategies - Recycle and Recover - are the strategies that are employed at the end of a product's lifecycle, i.e., when a product enters the waste treatment process. These include the classic form of recycling, i.e., the processing of materials to become secondary raw materials, which can be used again in production processes. 'Recover' is the thermal use of heat from the incineration of waste materials that can no longer be reintegrated into the material cycle.

The secondary flows of this group are accounted for in waste management as 'recycling'. This form of closed-loop circulation is therefore included directly in the calculation of the circularity rate (circular material use rate (CMU), see next chapter) and should ideally both replace primary raw materials and reduce waste. Because of the rebound effect and through the transport, site infrastructure and energy involved in the recycling process, reduction effects may also be compensated for. A concrete attribution to individual recycling measures is however not possible to undertake.

Circular economy indicators can represent absolute quantities or relative figures

A very diverse range of indicators are employed for monitoring and evaluating the circular economy at political level (BMK 2022; Eurostat 2024b) and in scientific research (Mayer et al. 2018; Helander et al. 2019; Moraga et al. 2019; Miatto et al. 2024). The following section provides a structural overview and discussion of these indicators, with a focus on those that are relevant for Austria's Circular Economy Strategy.

Absolute indicators describe the total mass (scale) of resource inputs or generated wastes

The overarching goal of the circular economy is to minimise socioeconomic inputs in terms of primary resources together with socioeconomic outputs (waste and emissions). In order to evaluate whether we are moving towards this goal, absolute indicators are of primary importance. These indicate whether the total quantity of inputs and outputs is falling. On the input side, this can be measured in terms of domestic material consumption (DMC) or material footprint (MF). DMC focuses on the materials that are used during production and consumption in Austria. MF in contrast encompasses Austrian final demand and the global material consumption that is linked to this. In the scientific literature (Mayer et al. 2018), a further indicator is proposed and employed: this refers to processed materials (PM). PM represents DMC taken together with recycled materials. According to Mayer et al. (2018) PM can also be defined as interim flow, because it not only takes account of those inputs that cross the system boundaries to nature and to other economies but also includes the internal flow of recycled materials. PM thus describes the total material consumption of production and consumption, regardless of whether these materials come from primary or secondary sources.

In their application, these indicators provide slightly varying results:

- Where DMC falls and the quantity of recycling flows rises, PM remains constant.
- Where DMC falls and the recycling volumes remain constant, then PM also decreases.

On the output side, an absolute indicator can measure waste, emissions or their sum total, i.e., domestic processed output (DPO). Circular economy studies generally focus on material wastes, and emissions are rarely included. This is likely to be due to the fact that emissions (yet) cannot be recycled.

The Austrian Circular Economy Strategy, sets a goal for DMC and for MF on the input side (see chapter "The Goals of the Austrian Circular Economy Strategy"). On the output side, the Strategy defines a goal for the "reduction of the material consumption of private households", which is proposed to be measured in terms of the generation of municipal waste.

Circularity or recycling rates reflect the relationship between two flows

In addition to absolute quantities, rates are often used as indicators that, for example, reflect the share of recycled flows in total inputs or total outputs. Rates are percentage rates and thus provide no information on the absolute quantities upon which they are based. For this another statement is presented, which is helpful in expanding upon absolute quantities given. By way of example: In Austria, the quantity of recycled materials can double in absolute terms without indicating any progress made towards the circular economy if the primary materials input also doubles, since the circularity rate remains at the same percentage level. Evaluating the progress made towards a circular economy can therefore only be achieved by examining both the circularity and recycling rates and the absolute reference quantities (total resource input or total waste).

Output-side recycling rates have been used for a relatively long time and enjoy wide recognition. They measure the share of recycled materials in relation to generated wastes and thereby provide information about how much of the generated wastes can be returned to socioeconomic use once again.

On the input side, the circularity rate or circular material use rate (CMU; Eurostat 2024c) is used. Mayer et al. (2018) also define this indicator as the input recycling rate. This indicator measures the share of secondary materials in the material consumption of society as a whole. It is important in this respect to note which components are included in the calculation of the circularity rate. In the Sankey diagrams from Eurostat (Eurostat 2024d) and Statistics Austria (see Figure 32), the node "processed material" represents the DMI + recycling. However, in calculations of the circularity rate, DMC + recycling is used. In other words, exports are removed in this calculation.

For the development of policy recommendations, further detail is required

The absolute indicators and rates detailed above are useful monitoring instruments to capture overall economic trends. They provide little guidance, however, for the development of policy recommendations. This requires a more detailed examination of sectors, products and fields of activity, among others:

- Recycling rates for specific materials, e.g., aluminium, glass or paper recycling rates are well-established and provide important information about technical capabilities.
- Recycling of renewable resources (biomass): Biomass is defined as a renewable resource and therefore the use of biotic raw materials is regarded as circular per se. However, the productive land available and its renewable biomass potential are limited, because overuse leads to the degradation of land and soil fertility. Thus, even in the case of biomass, circularity must be considered. This can relate on one hand to recycling within society, which primarily concerns cascading use. This sees biomass materials being utilised with ever decreasing quality through

a series of steps, for example in the use of wood for furniture, then for particle board, then paper and finally for energy generation. On the other hand, it is important in the case of outputs to nature to ensure that these outputs do not exceed or damage the regenerative capacity of ecological cycles.

- Ultimately, it is also important to consider recycling options outside the system being monitored and to develop empirical methods for recording these. Imports from countries/companies that have very good CE performance are preferable to those from other, less sustainable companies. The same considerations are valid for exports. CE locations require the best possible spatial distribution in accordance with supply and demand. Thus, it is not possible for every city, every province or every region within a country to provide recycling facilities for all types of materials. Sometimes it is more economically efficient to use a facility located beyond national borders, where this is more accessible geographically than any domestic facility. CE indicators should therefore also allow for the depiction of imports from and exports to CE-oriented companies as a second priority.
- Lastly, it must be noted that indicators from the first CE strategy group, Narrowing, have not yet been thoroughly integrated in the set of indicators with a systemic perspective. Given the importance and priority role accorded to these systemic strategies (in contrast to the other, more product-oriented strategies of the other R-strategy) a conceptual development of narrowing indicators is urgently required.

Visualising the circular economy in Sankey diagrams

To represent the material flows that are relevant for a circular economy analysis, Sankey diagrams are generally employed (Flow diagrams, see the Figures below). Creating a Sankey diagram is a complex undertaking, since depicting the circular economy process correctly and comprehensively requires a consistent system definition and a correct mass balance as key prerequisites. This means that all outputs must be equal to the inputs, adjusted for the changes to stocks (Krausmann et al. 2017; Eurostat 2018; Wiedenhofer et al. 2019). Most studies are based on the use of biophysical models, which link resource inputs on one hand and stocks and socioeconomic outputs on the other in a consistent way. The mathematical relation Inputs = Outputs + Stock changes can be used to cross-check or model missing components in the case of data gaps or unreliable quality.

Stocks and changes to stocks have not yet been recorded using statistical sources; furthermore, the long lifespan of some stocks (50-100 years in the case of buildings) means that a consistent record of the type and composition of e.g., building stocks and then the linked resource inputs and outputs over a time series is required. Without quantifying stocks, possible links including those extending beyond the year in question and feedback processes cannot be shown, and data inconsistencies may produce erroneous links and attributions.

In this section, two Sankey diagrams for Austria are presented together, their differences delineated and the resultant effects upon circularity indicators outlined.

The first Sankey diagram is compiled by Statistics Austria (Statistics Austria 2023e) (Figure 32) and similarly published by Eurostat. The data basis for this is provided by the MFA, the external trade statistics, and the waste management statistics. In the text that follows, the Statistics Austria Sankey diagram will be referred to as STAT-Sankey.

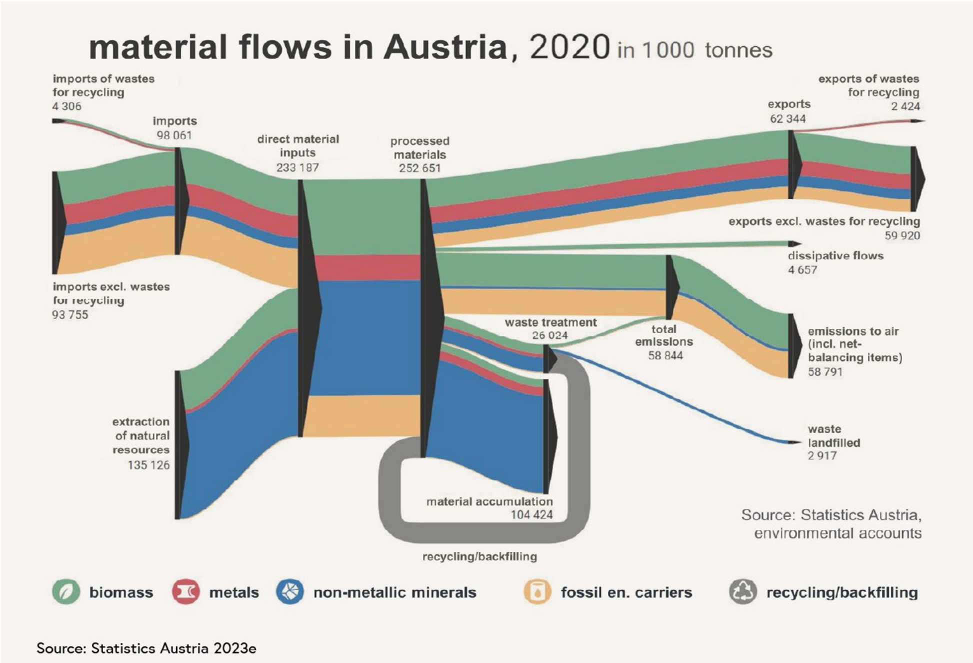


Figure 32: STAT-Sankey: The Austrian circular economy as a Sankey diagram, compiled by Statistics Austria. Austria 2020.

The second Sankey diagram is the result of a research study at the Institute of Social Ecology (SEC) (Jacobi et al. 2018), later reworked and published in the Circular Economy Gap Report (de Wit et al. 2019); see Figure 33. This Sankey diagram will be referred to here as the SEC-Sankey.

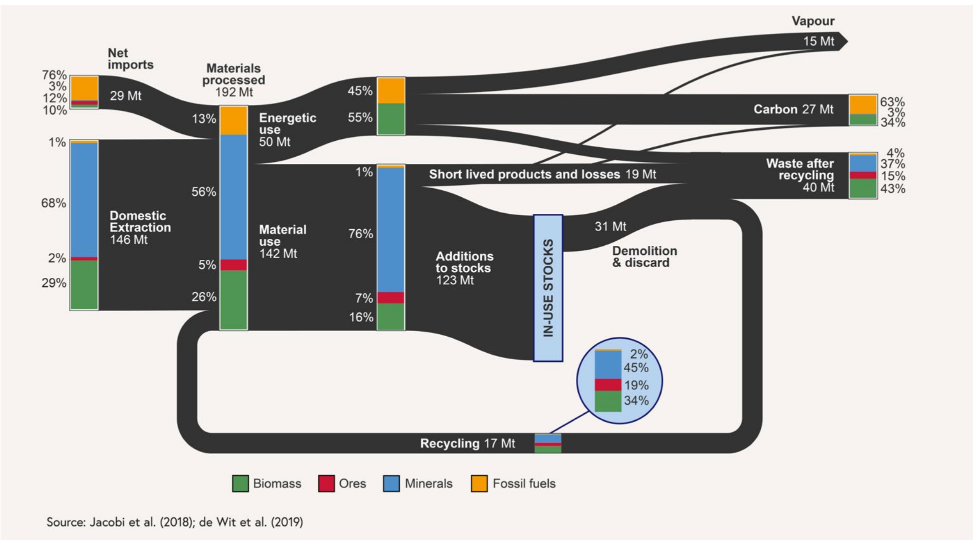


Figure 33: SEC-Sankey: The Austrian circular economy as a Sankey diagram compiled by the Institute of Social Ecology (SEC). Austria 2014.

The two Sankey diagrams do not present the same year, however the material consumption in both years is relatively similar and therefore certainly comparable. DMC calculated by Statistics Austria amounted to 157 Mt/a in 2014, and to 159 Mt/a in 2020 (Statistics Austria 2024). The figures in each diagram (STAT and SEC) show a slight variance; therefore, a comparative discussion should focus primarily on the overall scale of flows and the relationships to one another. The individual nodes and relevant flows in the Sankey diagram are briefly outlined here below (Nuss et al. 2017; for details, see: Jacobi et al. 2018; Mayer et al. 2018; Statistics Austria 2023e), in order to discuss differences and impacts on circularity indicators. The following discussion is a first step and should be regarded as the starting point for a more substantial discussion.

- **Input flows:** The inputs into Austria constitute on one hand the DE and on the other, the imports from other economies. Analogous to imports, exports are also presented on the output side in the STAT-Sankey. The SEC-Sankey presents the imports and exports as net imports (calculated as PTB = imports minus exports) on the input side. Imports in the STAT-Sankey are therefore larger than the net imports. The SEC-Sankey does not show any export flows.
- **Material input and processed material:** DE and imports result in the direct material input (DMI), one of the first nodes in STAT-Sankey. In the SEC-Sankey, the first node is the PM (processed materials in Figure 33). The secondary inputs from recycling are already included in this node and therefore corresponds to the 'processed material' node (STAT-Sankey) with the difference that exports are included in the STAT-Sankey while excluded in the SEC-Sankey. Like the DMC, the PM of the SEC-Sankey can therefore be added across countries without double counting.
- **Material and energy use:** The processed materials are subsequently divided according to their energy use (fossil energy carriers and biomass) or material use (all materials, but primarily non-metallic minerals, metals, biomass). The scale of the flows is the same in both Sankey diagrams.
- **Energy use and emissions:** Through energy use in combustion processes, materials are transformed into emissions. CO_2 emissions are additionally produced through production processes, e.g., in cement production or steel production. CO_2 emissions can be represented in the MFA as carbon emissions or as CO_2 emissions, i.e., including oxygen. The SEC-Sankey chooses to depict these as C emissions. Eurostat convention mandates the inclusion of oxygen in the emissions recorded (Eurostat 2018) in accordance with IPCC reporting. The oxygen that is bound with carbon as CO_2 in the incineration process is reported in accordance with Eurostat convention in the form of input balancing items (Eurostat 2018; Statistics Austria 2024). In the STAT-Sankey diagram, air emissions are calculated together with balancing items (oxygen, water vapour and other balancing items, see Eurostat 2018), so that the STAT-Sankey shows the CO_2 emissions excluding oxygen (O) in the context of completing the mass balance.

- **Material use and stocks:** The major share of materials that are subject to material use, are utilised for the creation and maintenance of stocks (buildings, roads, other infrastructures). In the STAT-Sankey, these flows are depicted as material accumulation, representing the net additions to stocks (NAS; Eurostat 2018). Outputs from stocks (largely demolition waste) are already deducted beforehand and form part of waste flows. In the SEC-Sankey, the inputs into stocks as well as the outputs from stocks are explicitly represented as such. Demolition waste flows then as output from stocks into waste treatment. Along with the materials that are accumulated in stocks, there are also materials for material use that become outputs in less than one year. These flows are defined in the SEC-Sankey as short-lived products and losses and include the dissipative use of products (e.g., fertiliser or salt, see chapter "All material inputs will become outputs - wastes and emissions"), dissipative losses (abrasion, losses and leakages, etc.; see chapter "All material inputs will become outputs - wastes and emissions"), and other short-lived goods with a lifespan of less than one year (e.g., sanitary items, cosmetics, medicines, some textiles, paper goods, packaging materials) or also food waste. In the SEC-Sankey these wastes from short-lived goods are supplemented by the demolition materials from stock reduction as well as by residual materials from incineration (ash) and from sewage treatment facilities (sewage sludge). A significant portion of these wastes are transformed into emissions in incineration facilities (flow from wastes to emissions in the STAT-Sankey). The remainder are deposited in landfill or recycled. In the STAT-Sankey the wastes (demolition material, short-lived products, ash, sewage sludge) are substantially less than those in the SEC-Sankey. The variance is primarily attributable to the demolition materials, which amount to 10 Mt/a in the STAT-Sankey (based on waste statistics; BMK 2023), whereas in the SEC-Sankey the figure is 30 Mt/a (based on mass-balanced stock-flow modelling; Jacobi et al. 2018; de Wit et al. 2019).
- **Waste depositing and recycling:** From the very different quantities of waste in both Sankey diagrams, the recycling materials (primarily demolition waste) flow back into socioeconomic use. In both Sankey diagrams, annual recycling flows amount to just below 20 Mt/a. In the STAT-Sankey, the markedly low waste quantities are reduced by deducting the recycled flows to almost zero, with input into landfill sites amounting to less than 4 Mt/a. In the SEC-Sankey, a not insignificant quantity of waste materials remains, which are deposited in landfills or other storage sites; at least half of these materials are demolition waste. The variance between the figures for demolition waste reflects the different methods of data collection in each case: in the STAT-Sankey, an accounting approach is chosen, and the data for demolition materials are sourced from waste statistics. The data in the SEC-Sankey are calculated using a system dynamics stock-flow model, based on spatially explicit information on material stocks and their resource inputs and outputs throughout the service life of stocks.

Where might data uncertainties be hidden in a Sankey diagram?

The different flow quantities that are represented in a Sankey diagram have very different data quality and are either based on data or modelling. The inputs (DE and imports) are based on data and their measurement fixed; this is also the case for exports and IPCC-relevant air emissions. The figures for waste are also data-based, however these are developed for another purpose (a focus on waste management throughout the various processing steps) and thus differ partly in terms of water content, statistical coverage, defined system boundaries, etc. Thus, to achieve a correct mass balance taking account of stock changes, the consistency between inputs and outputs must be very carefully checked (see also Statement 12). Differences and uncertainties in the data basis exist particularly in the following:

- Accounting for oxygen in emissions,
- Consistency of inputs and outputs with material stocks, for example in the case of demolition waste,
- Excavated soil, which is reported in the waste statistics, yet often not included as extraction on the input side,,
- Waste from agricultural production,
- And many smaller flows, such as: compost (often recorded on the output side but not on the input side or included but with differing water content), water vapour, residual materials from sewage treatment facilities, dissipative use and losses, food waste, etc.

This brief analysis of the differences between the Sankey diagrams shows the complex requirements from the data basis that exist in the background. Without a mass balance, which would ideally also be able to reflect real stock increases and reductions, errors are unavoidable. Such errors then transpose into those categories where the data basis tends to be insufficient. These concern particularly the changes in stocks and the demolition waste from stocks, but also smaller flows such as compost, ash/slag, or food waste. The most important element here is a mass balanced analysis of stocks. Without stock records, a consistent record of inputs in and outputs from stocks is needed. The better the data on the input side of the MFA correspond to the waste quantities from waste statistics, i.e., adhering to the same system boundaries and showing no instances of double counting, the smaller any error will be.

Finally, it should be noted that different methodological approaches have significant impacts on the validity and analysis of options for achieving a circular economy. In the STAT-Sankey, for example, waste quantities that go into landfill are very small in comparison to the SEC-Sankey. As a result, the recycling potential is very different in both calculations. Also, a thorough consideration of exports is necessary in the calculation of the circularity rate. E.g., exports are included in the STAT-Sankey within processed materials, which are thus significantly larger than in the SEC-Sankey, where exports are deducted before the “materials processed” node.

Austria in transition to a circular economy - progress on the four main goals

The main goals of the Austrian Circular Economy Strategy depend upon the data and results of the MFA, as already outlined in the previous chapters. In this section, the MFA results that are addressed as indicators in the Circular Economy Strategy are summarised in relation to the CE goals (see also Figure 34).

Goal 1: Reduction of domestic material consumption (DMC) to 14 t/cap/a by 2030 and reduction of material footprint (MF) to 7 t/cap/a by 2050

DMC remained constant between 2015 and 2021 at 18 t/cap/a, and a reduction was only recorded for 2022, to 17 t/cap/a (Figure 34). By 2030, DMC should have decreased to 14 t/cap/a, i.e., by -18 % or by -2.2 % per year.

The MF was 23 t/cap/a in 2015, before rising slightly in the following year to 24 t/cap/a, and then decreasing in 2020 to 22 t/cap/a. To reach the target of 7 t/cap/a in 2050, a reduction of 70 % or 2.3 % per year is needed. This target figure is very ambitious and the following chapter outlines and discusses possible ways forward.

Goal 2: Increasing domestic resource productivity (RP) by 50 % by 2030, compared to 2015

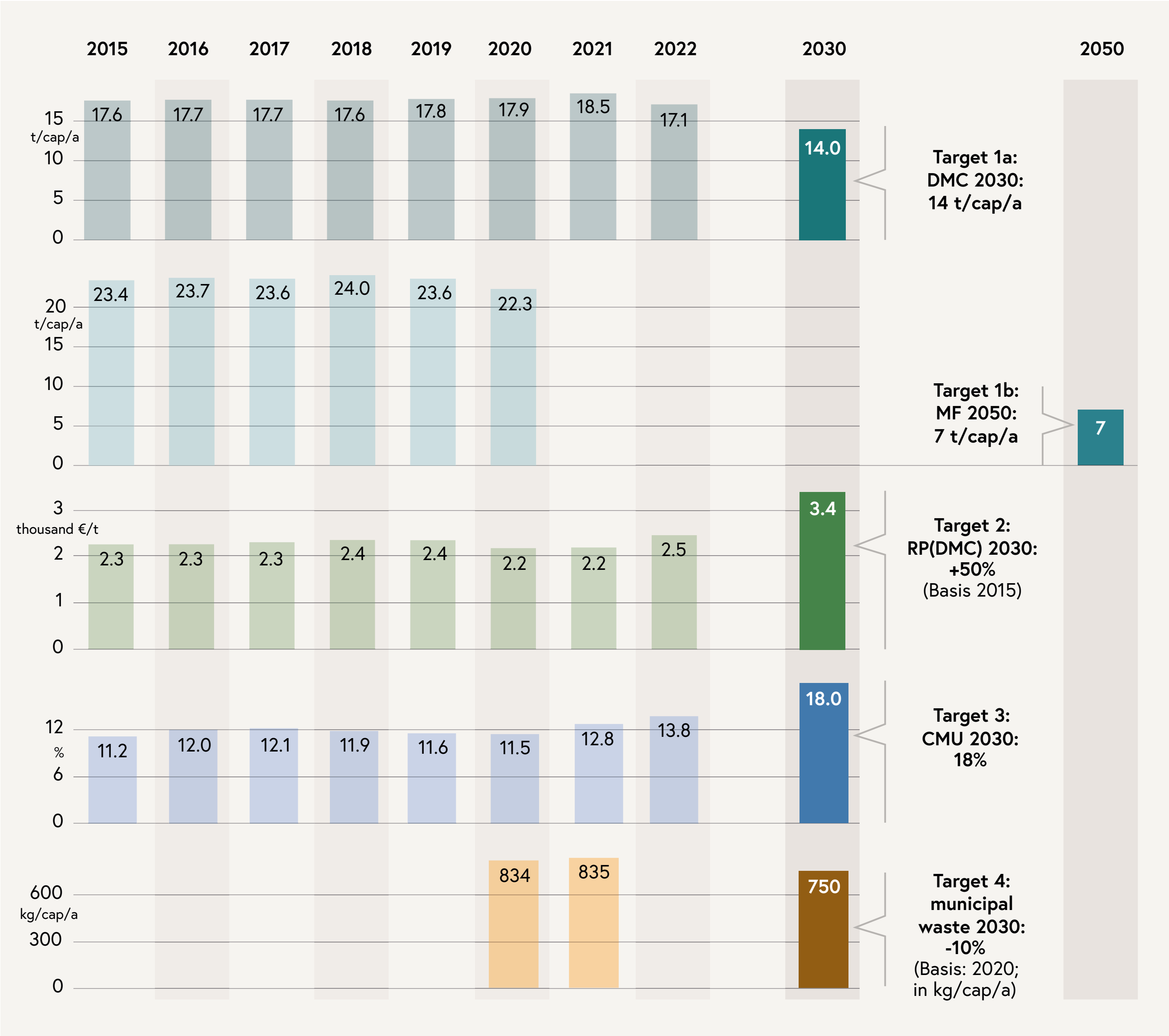
Resource productivity is related in the CE Strategy to DMC and is calculated as RP = GDP/DMC. In 2015, RP amounted to 2,266 Euro/t, so an increase of 50 % would mean that RP in 2030 should reach 3,400 Euro/t. Between 2015 and 2021 RP remained relatively constant at between 2,266 and 2,355 Euro/t. This figure decreased in 2020 and 2021 to 2,184 and 2,198 Euro/t respectively, before increasing sharply (by 12 %) in 2022 to 2,464 Euro/t (Figure 34). To achieve the target value, a further increase of 38 % or just under 5 % per year is required.

Goal 3: Increasing the circular material use rate (CMU) by 18 % in 2030

The circularity rate (circular material use rate, CMU; Eurostat 2024c) is calculated according to the Eurostat definition as the share of recycling and backfilling in DMC inclusive of recycling and backfilling. In 2015, the CMU was 11.2 %, increasing to 13.8 % by 2022 (Figure 34). To achieve the target set of 18 % in 2030, a further increase of 30 % will be required, i.e., just below 4 % per year.

Goal 4: Reduction of material consumption in private households by 10 % by 2030, compared with 2020

The fourth goal addresses private household consumption. Since there is still no data recording household consumption currently available, the volume of residential waste is used as an indicator to estimate this. The volume of residential waste in 2020 and 2021 was 834 and 835 kg/cap/a respectively (BMK 2024). The target set for 2030 involves a decrease of 10 % and thus a target value of 750 kg/cap/a. Achieving a 10 % reduction requires an annual change of -0.3 %.



Source: Data sources: DMC, MF, RP: (Statistics Austria 2024), CMU: (Eurostat 2024c), Residential waste: (BMK 2024)

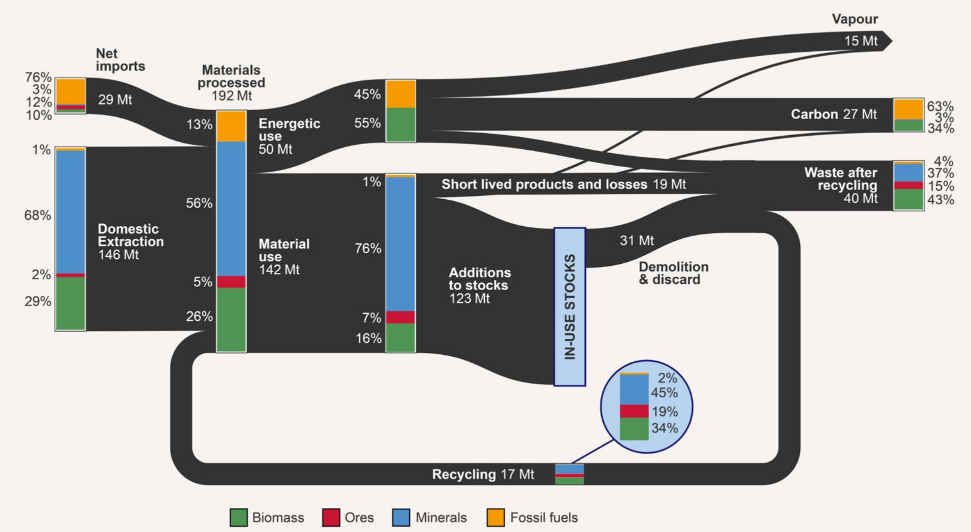
Figure 34: Goals of the Circular Economy Strategy and current trends.

Decarbonisation and the circular economy – scenarios for a possible future in Austria by 2040

This section is based on the empirical studies of the research project "Circular Economy and Decarbonisation: Synergies and trade-offs (ACeDC)" (Haas et al. 2024), supported by the Climate and Energy Fund[17] in the framework of the Austrian Climate Research Programme (ACRP). This project investigates how decarbonisation, i.e., phasing out the use of fossil energy carriers, and circular economy strategies interrelate. The project focuses on three areas of activity: electricity supply, transport and the building sector. It investigates what impact different scenarios for the transformation of the electricity, transport and building sectors by 2040 would have in relation to the circular economy goals and the climate neutrality aim of the Austrian government. This aims to create a better understanding of synergies and trade-offs related to different decarbonisation and circular economy strategy approaches.

The Sankey diagram is well suited to depicting the scale and distribution of material consumption in Austria (see Figure 35). Material inputs (on the left-hand side of the diagram) can be obtained from three sources: domestic extraction, imports or secondary raw materials from recycling. The sum total of these input flows are the processed materials (PM). The largest share of PM by weight is obtained through domestic extraction, in particular of non-metallic minerals, followed by imports. The smallest material flows on the input side are secondary raw materials from recycling.

Figure 35: the Austrian circular economy in 2014 as a Sankey diagram.



Source: Jacobi et al. (2018); de Wit et al. (2019)

17 forschung.boku.ac.at/fis/suchen.projekt_uebersicht?sprache_in=de&menue_id_in=300&id_in=13725

Material inputs are either consumed directly and become waste and emissions within one year, or flow into the production of socioeconomic stocks and remain for a longer period of time in socioeconomic use. Direct consumption includes both energy use (both metabolic and in the form of combustion for heating and electricity production) and also short-lived products such as packaging, newspapers and magazines, cleaning products, sun cream, etc. Material stocks are enlarged through the accumulation of materials, albeit at the same time also reduced through stocks reaching their product-specific end of life (EoL), as well as their premature disposal. Material volumes are released across all these flows and uses and can either be recycled and returned back to the value chain or ultimately find their way into landfill or direct emission into nature.

Material recovery and demand-side strategies have very varying impacts upon the different circularity rates. The circularity rate on the input side is derived from the relationship between the recovered material (Reuse, Recycling and Backfilling) and the PM. The circularity rate can on one hand be improved through increasing the quantities of materials recovered or on the other, through sufficiency measures, which lead to a reduction in processed materials.

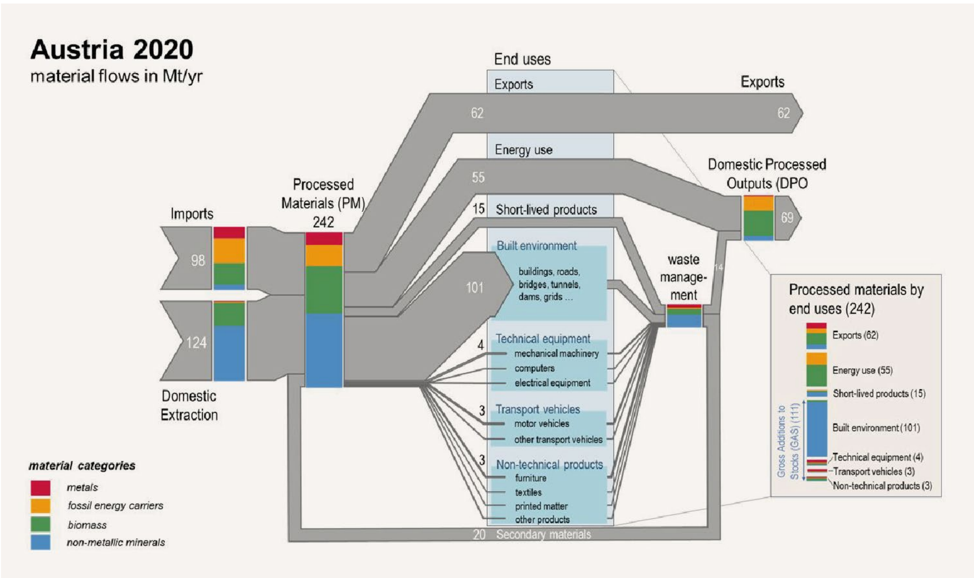
The circular economy in Austria in 2018 is represented in the Sankey diagram in Figure 35. In total, 192 million tonnes of material were processed and used within society. Of these, 17 million tonnes were obtained through recycling. The following circularity rates derive from this:

- The input circularity rate, i.e., the share of reuse, recycling und backfilling in PM was 9 %.
- The output circularity rate, measured as the share of reuse, recycling und backfilling in all inputs to the waste node, was 30 %.

Material consumption is closely coupled with energy use. Energy is used to extract materials, for transportation, processing and to produce, maintain or utilise stocks. When the number of motorised vehicles increases, this requires energy for utilisation and also regular maintenance and repair. Furthermore, cars require infrastructure such as road networks and parking facilities. Mineral raw materials are of central importance for the construction of stocks such as mobility infrastructures and buildings. The production technology and the sometimes very great volumes that need to be moved and processed mean that the processing of mineral raw materials is characterised by high levels of energy use and thus also high levels of emissions. At the same time, societies require numerous new raw materials and new infrastructures to achieve an energy transition. More materially efficient structures and infrastructures and greater sufficiency in our patterns of consumption (i.e., reduced demand) could therefore reduce our energy requirements and consequently the necessary energy infrastructure and related levels of demand for raw materials.

So that the aggregated results of the MFA can be better used to formulate recommendations for action, a more detailed view of the actual consumption of materials is required. Where and for what purpose are materials being used? What socioeconomic activities are particularly material-intensive and need to be subject to closer scrutiny, so that we can put resource conservation into practice? At the Institute of Social Ecology at the University of Natural Resources and Life Sciences, Vienna (BOKU), a dynamic stock-flow model was developed in recent years (Wiedenhofer et al. 2019), which aided the analysis of material consumption in Austria for 2020 according to final use categories. Figure 36 shows that 26 % of the processed materials in Austria leave the country as exports, while 6 % are used as short-lived consumer goods and become waste within the same year. The great bulk (46 %) of all processed materials (PM) accumulate in socioeconomic stocks, where they are contained for many years or decades. It is precisely these materials bound in stocks that are of decisive importance for the future use and circularity potential of resources, because they are not available during their utilisation phase for circular use, and because these stocks determine future flows for maintenance, repair and operating activities (see also the chapter "Biophysical stocks determine resource flows - Stock-Flow-Service-Nexus"). Thus, a closer view of these stocks is once again required: built infrastructure represents the largest category, comprising buildings, roads, other transport infrastructure (bridges, tunnels, parking facilities, and the infrastructure for public transport, such as railway tracks, etc.) but also energy infrastructure, sanitation systems and dams. Approximately 91 % of the materials used for the production and maintenance of stocks, or 42 % of the total processed materials (PM) are included in this category. The further stock categories are vehicles for transportation and non-technical products (e.g. furniture, textiles and printed matter) with a share of PM of 3 % in each case, as well as technical equipment and devices, representing a 2 % share of PM.

Figure 36: Socioeconomic use of materials processed in Austria (PM); a detailed Sankey diagram. Austria, 2020.



Austria in 2040 – How do decarbonisation and circular economy measures change resource use?

According to the strategy adopted by the government, Austria should be decarbonised by 2040. In terms of a circular economy, this means that the use of fossil energy carriers must be phased out. This reduces material consumption, while also necessitating the transformation of a wide range of sectors. As part of this project, a transformation of this kind for the building, transport and electricity sectors has been modelled.

Through different scenarios, measures from across the three strategic groups of Narrowing, Slowing and Closing were implemented to varying degrees, in order to model the mass balanced effects for all three sectors. The following assumptions were selected in these scenarios:

1. Baseline scenario: continuing to implement all current measures without the addition of further measures (darker bar in Figure 37),
2. pure decarbonisation,
3. decarbonisation in combination with the implementation of existing moderate circular economy measures,
4. decarbonisation in combination with further, ambitious circular economy measures based on sufficiency and reduced consumption.

Each of these four scenarios is also modelled in terms of two different economic projections. The first projection (in orange in Figure 37) is based on the assumption that the economy recovers relatively quickly from the COVID pandemic and continues along the development path in existence before the pandemic occurred. In the second projection (in blue in Figure 37), recovery from the economic shock takes place far more slowly and economic growth after the pandemic remains at 0 %. The following table shows the measures implemented in the three strategic groups (Table 2).

Table 2: Grouping of modelled measures according to the three strategic groups

Strategic group	Sektor	Decarbonisation	Decarbonisation and moderate CE	Decarbonisation and ambitious CE
Narrowing	**Building sector**	• Insulation of buildings (doubling of renovation rates by 2030) • Replacement of fossil fuels by renewable heating systems by 2040	• Insulation of buildings (doubling of renovation rates by 2030) • Replacement of fossil fuels by renewable heating systems by 2040 • Reduction of per capita floor area in new buildings by 25 % by 2025	• Insulation of buildings (doubling of renovation rates by 2030) • Replacement of fossil fuels by renewable heating systems by 2040 • No new building developments on unbuilt surfaces • 50 % of buildings replacing demolished stock to use timber construction by 2040
	Transport sector	• Electrification of vehicles (passenger and freight transport) by 2040 • Low modal split shift of passenger-kilometre from road to rail and active mobility (10 %) and of tonne-kilometre from road to rail (10 %).	• Electrification of vehicles (passenger and freight transport) by 2040 • Moderate modal split shift of passenger-kilometre from road to rail and active mobility (20 %) and of tonne-kilometre from road to rail (20 %). • Moderate reduction in passenger[18]- (-15 %) and tonne-kilometres (-25 %)	• Electrification of vehicles (passenger and freight transport) by 2040 • High modal split shift of passenger-kilometre from road to rail and active mobility (50 %) and of tonne-kilometre from road to rail (40 %). • Significant reduction in passengera- (-30 %) and tonne-kilometres (-50 %) • Doubling of the occupancy rate (car sharing) by 2040 • No additional roads after 2030
	Electricity sector	Transformation of electricity sector to using renewable energy	Transformation to effect slight reduction in electricity demand	Transformation to effect strong reduction in electricity demand
Slowing	**Building sector**	-	-	25 % reduction in demolition of buildings through lifetime extension
Closing	-	Continuation of current recycling rates	Recycling rates based on EU targets	Recycling rates exceeding EU targets

18 Reduction assumed only for non-active (mobility forms excluding travel on foot and cycling) passenger-kilometres

Table 2 shows what net effects the three strategies could achieve in terms of resource and energy use as well as wastes and emissions.

In the ACeDC research project (Haas et al. 2024), a DMC of 165 Mt/a (or 19 t/cap/a) was calculated for 2018, the PM was 186 Mt and the input circularity rate was 11 %. Material consumption in the three sectors - building, transport and electricity - amounted to 88 Mt, thus about 47 % of total processed materials (PM).

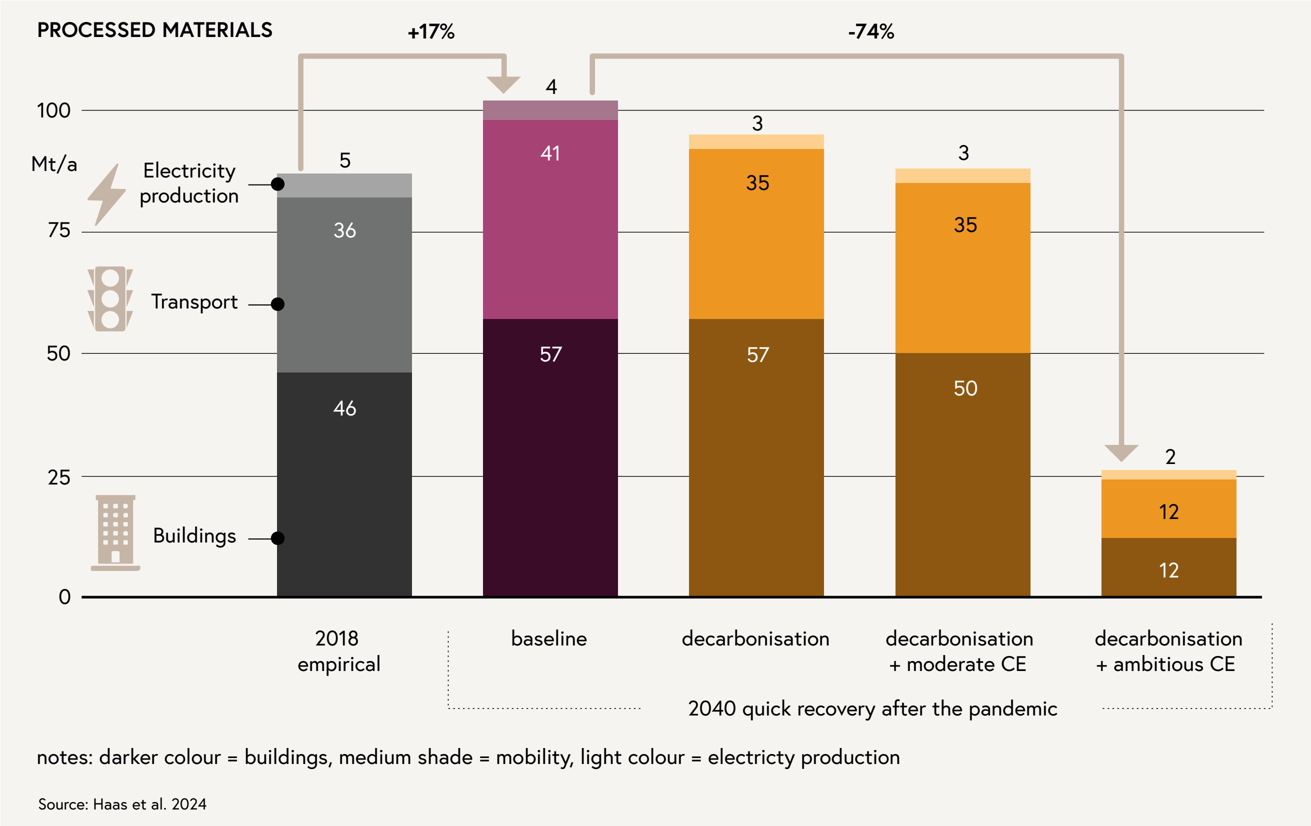


Figure 37: Reduction of processed materials in the building, transport and electricity sectors in 2018 and 2040 for four scenarios.

Figure 37 shows how implementing the measures (see Table 2) impacts upon Austrian material consumption (as PM). If the annual material input for stock expansion and maintenance of stocks within the three sectors (building, transport and electricity) were to continue until 2040, the PM for Austria would increase by 10 % in the case of a rapid economic recovery by 2040, rising from 180 to 204 million tonnes per year. A pure decarbonisation of the three sectors would reduce their PM only marginally, from 102 to 95 Mt/a. Yet the measures to create a circular economy that are currently discussed and concretely defined would also lead to a further, albeit similarly only small reduction in sectoral PM to 87 Mt/a in 2040. Only the implementation of ambitious measures would result in a significant reduction in sectoral PM to 26 Mt/a in 2040 (74 % less than in the baseline scenario).

The PM for the economy as a whole in 2040 would fall from 204 Mt/a in the baseline scenario to 128 Mt/a in the most extensive scenario (decarbonisation accompanied by ambitious circular economy measures). This represents a reduction in PM of 37 %.

Assuming a slow recovery and consequent 0 % growth rate for the economy, the PM in the baseline scenario would amount to 161 Mt/a in 2040, representing a reduction of 13 % in comparison with 2018. Decarbonisation in combination with ambitious circular economy measures would lead to a reduction of 45 % in comparison with the baseline scenario, to 89 Mt/a in 2040.

When the influence of various measures upon decarbonisation and the progress towards a circular economy in 2040 (Figure 38) is considered, it can be seen that although a few specific measures such as thermal renovation result in a small net increase in total material consumption, most measures result in a reduction.

In the case of pure decarbonisation, reduction strategies demonstrate little effectiveness. In the building sector, decarbonisation of heating systems in buildings, i.e. replacing fossil fuel boilers with heating systems using renewable energies (such as green power operated heat pumps and wood pellet boilers) and thermal renovation adaptations, produces only minimal net changes, since the insulation materials, new heating system equipment, more pellets and wood chips counteract the removal of fossil energy carriers in the building sector. Increasing the thickness of insulation materials would however mean that thermal renovation would lead to a small reduction. Stronger impacts are seen in the case of removing fossil energy use through electrification from vehicle transport, the modest level of transfer from road to rail (modal split shift) and in electricity production.

An additional implementation of moderate circular economy strategies also leads to only slight reductions in material consumption. A reduction in per-capita living area in new buildings (in this case by 25 % from 2025) has the greatest impact, while a stronger modal split shift i.e., transfer of transport activities from road to rail and to active mobility, as well as a small reduction in traffic volume (e.g. due to increased home working) only have a minor impact in material terms.

Narrowing measures show significant effects only where more extensive circular economy strategies are implemented. Thus, for example, ambitious sufficiency-oriented measures such as halting the construction of roads and of buildings on greenfield sites in conjunction with Slowing strategies such as extending the useful lifespan of buildings (thereby reducing demolition by 25 %) could create a reduction of 37 million tonnes in materials used. Increasing the share of timber construction in new building projects has comparatively little impact on total material consumption. Narrowing in the transport sector, halting the expansion of the road network (while continuing maintenance of the existing network) could produce a reduction in the PM of 23 Mt/a – primarily asphalt, sand and crushed rock. Further measures in the area of slowing strategies, including an increased modal split shift, greater reductions in traffic volumes and doubling of car-sharing activities produce only minor changes in material consumption.

In the building, transport and electricity production sectors, the Slowing strategies modelled demonstrated only minimal effects in most cases. This is due on one hand to the short timeframe of 2018-2040 to which the scenarios were applied and on the other, to the fact that by 2040 all vehicles, heating systems and electricity production facilities have to be replaced by alternatives that can be operated using renewable energy sources. The great majority of these new vehicles and facilities will possess normal service lives that extend beyond 2040. The impacts of Slowing strategies would only become evident in these sectors over a much longer scenario timeframe. Only an increase in the service life of already existing buildings, and the reduction in demolition that would accompany this, shows relevant results within this period.

Closing strategies in the form of increasing recycling rates are not reflected in the PM, since this represents the total of primary and secondary raw materials and recycling only replaces primary with secondary raw materials. Nonetheless recycling does indeed reduce the total quantity of primary raw materials required.

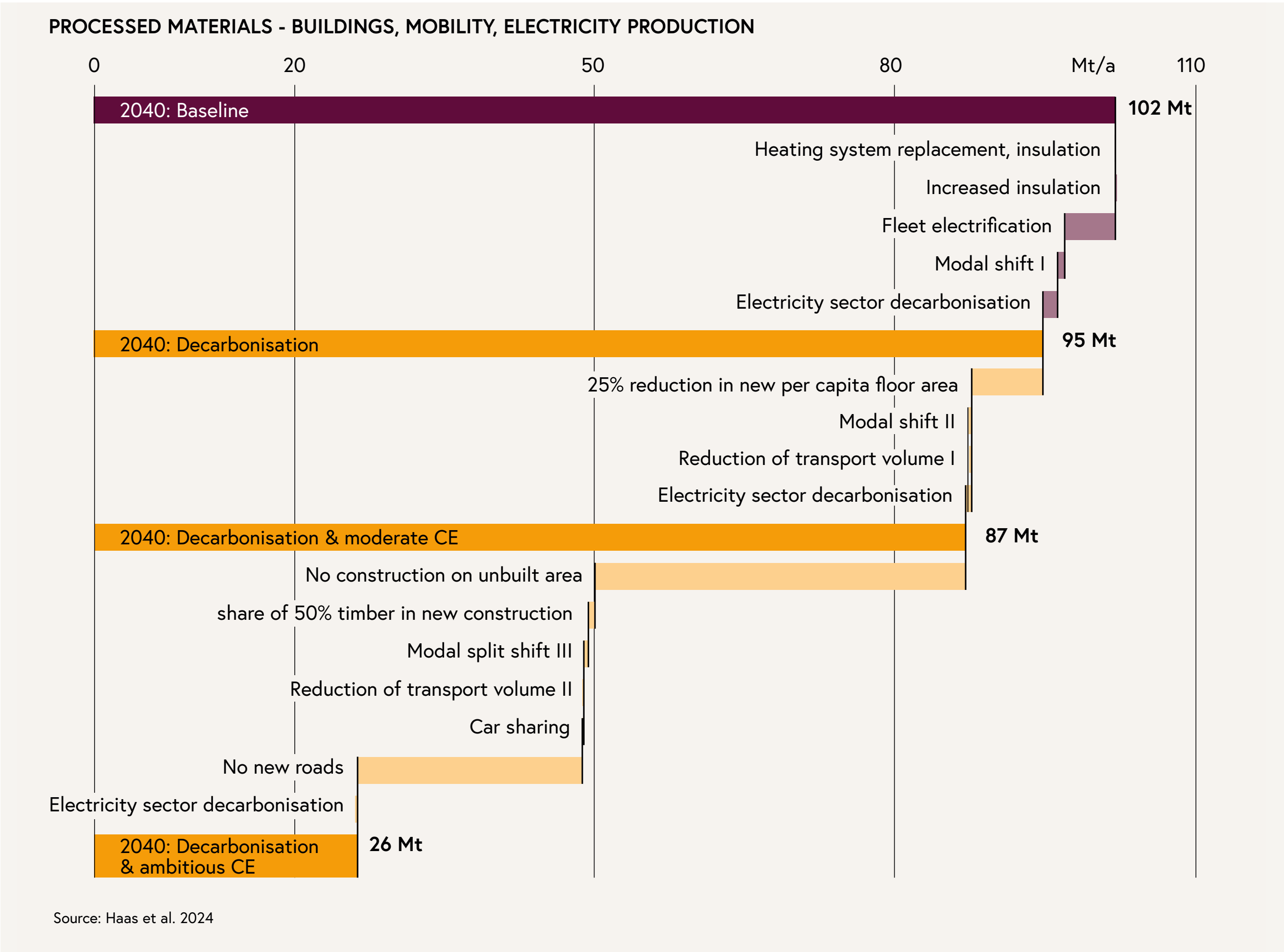
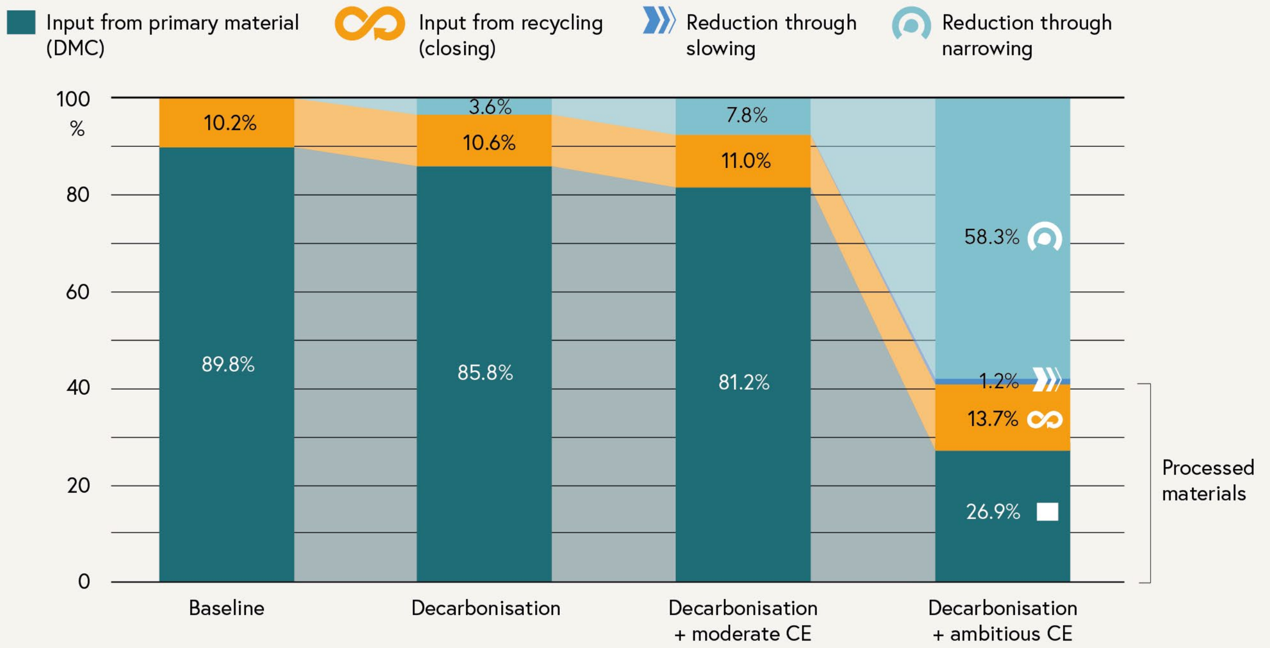


Figure 38: Effect of measures upon Austria's resource consumption in 2040 for the baseline, decarbonisation, decarbonisation and moderate circular economy (CE), and decarbonisation and ambitious circular economy (CE+).

Sustainable resource use can be achieved on one hand through a reduction in the absolute consumption of tonnes of primary materials, but also through changes in the composition of materials used. This concerns both the use of renewable resources, with consideration for the narrow limits of ecological regeneration rates, and of toxic or critical materials. Specific measures, such as, for example, changes in modal split or in car sharing, although they may not appear particularly significant from the perspective of mass flows, are absolutely relevant in terms of the use of critical materials. Many green technologies such as electric vehicles (EVs) or wind turbines use neodymium and other rare earth elements. The use of fewer EVs or consumption of less electricity thus reduces the use of these critical raw materials.

As is evident in Figure 39, narrowing strategies have the greatest influence upon the reduction of material consumption and can reduce the PM by half by 2040, if ambitious measures are implemented. Slowing strategies are of only minor relevance within the short time period to 2040, since the service life of many products and infrastructures is longer than the period under consideration in this study. However, over a longer time period, these strategies also show great potential for producing further reductions in the PM.

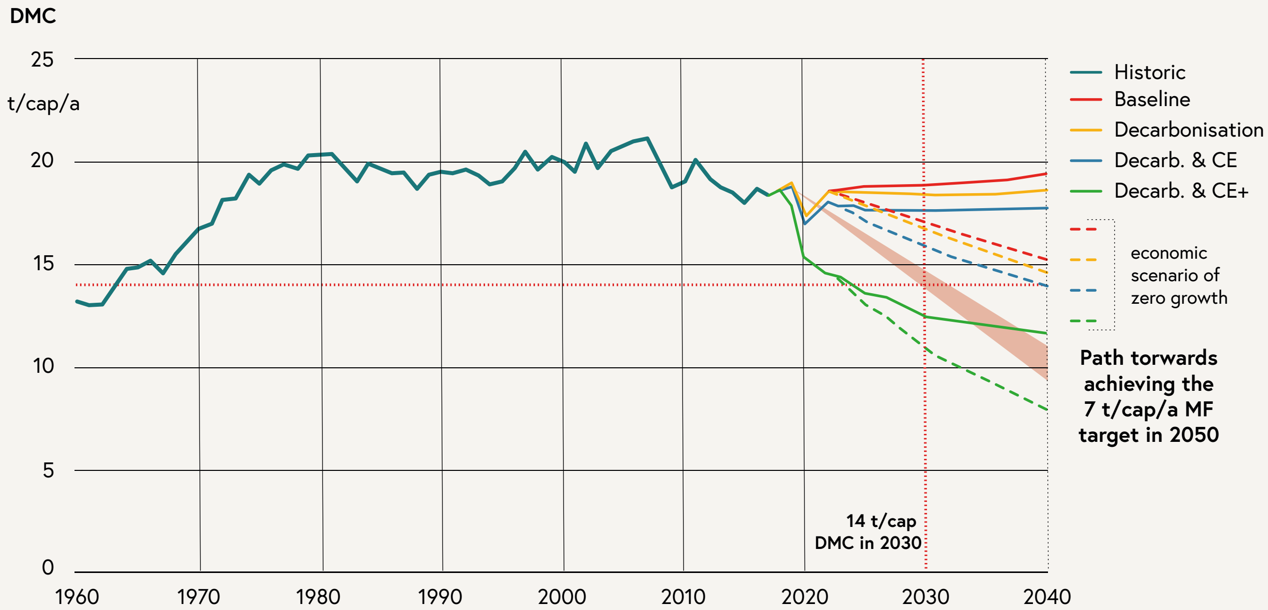
PROCESSED MATERIALS 2040



Source: Haas et al. 2024; Values are rounded, rounding differences are not balanced.

Figure 39: Percentage reductions of processed materials within the building, transport and electricity sectors, divided according to the three strategic groups of Narrowing, Slowing and Closing.

The federal government has set a material footprint target for 2050 of 7 t/cap/a (BMK 2022), which represents domestic material consumption of approximately 6 t/cap/a. Since 2000 the highest consumption was recorded for 2007 of approximately 22 t/cap/a, while Austria's domestic material consumption in the ACeDC project was 18 t/cap/a for 2018 (Haas et al. 2024). In addition, the Circular Economy Strategy (BMK 2022) sets out a domestic material consumption target for 2030 of 14 t/cap/a and year.



Notes: Decarb. = Decarbonisation, CE = moderate circular economy measures, CE+ = ambitious circular economy measures.

Source: Haas et al. 2024

Figure 40: Historical domestic material consumption (in black) and trends in the context of agreed targets for material consumption and material footprint (BKM 2022).

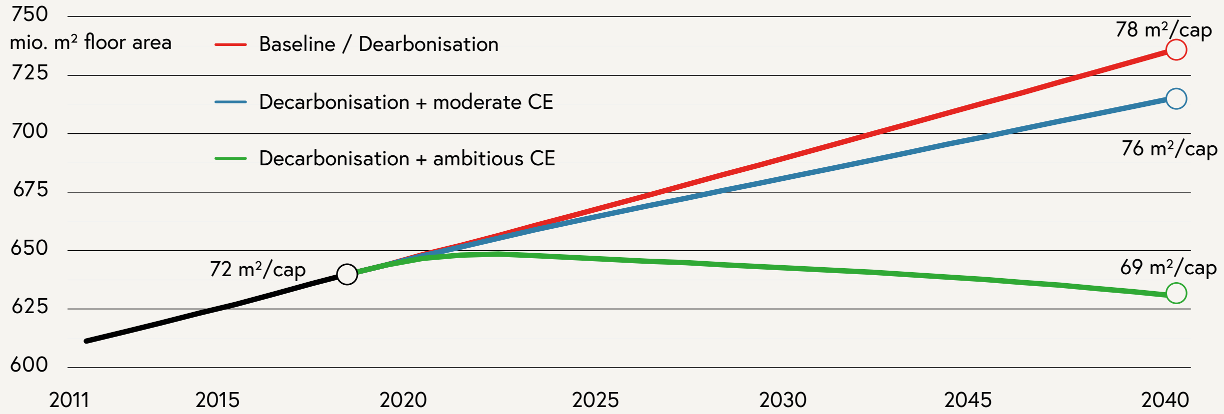
To achieve the DMC target of 14 t/cap/a in 2030, there needs to be a significant move away from the current development pathway. Figure 40 shows that purely continuing with the current trend (red line) will not achieve the target set. In the case of GDP recovery following the COVID pandemic (solid line), pure decarbonisation in combination with moderate circular economy strategies leads to a further increase in material consumption. Only ambitious circular economy measures show a reduction in per capita material consumption even where there is economic growth. In the case of economic growth being at zero, (dotted line) each scenario leads to a reduction in per capita material consumption. Decarbonisation with ambitious circular economy strategies (green) is required to achieve both goals.

The scenarios for the building, transport and electricity sectors show that although recycling as a strategy is important, it is only linked here to very minimal potential for reducing material consumption. Narrowing strategies are seen as making the greatest difference in the period to 2040. These have the potential to reduce material use in all three sectors by up to 70 %. The strategies described above can produce significant reductions in per capita material consumption. Where the per capita domestic material consumption in 2040 sinks in the ambitious scenario by 40 % from 19 to 12 tonnes (and by 59 % to 8 tonnes in the case of zero economic growth), the per capita area use only falls by 14 %. In the transport sector, automobile ownership falls sharply from 0.63 auf 0.07 vehicles per capita[19] in 2040. At the same time, the use of other forms of mobility, including car sharing, public transport, cycling or walking, increases. As a consequence, passenger transport is reduced from 15,200 to 11,400 passenger kilometres i.e., only by 25 %. Alongside changes in mobility forms, changes to working patterns, e.g., increasing use of home office spaces and the associated reduction in commuter travel, also make a contribution. Beyond this, different patterns of demand in rural and urban regions must be taken into consideration, which lead to a reallocation of aggregated averages. The reduction of tonne kilometres by 45 % is based on the reduced material consumption and associated reduction in materials transport. Combined with measures in the other sectors such as food and industry, which were not the subject of this research project, achieving the circular economy goals does not stand in opposition to a "good life for all" (Raworth 2017; O'Neill et al. 2018; Görg et al. 2023). It is far more the case that CE measures contribute to preserving the basis of our existence and the natural environment, since a continued high level of resource consumption is associated with huge risks.

The relationship between material stocks and material consumption as well as the services derived from this can be depicted through the example of the building sector (see Figure 41). The measures implemented lead in the case of the building sector to a reduction in the growth of material stocks – and in the case of the most ambitious scenario, even to the saturation of material stocks (Figure 41b). Given the long service life of buildings, there is no resulting reduction in stocks. However, considerable reductions can be seen in annual material consumption (Figure 41c) due to changes made to new building construction, which can largely be attributed to a ban on new building developments on greenfield sites. Thus, the material consumption of the building sector falls in 2040 from 45 million in the baseline scenario to less than 5 million tonnes in the ambitious scenario. Since provision of heated living space is primarily linked with building stocks and not with material consumption, these enormous changes in material consumption lead to only a moderate reduction in per capita floor space, from 78 m^2 in the baseline scenario to 69 m^2 per capita in the ambitious CE scenario.

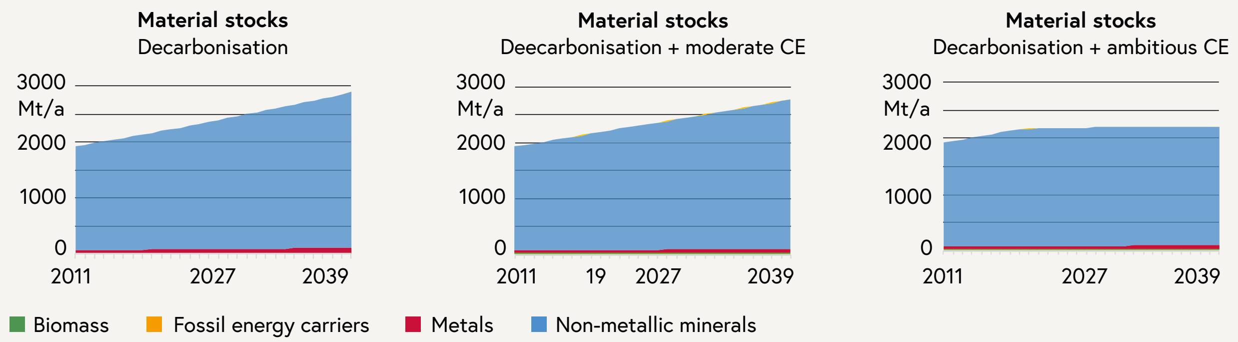
19 The per capita figure is calculated for the population as a whole, and thus also includes children and the elderly.

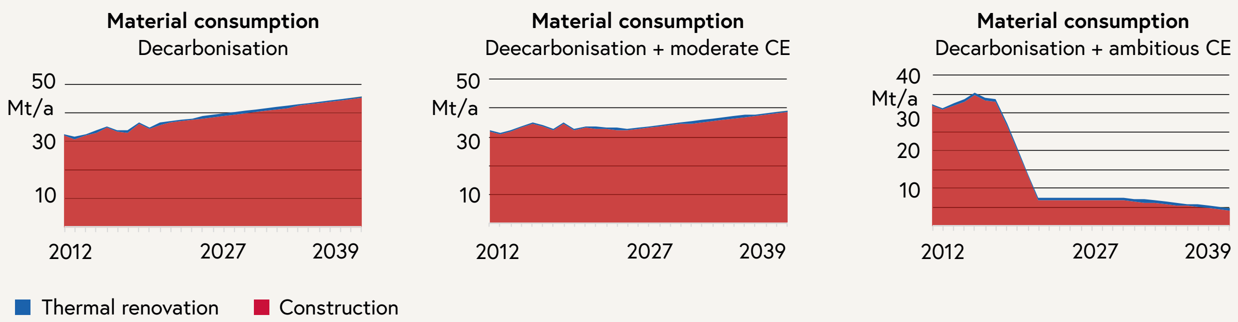
HEATED FLOOR AREA IN RESIDENTIAL AND COMMERCIAL BUILDINGS



Notes: (a) Trends for heated floor space per capita for the baseline scenario or a pure decarbonisation (red), as well as for decarbonisation with moderate (blue) and ambitious (green) circular economy strategies; (b) development of material stocks, and (c) material consumption in the building sector.

Source: Haas et al. 2024





Source: Haas et al. 2024

Figure 41: Trends for heated living space, material stocks and material consumption in the building sector; 2011-2040.

4 Summary and outlook

Statement 19 – The question is not whether there will be a societal transformation but rather how far-reaching it can and will be: In light of the increasing ecological crisis, and particularly the climate crisis, the realisation is growing that a fundamental transformation of society is required. The question is no longer whether there will be such a transformation but rather how far-reaching it can and will be. Will the expanded use of renewable energies go hand in hand with increasing use of fossil fuels or will there be a significant reduction in the latter? Can we achieve a resource-conserving form of prosperity, which can be experienced by people as wellbeing rather than as deprivation? The resource report provides impressive evidence that resource consumption in Austria must be reduced. The challenge for policy-makers, business, civil society and the scientific community is to identify the options for achieving a reduction and to implement them in practice. – Univ.-Prof. Dr. Ulrich Brand, Department of Political Science, University of Vienna

Resource consumption drives the transgression of planetary boundaries

Environmental problems are becoming ever more present, as we experience heatwaves, biodiversity loss, the burden of disease linked to environmental changes, and many more. Socioeconomic resource use can be seen as the key factor behind these environmental problems. We are using an increasing quantity of resources (material, energy, water, soil) and in so doing are already transgressing six of the nine planetary boundaries (Richardson et al. 2023). We therefore need to reduce resource consumption significantly, rapidly and sustainably. Material flow accounts serve as the monitoring instrument (Haberl et al. 2019), for recording and analysing the economy-wide material consumption of Austria according to material categories (the four major categories are: biomass, fossil energy carriers, metals and non-metallic minerals). In 2022, Austria used 154 million tonnes of materials per year or 17 t/cap/a. Material consumption in Austria has largely stabilised since the 1980s, however remaining at a high level in international comparison (ranked in 15th place among the EU27 Member States). The material consumption in 2022 of the EU, for example, was 13 t/cap/a, and Italy had the lowest material consumption among EU countries, using only 7 t/cap/a.

In addition to the materials that are extracted within the country, Austria makes use of resources from other countries. Austria is a net importer of resources, and the physical trade balance (PTB = imports-exports in tonnes) in 2022 amounted to 30 Mt/a or 3 t/cap/a. Additional material and energy consumption take place throughout the extraction, processing and transportation involved in the production of processed goods that are distributed to other countries through external trade. If the responsibility for this material consumption along the supply chain is assigned to Austria, this results in a material footprint for Austria of 22 t/cap/a in 2020.

Material consumption is a driver of many environmental problems, including in Austria. The consumption of non-metallic minerals (54 % of DMC) is driven primarily by the construction and maintenance of socioeconomic stocks (roads, houses and other infrastructure). These stocks have multiple impacts upon very diverse planetary boundaries. Construction raw materials require a large range of resources that involve the use of considerable quantities of energy for their extraction, processing and transport. After construction, stocks require energy for their heating, lighting and transport use i.e., for their operation. Energy consumption produces CO_2 emissions but also indirect resource consumption through the required expansion of energy infrastructure. Socioeconomic stocks have an impact on land use and ultimately on biodiversity. This is because increasing quantities of stocks lead to ever larger areas of land being sealed and natural areas that were previously contiguous becoming fragmented by road networks. Both have a negative impact on ecosystems and species loss as well as biodiversity loss occur as a result. A reduction in material consumption is therefore a central lever in current environmental policy and can make a decisive contribution to achieving decarbonisation and protecting biodiversity.

Decoupling resource use from economic growth and increasing resource productivity is a central approach taken in many policy programmes (UN 2015; European Commission 2019; BMK 2022). Unfortunately, almost no examples of absolute decoupling (i.e., a reduction of resource consumption with increasing economic output) have been recorded to date (OECD 2018; Hickel 2019; Hickel and Kallis 2019; Jackson and Victor 2019; UN IRP 2019a; Haberl et al. 2020; Vogel and Hickel 2023). Only the many crises of recent years are leading to absolute decoupling in Austria both for domestic material consumption and from a consumption-based footprint perspective. Resource productivity based on DMC (GDP/DMC) rose between 2008 and 2020 by 9 % while DMC was reduced by 4 %. Resource productivity based on the MF (GDP/MF) rose between 2008 and 2020 by 10 %, while the MF in this period fell by 5 %. It remains to be seen whether this trend can be maintained beyond the crises that have occurred. Developments in the last 1-2 years provide some hope in this respect, however, current trends of decline must be stabilized.

Since the first circular economy programme was published (European Commission 2014), the circular economy has become the central framework for sustainable resource use, which can also make a significant contribution to decarbonisation. A circular economy means the transformation of the linear “throwaway society” into a circular, sustainable society existing within planetary boundaries. This involves more than the recycling of waste, as the circular economy is conceived in terms of the 10 R-strategies: the entire production chain should from the very beginning (Rethink, Refuse, Reduce) reduce resource inputs (Narrowing), while in a second step materials should remain for longer in socioeconomic use (Slowing) and only as a final step should materials at the end of the product service life be recycled and material cycles be closed (Closing) (Potting et al. 2017).

The Austrian Federal Government has recognised the importance of a circular economy and published a Circular Economy Strategy in 2022 (BMK 2022), in which four ambitious overarching goals were defined:

1. Reduction of resource consumption to:
   a) 14 t/cap/a DMC by 2030
   b) 7 t/cap/a material footprint (MF) by 2050
2. Increase of domestic resource productivity by 50 % by 2030
3. Increase of circularity rate to 18 % bis 2030
4. Reduction of material consumption by private households by 10 % by 2030

The empirical basis for monitoring progress on these goals is provided by the material flow accounts (Haberl et al. 2019; Neubauer and Gierlinger 2022; Statistics Austria 2024). Results from the MFA presented in this report show that Austria is in some respects on the right path, but that reductions in resource consumption must be further monitored and, in some cases, accelerated.

Achieving a material footprint of 7 t/cap/a is only conceivable through the implementation of ambitious circular economy measures

Scientific analysis and the policy basis for the circular economy are already in place, and what is now required is an ambitious implementation programme. Results from the research project "Circular economy and decarbonisation. Synergies and trade-offs" (Haas et al. 2024) showed what decarbonisation and dematerialisation could look like by 2040. Calculations were made across different future scenarios for the building, mobility and electricity sectors regarding the impacts decarbonisation strategies and additional circular economy measures could have upon material consumption. Only the introduction of ambitious circular economy measures showed potential for significantly reducing material consumption, i.e., to 12 t/cap/a in the case of a rapid recovery from the COVID pandemic and 8 t/cap/a in the case of a slower recovery from the COVID pandemic with zero growth. The largest effect could be achieved by halting construction on unsealed land areas. This is a measure that does not reduce individual living space excessively (see also Bärnthaler 2024), but which retains green space in high-density developments and thereby drastically reduces material consumption while also making a positive contribution to health, biodiversity and the stabilisation of the local climate.

The research results confirm that courageous steps must be taken which place socioeconomic stocks and their reduction in the spotlight. Circular economy strategies from the Narrowing group include measures for reducing economy-wide resource flows and demonstrate the greatest impact. Precisely these circular economy measures are among the hardest to implement using current approaches. The R-strategies of Rethink and Refuse promote new approaches to existing patterns of production and consumption. The focus should no longer be on the most efficient production of goods (techno-economic solutions, Bärnthaler 2024) but priority should rather be given to the needs of society, and finding solutions to social problems. In this context, innovative planning and business concepts are required that are not dependent on the continually increasing output of material goods but that develop entirely new and cross-sectoral business models in collaboration with wider society and local neighbourhoods and regions. Examples of this include the wide variety of sharing initiatives, as well as new models of public infrastructure (mobility concepts), the design of public space, new forms of residential living and a new and different use of existing structures, to avoid the need to produce new ones. The measures included in Slowing strategies, i.e., the slowing of throughput rates, have great and still unexploited potential through measures extending service life, such as reuse, repair and repurposing.

A significant reduction in resource flows requires a far-reaching transformation of society

As early as 2011, the German Advisory Council on Global Change (WBGU) talked about a new social contract and the need for a great transformation in a report called "World in Transition" (WBGU 2011). The WBGU concluded that: "the requisite transformation encompasses profound changes to infrastructures, production processes, regulation systems and lifestyles, and extends to a new kind of interaction between politics, society, science and the economy. Various multilevel path dependencies and obstacles must be overcome. Furthermore, the transformation can only succeed if nation states put global cooperation mechanisms before their own short term oriented interests, in order to make a trend reversal, particularly as far as the global economy is concerned, towards climate friendliness and sustainability possible. And not least, from a global perspective, this is also about issues of fairness – issues that need resolving" (WBGU 2011: Summary for Policy-Makers, p.1). Insights into just how necessary such a transformation of society is - for Austria too - have continued to grow since that time (Görg et al. 2023; Novy et al. 2023). In a policy brief from the European Environment Agency (EEA 2023) the EEA also discusses the fact that efficiency gains are not sufficient to meet the challenges of current crises for the climate, resources, biodiversity and pollution, but rather that changes in consumption patterns and a significant reduction in absolute volumes are urgently needed.

Current debates regarding societal transformation focus particularly upon the role of demand-side measures, i.e., with the question of how much resource consumption is required to provide a sustainable level of prosperity (O'Neill et al. 2018; Millward-Hopkins et al. 2020; Millward-Hopkins 2022; Vélez-Henao and Pauliuk 2023; Pauliuk 2024). Based on Kate Raworth's doughnut economics (Raworth 2017), sustainable consumption corridors are discussed (Pirgmaier 2020; Fuchs et al. 2021; Sahakian et al. 2021; EEA 2023; Bärnthaler 2024), which operate between social minimum standards for a good life and planetary boundaries. This approach places the focus on a wellbeing economy and not a growth economy (EEA 2023). The EEA sees the circular economy as a key strategy within this transition.

As mentioned in the chapter on stocks, demand-side decisions cannot only be limited to the consumption preferences of individuals, but rather it is precisely the material-intensive infrastructures (provisioning systems; Schaffartzik et al. 2021) that create the context for demand-side changes that require more attention during a transformation. Provisioning systems are central structures that provide goods and services, which characterise daily life and either enable or restrict consumer choices, and are thereby directly linked with wellbeing and resource consumption (Jonas et al. 2023). Another important factor related to demand-side measures is the role of inequality. The 10 % of the global population with the highest income are responsible for approximately 34 % of global GHG emissions, while the poorest 50 % only cause 15 % of all emissions. Similar inequalities are evident even in highly industrialised countries such as Austria (Hubacek et al. 2017; Otto et al. 2019). Current research studies therefore make reference to the strong link between ecological crises, distributive justice issues and the high ecological costs of distributive inequality (Millward-Hopkins 2022; Bärnthaler 2024).

How the major material flows pull smaller but critical ones along with them

When shifting the focus to the major mass flows and the reduction of materials relevant for stocks, smaller material flows play a relatively minor role. Nonetheless, the use of strategic raw materials, including many critical raw materials, is also closely bound up with existing built infrastructure. Every house requires a high-tech heating system that is fed to some degree by electricity from renewable energies and the energy infrastructure that underpins this. Infrastructures contain very many future technologies that in terms of their mass do not appear particularly relevant. A reduction in stocks can therefore also reduce the demand for these critical raw materials and for energy. At the same time, the raw materials that we nonetheless require must be used in accordance with the criteria of the circular economy (lengthening service life through slowing the throughput rate (Slowing), and closing material cycles, (Closing)). Since many of the raw materials that are relevant for future needs must be obtained from other countries, socially and ecologically sustainable production structures and circular economy elements along the global supply chains need to be considered. The 2030 Raw Materials Master Plan adopted in 2021 and the Critical Raw Materials Act (CRMA), together with the EU Corporate Sustainability Due Diligence Directive, which came into force in July 2024, can all make an important contribution towards this.

A circular economy can successfully integrate resource conservation and decarbonisation

The ultimate aim of an integrated approach to the circular economy is to minimise both material inputs from nature and emissions and waste flows into nature (Korhonen et al. 2018). This can only be achieved when the strategies of Refuse, Rethink and Reduce are adhered to as a priority. This matters for small products as much as for industrial facilities and large-scale infrastructures, which provide the requisite services for society, while remaining for as long as possible in service and requiring as little maintenance as possible. A radically different approach to resources such as this reduces waste flows, which can subsequently be recycled using the least possible effort in almost all cases. This means applying the "circular by design" principle across all life phases and scale levels of materials usage. The transformation of linear economies into circular economies is challenging and represents not a "quick success, but rather a major long-term undertaking" (Kirchherr et al. 2017, 228).

5 Methods

Material flow accounting – Concept, data basis and methods

Material flow accounting and analysis is an internationally harmonised accounting system (UN 2017; Eurostat 2018; UNEP 2021) for the material inputs, stocks and outputs of a socioeconomic system. Solid, gaseous and liquid materials are accounted for, excluding water and air, and are recorded in physical units (mass, usually in tonnes). Material flow accounting forms part of the environmental accounts[20].

Concept

Material flow accounting (MFA) measures all material flows that are necessary for the production, operation and maintenance of biophysical structures of a society. These biophysical structures (or "stocks") by definition include all humans and artefacts together with all livestock (animal husbandry and aquaculture). Artefacts are defined in analogy to the System of National Accounts (SNA) as all infrastructures, buildings, vehicles and machinery, and in contrast to the SNA also include durable consumer goods.

In order to record the material exchange relationships within a societal system (or socioeconomic system, or national economy), two system boundaries must be defined within the MFA framework:

- The boundary between the socioeconomic system and its natural environment, from which material is extracted and into which emissions and wastes are discharged;
- The boundary between the socioeconomic system and other socioeconomic systems (national economies), from which goods are imported and to which goods are exported (see Figure 1).

Water and air are not recorded in the material flow accounts as extractions from the natural environment, unless they are incorporated in raw materials or goods; the latter relates to e.g., harvested grain, fruit, vegetables and various goods for international trade (e.g., drinks, timber). In the data recorded for domestic extraction (DE), the water content of grazed biomass, harvest byproducts and timber is by convention converted to 15 %.

Inputs into the socioeconomic system are in the first instance raw materials from domestic extraction (DE) and imported raw materials and processed goods (imports). Domestic extraction accounts for all raw materials that are extracted from nature. These include raw materials from agriculture and forestry (e.g., arable produce, products from mowing, timber) and from mining (e.g., coal, iron ore, limestone, salt). Imports, in contrast, comprise products with very varying degrees of processing, from iron ore to mobile telephones. Outputs of the socioeconomic system are on one hand wastes and emissions (domestic processed output, DPO) and exports on the other hand. The intermediate

20 umweltgesamtrechnung.at

material inputs of imports and exports can be expressed in raw material equivalents (RME). The RME are composed of the mass of the traded goods themselves together with all the material inputs that were required for the upstream production processes. They are calculated to render the outsourcing effects of international trade visible

When raw materials are extracted, additional materials are moved that do not flow into the socioeconomic system as used extraction, i.e. they are not intended to provide a service to society. These flows are accounted for in the MFA as unused extraction. This category includes, for example, overburden from mining, soil excavated during infrastructure development or harvest residues. Other environmental impacts (e.g. soil erosion), which result from socioeconomic use of resources, are not recorded in the MFA and are recorded using other measuring and monitoring instruments.

The application of the law of conservation of mass is decisive for the consistency of MFA. This stipulates that materials and energy within a closed system can be neither created nor destroyed: Inputs = Outputs +/- changes to stocks

In order to complete the material balance, balancing items must be included in MFA on both input and output sides (water vapour, air as an input in combustion processes, etc.). Those interested can find a detailed description of the treatment of these balancing items in the methodology handbooks of Eurostat (Eurostat 2001; Eurostat 2018).

Material flows are usually presented in four material categories: biomass, non-metallic minerals, metals and fossil energy carriers. Biomass refers to all resources of plant origin that are extracted from the environment by humans or animals. This also involves recording grazed biomass. This category also includes fishing and hunting, i.e., biomass of animal origin, extracted from wild animal populations. Metals and non-metallic minerals are included in the MFA as "run of mine". This means that mineral materials are recorded at the mass they exhibited upon their exit from mining facilities, i.e., inclusive of surrounding waste rock. Fossil energy carriers (also energy raw materials) comprise non-metallic mineral raw materials that were created in geological prehistory from biomass. Conventional energy raw materials include lignite and coal, oil and natural gas.

All direct flows, which exceed the defined system boundaries (domestic extraction, imports, exports) are recorded and accounted for in the basic module of the MFA. These data are used to calculate a variety of indicators, including the key indicator used by the European Statistical Office, domestic material consumption (DMC). This represents domestic material extraction plus imports and minus exports (DMC = DE + imports – exports). Domestic material consumption comprises all materials that are consumed in the socioeconomic system, whether in economic production processes or in final consumption. The DMC can also be formulated as the sum of all those materials that remain in society and are transformed into wastes or emissions ("waste potential").

Imports and exports play an increasingly significant role in domestic material consumption. From a global perspective, trade results in the outsourcing of production steps. Consequently, the production of imported and exported goods involves material and energy intermediate inputs that are not recorded in domestic material consumption.

If the material consumption is calculated taking account of these intermediate inputs for imported and exported goods, this results in the material footprint (MF), also defined as raw material consumption (RMC). The MF comprises all raw materials that are used in the production of goods for domestic consumption.

Data basis and methodology

A detailed description of data collection for the Austrian MFA can be found in the standard documentation on material flow accounts published by Statistics Austria (Neubauer et al. 2023). The most important details are summarised in this section.

Data required to produce the MFA are drawn from existing data sets from within the official statistics. For Austrian domestic extraction (DE), the following statistical sources are drawn upon for each material category:

- Biomass: plant production, agricultural statistics and timber felling reports
- Fossil energy carriers: energy balances
- Non-metallic minerals: Austrian mining yearbook, economic statistics and supply and use tables
- Metals: Austrian mining yearbook

Quantification of imported and exported materials is derived from the foreign trade statistics produced by Statistics Austria, which provide the economic value and mass of all traded goods.

Alongside the compilation of data, it is necessary in many cases to convert recorded figures into metric tonnes as the common unit of measurement. In Austria, for example, logging data is recorded in solid cubic metres, vineyard grape harvests in hectolitres and extraction of natural gas and brine in cubic metres. Furthermore, some flows relating to domestic extraction are either not recorded at all or are only partially recorded in the statistics. In such cases, estimations are required.

Not all raw materials for societal use are recorded in the official statistics. These material flows, which are in some cases on a very large scale, must be estimated using methods designed specifically for this purpose. Domestic extraction of harvest byproducts (primarily straw and plant leaves used as fodder) and grazed grass are not captured in the agricultural statistics. In the case of arable crop production in Austria, from the harvest of which straw is yielded, coefficients exist for the relation of crop yield to total plant mass (harvest indices). 75 % of straw yield is used (particularly as animal litter), while the remaining 25 % remains as unused extraction in situ and is therefore not included in the MFA. Alongside straw, beet leaves are also extracted as a harvest byproduct and used as fodder plants. Coefficients are also used for the relation of crop yield to leaves and the unused share. Biomass directly grazed by livestock (particularly grass) is also not captured statistically. The calculation of grazed biomass is based on grazing land from farm structure surveys and on yield factors taken from green fodder balances. Separate consideration is given to pastures, permanent pastures, alpine pastures. Grazed biomass is standardized to a water content of 15 %. Cross checks using demand side estimations are made, which involve estimating the feed requirements of livestock needing coarse fodder (ruminant species and horses) in relation to the supply of commercial feedstuff (concentrated feed) and fodder plants. Adjustments are made for the feedstuff supply that is fed to chickens and pigs.

Reporting of extraction of construction materials (sand and gravel) is similarly incomplete in the official statistics. In Austria a three-step procedure has been developed and implemented drawing on short-term business statistics and material input statistics to estimate non-reported extraction data. The short-term business statistics do not include the data related to companies below a certain reporting threshold on one hand and on the other, the production that takes place outside of the productive sector. In both cases, an estimation must be performed in order to derive a comprehensive coverage of the extraction of construction materials. Production data for smaller companies is estimated along sectors by using production surveys of reporting units. Extraction of construction raw materials in non-producing sectors, which include agriculture, trade and transport, is extrapolated with the help of the Austrian supply and use tables. These tables report the production of construction raw materials in non-producing sectors in monetary values. Using the average annual prices derived from the extrapolated total production, the mass in tonnes corresponding to the estimated value can be calculated.

Implementation in the statistics

The material flow accounts for Austria comprise a time series from 2000 and are expanded each year to include the latest data by Statistics Austria. In earlier reports (BMLFUW and BMWFJ 2011; BMLFUW and BMWFW 2015; BMK and BMLRT 2020), reference was made to a time series from 1960, which, however, could not be continued due to alterations to the statistical classifications systems. At the European level, the data from national MFA accounts are collated and published on an annual basis by Eurostat. An EU15 time series is available from 1970, whereas the time series for the EU27 countries begins in 2000. Since 2011, the compilation of material flow data within the European Union has been subject to the requirements of a Regulation (EU 2011).

Material flow analysis in Austria

Austria has played a leading role in Europe since the 1990s in the development of material flow analysis and the inventory of relevant methodologies, and has made a significant contribution to the establishment of material flow accounting within European environmental statistics. The research institutions in Austria that are focused on different aspects of material flow analysis - often with support from the current Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK) - include the Institute of Social Ecology (SEC) at BOKU University (boku.ac.at/wiso/sec), the Institute for Ecological Economics at the Vienna University of Economics and Business (WU) (wu.ac.at/ecolecon) and the Institute of Water Quality and Resource Management, Research Unit of Waste and Resource Management, Vienna University of Technology (TU Wien). (tuwien.at/cee/iwr/ressourcen).

International Databases

Data within material flow accounts and particularly those pertaining to material consumption and the material footprint in Austria, the EU and many countries around the world have been systematically made available for public access via a variety of institutions:

- Austria: current data on material consumption in Austria are available via Statistics Austria statistik.at/statistiken/energie-und-umwelt/umwelt/materialflussrechnung
- EU: MFA data for the Member States of the EU can be accessed via the data server of Eurostat, the statistical office of the EU: ec.europa.eu/eurostat/data/database (Environment and energy/Environment/Material flows and resource productivity)
- UN IRP: MFA data for all countries in the world (1970-2024) are available in the UN IRP database: resourcepanel.org/global-material-flows-database Analyses and visualisations relating to the UN data can be found on the UN website for SCP hotspot analysis: scp-hat.lifecycleinitiative.org
- The Institute for Ecological Economics (Sustainable Resource Use research group) supported by the BMK maintains the website materialflows.net, on which data on global extraction of materials by country since 1970 and a range of data visualisations can be found.
- The Institute of Social Ecology provides a range of national and global data sets and analyses on material consumption via the Institute's homepage: boku.ac.at/wiso/sec/data-download

Project ACeDC – Methods behind the circularity measures in the buildings and mobility modules

Circular economy and buildings

Both building stocks and the annual construction of new buildings have a significant impact on the energy consumption of a country. A house is the end product in a long chain of emissions-intensive processes, from the extraction of raw materials such as iron ore or limestone within or outside the country (see Material Footprint), from transport to production sites, the processing of these raw materials, further processing to create intermediate products such as cement or steel, the manufacture of finished products such as reinforced concrete, transport to construction sites and finally the addition to stocks through the construction of a new building.

In 2017, Austrian steel production alone caused 12.8 million tonnes of CO_2-equivalents while producing 8.1 million tonnes[21] of steel. This represented approximately 20 % of total Austrian emissions in 2019[22]. Alongside the steel industry, cement production is also a major contributor to emissions. Although Austria, through the use of modern kiln technology, remains well below the global intensity of 637 kgCO_2 per tonne of cement, producing 525 kgCO_2 per tonne, the sector was still responsible for almost three million tonnes of CO_2-equivalents in 2020[23] (Mauschitz 2021, VÖZ 2022), which represents 5 % of total annual emissions for Austria (UBA 2021).

Buildings also consume energy and thereby cause emissions during their service life. In 2018, buildings caused 9.7 million tonnes of CO_2-equivalents, which corresponded to approximately 10 % of national greenhouse gas emissions (UBA 2020). Approximately 500,000 oil-fired boilers and 850,000 gas heating systems are still in use today in Austria.[24]

There is a diverse range of strategies for the building sector in the context of the circular economy, aimed at supporting decarbonisation and reducing emissions. For example, the Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK) as part of a 2023/24 refurbishment campaign provides subsidies for thermal building renovation and adaptation, and through its campaign "Raus aus Öl und Gas" promotes the replacement of fossil heating systems with heat pumps and biomass boilers[25]. In 2018, the thermal renovation rate was 1.4 %. This includes both comprehensive thermal adaptations and also the equivalent sum of individual refurbishment measures in relation to existing stocks in that year[26].

Alongside such renovation or technology-replacement measures, other measures that can be implemented before or during the construction of buildings have the potential to accelerate decarbonisation. Increasing the standard thickness of insulating material for new buildings[27] can significantly reduce the energy requirements for residential buildings. Equally, altering the composition of building materials can have a positive impact on resource consumption. Timber engineering, for example, makes use of a renewable raw material and simultaneously replaces the need for emissions-intensive concrete. However, timber construction is not a cure-all, since it involves a reduction in living forest, which is a CO_2 sink. In addition, a timber-based transformation of construction engineering raises the question as to what extent the quantities of domestic or imported timber could

21 umweltbundesamt.at/fileadmin/site/publikationen/rep0738.pdf
22 Umweltbundesamt (Federal Environment Agency) 2021: Greenhouse gas balance in 2019 by sector, umweltbundesamt.at/news210119/sektoren
23 zement.at/publikationen/emissionsberichte
24 oesterreich.gv.at/de/themen/umwelt_und_klima/energie_und_ressourcen_sparen/1/raus_aus_oel
25 oesterreich.gv.at/de/themen/umwelt_und_klima/energie_und_ressourcen_sparen/1/sanierungsoffensive
26 UBA & IIBW (2020): Definition and measurement of thermal energy refurbishment rates in Austria. iibw.at/documents/2020%20IIBW_UBA%20Sanierungsrate.pdf
27 oib.or.at/sites/default/files/erlaeuternde_bemerkungen_richtlinie_6_12.04.19_0.pdf

then satisfy domestic material demand, both in quantitative and qualitative terms. At the same time, although in structural terms it has been hard to conceive of construction without many specific components, such as foundations, initial pilot projects have shown that a complete avoidance of concrete in construction is possible, even if this cannot be applied in all cases. With a growing population, a sufficiency approach also provides an option through reducing per capita living space and reducing material input in new buildings, soil sealing and energy consumption.

Circular economy and mobility

In 2018, the transport sector, excluding national air transport, caused more than 23.8 million tonnes of CO_2-equivalents, which represented approximately 30 % of total national greenhouse gas emissions. This is primarily due to the currently widespread use of fossil fuels such as diesel and petrol. Road transport accounts for 95 % of these emissions. Passenger transport by road (private vehicles, motorbikes, buses) accounted for approximately 63 % of all road transport emissions, at 14.8 million tonnes of CO_2-equivalents (petrol vehicles: 4.7 Mt CO_2eq, diesel vehicles: 9.6 Mt CO_2eq.). The remaining 37 % of these emissions are attributable to road-based freight transport, amounting to 8.7 million tonnes of CO_2-equivalents (UBA 2020). Total passenger transport in 2018 involved the consumption of approximately 3.7 million tonnes of fossil fuels for mobility, whereas freight transport consumed only 0.4 million tonnes. Electric vehicles continued to play a minor role, comprising less than 2 % of existing vehicle stocks, and consuming approximately 477 GWh electricity[28]. In 2019, 2.8 % of all newly registered passenger cars in Austria possessed battery-electric drive systems (UBA 2020).

In 2018, passenger cars and motorised two-wheel vehicles accounted for 69 % of personal transport activities, amounting to 79 billion passenger kilometres (pkm). Approximately 27 % – representing 31 billion pkm – were provided by public transport (rail, tram, subway or bus)[29]. Active mobility, involving travel on foot or by bicycle, comprised only 4 % (four billion pkm) of passenger transport activity in Austria[30]. From a resource use perspective, active mobility is preferable, since it requires no fuel consumption and thus represents the least material and emissions-intensive mode of transportation. This is followed by public transport, due to a far smaller material input per capita than private passenger transport, which has seen reduced occupancy rates in recent years (UBA 2020). In the case of freight transport, approximately 54 % of transport, representing 26 billion tonne-kilometres (tkm), took place on roads. The remaining 46 % comprised freight transport by rail, amounting to 22 billion tkm (OECD 2022).

The Mobility Master Plan 2030 has as its aim the decarbonisation of the stocks of passenger vehicles, motorised two-wheelers and utility vehicles including buses by

---

28 statistik.at/statistiken/tourismus-und-verkehr/fahrzeuge/kfz-bestand

29 EU transport in figures. Statistical pocketbook 2020. publications.europa.eu/resource/cellar/da0cd68e-1fdd-11eb-b57e-01aa75ed71a1.0001.03/DOC_1

30 Österreich unterwegs 2013/14 bmk.gv.at/themen/verkehrsplanung/statistik/oesterreich_unterwegs/berichte.html

2040. In reality a complete decarbonisation of the vehicle fleet can only be achieved when the decarbonisation of electricity production is attained. At the same time, ambitious goals to shift mobility to public transport, active mobility and rail freight transport were also set out[31]. The COVID pandemic also showed in Austria that reduced demand for long-distance travel can also enable lower traffic volumes. Thus, in future, increased home working practices could lead to a decrease in commuter trips and reduce the need for private vehicle ownership. Equally, improved access to public transport networks and an expanded and more closely interlinked bicycle network in urban spaces such as Vienna could achieve a significant reduction in annual acquisitions of private vehicles, in traffic volumes and in associated emissions, while car-sharing could make an additional contribution to resource savings.

31 bmk.gv.at/themen/mobilitaet/mobilitaetsmasterplan/mmp2030.html

6 Appendix

Glossary

Environmental accounts are accounts in monetary and physical units, which supplement the national accounts to provide a comprehensive picture of the interrelations between the economy and the environment. For this purpose, ecological data concerning raw materials, energy, water or land use, wastes and waste water disposal as well as air emissions, are set against economic 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.

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 functions as 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 connected to the natural system via biophysical structures. The communication system of society comprises subsystems including the economy, law, politics and education. Biophysical elements of society include the human population, its infrastructures and artefacts, as well as, by definition, 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** understands 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 socioeconomic 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 solid wastes or gaseous or liquid emissions. Physical accounts can be used to record this metabolism.

Material Flow Accounting (MFA) is an accounting tool for the material inputs and outputs of a socioeconomic system. MFA is complementary to national (economic) accounts and forms part of the environmental accounts. It records all material extraction 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. Resources are extracted from the from the natural environment of the domestic territory (domestic extraction, DE) enter the system as inputs and flow back into it as gaseous or liquid emissions and solid wastes (DPO, domestic processed output). Imports enter the system from other economies and exports leave the system to flow into other economies.

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. Their specific quality, which makes them useful for society, is usually lost in this process. In the empirical analysis, this report focuses on material resources, i.e., on biomass, fossil energy carriers, metallic and non-metallic minerals.

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.

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

Fossil energy carriers/raw materials 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.

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.

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.

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

Domestic extraction (DE) encompasses all materials and raw materials extracted by resident units from the natural environment. These include the agricultural harvest, felled timber and the products of mining.

Physical **imports and exports** comprise all traded goods 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, these traded products 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 recorded under the category "non-assignable" and include on one hand manufactured products containing an unknown mix of materials, which prevents their allocation to one of the four material categories, and on the other raw materials or goods not specified in the statistics for reasons of confidentiality.

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

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 materials enter 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 provide materials on the global market for use in other countries.

Domestic processed output (DPO) includes all materials, which following their use in socioeconomic 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, dissipative uses and losses, as well as unregulated deposited wastes.

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

Material footprint (MF) reflects the domestic material consumption in raw material equivalents. This means that it comprises domestic extraction plus imports measured in RME, minus 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.

Resource productivity (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.

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 efficiency increases more slowly than economic growth; and decoupling with decreasing resource consumption (absolute decoupling), in which resource efficiency increases at a faster rate than economic growth.

The concept of **planetary boundaries** (also planetary load limits; 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 occur when these thresholds are exceeded. Scientists have defined nine of these planetary boundaries (Rockström et al. 2009b; W. Steffen et al. 2015): climate change, acidification of oceans, stratospheric ozone depletion, biogeochemical cycles of nitrogen and phosphorus, freshwater consumption, land use changes, biodiversity losses, chemical pollution and introduction of novel substances, and atmospheric aerosol pollution.

Abbreviations

GDP	gross domestic product
CRM	critical raw materials
DE	domestic extraction
DMC	domestic material consumption
DMI	direct material input
DPO	domestic processed output, i.e. emissions and wastes
EU27	the 27 Member States of the European Union (from 2020)
LCA	life cycle assessment
MF	material footprint
MFA	material flow accounting
PTB	physical trade balance
RMC	raw material consumption
RME	raw material equivalents
VGR	System of National Accounts

Units

/a	per annum
cap	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 tonne

Data tables

Data Table 1: Austrian material flows in million tonnes per year, growth and composition of flows by material category. 2000 and 2022. (Values are rounded. Possible rounding differences have not been balanced. Source: Statistics Austria 2024)

	material flows (1000 t/a)		growth	share of flow in totals	
	2000	2022	2000 - 2022	2000	2022
Domestic extraction (DE)	**127.682**	**124.649**	**-2 %**	-	-
Biomass	31.970	36.646	15 %	25 %	29 %
Fossil energy carriers	3.765	996	-74 %	3 %	1 %
Metals	2.896	4.891	69 %	2 %	4 %
Non-metallic minerals	89.052	82.116	-8 %	70 %	66 %
Imports	**66.771**	**92.318**	**38 %**	-	-
Biomass	17.395	26.020	50 %	25 %	28 %
Fossil energy carriers	25.163	29.034	15 %	40 %	31 %
Metals	13.652	20.314	49 %	20 %	22 %
Non-metallic minerals	7.113	9.815	38 %	10 %	11 %
Non-assignable	3.448	7.075	105 %	5 %	8 %
Wastes	0	59	-	0 %	0 %
Exports	**40.361**	**62.599**	**55 %**	-	-
Biomass	15.626	23.920	53 %	37 %	38 %
Fossil energy carriers	5.770	9.434	63 %	17 %	15 %
Metals	9.579	14.800	55 %	23 %	24 %
Non-metallic minerals	6.680	9.103	36 %	16 %	15 %
Non-assignable	2.706	5.202	92 %	7 %	8 %
Wastes	0	141	0 %	0 %	0 %
Domestic material consumption (DMC)	**154.092**	**154.368**	**0 %**	-	-
Biomass	33.739	38.746	15 %	23 %	25 %
Fossil energy carriers	23.158	20.597	-11 %	16 %	13 %
Metals	6.969	10.405	49 %	4 %	7 %
Non-metallic minerals	89.484	82.828	-7 %	57 %	54 %
Non-assignable	742	1.874	153 %	0 %	1 %
Wastes	0	-81	0 %	0 %	0 %

Data Table 2: Austrian domestic material consumption (DMC) in tonnes per capita and year by material category and growth between 2000 and 2018. (Values are rounded. Possible rounding differences have not been balanced. Source: Statistics Austria 2024)

	material flows (t/cap/a)		growth	share in totals	
	2000	2022	2000 - 2022	2000	2022
Domestic material consumption (DMC)	**19**	**17**	**-4 %**	**-**	**-**
Biomass	4,2	4,3	11 %	22 %	25 %
Fossil energy carriers	2,9	2,3	-13 %	15 %	13 %
Metals	0,9	1,1	39 %	5 %	7 %
Non-metallic minerals	11,2	9,1	-12 %	58 %	54 %
Non-assignable	0,1	0,2	183 %	0 %	1 %
Wastes	0,0	0,0	0 %	0 %	0 %

Data Table 3: Austrian resource productivity and its components of domestic material consumption and gross domestic product, 2000 and 2022, together with growth between 2000 and 2022. (Source: Statistics Austria 2024)

			growth
	2000	2022	2000 - 2022
Resource productivity RP-DMC (BIP/DMC)	1.821	2.464	35 %
Domestic material consumption (DMC; Mt/a)	154	154	0 %
Gross domestic product (GDP; M€/a)	280.579	380.417	36 %

Data Table 4: Austrian material flows by material category in million tonnes per year, 2000 – 2022. (Values are rounded. Possible rounding differences have not been balanced. Source: Statistics Austria 2024)

	’00	’01	’02	’03	’04	’05	’06	’07	’08	’09	’10	’11	’12	’13	’14	’15	’16	’17	’18	’19	’20	’21	’22
Domestic extraction (DE)	**128**	**124**	**134**	**127**	**133**	**136**	**136**	**141**	**139**	**128**	**126**	**132**	**123**	**122**	**129**	**123**	**124**	**123**	**123**	**125**	**123**	**131**	**125**
Biomass	32	33	34	33	36	37	37	38	41	37	37	39	36	35	39	35	39	35	35	35	36	38	37
Fossil energy carriers	4	4	4	4	3	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1
Metals	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4	5	5	5	5
Non-metallic minerals	89	84	93	87	91	93	94	97	93	85	83	88	82	82	85	82	80	82	83	84	82	87	82
Imports	**67**	**69**	**72**	**75**	**79**	**83**	**89**	**92**	**90**	**81**	**89**	**93**	**93**	**91**	**88**	**91**	**94**	**98**	**99**	**100**	**98**	**101**	**92**
Biomass	17	17	17	18	20	20	23	23	22	22	23	24	23	25	24	25	26	27	28	28	29	29	26
Fossil energy carriers	25	27	29	31	31	33	33	33	33	31	33	34	34	32	31	32	34	34	34	36	32	33	29
Metals	14	14	14	15	16	17	19	21	21	15	20	22	21	19	18	19	19	21	21	19	18	21	20
Non-metallic minerals	7	7	7	7	8	8	9	10	9	8	8	9	8	9	10	10	9	10	10	10	9	10	10
Non-assignable	3	4	4	4	4	4	5	5	5	5	5	6	6	6	6	6	6	6	5	7	10	7	7
Wastes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Exports	**40**	**43**	**46**	**48**	**52**	**54**	**57**	**63**	**63**	**54**	**59**	**60**	**59**	**59**	**60**	**62**	**64**	**65**	**66**	**66**	**62**	**66**	**63**
Biomass	16	16	17	18	19	20	21	22	22	20	21	22	21	21	21	22	23	23	24	24	24	25	24
Fossil energy carriers	6	7	8	8	9	10	10	12	12	10	11	12	11	11	11	11	12	12	12	12	11	11	9
Metals	10	10	10	11	12	12	13	14	15	11	13	14	14	14	15	14	15	16	15	15	14	15	15
Non-metallic minerals	7	7	8	8	8	8	9	10	10	8	9	9	8	8	9	9	9	9	9	9	9	10	9
Non-assignable	3	3	3	3	4	4	4	4	5	4	4	4	4	4	4	5	5	5	5	5	5	5	5
Wastes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Domestic material consumption (DMC)	**154**	**150**	**159**	**153**	**160**	**165**	**168**	**170**	**166**	**155**	**156**	**165**	**157**	**154**	**157**	**152**	**155**	**155**	**156**	**158**	**160**	**165**	**154**
Biomass	34	34	34	32	37	37	39	38	41	38	38	41	38	39	41	38	42	39	39	39	42	42	39
Fossil energy carriers	23	24	25	27	25	26	26	24	23	23	24	24	25	23	22	22	24	24	23	25	23	22	21
Metals	7	7	7	7	7	8	9	10	9	7	10	11	10	9	7	8	8	9	10	9	9	11	10
Non-metallic minerals	89	84	92	87	90	93	93	97	92	85	83	88	82	82	86	83	80	82	84	84	82	88	83
Non-assignable	1	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	2	5	2	2
Wastes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Data Table 5: Austrian domestic material consumption (DMC) by material category (t/cap/a), 2000 – 2022. (Values are rounded. Possible rounding differences have not been balanced. Source: Statistics Austria 2024)

	’00	’01	’02	’03	’04	’05	’06	’07	’08	’09	’10	’11	’12	’13	’14	’15	’16	’17	’18	’19	’20	’21	’22
Domestic material consumption (DMC)	**19**	**19**	**20**	**19**	**20**	**20**	**20**	**21**	**20**	**19**	**19**	**20**	**19**	**18**	**18**	**18**	**18**	**18**	**18**	**18**	**18**	**18**	**17**
Biomass	4	4	4	4	5	5	5	5	5	5	5	5	4	5	5	4	5	4	4	4	5	5	4
Fossil energy carriers	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2
Metals	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Non-metallic minerals	11	10	11	11	11	11	11	12	11	10	10	10	10	10	10	10	9	9	9	9	9	10	9
Non-assignable	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Wastes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Data Table 6: Austrian resource productivity (Euro/kg/a) and its components of domestic material consumption (DMC; Mt/a) and gross domestic product (GDP; billion Euro/a), 2000 – 2022. (Values are rounded. Possible rounding differences have not been balanced. Source: Statistics Austria 2024)

	’00	’01	’02	’03	’04	’05	’06	’07	’08	’09	’10	’11	’12	’13	’14	’15	’16	’17	’18	’19	’20	’21	’22
Resource productivity (RP-DMC; Euro/t/a)	**1.821**	**1.895**	**1.812**	**1.902**	**1.875**	**1.855**	**1.889**	**1.929**	**2.008**	**2.070**	**2.096**	**2.036**	**2.158**	**2.205**	**2.167**	**2.266**	**2.268**	**2.312**	**2.361**	**2.355**	**2.184**	**2.198**	**2.464**
Domestic material consumption (DMC; Mt/a)	154	150	159	153	160	165	168	170	166	155	156	165	157	154	157	152	155	155	156	158	160	165	154
Gross domestic product (GDP; billion €/a)	281	284	289	292	300	306	317	328	333	321	327	336	338	338	341	344	351	359	368	373	348	363	380

Data Table 7: Austrian material footprint, 2008 – 2020. (Values are rounded. Possible rounding differences have not been balanced. Source: Statistics Austria 2024)

	material flows (Mt/a)		growth	material flows (t/cap/a)		growth
	2008	2020	2008 - 2020	2008	2020	2008 - 2020
Material footprint (MF)	**208.685**	**198.532**	**-5%**	**25**	**22**	**-11%**
Biomass	41.746	41.834	0%	5,0	4,7	-6%
Fossil energy carriers	39.617	38.596	-3%	4,8	4,3	-9%
Metals	25.995	25.731	-1%	3,1	2,9	-8%
Non-metallic minerals	101.327	92.371	-9%	12,2	10,4	-15%

Table 8: Austrian domestic output to nature (DPO) by sub-category, 2000 – 2022. (Values are rounded. Possible rounding differences have not been balanced. Source: Statistics Austria 2024)

	material flows (Mt/a)		growth	share in totals	
	2000	2022	2000 - 2022	2000	2022
Domestic processed outputs (DPO)	**82.685**	**93.761**	**15%**	**-**	**-**
Emissions to air	77.626	89.145	15%	94%	95%
Waste disposal to the environment	0	0	-	0%	0%
MEMO wastes landfilled	85	50	-42%	2%	4%
Emissions to water	4.971	4.562	-8%	0%	0%
Dissipative use of products	2	5	106%	6%	5%
Dissipative losses	1.570	4.112	162%	0%	0%

	material flows (t/cap/a)		growth	share in totals	
	2000	2022	2000 - 2022	2000	2022
Domestic processed outputs (DPO)	**10**	**10**	**0%**	**-**	**-**
Emissions to air	9,7	9,8	2%	94%	95%
Waste disposal to the environment	0,0	0,0	-	0%	0%
MEMO wastes landfilled	0,2	0,5	132%	2%	4%
Emissions to water	0,0	0,0	-48%	0%	0%
Dissipative use of products	0,6	0,5	-19%	6%	5%
Dissipative losses	0,0	0,0	82%	0%	0%

References

Bärnthaler, Richard. 2024. When enough is enough: Introducing sufficiency corridors to put techno-economism in its place. Ambio. doi.org/10.1007/s13280-024-02027-2.

Behnassi, Mohamed, and Mahjoub El Haiba. 2022. Implications of the Russia–Ukraine war for global food security. Nature Human Behaviour 6: 754–755. doi.org/10.1038/s41562-022-01391-x.

Bernstein, Aaron S., Amy W. Ando, Ted Loch-Temzelides, Mariana M. Vale, Binbin V. Li, Hongying Li, Jonah Busch, et al. 2022. The costs and benefits of primary prevention of zoonotic pandemics. Science Advances 8: eabl4183. doi.org/10.1126/sciadv.abl4183.

BMLFRW. 2023. Trinkwasserverbrauch und Wasserversorgung (drinking water consumption and water supply). Federal Ministry of Agriculture, Forestry, Regions and Water Management.

BMF. 2022. Österreichisches Montan-Handbuch 2022. 96. Jahrgang. Vienna: Federal Ministry of Finance.

BMF. 2023. World Mining Data 2023. Authors: Christian Reichl and Michael Schatz. Volume 38. Vienna: Federal Ministry of Finance.

BMK. 2021. Umweltgesamtrechnungen (environmental accounts). Vienna: Federal Ministry of Climate Action, Environment, Energy, Mobility, Innovation and Technology.

BMK. 2022. Kreislaufwirtschafts-Strategie (circular economy strategy). Vienna: Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology.

BMK. 2023. Bundes-Abfallwirtschaftsplan 2023. Teil 1 (federal waste management plan. Part 1). Vienna: Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology.

BMK. 2024. Erster Fortschrittsbericht zur österreichischen Kreislaufwirtschaftsstrategie (first progress report on Austria's circular economy strategy). May 2024. Vienna: Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology.

BMK and BMLRT. 2020. Resource Use in Austria 2020. Volume 3. Autors: Nina Eisenmenger, Barbara Plank, Eva Milota, Sylvia Gierlinger. Vienna: Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology, and Federal Ministry of Agriculture, Regions and Tourism.

BMLFUW and BMWFJ. 2011. Resource Use in Austria – Report 2011. Autors: Nina Eisenmenger, Anke Schaffartzik, Fridolin Krausmann, Eva Milota. Vienna: Federal Ministry of Agriculture, Forestry, Environment and Water Management and Federal Ministry of Economy, Family and Youth.

BMLFUW and BMWFW. 2015. Resource Use in Austria – Report 2015. Autors: Anke Schaffartzik, Nina Eisenmenger, Fridolin Krausmann, Eva Milota. Vienna: Federal Ministry of Agriculture, Forestry, Environment and Water Management and Federal Ministry of Science, Research and Economy.

BMLRT. 2021. Masterplan Raw Materials 2030. Vienna: Federal Ministry of Agriculture, Regions and Tourism.

BMNT, BMBWF, and BMVIT. 2019. Bioeconomy. A Strategy for Austria. Vienna: Federal Ministry of Sustainability and Tourism, Federal Ministry of Education, Science and Research, Federal Ministry of Transport, Innovation and Technology. bmluk.gv.at/dam/jcr:69bdc92b-83fe-468a-9ec0-4d29295a505b/Oe_Biooekonomie_Strategie_en.pdf

Brand, Ulrich, Christoph Görg, and Markus Wissen. 2020. Overcoming neoliberal globalization: social-ecological transformation from a Polanyian perspective and beyond. Globalizations 17: 161–176. doi.org/10.1080/14747731.2019.1644708.

Brand-Correa, Lina I., Giulio Mattioli, William F. Lamb, and Julia K. Steinberger. 2020. Understanding (and tackling) need satisfier escalation. Sustainability: Science, Practice and Policy 16: 309–325. doi.org/10.1080/15487733.2020.1816026.

Carmona, Luis Gabriel, Kai Whiting, and Jonathan Cullen. 2022. A stock-flow-service nexus vision of the low carbon economy. Energy Reports 8: 565–575. doi.org/10.1016/j.egyr.2022.10.086.

Chancel, Lucas. 2022. Global carbon inequality over 1990–2019. Nature Sustainability 5: 931–938. doi.org/10.1038/s41893-022-00955-z.

Chowdhury, Priyabrata, Sanjoy Kumar Paul, Shahriar Kaisar, and Md. Abdul Moktadir. 2021. COVID-19 pandemic related supply chain studies: A systematic review. Transportation Research Part E: Logistics and Transportation Review 148: 102271. doi.org/10.1016/j.tre.2021.102271.

Creutzig, Felix, J. Roy, P. Devine-Wright, J. Diaz-José, F.W. Geels, Arnulf Grubler, N. Maizi, et al. 2022. Demand, services and social aspects of mitigation. In Climate Change 2022 - Mitigation of Climate Change: Working Group III Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Ed. Intergovernmental Panel

On Climate Change (IPCC), 1. Aufl. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. doi.org/10.1017/9781009157926.

CSIRO. 2022. Technical annex for Global Material Flows Database - 2021 edition. Last Revised: 30th August 2022. Australia's National Science Agency.

Dobson, Andrew P., Stuart L. Pimm, Lee Hannah, Les Kaufman, Jorge A. Ahumada, Amy W. Ando, Aaron Bernstein, et al. 2020. Ecology and economics for pandemic prevention. Science 369: 379–381. doi.org/10.1126/science.abc3189.

Dorninger, Christian, Alf Hornborg, David J. Abson, Henrik von Wehrden, Anke Schaffartzik, Stefan Giljum, John-Oliver Engler, Robert L. Feller, Klaus Hubacek, and Hanspeter Wieland. 2021. Global patterns of ecologically unequal exchange: Implications for sustainability in the 21st century. Ecological Economics 179: 106824. doi.org/10.1016/j.ecolecon.2020.106824.

EEA. 2023. Conditions and pathways for sustainable and circular consumption in Europe. Briefing no. 11/2023. Copenhagen, Denmark: European Environment Agency.

Eisenmenger, Nina, Dominik Wiedenhofer, Anke Schaffartzik, Stefan Giljum, Martin Bruckner, Heinz Schandl, Thomas O. Wiedmann, Manfred Lenzen, Arnold Tukker, and Arjan Koning. 2016. Consumption-based material flow indicators — Comparing six ways of calculating the Austrian raw material consumption providing six results. Ecological Economics 128: 177–186. doi.org/furlan.

Elhacham, Emily, Liad Ben-Uri, Jonathan Grozovski, Yinon M. Bar-On, and Ron Milo. 2020. Global human-made mass exceeds all living biomass. Nature 588: 442–444. doi.org/10.1038/s41586-020-3010-5.

Eora. 2014. The Eora MRIO Database. worldmrio.com

EU. 2011. Regulation on European environmental economic accounts. Regulation (EU) No 691/2011. Official Journal of the European Union. Brussels: European Parliament and Council.

European Commission. 2011. A resource-efficient Europe – Flagship initiative under the Europe 2020 Strategy. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions COM(2011) 21. Brussels.

European Commission. 2014. Towards a circular economy: A zero waste programme for Europe. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions COM(2014) 398 final/2. Brussels.

European Commission. 2019. The European Green Deal. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions COM(2019) 640 final. Brussels.

European Commission. 2023a. A revised monitoring framework for the circular economy. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions COM(2023) 306 final. Brussels.

European Commission. 2023b. Circular Economy. environment.ec.europa.eu/topics/circular-economy_en

European Commission. 2023c. establishing a framework for ensuring a secure and sustainable supply of critical raw materials and amending Regulations (EU) 168/2013, (EU) 2018/858, 2018/1724 and (EU) 2019/1020. Regulation of the European Parliament and of the Council COM(2023) 160 final. Brussels.

Eurostat. 2001. Economy-wide material flow accounts and derived indicators. A methodological guide. Official Publications of the European Communities. Luxembourg: European Commission.

Eurostat. 2002. Material use in the European Union 1980-2000. Indicators and Analysis. Luxembourg: Eurostat, Office for Official Publications of the European Communities, prepared by Weisz, H., Fischer-Kowalski, M., Amann, C., Eisenmenger, N., Hubacek, K., and Krausmann, F.

Eurostat. 2015. Water statistics - Statistics Explained. ec.europa.eu/eurostat/statistics-explained/index.php?title=Water_statistics&oldid=204654

Eurostat. 2018. Economy-wide material flow accounts. Handbook 2018 edition. Luxembourg: European Union.

Eurostat. 2023a. Eurostat databases. ec.europa.eu/eurostat/data/database

Eurostat. 2023b. Material flow accounts statistics - material footprints. Statistics explained. ec.europa.eu/eurostat/statistics-explained/index.php?title=Material_flow_accounts_statistics_-_material_footprints

Eurostat. 2023c. Database. Material flow accounts. ec.europa.eu/eurostat/databrowser/view/env_ac_mfa/default/table?lang=en

Eurostat. 2023d. Database. Material footprints. ec.europa.eu/eurostat/databrowser/view/env_ac_rme/default/table?lang=en

Eurostat. 2023e. Waste. Targets.

Eurostat. 2024a. Database. Material flow accounts - domestic processed output. ec.europa.eu/eurostat/databrowser/view/env_ac_mfadpo/default/table?lang=en

Eurostat. 2024b. EU circular economy monitoring framework. ec.europa.eu/eurostat/web/circular-economy/monitoring-framework

Eurostat. 2024c. Circular material use rate. ec.europa.eu/eurostat/databrowser/view/cei_srm030/default/table?lang=en&category=cei.cei_srm

Eurostat. 2024d. Eurostat. Statistics Explained. Circular economy - material flows. ec.europa.eu/eurostat/statistics-explained/index.php?title=Circular_economy_-_material_flows#Circularity_rate

Fanning, Andrew L., Daniel W. O'Neill, Jason Hickel, and Nicolas Roux. 2022. The social shortfall and ecological overshoot of nations. Nature Sustainability 5: 26–36. doi.org/10.1038/s41893-021-00799-z.

FAO. 2023. FAOSTAT statistical database. faostat.fao.org

Fishman, Tomer, Heinz Schandl, and Hiroki Tanikawa. 2015. The socio-economic drivers of material stock accumulation in Japan's prefectures. Ecological Economics 113: 76–84. doi.org/10.1016/j.ecolecon.2015.03.001.

Forrester, Jay W. 1994. System dynamics, systems thinking, and soft OR. System Dynamics Review 10: 245–256. doi.org/10.1002/sdr.4260100211.

Fuchs, Doris, Marlyne Sahakian, Tobias Gumbert, Antonietta Di Giulio, Michael Maniates, Sylvia Lorek, and Antonia Graf. 2021. Consumption Corridors. Living a Good Life within Sustainable Limits. London and New York: Routledge, Taylor & Francis Group.

Giljum, Stefan, Victor Maus, Nikolas Kuschnig, Sebastian Luckeneder, Michael Tost, Laura J. Sonter, and Anthony J. Bebbington. 2022. A pantropical assessment of deforestation caused by industrial mining. Proceedings of the National Academy of Sciences 119: e2118273119. doi.org/10.1073/pnas.2118273119.

Giljum, Stefan, Hanspeter Wieland, Stephan Lutter, Nina Eisenmenger, Heinz Schandl, and Anne Owen. 2019. The impacts of data deviations between MRIO models on material footprints: A comparison of EXIOBASE, Eora, and ICIO. Journal of Industrial Ecology 23: 946–958. doi.org/10.1111/jiec.12833.

Gingrich, Simone, Maria Niedertscheider, Thomas Kastner, Helmut Haberl, Georgia Cosor, Fridolin Krausmann, Tobias Kuemmerle, et al. 2015. Exploring long-term trends in land use change and aboveground human appropriation of net primary production in nine European countries. Land Use Policy 47: 426–438. doi.org/10.1016/j.landusepol.2015.04.027.

Görg, Christoph, Ulrich Brand, Helmut Haberl, Diana Hummel, Thomas Jahn, and Stefan Liehr. 2017. Challenges for Social-Ecological Transformations: Contributions from Social and Political Ecology. Sustainability 9: 1045. doi.org/10.3390/su9071045.

Görg, Christoph, Verena Madner, Andreas Muhar, Andreas Novy, Alfred Posch, Karl W. Steininger, and Ernest Aigner, eds. 2023. APCC Special Report: Strukturen für ein klimafreundliches Leben. Berlin, Heidelberg: Springer Berlin Heidelberg. doi.org/10.1007/978-3-662-66497-1.

Graedel, T. E. 2010. Metal stocks in society: scientific synthesis. Working Group on the Global Metal Flows. Nairobi: UNEP.

Grafström, Jonas, and Siri Aasma. 2021. Breaking circular economy barriers. Journal of Cleaner Production 292: 126002. doi.org/10.1016/j.jclepro.2021.126002.

Haas, Willi, Fridolin Krausmann, Dominik Wiedenhofer, and Markus Heinz. 2015. How Circular is the Global Economy? An Assessment of Material Flows, Waste Production, and Recycling in the European Union and the World in 2005. Journal of Industrial Ecology 19: 765–777. doi.org/10.1111/jiec.12244.

Haas, Willi, Fridolin Krausmann, Dominik Wiedenhofer, Christian Lauk, and Andreas Mayer. 2020. Spaceship earth's odyssey to a circular economy - a century long perspective. Resources, Conservation and Recycling 163: 105076. doi.org/10.1016/j.resconrec.2020.105076.

Haas, Willi, Ina Meyer, Doris Virág, Gerald Kalt, André Baumgart, Nina Eisenmenger, Mark Sommer, and Kurt Kratena. 2024. Circular Economy and Decarbonisation: Synergies and trade-offs (CE DC). Final report ACRP research project KR19AC0K17512. Vienna.

Haas, Willi, Andreas Muhar, Christian Dorninger, and Katharina Gugerell. 2023. Kapitel 23. Synthese: Pfade zur Transformation struktureller Bedingungen für ein klimafreundliches Leben. In APCC Special Report: Strukturen für ein klimafreundliches Leben (APCC SR

Klimafreundliches Leben), eds. Christoph Görg, Verena Madner, Andreas Muhar, Andreas Novy, Alfred Posch, Karl W. Steininger, and Ernest Aigner. Berlin: Springer Spektrum.

Haberl, Helmut, Marina Fischer-Kowalski, Fridolin Krausmann, and Verena Winiwarter, eds. 2016. Social ecology: society-nature relations across time and space. Human-Environment Interactions volume 5. Switzerland: Springer.

Haberl, Helmut, Markus Löw, Alejandro Perez-Laborda, Sarah Matej, Barbara Plank, Dominik Wiedenhofer, Felix Creutzig, Karl-Heinz Erb, and Juan Antonio Duro. 2023. Built structures influence patterns of energy demand and CO_2 emissions across countries. Nature Communications 14: 3898. doi.org/10.1038/s41467-023-39728-3.

Haberl, Helmut, Martin Schmid, Willi Haas, Dominik Wiedenhofer, Henrike Rau, and Verena Winiwarter. 2021. Stocks, flows, services and practices: Nexus approaches to sustainable social metabolism. Ecological Economics 182: 106949. doi.org/10.1016/j.ecolecon.2021.106949.

Haberl, Helmut, Dominik Wiedenhofer, Karl-Heinz Erb, Christoph Görg, and Fridolin Krausmann. 2017. The Material Stock–Flow–Service Nexus: A New Approach for Tackling the Decoupling Conundrum. Sustainability 9: 1049. NE-box. doi.org/10.3390/su9071049.

Haberl, Helmut, Dominik Wiedenhofer, Stefan Pauliuk, Fridolin Krausmann, Daniel B. Müller, and Marina Fischer-Kowalski. 2019. Contributions of sociometabolic research to sustainability science. Nature Sustainability 2: 173–184. NE-box. doi.org/10.1038/s41893-019-0225-2.

Haberl, Helmut, Dominik Wiedenhofer, Franz Schug, David Frantz, Doris Virág, Christoph Plutzar, Karin Gruhler, et al. 2021. High-resolution maps of material stocks in buildings and infrastructures in Austria and Germany. Environmental Science & Technology accepted.

Haberl, Helmut, Dominik Wiedenhofer, Doris Virág, Gerald Kalt, Barbara Plank, Paul Brockway, Tomer Fishman, et al. 2020. A systematic review of the evidence on decoupling of GDP, resource use and GHG emissions, part II: synthesizing the insights. Environmental Research Letters. doi.org/10.1088/1748-9326/ab842a.

Helander, Hanna, Anna Petit Boix, Sina Leipold, and Stefan Bringezu. 2019. How to monitor environmental pressures of a circular economy: An assessment of indicators. Journal of Industrial Ecology 23: 1278–1291. doi.org/10.1111/jiec.12924.

Hickel, Jason. 2019. The contradiction of the sustainable development goals: Growth versus ecology on a finite planet. Sustainable Development 27: 873–884. doi.org/10.1002/sd.1947.

Hickel, Jason, and Giorgos Kallis. 2019. Is Green Growth Possible? New Political Economy: 1–18. doi.org/10.1080/13563467.2019.1598964.

Hubacek, Klaus, Giovanni Baiocchi, Kuishuang Feng, Raúl Muñoz Castillo, Laixiang Sun, and Jinjun Xue. 2017. Global carbon inequality. Energy, Ecology and Environment 2: 361–369. doi.org/10.1007/s40974-017-0072-9.

Infante-Amate, Juan, and Fridolin Krausmann. 2019. Trade, Ecologically Unequal Exchange and Colonial Legacy: The Case of France and its Former Colonies (1962–2015). Ecological Economics 156: 98–109. NE-box. doi.org/10.1016/j.ecolecon.2018.09.013.

IPCC. 2023. Summary for Policymakers. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. First. Geneva, Switzerland: Intergovernmental Panel on Climate Change (IPCC). doi.org/10.59327/IPCC/AR6-9789291691647.

Jackson, Tim. 2014. Sustainable consumption. In Handbook of Sustainable Development, eds. Giles Atkinson, Simon Dietz, Eric Neumayer, and Matthew Agarwala. Edward Elgar Publishing. doi.org/10.4337/9781782544708.00029.

Jackson, Tim, and Peter A. Victor. 2019. Unraveling the claims for (and against) green growth. Science 366: 950–951. doi.org/10.1126/science.aay0749.

Jacobi, Nikolai, Willi Haas, Dominik Wiedenhofer, and Andreas Mayer. 2018. Providing an economy-wide monitoring framework for the circular economy in Austria: Status quo and challenges. Resources, Conservation and Recycling 137: 156–166. NE-box. doi.org/10.1016/j.resconrec.2018.05.022.

Jandl, Robert, Ulrike Tappeiner, Cecilie Birgitte Foldal, and Karlheinz Erb, eds. 2024. APCC Special Report: Landnutzung und Klimawandel in Österreich. Berlin, Heidelberg: Springer Berlin Heidelberg. doi.org/10.1007/978-3-662-67864-0.

Jonas, Michael, Andreas Novy, Richard Bärnthaler, Veronica Karabaczek, Leonhard Plank, and Thomas Schinko. 2023. Kapitel 27. Theorien des Wandels und der Gestaltung von Strukturen: Bereitstellungsperspektive. In APCC Special Report: Strukturen für ein klimafreundliches Leben (APCC SR Klimafreundliches Leben), eds. Christoph Görg, Verena Madner, Andreas Muhar, Andreas Novy, Alfred Posch, Karl W. Steininger, and Ernest Aigner. Berlin, Heidelberg: Springer Spektrum.

Kirchherr, Julian, Denise Reike, and Marko Hekkert. 2017. Conceptualizing the circular economy: An analysis of 114 definitions. Resources, Conservation and Recycling 127: 221–232. doi.org/10.1016/j.resconrec.2017.09.005.

de Koning, Arjan, Martin Bruckner, Stephan Lutter, Richard Wood, Konstantin Stadler, and Arnold Tukker. 2015. Effect of aggregation and disaggregation on embodied material use of products in input–output analysis. Ecological Economics 116: 289–299. doi.org/10.1016/j.ecolecon.2015.05.008.

Korhonen, Jouni, Antero Honkasalo, and Jyri Seppälä. 2018. Circular Economy: The Concept and its Limitations. Ecological Economics 143: 37–46. doi.org/10.1016/j.ecolecon.2017.06.041.

Krausmann, Fridolin, Christian Lauk, Willi Haas, and Dominik Wiedenhofer. 2018. From resource extraction to outflows of wastes and emissions: The socioeconomic metabolism of the global economy, 1900–2015. Global Environmental Change 52: 131–140. doi.org/10.1016/j.gloenvcha.2018.07.003.

Krausmann, Fridolin, Heinz Schandl, Nina Eisenmenger, Stefan Giljum, and Tim Jackson. 2017. Material Flow Accounting: Measuring Global Material Use for Sustainable Development. Annual Review of Environment and Resources 42: 647–675. doi.org/10.1146/annurev-environ-102016-060726.

Krausmann, Fridolin, Dominik Wiedenhofer, and Helmut Haberl. 2020. Growing stocks of buildings, infrastructures and machinery as key challenge for compliance with climate targets. Global Environmental Change 61: 102034. doi.org/10.1016/j.gloenvcha.2020.102034.

Krausmann, Fridolin, Dominik Wiedenhofer, Christian Lauk, Willi Haas, Hiroki Tanikawa, Tomer Fishman, Alessio Miatto, Heinz Schandl, and Helmut Haberl. 2017. Global socioeconomic material stocks rise 23-fold over the 20th century and require half of annual resource use. Proceedings of the National Academy of Sciences 114: 1880–1885. doi.org/10.1073/pnas.1613773114.

Lade, Steven J., Will Steffen, Wim De Vries, Stephen R. Carpenter, Jonathan F. Donges, Dieter Gerten, Holger Hoff, Tim Newbold, Katherine Richardson, and Johan Rockström. 2019. Human impacts on planetary boundaries amplified by Earth system interactions. Nature Sustainability 3: 119–128. doi.org/10.1038/s41893-019-0454-4.

Lauk, Christian, Lisa Kaufmann, Michaela C. Theurl, Fritz Wittmann, Michael Eder, Stefan Hörtenhuber, Bernhard Freyer, and Fridolin Krausmann. 2022. Demand side options to reduce greenhouse gas emissions and the land footprint of urban food systems: A scenario analysis for the City of Vienna. Journal of Cleaner Production 359: 132064. doi.org/10.1016/j.jclepro.2022.132064.

Lenton, Timothy M., Johan Rockström, Owen Gaffney, Stefan Rahmstorf, Katherine Richardson, Will Steffen, and Hans Joachim Schellnhuber. 2019. Climate tipping points — too risky to bet against. Nature 575: 592–595. doi.org/10.1038/d41586-019-03595-0.

Lenzen, Manfred, Arne Geschke, Muhammad Daaniyall Abd Rahman, Yanyan Xiao, Jacob Fry, Rachel Reyes, Erik Dietzenbacher, et al. 2017. The Global MRIO Lab – charting the world economy. Economic Systems Research 29: 158–186. doi.org/10.1080/09535314.2017.1301887.

Lenzen, Manfred, Arne Geschke, James West, Jacob Fry, Arunima Malik, Stefan Giljum, Llorenç Milà I Canals, et al. 2021. Implementing the material footprint to measure progress towards Sustainable Development Goals 8 and 12. Nature Sustainability 5: 157–166. doi.org/10.1038/s41893-021-00811-6.

Lenzen, Manfred, Daniel Moran, Keiichiro Kanemoto, Barney Foran, L. Lobefaro, and Arne Geschke. 2012. International trade drives biodiversity threats in developing nations. Nature 486: 109–112. NE-box.

Lenzen, Manfred, Daniel Moran, Keiichiro Kanemoto, and Arne Geschke. 2013. Building Eora: a Global Multi-Region Input-Output Database at High Country and Sector Resolution. Economic Systems Research 25: 20–49. doi.org/10.1080/09535314.2013.769938.

Luckeneder, Sebastian, Stefan Giljum, Anke Schaffartzik, Victor Maus, and Michael Tost. 2021. Surge in global metal mining threatens vulnerable ecosystems. Global Environmental Change 69: 102303. doi.org/10.1016/j.gloenvcha.2021.102303.

Marques, Alexandra, Inês S. Martins, Thomas Kastner, Christoph Plutzar, Michaela C. Theurl, Nina Eisenmenger, Mark A. J. Huijbregts, et al. 2019. Increasing impacts of land use on biodiversity and carbon sequestration driven by population and economic growth. Nature Ecology & Evolution. NE-box. doi.org/10.1038/s41559-019-0824-3.

Mayer, Andreas, Willi Haas, Dominik Wiedenhofer, Fridolin Krausmann, Philip Nuss, and Gian Andrea Blengini. 2018. Measuring Progress towards a Circular Economy. A Monitoring Framework for Economy-wide Material Loop Closing in the EU28. Journal of Industrial Ecology. doi.org/10.1111/jiec.12809.

Meadows, D.H., D.L. Meadows, J. Randers, and W.W. Behrens. 1972. The Limits to Growth: A Report for the Club of Rome's Project on the Predicament of Mankind. New York: Universe Books.

Miatto, Alessio, Nargessadat Emami, Kylie Goodwin, James West, Mohammad Sadegh Taskhiri, Thomas Wiedmann, and Heinz Schandl. 2024. Australia's circular economy metrics and indicators. Journal of Industrial Ecology: jiec.13458. doi.org/10.1111/jiec.13458.

Millward-Hopkins, Joel. 2022. Inequality can double the energy required to secure universal decent living. Nature Communications 13: 5028. doi.org/10.1038/s41467-022-32729-8.

Millward-Hopkins, Joel, Julia K. Steinberger, Narasimha D. Rao, and Yannick Oswald. 2020. Providing decent living with minimum energy: A global scenario. Global Environmental Change 65: 102168. doi.org/10.1016/j.gloenvcha.2020.102168.

Moraga, Gustavo, Sophie Huysveld, Fabrice Mathieux, Gian Andrea Blengini, Luc Alaerts, Karel Van Acker, Steven de Meester, and Jo Dewulf. 2019. Circular economy indicators: What do they measure? Resources, Conservation and Recycling 146: 452–461. NE-box. doi.org/10.1016/j.resconrec.2019.03.045.

Morseletto, Piero. 2020. Targets for a circular economy. Resources, Conservation and Recycling 153: 104553. NE-box. doi.org/10.1016/j.resconrec.2019.104553.

Neubauer, Milla, and Sylvia Gierlinger. 2022. Umweltgesamtrechnungen Modul Materialflussrechnung. Zeitreihe 2000 bis 2020. Projektbericht (environmental accounts, module material flow accounts. Time series 2000 to 2020. Project Report). Vienna: Statistics Austria.

Neubauer, Milla, Sylvia Gierlinger, Sascha Baud, and Statistik Austria, Direktion Raumwirtschaft, Bereich Energie, Umwelt. 2023. Standard-Dokumentation, Metainformationen (Definitionen, Erläuterungen, Methoden, Qualität) zur Materialflussrechnungen. Vienna: Statistics Austria.

Neunteufel, Roman, Nadine Sinemus, and Maximilian Grunert. 2021. Virtuelles Wasser 2021. Wasserfußabdruck - der Wasserverbrauch für Güter des täglichen Bedarfs. (virtual water 2021. Water footprint – water use for goods of daily needs.) Bundesministerium für Landwirtschaft, Regionen und Tourismus und Österreichische Vereinigung für das Gas- und Wasserfach. Autor:innen von der Universität für Bodenkultur Wien, Inst. für Siedlungswasserbau, Industriewasserwirtschaft und Gewässerschutz. Vienna: Federal Ministry of Agriculture, Regions and Tourism.

Novy, Andreas, Richard Bärnthaler, and Magdalena Prieler. 2023. Zukunftsfähiges Wirtschaften: Herausforderungen der sozialökologischen Transformation. 2., überarbeitete Auflage. Arbeitsgesellschaft im Wandel. Weinheim Basel: Beltz Juventa.

Nuss, Philip, Gian Andrea Blengini, Willi Haas, Andreas Mayer, Viorel Nita, and Pennington David. 2017. Development of a Sankey Diagram of Material Flows in the EU Economy based on Eurostat Data. EUR 28811. JRC Technical Reports. Luxembourg: Publication Office of the European Union.

OECD. 2018. Global Material Resources Outlook to 2060: Economic Drivers and Environmental Consequences. ENV/EPOC/WPEI(2015)1. Paris: OECD Publishing.

OECD. 2023. Green growth and sustainable development.

O'Neill, Daniel W., Andrew L. Fanning, William F. Lamb, and Julia K. Steinberger. 2018. A good life for all within planetary boundaries. Nature Sustainability 1: 88–95. NE-box. doi.org/10.1038/s41893-018-0021-4.

ÖROK. 2024. Flächeninanspruchnahme bis 2021 (land take until 2021). oerok.gv.at/raum/daten-und-grundlagen/ergebnisse-oesterreich-2022

Ottelin, Juudit, Hale Cetinay, and Paul Behrens. 2020. Rebound effects may jeopardize the resource savings of circular consumption: evidence from household material footprints. Environmental Research Letters 15: 104044. doi.org/10.1088/1748-9326/abaa78.

Otto, Ilona M., Kyoung Mi Kim, Nika Dubrovsky, and Wolfgang Lucht. 2019. Shift the focus from the super-poor to the super-rich. Nature Climate Change 9: 82–84. doi.org/10.1038/s41558-019-0402-3.

ÖVGW. 2019. Die Österreichische Trinkwasserwirtschaft. Branchendaten und Fakten. Kurzzusammenfassung ÖVGW-Branchenbild 2018 mit Ergänzungen Februar 2019. Österreichische Vereinigung für das Gas- und Wasserfach.

Owen, Anne, Kjartan Steen-Olsen, John Barrett, Thomas Wiedmann, and Manfred Lenzen. 2014. A STRUCTURAL DECOMPOSITION APPROACH TO COMPARING MRIO DATABASES. Economic Systems Research 26: 262–283. NE-box. doi.org/10.1080/09535314.2014.935299.

Parrique, Timothée, Jonathan Barth, François Briens, Christian Kerschner, Alejo Kraus-Polk, Anna Kuokkanen, and Joachim H. Spangenberg. 2019. Decoupling Debunked. Evidence and arguments against green growth as a sole strategy for sustainability. European Environmental Bureau.

Pauliuk, Stefan. 2024. Decent living standards, prosperity, and excessive consumption in the Lorenz curve. Ecological Economics 220: 108161. doi.org/10.1016/j.ecolecon.2024.108161.

Pauliuk, Stefan, and Niko Heeren. 2021. Material efficiency and its contribution to climate change mitigation in Germany: A deep decarbonization scenario analysis until 2060. Journal of Industrial Ecology 25: 479–493. doi.org/10.1111/jiec.13091.

Pauliuk, Stefan, Niko Heeren, Peter Berrill, Tomer Fishman, Andrea Nistad, Qingshi Tu, Paul Wolfram, and Edgar G. Hertwich. 2021. Global scenarios of resource and emission savings from material efficiency in residential buildings and cars. Nature Communications 12: 5097. doi.org/10.1038/s41467-021-25300-4.

Pauliuk, Stefan, and Daniel B. Müller. 2014. The role of in-use stocks in the social metabolism and in climate change mitigation. Global Environmental Change 24: 132–142. NE-box. doi.org/10.1016/j.gloenvcha.2013.11.006.

Persson, Linn, Bethanie M. Carney Almroth, Christopher D. Collins, Sarah Cornell, Cynthia A. De Wit, Miriam L. Diamond, Peter Fantke, et al. 2022. Outside the Safe Operating Space of the Planetary Boundary for Novel Entities. Environmental Science & Technology 56: 1510–1521. doi.org/10.1021/acs.est.1c04158.

Pichler, Peter-Paul, Ingram S Jaccard, Ulli Weisz, and Helga Weisz. 2019. International comparison of health care carbon footprints. Environmental Research Letters 14: 064004. NE-box. doi.org/10.1088/1748-9326/ab19e1.

Pirgmaier, Elke. 2020. Consumption corridors, capitalism and social change. Sustainability: Science, Practice and Policy 16: 274–285. doi.org/10.1080/15487733.2020.1829846.

Pladerer, Christian, and Philipp Hietler. 2019. Abfallvermeidung in der österreichischen Lebensmittelproduktion. Österreichische Wasser- und Abfallwirtschaft 71: 238–245. doi.org/10.1007/s00506-019-0578-9.

Potting, José, Marko P Hekkert, Ernst Worrell, and Aldert Hanemaaijer. 2017. Circular Economy: Measuring Innovation in the Product Chain. 2544. Planbureau voor de Leefomgeving. Utrecht University Repository in Netherlands Research Portal.

Raworth, Kate. 2017. Doughnut economics: seven ways to think like a 21st-century economist. Chelsea Green Publishing.

Richardson, Katherine, Will Steffen, Wolfgang Lucht, Jørgen Bendtsen, Sarah E. Cornell, Jonathan F. Donges, Markus Drüke, Ingo Fetzer, Govindasamy Bala, Werner von Bloh, et al. 2023. Earth beyond six of nine planetary boundaries. Science Advances 9. American Association for the Advancement of Science: eadh2458. doi.org/10.1126/sciadv.adh2458.

Ripple, William J., Christopher Wolf, Timothy M. Lenton, Jillian W. Gregg, Susan M. Natali, Philip B. Duffy, Johan Rockström, and Hans Joachim Schellnhuber. 2023. Many risky feedback loops amplify the need for climate action. One Earth 6: 86–91. doi.org/10.1016/j.oneear.2023.01.004.

Rockström, Johan, Will Steffen, Kevin Noone, Åsa Persson, F. Stuart Chapin, Eric F. Lambin, Timothy M. Lenton, et al. 2009a. A safe operating space for humanity. Nature 461: 472–475. NE-box. doi.org/10.1038/461472a.

Rockström, Johan, Will Steffen, Kevin Noone, Åsa Persson, F. Stuart Chapin, Eric Lambin, Timothy M. Lenton, et al. 2009b. Planetary Boundaries: Exploring the Safe Operating Space for Humanity. Ecology and Society 14. NE-box.

Sahakian, Marlyne, Doris Fuchs, Sylvia Lorek, and Antonietta Di Giulio. 2021. Advancing the concept of consumption corridors and exploring its implications. Sustainability: Science, Practice and Policy 17: 305–315. doi.org/10.1080/15487733.2021.1919437.

Schaffartzik, Anke, Nina Eisenmenger, Fridolin Krausmann, and Helga Weisz. 2014. Consumption-based Material Flow Accounting: Austrian Trade and Consumption in Raw Material Equivalents 1995-2007. Journal of Industrial Ecology 18: 102–112. doi.org/10.1111/jiec.12055.

Schaffartzik, Anke, and Fridolin Krausmann. 2021. A socio-metabolic perspective on (material) growth and inequality. In The Routledge Handbook of the Political Economy of the Environment, eds. Éloi Laurent and Klara Zwickl, 1st Edn. London: Routledge. doi.org/10.4324/9780367814533.

Schaffartzik, Anke, Melanie Pichler, Eric Pineault, Dominik Wiedenhofer, Robert Gross, and Helmut Haberl. 2021. The transformation of provisioning systems from an integrated perspective of social metabolism and political economy: a conceptual framework. Sustainability Science 16: 1405–1421. doi.org/10.1007/s11625-021-00952-9.

Schirpke, Uta, Erich Tasser, Stefan Borsky, Martin Braun, Josef Eitzinger, Veronika Gaube, Michael Getzner, et al. 2023. Past and future impacts of land-use changes on ecosystem services in Austria. Journal of Environmental Management 345: 118728. doi.org/10.1016/j.jenvman.2023.118728.

Schlatzer, Martin, and Thomas Lindenthal. 2020. Einfluss von unterschiedlichen Ernährungsweisen auf Klimawandel und Flächeninanspruchnahme in Österreich und Übersee (DIETCCLU). Endbericht von StartClim2019. Endbericht von StartClim2019. fibl.org/fileadmin/documents/de/news/2020/startclim_endbericht_2012.pdf.

Schoer, Karl, Jan Weinzettel, Jan Kovanda, Jürgen Giegrich, and Christoph Lauwigi. 2012. Raw Material Consumption of the European Union – Concept, Calculation Method, and Results. Environmental Science & Technology 46: 8903–8909. NE-box. doi.org/10.1021/es300434c.

Soonsawad, Natthanij, Raymundo Marcos Martinez, and Heinz Schandl. 2022. Material demand, and environmental and climate implications of Australia's building stock: Current status and outlook to 2060. Resources, Conservation and Recycling 180: 106143. doi.org/10.1016/j.resconrec.2021.106143.

Sorrell, Steve, Birgitta Gatersleben, and Angela Druckman. 2020. The limits of energy sufficiency: A review of the evidence for rebound effects and negative spillovers from behavioural change. Energy Research & Social Science 64: 101439. doi.org/10.1016/j.erss.2020.101439.

Stadler, Konstantin, Richard Wood, Tatyana Bulavskaya, Carl-Johan Södersten, Moana Simas, Sarah Schmidt, Arkaitz Usubiaga, et al. 2018. EXIOBASE 3: Developing a Time Series of Detailed Environmentally Extended Multi-Regional Input-Output Tables: EXIOBASE 3. Journal of Industrial Ecology. doi.org/10.1111/jiec.12715.

Statistics Austria. 2023a. Physische Energieflussrechnungen. (physical energy flow accounts) statistik.at/statistiken/energie-und-umwelt/energie/physische-energieflussrechnungen

Statistics Austria. 2023b. Bodennutzung (land use). statistik.at/statistiken/land-und-forstwirtschaft/betriebsstruktur/bodennutzung

Statistics Austria. 2023c. Materialflussrechnung (material flow accounts). statistik.at/statistiken/energie-und-umwelt/umwelt/materialflussrechnung

Statistics Austria. 2023d. Bruttoinlandsprodukt und Hauptaggregate (Gross domestic product and main aggregates). statistik.at/statistiken/volkswirtschaft-und-oeffentliche-finanzen/volkswirtschaftliche-gesamtrechnungen/bruttoinlandsprodukt-und-hauptaggregate

Statistics Austria. 2023e. Circular Economy. Material Flows in Austria in the year 2023 in 1 000 tons. kreislaufwirtschaft.statistik.at/kreislaufwirtschaft/en

Statistics Austria. 2024. Material flow accounts. statistik.at/en/statistics/energy-and-environment/environment/material-flow-accounts

Steffen, W., K. Richardson, J. Rockstrom, S. E. Cornell, I. Fetzer, E. M. Bennett, R. Biggs, et al. 2015. Planetary boundaries: Guiding human development on a changing planet. Science 347: 1259855–1259855. NE-box. doi.org/10.1126/science.1259855.

Steffen, Will, Wendy Broadgate, Lisa Deutsch, Owen Gaffney, and Cornelia Ludwig. 2015. The trajectory of the Anthropocene: The Great Acceleration. The Anthropocene Review 2: 81–98. NE-box. doi.org/10.1177/2053019614564785.

Steinberger, Julia K., and J. Timmons Roberts. 2010. From constraint to sufficiency: The decoupling of energy and carbon from human needs, 1975–2005. Ecological Economics 70: 425–433. NE-box. doi.org/10.1016/j.ecolecon.2010.09.014.

Sweeney, Linda Booth, and John D. Sterman. 2000. Bathtub dynamics: initial results of a systems thinking inventory. System Dynamics Review 16: 249–286. doi.org/10.1002/sdr.198.

Tanikawa, Hiroki, Tomer Fishman, Seiji Hashimoto, Ichiro Daigo, Masahiro Oguchi, Alessio Miatto, Shigesada Takagi, Naho Yamashita, and Heinz Schandl. 2021. A framework of indicators for associating material stocks and flows to service provisioning: Application for Japan 1990–2015. Journal of Cleaner Production 285: 125450. doi.org/10.1016/j.jclepro.2020.125450.

Tanikawa, Hiroki, Tomer Fishman, Feng Shi, Ji Han, Heinz Schandl, and Fridolin Krausmann. 2012. Is there a material stock saturation of nations?

Umweltbundesamt (Federal Environment Agency). 2023a. Treibhausgas-Bilanz Österreichs 2021 (Greenhouse Gas Balance 2021). umweltbundesamt.at/news230123

Umweltbundesamt (Federal Environment Agency). 2023b. Treibhausgas-Bilanz Österreichs 2021. Daten & Grafiken. (Greenhouse Gas Balance 2021. Data and Graphs.) umweltbundesamt.at/news220123/thg-daten-1

Umweltbundesamt (Federal Environment Agency). 2024a. Flächeninanspruchnahme bis 2021 (land take until 2011). umweltbundesamt.at/umweltthemen/boden/flaechen-inanspruchnahme-bis-2021

Umweltbundesamt (Federal Environment Agency). 2024b. Treibhausgas-Bilanz Österreichs 2022 (Greenhouse Gas Balance 2022). umweltbundesamt.at/news240116

UN. 2015. Sustainable development goals. 17 Goals to Transform Our World. un.org/sustainabledevelopment

UN. 2017. System of Environmental Economic Accounting (SEEA). seea.un.org

UN. 2023. System of Environmental Economic Accounts for Water. SEEA-Water. seea.un.org/content/seea-water

UN Environment. 2024. SCP HotspotAnalysis. Hotspot Analysis Tool for Sustainable Consumption and Production to support science-based national policy frameworks. SCP-HAT 3.0. scp-hat.lifecycleinitiative.org

UN IRP. 2011. Decoupling natural resource use and environmental impacts from economic growth. Report of the International Resource Panel. Authors: Marina Fischer-Kowalski, Mark Swilling, Ernst U. von Weizsäcker, Y. Ren, Yuichi Moriguchi, W. Crane, Fridolin Krausmann, Nina Eisenmenger, Stefan Giljum, P. Hennicke, P. Romero Lankao, A. Siriban Manalang, S. Sewerin. Paris: United Nations Environment Programme.

UN IRP. 2019a. Global Resources Outlook 2019: Natural Resources for the Future We Want. Report of the International Resource Panel. Authors: Oberle, B., Bringezu, S., Hatfield-Dodds, S., Hellweg, S., Schandl, H., Clement, J., and Cabernard, L., Che, N., Chen, D., Droz-Georget , H., Ekins, P., Fischer-Kowalski, M., Flörke, M., Frank, S., Froemelt , A., Geschke, A., Haupt , M., Havlik, P., Hüfner, R., Lenzen, M., Lieber, M., Liu, B., Lu, Y., Lutter, S., Mehr , J., Miatto, A., Newth, D., Oberschelp , C., Obersteiner, M., Pfister, S., Piccoli, E., Schaldach, R., Schüngel, J., Sonderegger, T., Sudheshwar, A., Tanikawa, H., van Der Voet, E., Walker, C., West, J., Wang, Z., Zhu, B. Nairobi, Kenya: United Nations Environment Programme.

UN IRP. 2019b. Mineral Resource Governance in the 21st Century: Gearing extractive industries towards sustainable development. Ayuk, E. T., Pedro, A. M., Ekins, P., Gatune, J., Milligan, B., Oberle B., Christmann, P., Ali, S., Kumar, S. V, Bringezu, S., Acquatella, J., Bernaudat, L., Bodouroglou, C., Brooks, S., Buergi Bonanomi, E., Clement, J., Collins, N., Davis, K., Davy, A., Dawkins, K., Dom, A., Eslamishoar, F., Franks, D., Hamor, T., Jensen, D., Lahiri-Dutt, K., Petersen, I., Sanders, A. R. D. A Report by the International Resource Panel. Nairobi, Kenya: United Nations Environment Programme.

UN IRP. 2023. Global Material Flows Database. resourcepanel.org/global-material-flows-database

UN IRP. 2024. Global Material Flows Database. resourcepanel.org/global-material-flows-database

UNDP. 2019. Human Development Report 2019. Beyond income, beyond averages, beyond today: Inequalities in human development in the 21st century. New York: United Nations Development Programme.

UNEP. 2021. The use of natural resources in the economy. A Global Manual on Economy Wide Material Flow Accounting. Lead Authors: Heinz Schandl (Commonwealth Scientific and Industrial Research Organisation (CSIRO), James West (CSIRO), Stephan Lutter (Vienna University of Economics and Business), Nina Eisenmenger (University of Natural Resources and Life Sciences Vienna), Alessio Miatto (Nagoya University) and Myriam Linster (OECD). Nairobi, Kenya: United Nations Environment Programme.

UNEP. 2023. Green economy. unep.org/explore-topics/green-economy

UNEP. 2024. Global Resources Outlook 2024: Bend the Trend – Pathways to a liveable planet as resource use spikes. Nairobi, Kenya: International Resource Panel.

UNSW Sydney. 2023. industrial ecology virtual laboratory. GLORIA. ielab.info/resources/gloria

Vélez-Henao, Johan Andrés, and Stefan Pauliuk. 2023. Material Requirements of Decent Living Standards. Environmental Science & Technology 57: 14206–14217. doi.org/10.1021/acs.est.3c03957.

Vogel, Jefim, and Jason Hickel. 2023. Is green growth happening? An empirical analysis of achieved versus Paris-compliant CO_2–GDP decoupling in high-income countries. The Lancet Planetary Health 7: e759–e769. doi.org/10.1016/S2542-5196(23)00174-2.

WBGU, Eds. 2011. World in Transition – A Social Contract for Sustainability. Flagship Report. Berlin: Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen (WBGU) German Advisory Council on Global Change. wbgu.de/en/publications/publication/welt-im-wandel-gesellschaftsvertrag-fuer-eine-grosse-transformation

Weber, Leopold. 2008. Rohstoffsicherungsaktivitäten der EU und ihre Auswirkungen auf nationaler Ebene. BHM Berg- und Hüttenmännische Monatshefte. Springer Wien, New York Jg.153: 289–295.

Weisz, Helga, Fridolin Krausmann, Christof Amann, Nina Eisenmenger, Karl-Heinz Erb, Klaus Hubacek, and Marina Fischer-Kowalski. 2006. The physical economy of the European Union: Cross-country comparison and determinants of material consumption. Ecological Economics 58: 676–698. NE-box. doi.org/10.1016/j.ecolecon.2005.08.016.

White, Rebekah J., and Orly Razgour. 2020. Emerging zoonotic diseases originating in mammals: a systematic review of effects of anthropogenic landuse change. Mammal Review 50: 336–352. doi.org/10.1111/mam.12201.

Wiedenhofer, Dominik, Tomer Fishman, Christian Lauk, Willi Haas, and Fridolin Krausmann. 2019. Integrating Material Stock Dynamics Into Economy-Wide Material Flow Accounting: Concepts, Modelling, and Global Application for 1900–2050. Ecological Economics 156: 121–133. NE-box. doi.org/10.1016/j.ecolecon.2018.09.010.

Wiedenhofer, Dominik, Tomer Fishman, Barbara Plank, Alessio Miatto, Christian Lauk, Willi Haas, Helmut Haberl, and Fridolin Krausmann. 2021. Prospects for a saturation of humanity's resource use? An analysis of material stocks and flows in nine world regions from 1900 to 2035. Global Environmental Change 71: 102410. doi.org/10.1016/j.gloenvcha.2021.102410.

Wiedenhofer, Dominik, Julia K. Steinberger, Nina Eisenmenger, and Willi Haas. 2015. Maintenance and Expansion: Modeling Material Stocks and Flows for Residential Buildings and Transportation Networks in the EU25: Stocks and Flows in the EU25. Journal of Industrial Ecology 19: 538–551. doi.org/10.1111/jiec.12216.

Wiedmann, Thomas O., Heinz Schandl, Manfred Lenzen, Daniel Moran, Sangwon Suh, James West, and Keiichiro Kanemoto. 2015. The material footprint of nations. Proceedings of the National Academy of Sciences 112: 6271–6276. NE-box. doi.org/10.1073/pnas.1220362110.

Willett, Walter, Johan Rockström, Brent Loken, Marco Springmann, Tim Lang, Sonja Vermeulen, Tara Garnett, et al. 2019. Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. The Lancet 393: 447–492. doi.org/10.1016/S0140-6736(18)31788-4.

de Wit, Marc, Willi Haas, Michelle Steenmeijer, Doris Virág, Joost Van Barneveld, and Jacco Verstraeten-Jochemsen. 2019. The Circularity Gap Report Austria. Closing the Circularity Gap in Austria. Circle Economy and ARA.

WU Vienna. 2023. Materialflows.net. The Material Flow Analysis Portal. Material flows between world regions/countries. Visualisation based upon the UN IRP Global Material Flows Database. Vienna University of Economics and Business (WU Vienna) – Institute for Ecological Economics. Available online at: materialflows.net/visualisation-centre.

Zeit Online. 2022. Das Angebot ist knapp. Die Ukraine besitzt seltene Bodenschätze, die für Europas Energiewende zentral sind. Ein wenig beachtetes Kriegsmotiv, sagt die Politikwissenschaftlerin Olivia Lazard., December 5.

Zhou, Xi-Yin, Gang Lu, Zhicheng Xu, Xiaoqing Yan, Soon-Thiam Khu, Junfeng Yang, and Jian Zhao. 2023. Influence of Russia-Ukraine War on the Global Energy and Food Security. Resources, Conservation and Recycling 188: 106657. doi.org/10.1016/j.resconrec.2022.106657.

List of Figures

List of Tables

List of Statements