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Bend the trend

Pathways to a liveable planet as resource use spikes

International Resource Panel

Global Resources Outlook 2024

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List of abbreviations

BAT	best available technology
BECCS	Bio-energy with carbon capture and storage
CBD	Convention on Biological Diversity
CCS	carbon capture and storage
CTU	comparative toxic units
DALYs	Disability Adjusted Life Years
DE	domestic extraction
DMC	domestic material consumption
DPSIR	Drivers-Pressures-State-Impact-Response
EECCA	Eastern Europe, Caucasus and Central Asia region
FAO	Food and Agriculture Organization of the United Nations
G7	Group of Seven
G20	Group of Twenty
GDP	gross domestic product
GHG	greenhouse gases
GRO	Global Resources Outlook
Gt	gigaton
GWP	Global Warming Potentials
HDI	Human Development Index
IHDI	inequality-adjusted human development index
IEA	International Energy Agency
IPAT	Impact = Population x Affluence x Technology
IPCC	Intergovernmental Panel on Climate Change
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IRP	International Resource Panel
LCA	life cycle assessment
MF	material footprint
MFA	material flows analysis
MI	material intensity
MJ	megajoule
Mt	million tons
OECD	Organisation for Economic Co-operation and Development
PDF	potentially disappeared fraction of species
PM	particulate matter
PTB	physical trade balance
R&D	research and development
RTB	raw material trade balance
SBTs	Science-based Targets
SCP	sustainable consumption and production
SDG	Sustainable Development Goals
SSP	Shared Socioeconomic Pathways
TWh	TeraWatt hours
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification
UNCHE	United Nations Conference on the Human Environment
UNCTAD	United Nations Conference on Trade and Development
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNICEF	United Nations Children's Fund
UNIDO	United Nations Industrial Development Organization
USA	United States of America
WHO	World Health Organization

Glossary[1]

Absolute decoupling: Absolute decoupling is a shorthand description of a situation in which resource productivity grows faster than economic activity (GDP) and resource use is absolutely declining. See also: decoupling, relative decoupling and impact decoupling.

Bioeconomy: This refers to all sectors and systems that rely on biomass including biological resources (animals, plants, micro-organisms and derived biomass, including organic waste), their functions and principles. It includes and interlinks: land and marine ecosystems and the services they provide; all primary production sectors that use and produce biological resources (agriculture, forestry, fisheries and aquaculture); and all economic and industrial sectors that use biological resources and processes to produce food, feed, bio-based products, energy and services (adapted from the European Union (EU) Bioeconomy Strategy (COM/2018/673)). It also refers to conservation and regeneration of biological resources, including related knowledge, science, technology and innovation to provide solutions (see Food and Agriculture Organization of the United Nations [FAO],[2] based on Global Bioeconomy Summit Communiqué 2020).[3] This GRO report considers that the sustainable use of biomass must be based on prioritizing the use of biomass for maximum well-being and minimal impact.

Biomass: Crops, grazed biomass, fodder crops, wood, wild catch and harvest.

Capital formation: Capital formation refers to additions of capital stock, such as the build-up of infrastructure, equipment and transportation assets. In multi-regional input-output assessments, this is reported as part of the final demand per sector and region.

Circular economy: The circular economy is one where the value of products, materials and resources is maintained for as long as possible in the economy, and the generation of waste is minimized. This is in contrast to a linear economy, which is based on the "extract, make and dispose" model of production and consumption.

Consumption: The use of products and services for (domestic) final demand, namely for households, government and investments. The consumption of resources can be calculated by attributing the life-cycle-wide resource requirements to those products and services (for example by input-output calculation).

Consumption perspective: It allocates the use of natural resources or the related impacts throughout the supply chain to the region where these resources, incorporated in various commodities, are finally consumed by industries, governments and households.

Cradle-to-grave: Denotes the system boundaries of a full life-cycle assessment study, considering all life-cycle stages, including raw material extraction, production, transport, use and final disposal. Also termed "life-cycle perspective".

Disability Adjusted Life Years (DALYs): Measure for health impacts (referring to particulate matter health impacts in this report). It quantifies the amount of life years lost or lived with health impairment. Based on World Health Organization [WHO] 2019.

Decoupling: Decoupling is when resource use or some environmental pressure or impact grows at a slower rate than the economic activity causing it (relative decoupling) or declines while the economic activity continues to grow (absolute decoupling).

Demand-side measures: Policies and programmes to influence the demand for goods and/or services. In the energy sector, demand-side management aims to reduce demand for electricity and other forms of energy required to deliver energy services. Source: Intergovernmental Panel on Climate Change [IPCC] 2018a.

Drivers-pressures-state-impacts-response (DPSIR) framework: The DPSIR framework aims to provide a step-wise description of the causal chain linking economic activity (drivers), pressures (such as emissions of pollutants), changes in the state of the environment (including land cover change) and impacts (diminished human health, biodiversity loss and others). This then leads

1 This builds on the IRP glossary, https://www.resourcepanel.org/glossary.
2 https://www.fao.org/in-action/sustainable-and-circular-bioeconomy/en/#:~:text=The%20bioeconomy%20is%20the%20production%2C%20utilization%2C%20conservation%2C%20and,a%20sustainable%20economy%20%28Global%20Bioeconomy%20Summit%20Communiqu%C3%A9%2C%202020%29
3 https://gbs2020.net/wp-content/uploads/2020/11/GBS2020_IACGB-Communique.pdf

to a societal response aimed at adapting those driving forces to reduce impacts. It should not be understood as a reactive governance approach that waits for irreversible changes to the environment before responding, but rather an approach that supports preventative action and that can be used as an analytical tool for linking human-nature systems in future modelling to help steer a transition.

Employment: This term denotes the number of full-time equivalent positions (used in Chapter 3).

Environmental impacts: Harmful effects of human activities on ecosystems and human health. The present report includes the following methods and impact categories (see Table 3.1 for a full list):

1. Climate change impacts: Emissions contributing to climate change (such as CO_2, CH_4, N_2O) are weighed according to the concentration change they produce in the atmosphere multiplied with the radiative forcing of the respective gas, a substance property describing how much energy the substance can absorb. This effect of altering the energy balance of the earth is accumulated over a defined time horizon (typically 100 years) and published by IPCC as "Global Warming Potentials, GWPs" (IPCC 2013). Impacts are called climate change impacts, but are also known as a carbon footprint or greenhouse gas (GHG) emissions. All emissions are expressed as kg CO_2-equivalents.

2. Ecotoxicity: Emissions of toxic substances are transported, degraded and transferred between various environmental compartments (air, water and soil), where they may lead to direct exposure (including inhalation of air with pollutants) or indirect exposure (such as crop uptake of pollutants from soil and ingestion of crop as food). Toxic effects may occur after exposure.

3. Biodiversity loss: Land use or eutrophication reduces natural habitat size or alters the nutrient supply, thereby degrading ecosystems and leading to species extinctions.

4. Water stress: Water stress refers to the impacts of water consumption on water as a flow resource. Additionally, absolute water scarcity (availability per area) is considered to combine natural and human-induced water stress in a single indicator. Based on Boulay *et al.* (2018).

Extraction: amount of material extracted from the natural environment for use in the economy. It includes extractive activities such as mining, as well as agricultural and wood harvest.

Fair consumption space: The need to curb overconsumption while ensuring consumption opportunities needed for fulfilling basic needs, decent living standards and human dignity. Source: United Nations Environmental Programme [UNEP] 2022b.

Footprints: Footprints can measure different types of pressure and impact including resource use (such as materials and water), pollution emissions and environmental impacts (climate change, water scarcity, biodiversity losses and so forth). In the context of the International Resource Panel (IRP) flagship report, Global Resources Outlook 2019, the term footprints is used to represent the whole system of environmental pressures and impacts exerted by human activity, including direct pressures and impacts occurring within the geographical boundary where the activity occurs and indirect/or supply chain pressures and impacts inside and outside (transboundary ones).

Fossil fuels: Coal, anthracite, lignite, peat, gas, oil and tar sands.

Health impacts: Harmful effects of human activities on the health of a population. In the present report, the environmental health impacts of particulate matter (PM) were assessed (as the latter is the main cause of the former). This includes cardiovascular and respiratory diseases caused by fine primary particulate matter emissions or secondary particulate matter, which is formed from precursor gases transformed to particulate matter in the atmosphere (SOx, NOx and ammonia).

Impact assessment: This is used interchangeably with the term life-cycle impact assessment. It denotes a "phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts" of a system (according to the International Organization for Standardization (ISO 14040)). It links environmental impacts to emissions and primary resource use. Life-cycle impact assessment is defined as the phase of life-cycle assessment (see below) aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system. Based on ISO 14044 (2006).

Impact decoupling: Impact decoupling refers to a slower rate of growth in environmental impacts than in the economic activity causing it (relative decoupling) or an absolute decline in impacts while the economic activity continues to grow (absolute decoupling). Impact decoupling from resource-use growth refers to a slower rate of growth in environmental impacts than resource use (relative decoupling) or an absolute decline in impacts while resource use continues to grow (absolute decoupling).

Income groups: This report provides analysis based on income groups. The income group classification comes from the United Nations, which is based on thresholds established by the World Bank to ensure compatibility with classifications used in other international organizations. There are four income group categories: high-income, upper middle-income, lower middle-income and low-income (see Annex 1). These categories are used in all assessments of the report. However, for Chapter 4, income grouping relies on the country and regional groups of the underlying models (see section 8.4 in the annex).

Input-output (I-O) method: Input-output tables describe the interdependence of all production and consumption activities in an economy. In an input-output model, the economy is represented by industry sectors (including resource extraction, processing, manufacturing and service sectors) and final demand categories (including households, government, investment, export and stock changes). Integrating information on emissions and resource use caused by sectors and final demand allows environmentally extended IO tables (eeIOT) to be provided. These can be used to calculate environmental pressures induced by production sectors or final demand categories in a way a similar to value-added or labour.

Just transition: While definitions vary across thematic and geographic contexts, a just transition means greening the economy in a way that is as fair and inclusive as possible to everyone concerned, creating decent work opportunities and leaving no one behind (International Labour Organization (ILO)).[4] According to this GRO report, addressing the structurally unequal distribution of costs and benefits of our current models of resource use is key to a just transition towards sustainable resource use. A just transition also relates to the principles of sufficiency (see below), which call for an increase of resource use in low-development contexts to promote dignified living standards, and the reduction of resource use in the context of higher consumption footprint. A just transition requires compensation for the actors and communities that will be negatively affected by the actions deployed for the transition.

Life-Cycle Assessment: Life-Cycle Assessment (LCA) is the assessment of impacts associated with all life stages of a product or service from cradle to grave (see definition above).

Life-cycle perspective: A life cycle perspective includes consideration of the environmental aspects of an organization's activities, products and services that it can control or influence. Stages in a life cycle include acquisition of raw materials, design, production, transportation/delivery, use, end of life treatment and final disposal (ISO n.d.). Also termed "cradle-to-grave".

Materials: Materials are substances or compounds. They are used as inputs for production or manufacturing because of their properties. A material can be defined at different stages of its life cycle: unprocessed (or raw) materials, intermediate materials and finished materials. For example, iron ore is mined and processed into crude iron, which in turn is refined and processed into steel. Each of these can be called materials. Steel is then used as an input in many other industries to make finished products. Throughout the report, assessments refer to material resources (biomass, fossil fuels, metals and non-metallic minerals, see below), with the term often shortened to "materials".

Material resources: Biomass, fossil fuels, metals and non-metallic minerals. Throughout the report, assessments refer to material resources as "materials" (see above).

Material flow analysis: Material flow analysis (MFA) comprises a group of methods to analyse the physical flows of materials into, through and out of a given system. This can be applied at different levels of scale including products, firms, sectors, regions and whole economies. The analysis may focus on individual substance or material flows, or aggregated flows such as resource groups (fossil fuels, metals or minerals). Economy-wide MFA (ewMFA) is applied to entire economies and provides the basis for producing indicators on the metabolic performance of countries in terms of material inputs and consumption (such as Direct Material Input (DMI), Domestic Material Consumption (DMC), Total Material Requirement (TMR) and Total Material Consumption (TMC)).

Metals: Metals are elements (or mixtures of elements) characterized by specific properties such as conductivity of electricity. Major engineering metals include aluminium, copper, iron, lead, steel and zinc. Precious metals include gold, palladium, platinum, rhodium and silver, while specialty metals include antimony, cadmium, chromium, cobalt, magnesium, manganese, mercury, molybdenum, nickel, tin, titanium and tungsten. Because metals are elements, they are not degradable and cannot be depleted in an absolute sense: once in the environment they do not disappear. However, some, like heavy metals, may accumulate in soils, sediments and organisms – with impacts on human and ecosystem health.

Multilateral Environmental Agreement (MEA): Legally binding instruments between two or more nation States, dealing with environmental aspects. Most MEAs have been adopted after the 1972 United Nations Conference on the Human Environment (UNCHE). The United Nations Framework Convention on Climate Change (UNFCCC), Convention on Biological Diversity (CBD) and the Convention to Combat Desertification (UNCCD) are some of the most significant examples of MEAs at global level, forming the international legal basis for global efforts to address these environmental issues.

4 https://www.ilo.org/global/topics/green-jobs/WCMS_824102/lang--en/index.htm

Non-metallic minerals: Materials such as sand, gravel, limestone, gypsum and clay that are mostly used for construction but also for industrial applications.

Planetary boundaries: Estimate of a safe operating space for humanity with respect to the functioning of key Earth System processes, referring to biophysical processes of the Earth System that determine the self-regulating capacity of the planet. According to this concept, the boundary level should not be transgressed if unacceptable global environmental change is to avoided (in terms of the risks humanity faces in the transition of the planet from the Holocene to the Anthropocene). The original work by Rockström *et al.* (2009) refers to nine planetary boundaries.

Production perspective: It allocates the use of natural resources or the impacts related to natural resource extraction and processing to the location where they physically occur (Wood *et al.* 2018).

Provisioning system: Recently emerged and increasingly relevant concept that groups together related ecological, technological, institutional and social elements that interact to transform natural resources to satisfy foreseen human needs. Using this approach means that resource use and related impacts are allocated to the systems where final consumption takes place. Source: Fanning *et al.* (2020)

Relative decoupling: In relative decoupling the growth rate of the environmentally relevant parameter (such as resources used or environmental impact) is lower than the growth rate of the relevant economic indicator (for example GDP).

Resource efficiency: In general terms, resource efficiency describes the overarching goals of decoupling — increasing human well-being and economic growth while lowering the amount of resources required and negative environmental impacts associated with resource use. In other words, this means doing better with less. In technical terms, resource efficiency means achieving higher outputs with lower inputs and can be reflected by indicators such as resource productivity (including GDP/resource consumption). Ambitions to achieve a resource-efficient economy therefore refer to systems of production and consumption that have been optimized with regard to resource use. This includes strategies of dematerialization (savings, reduction of material and energy use) and re-materialization (reuse, remanufacturing and recycling) in a systems-wide approach to a circular economy, as well as infrastructure transitions within sustainable urbanization.

Resource productivity: As an indicator on the macro-economic level, total resource productivity is calculated as GDP/TMR (Organisation for Economic Co-operation and Development [OECD] 2008). It may be presented together with indicators of labour or capital productivity. Resource productivity is the inverse of resource intensity.

Resources: Resources — including land, water and materials — are seen as parts of the natural world that can be used in economic activities to produce goods and services. Material resources (see above) are biomass, fossil fuels, metals and non-metallic minerals.

Resource decoupling: Resource decoupling means delinking the rate of use of primary resources from economic activity. Absolute resource decoupling would mean that the Total Material Requirement of a country decreases while the economy grows. It follows the same principle as dematerialization, that is implying the use of less material, energy, water and land to achieve the same (or better) economic output.

Resource-intensive provision system: Provisioning systems with high demand for resources.

Safe operating space: Safe operating space is a concept developed by Rockström *et al.* (2009) that reflects a corridor for human development where the risks of irreversible and significant damage to global life-sustaining systems seem tolerably low.

Shared socioeconomic pathways (SSP): SSPs are socioeconomic narratives that outline broad characteristics of the global future and country-level population, global domestic product and urbanization projections. Such SSPs are not scenarios themselves, but their building blocks (Riahi *et al.* 2016).

Sufficiency: Concept gaining traction in the policy agenda which, from a resource perspective, refers to the need to: increase resource use in low-development contexts to enable dignified living, while reducing consumption levels in those parts of the population who live well above the capacity of the planet (adapted from Fanning *et al.* 2022). This concept goes back to the 1972 UNCHE Conference in Stockholm, Sweden, which take human dignity as a central concept and explicitly links it to the use of natural resources and the state of the environment. This refers to differences between countries but also between different fractions of the population within countries.

Sustainable consumption and production: At the Oslo Symposium in 1994, the Norwegian Ministry of Environment defined sustainable consumption and production as: the use of services and related products that respond to basic needs and bring a better quality of life while minimizing the use of natural resources and toxic materials, as well as the emissions of waste and pollutants over the life cycle of the service or product (so as not to jeopardize the needs of future generations). Ensuring sustainable consumption and production patterns has become an explicit goal of the United Nations Sustainable Development Goals (SDGs) (Goal number 12), with the specific target of achieving sustainable management and efficient use of natural resources by 2030. The concept thus combines with economic and environmental processes to support the design of policy instruments and tools in a way that minimizes problem shifting and achieves multiple objectives — such as SDGs — simultaneously.

Sustainable resource management: Sustainable resource management means both (a) ensuring that consumption does not exceed levels of sustainable supply and (b) ensuring that the Earth's systems are able to perform their natural functions (such as preventing disruptions like in the case of greenhouse gases (GHGs) affecting the ability of the atmosphere to regulate the Earth's temperature). It requires monitoring and management at various scales. The aim of sustainable resource management is to ensure the long-term material basis of societies in a way that prevents resource extraction or waste disposal/emissions from exceeding the thresholds of a safe operating space.

Systemic: Features or developments that affect the whole organization of an entity, considering the interlinkages and interdependencies between its different elements.

Systems approach: This approach is derived from systems thinking, which is used to identify and understand systems, as well as to predict behaviours and devise modifications to produce desired effects (Arnold and Wade 2015). This report applies the DPSIR Framework to assess the linkages between the use of natural resources in society, through production-consumption systems and essential infrastructure and food provisioning services, as they impact economic development, human well-being and the environment (as reflected in multiple SDGs). The system approach (1) considers the total material throughput of the economy from resource extraction and harvest to final disposal, and their environmental impacts, (2) relates these flows to activities in production and consumption across spatial scale, time, nexus and boundary dimensions, and (3) searches for leverage points for multi-beneficial changes (technological, social or organizational), all encouraged by policies to achieve sustainable production/consumption and multi-scale sustainable resource management.

Trade-off: Trade-off describes a situation where one option occurs at the expense of another. The Resource Panel describes trade-offs between environmental impacts (such as renewable energy technology and critical metal consumption), as well as social, ecological and economic objectives (such as cropland expansion and biodiversity loss).

Transition: Process towards a transformation.

Transformation: Overall change or outcome of large-scale shifts in technological, economic and social systems.

Value added: Value created through the production of goods and services. It is calculated by subtracting the cost of intermediate consumption from the total output value. Value added also serves as a measure of the income available for the contributions of labour and capital to the production process.

Value chain: It is comprised of all the activities that provide or receive value from designing, making, distributing, retailing and consuming a product (or providing the service from a product), including the extraction and provision of raw materials, as well as the activities after its useful service life. In this sense, the value chain covers all stages in a product's life, from supply of raw materials through to disposal after use, and encompasses the activities linked to value creation such as business models, investments and regulation. All stages in the value chain (and in the transport of intermediate and finished products between the value chain stages) require raw materials and energy, while also introducing emissions into the environment. In addition, the value chain is comprised of the actors undertaking the activities and the stakeholders that can influence the activities. The chain thus incorporates not only the physical processes, such as farms and factories, but also the business models and the way products are designed, promoted and offered to consumers (based on UNEP 2021a).

Well-being decoupling: Decoupling (see above) considering well-being metrics instead of economic activity.

Foreword

Natural resources are the basis on which all economies and societies are built, making their sustainable management critical to ending poverty and reducing inequalities. They are also essential to drive the transition to net-zero. To stay below a 2°C temperature rise by 2050, we will need over three billion tonnes of energy transition minerals and metals for wind power, solar and more. Aiming for 1.5°C to maximize climate justice would mean even greater demand. Right now, however, resources are extracted, processed, consumed and thrown away in a way that drives the triple planetary crisis – the crisis of climate change, the crisis of nature and biodiversity loss, and the crisis of pollution and waste. We must start using natural resources sustainably and responsibly.

The 2024 edition of the Global Resources Outlook, from the International Resource Panel, shows that it is both possible and profitable to decouple economic growth from environmental impacts and resource use. In fact, sustainable resource use and consumption can reduce resource use and environmental impacts in wealthier countries, while creating the space for resource use to grow where it is most needed. It is important to note that the circular models we must follow are not just about recycling; they are about keeping materials in use for as long as possible, and rethinking how we design and deliver goods as well as services, thereby creating new business models.

If the policies and shifts outlined in this report are followed, the 2060 picture will be significantly rosier than under current models. We could have a global GDP three per cent larger than predicted and reduced economic equalities. Growth in material use could fall by 30 per cent. Greenhouse gas emissions could be reduced by more than 80 per cent. Such results would be a huge win for people and planet.

The bottom line is that sustainable and responsible resource use and consumption is a key enabling factor for the success of virtually every international agreement and initiative aimed at carving out a better future – from the new Global Framework on Chemicals and upcoming legally binding instrument on plastic pollution to the Paris Agreement and the Sustainable Development Goals.

The scientific community is united about the urgent need for decisive policies to enable a sustainable future. We need bold and immediate actions at scale to rebalance humanity's relationship with the natural world and the resources it provides. I call on all policymakers to read this report and act on its findings as part of a united global push to make this world a better, more sustainable home for everyone.

Inger Andersen
Executive Director
United Nations Environment Programme

Preface

The messages from this report could not be clearer: It is no longer whether a transformation towards global sustainable resource consumption and production is necessary, but how to urgently make it happen.

The scale of impacts linked to the way material resources are extracted and processed for our global economy are astounding — over 55 per cent of greenhouse gas emissions driving us to the brink of climate catastrophe, up to 40 per cent of particulate matter health related impacts costing over 200 million disability-adjusted life years every year, and over 90 per cent of total land use related biodiversity loss that is the lynchpin of vibrant ecosystems and life on Earth. If not addressed, the impacts of our resource use will derail all hope of meeting Multilateral Environmental Agreements like the United Nations Framework Convention on Climate Change, the United Nations Convention to Combat Desertification and the Convention on Biological Diversity.

Despite this, our insatiable use of resources has tripled over the last fifty years. As nations continue their urbanisation and industrialization, and the global middle class expands, there is a corresponding uptick in material use, waste, emissions, as well as water and land consumption. If we do not change, we could see resource use up by 60 per cent from 2020 levels by 2060. Our current deeply unsustainable systems of consumption and production will cumulate in catastrophic impacts on the earth systems and ecological processes that underpin human well-being and the diversity of life on our planet.

This can, and must, change. We should not accept that meeting human needs has to be resource intensive and we must stop stimulating extraction based economic success. This report demonstrates that compared to current trends, it is still possible to reduce resource use while growing the economy, reducing inequality, improving well-being and dramatically reducing environmental impacts.

Based on the outcomes of state-of-the-art scenario modelling, we outline five critical actions at all levels of governance that are essential to enable transitions to resource-efficient and sustainable consumption and production. These changes across the most resource-intensive systems that deliver shelter, nutrition, mobility and energy can improve well-being for all within planetary boundaries. Designing solutions for 'provisioning systems' incentivizes cross-sector innovation. This systems approach is a foundation of building the future-fit socio-economic models that use less resources and multiply the co-benefits for people and planet.

A monumental push towards sustainable resource management and enhancements in resource productivity is imperative. This must go hand-in-hand with responsible consumption, facilitated by strategic infrastructure investments, to guide the global economy towards sustainable and equitable utilization.

These findings are strongly aligned with the conclusions of other recognized science-policy panels. Scientists bring the best knowledge and illustrate potential pathways forward in increasingly bold manner. For UNEA-6, we hope that these findings will inform countries and spur action based on systemic plans and pledges with a central focus on resource use. With decisive action, political courage and bold boardroom decisions, a sustainable future – meaning a decent life for all within planetary boundaries – is possible.

Janez Potočnik and Izabella Teixeira
IRP Co-Chairs

Guitar photographer
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Key messages

1. Increasing resource use is the main driver of the triple planetary crisis.

Extraction and processing of material resources (fossil fuels, minerals, non-metallic minerals and biomass) account for over 55 per cent of greenhouse gas emissions (GHG) and 40 per cent of particulate matter health related impacts. If land use change is considered, climate impacts grow to more than 60 per cent, with biomass contributing the most (28 per cent) followed by fossil fuels (18 per cent) and then non-metallic minerals and metals (together 17 per cent). Biomass (agricultural crops and forestry) also account for over 90 per cent of the total land use related biodiversity loss and water stress. All environmental impacts are on the rise.

2. Material use has increased more than three times over the last 50 years. It continues to grow by an average of more than 2.3 per cent per year.

Material use and its impact continue to rise at a greater rate than increases in well-being (as measured by inequality-adjusted Human Development Index). The built environment and mobility systems are the leading drivers of rising demand, followed by food and energy systems. Combined, these systems account for about 90 per cent of global material demand. Material use is expected to increase to meet essential human needs for all in line with the Sustainable Development Goals (SDGs). Without urgent and concerted action to change the way resources are used, material resource extraction could increase by almost 60 per cent from 2020 levels by 2060, from 100 to 160 billion tonnes, far exceeding what is required to meet essential human needs for all in line with the SDGs.

3. Climate and biodiversity impacts from material extraction and processing greatly exceed targets based on staying within 1.5 degrees of climate change and avoiding biodiversity loss.

Analysis of scientific targets developed on the basis of Multilateral Environmental Agreements (MEAs) (such as the United Nations Framework Convention on Climate Change [UNFCCC], Convention on Biological Diversity [CBD] and United Nations Convention to Combat Desertification [UNCCD]) and scientific literature demonstrates the extent to which environmental impacts from resource use could derail their achievements. Integrating sustainable resource use in the implementation of MEAs is necessary to meet agreed climate, biodiversity, pollution and land degradation neutrality outcomes. Action is required now to lower GHG emissions, paying attention to the crucial role of materials. A sustainable and circular bioeconomy must be based on prioritizing the use of biomass to maximize well-being and minimize impact, while conversion of biodiversity-and carbon-rich natural systems must be avoided and reversed to promote net nature-positive outcomes.

4. Delivering on the SDGs for all requires decoupling, so that the environmental impacts of resource use fall while the well-being contributions from resource use increase.

Resource efficiency and supporting policies can reduce material resource use and dramatically reduce environmental impacts in high and upper middle-income countries (absolute decoupling) while improving well-being and boosting economic growth. This can also create the space for resource use to grow where it is most needed. There has so far been no evidence of widespread absolute decoupling at the global level. In low and lower middle-income countries policy should focus on reducing environmental pressures and impacts and improving resource efficiency, acknowledging increases in resource use (relative decoupling) will be required to reduce inequalities and improve well-being. These actions are aligned with the emerging understanding of just transitions, sufficiency and pathways towards sustainable resource use.

5. High-income countries use six times more materials per capita and are responsible for ten times more climate impacts per capita than low-income countries.

This inequality must be addressed as a core element of any global sustainability effort. The per capita material footprint of high-income countries, the highest of all income groups, has remained relatively constant since 2000. Upper middle-income countries have more than doubled their material footprint per capita approaching high-income levels, while their per capita impacts continue to be lower than high-income countries. Through global trade, high-income countries displace environmental impacts to all other income country groups. Per capita resource use and related environmental impacts in low-income countries has remained comparatively low and almost unchanged since 1995.

6. Compared to historical trends, it is possible to reduce resource use while growing the economy, reducing inequality, improving well-being and dramatically reducing environmental impacts.

Scenario modelling illustrates the potential to reduce and rebalance global per capita material use, with absolute reductions from around 2040 driven by reductions in high and upper middle-income nations that outweigh, in aggregate, increases in low and lower middle-income nations. The policies and shifts that could drive these change also reduce economic inequalities and boost global income growth. Integrated action on resource efficiency, climate and energy, food and land achieve significantly larger positive effects than any one of these policy areas for action would in isolation. Taken together, these actions demonstrate that by 2060, it is possible to achieve a world with global GDP about 3 per cent larger alongside a global Human Development Index 7 per cent higher than could be expected by following historical trends. Compared to historical trends such measures could mitigate growth in material use by 30 per cent. GHG emissions could be reduced by more than 80 per cent from current levels by 2060, consistent with the Paris Agreement, along with absolute reductions in energy use, agricultural land area, and other pressures. Fully embracing this scenario is the obvious choice.

7. Bold policy action is critical to phase out unsustainable activities, speed up responsible and innovative ways of meeting human needs and promote social acceptance of the necessary transitions.

The pathway towards sustainability is increasingly steep and narrow because much time has been lost and many policy commitments embedded in MEAs not delivered on. Urgent action is needed to institutionalise resource governance including embedding resources in the delivery of MEAs, defining sustainable resource use paths on all governance levels and, for example, developing multi-scale institutional arrangements in support of sustainable natural resource management. Equally important is reflecting the true costs of resources in the structure of the economy and the redirecting of finance towards sustainable resource use including through setting economic incentives correctly (including for example incentives addressing the rebound effect and subsidies reform), making trade and trade agreements engines of sustainable resource use, mainstreaming sustainable consumption options and creating circular, resource-efficient and low-impact solutions and business models.

8. The prevailing approach of focusing almost exclusively on supply-side (production) measures must be supplemented with a much stronger focus on demand-side (consumption) measures.

We reject the assumption that meeting essential human needs should be resource-intensive. Structurally lowering or avoiding resource-intensive demand in high consumption contexts is necessary. By addressing the demand-side, we are also addressing questions of global equity and sufficiency. For example, dietary changes reducing high-impact commodities including animal protein and food loss and waste can decrease the land needed for food by five per cent by 2060 compared to 2020 levels while more equitably ensuring adequate nutrition for all. Reducing the need for mobility and enabling mobility through shared and active transport can reduce related material stock requirements (-50 per cent), energy demands (-50 per cent) and GHG emissions (-60 per cent) by 2060 compared to current trends. Compact and balanced neighbourhoods using more recycled building content, lifespan extension and other circular economy measures can decrease building material stocks by 25 per cent by 2060, which leads to a 30 per cent decrease in energy demand and 30 per cent decrease in GHG emissions compared to current trends.

9. The scientific community is united around the urgency of resolute action and bold evidence-based decisions that protect the interests and well-being of all, including future generations.

The alignment in messages coming from the International Resource Panel, the Intergovernmental Panel on Climate Change and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services must be considered as a strong statement of urgency from the scientific community. The only choice is to stabilize and balance the human relationship with the rest of nature. Weak, partial, fragmented or slow policies will not work. This can only be possible with far-reaching and truly systemic shifts in energy, food, mobility and the built environment implemented at an unprecedented scale and speed. Leaders across all sectors, including government at all levels, business and civil society must act now. We can make these changes, and improve human well-being around the world, but the window of opportunity is closing.

Natalia Paklina
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01

Introduction — Transformation in resource consumption and production is possible and requires immediate and decisive action

Authors: Hans Bruyninckx, Beatriz Vidal, Hala Razian and Rebecca Nohl

Main findings

The role of natural resources use and management as a key driver for the triple planetary crisis has been underestimated by the global, regional and national sustainability agendas. Based on data analysis and modelling, this report illustrates why resources are so important and how critical they are to achieving the United Nations Sustainable Development Goals (SDGs) and addressing the triple planetary crisis.

In order to deliver on the SDGs and the targets and obligations under multilateral environmental agreements, resource use and management need to be explicitly integrated at the core of efforts to fight climate change, biodiversity loss and pollution.

Targeted and coordinated actions at scale are needed to decouple human well-being improvement from the environmental impacts derived from resource use. Absolute decoupling (reduced consumption) is essential in contexts with high resource-consumption footprints, alongside relative decoupling in those contexts that still need to develop.

It is essential to consider the highly unequal distribution of costs and benefits in natural resource use when designing new and sustainable ways forward.

Such transformation towards sustainable resource use needs to scale up sustainable consumption and production and phase out most resource-intensive and environmentally impactful practices. This is possible if bold policy choices, implemented at scale and speed, are accepted. This is necessary to overcome many different barriers and lock-ins.

A provisioning system lens is a useful approach to understand the dynamics of resource use and how it contributes to key elements of human development. This report focuses on the resource-intensive provisioning systems of food, built environment, mobility and energy.

It is essential to focus not only on measures on the supply (production) side of these systems but also on the demand (consumption) side. This should include strong operationalization of concepts such as justice and sufficiency.

1.1. Introduction

The global economy is consuming ever more natural resources. The prevailing resource extraction and use models are a contributing and major causal factor of what is known as the triple planetary crisis (climate change, biodiversity loss and pollution). Moreover, natural resource use is highly unequal and creates strong differences in the distribution of costs and benefits, with the poor particularly disadvantaged throughout the cycle of use. The current model also fails to deliver acceptable human development conditions for many on the planet. Without a systems-wide shift towards sustainable resource use, the current trajectories will contribute further to the surpassing of planetary boundaries (Steffen *et al.* 2015; Rockström *et al.* 2023) and the inequalities that are characteristic of the global economy. This has also been framed as humanity transgressing a safe operating space.

This Global Resources Outlook 2024 report brings together the best available data, modelling and assessments to analyse trends, impacts and distributional effects of resource use. It also describes the potential to turn negative trends around and put humanity on a trajectory towards sustainability.

1.2. Sustainable and equitable natural resource use and management are essential to meet human needs for all and safeguard the planet's life-support systems

Natural resources (see Box 1.1) are directly or indirectly linked to all 17 Sustainable Development Goals (SDGs) (see Figure 1.1). The way societies use natural resources through linear consumption and production patterns determines the trajectories of environmental impacts and human well-being (IRP 2017). The use of natural resources is therefore intrinsically linked to the global community's capacity to achieve sustainability, and deliver on multilateral environmental agreements (MEAs) relating to climate, biodiversity, land degradation and other issues.

Scientific assessments (for example IRP 2017; IRP 2019a; Fanning *et al.* 2022 and the present study) confirm that the current model of natural resource use to deliver economic growth and social development is driving an unprecedented triple planetary crisis of climate change, biodiversity loss and pollution (see Box 1.2). Moreover, the natural resource agenda is not only an environmental agenda, as it also relates to the long-term capacity of natural systems to deliver well-being for all, and given current inequality, especially to those who are lacking the basic material conditions for a decent life.

Box 1.1. Resource categories covered by this report

This report studies natural resources which are essential for producing goods and services to meet human needs, based on the following categories (see also the glossary):

Biomass: crops for food, energy and bio-based materials, as well as wood for energy and industrial uses

Fossil fuels: including coal, gas and oil

Metals: such as iron, aluminum and cooper

Non-metallic minerals: sand, gravel, limestone and minerals used for industrial applications

Land

Water

Throughout the report, assessments refer to material resources (biomass, fossil fuels, metals and non-metallic minerals), also referred to as "materials".

Figure 1.1: Natural resources and the SDGs.

Source: Adapted from IRP (2022) and IRP (2019a).

Box 1.2. The triple planetary crisis and the Global Resources Outlook 2024

(Hala Razian, Namita Sharma and Iris Lassus)

The triple planetary crisis is a science-based framework adopted by the United Nations system that refers to three interlinked global environmental crises: climate change, biodiversity loss and pollution. Acting on this triple crisis lies at the core of the strategy of the United Nations Environmental Programme (UNEP). Unsustainable patterns of consumption and production are identified as the common thread of this triple crisis.

In 2021, the United Nations Secretary-General, in his opening remarks to the Fifth Session of the United Nations Environment Assembly (UNEA), warned of growing inequalities among people and countries "in the face of a triple environmental emergency – climate disruption, appalling biodiversity decline and a pollution epidemic".[5] Subsequently, at the Resumed Fifth Session of UNEA in 2022, the world's ministers of environment called for "decisive, adequate and coherent implementation of the actions and commitments (…) addressing the triple crisis of our common environment – climate change, biodiversity loss and pollution".[6]

The framework and terminology have since been used across academic journals and intergovernmental organizations.[7] While the framework could not encompass all global environmental challenges that the world is currently facing, the Global Resources Outlook 2024 applies this framing for two reasons. First, the Global Resources Outlook 2024 is presented primarily to UNEA at the request of that forum.[8] Second, the framing is a useful tool to contextualize the findings of the report, which aims to shed more light on the relevance of resource use for implementing global agendas related to the crisis. This report further considers land degradation as represented under the UN Framework Convention to Combat Desertification in its assessment, and such considerations fall under the biodiversity loss axis of the triple planetary crisis.

1.3. Worrying trends and new challenges in resource consumption and production since 2019

Since the 2019 edition of this report series was published, trends in global resource use have continued or accelerated: between 2015 (reference year of the 2019 edition) and 2023 there was no absolute decoupling of any environmental impact on the global scale, and all impacts increased in absolute terms with only a few temporary exceptions (such as a resource use decrease during the COVID-19 pandemic).

Recent events and changes in global geopolitics continue to have an impact on how resources are managed. In the last few years, the COVID-19 pandemic and recent global inflation have highlighted the vulnerability of the global supply chain of material resources (also referred to as "materials"), as well as the need to secure the supply of essential materials while reducing materials demand at the same time. This has been reflected in a surge of resource policy developments, particularly on energy use, plus business actions to restructure supply chains and reduce supply disruption risks. Companies and countries are investing in extraction and processing projects in producing countries.[9]

Alongside the vulnerability of supply chains, material demand (including materials classed as critical)[10] is expected to continue increasing in the coming decades. This will be in order to feed an increasing population with changing models of consumption and to supply the materials required for goods, infrastructure and services, as well as for the deployment of the clean energy transition (see Historic trends scenario in Chapter 4 and Box 1.3).

5 UNEP/EA.5/25 Proceedings of the United Nations Environment Assembly at its fifth session.
6 UNEP/EA.5/HLS.1. Ministerial declaration of the United Nations Environment Assembly at its fifth session: Strengthening actions for nature to achieve the Sustainable Development Goals.
7 See, for instance, the UNEP Medium Term Strategy.
8 Resolutions UNEA-2/8, UNEA-4/1, and UNEA-5.2/11.
9 While countries can be producing and consuming countries at the same time, this refers to countries that are producers based on their net trade balance.
10 Materials that are of high economic importance to the country or region concerned, and where the supply chain is perceived as vulnerable or fragile, for geological or geopolitical reasons.

Box 1.3. The demand for minerals and metals for the clean energy transition

(Based on IRP 2024b and the impacts on indigenous communities developed by Sofia Baudino)

Future mineral demand scenarios for the clean energy transition[11] project very high increases in material demand up to 2040 or 2050, and point to potential risks of imminent supply/demand imbalances. For instance, copper is required for all power generation and transport technologies. Lithium, cobalt and graphite are needed for electric car batteries, as is nickel, which is also used in a number of power generation technologies. Rare earth magnets are needed for offshore wind turbines. Nickel and platinum group metals (PGMs) are important for hydrogen production, and Rare Earth Elements (REEs) play a role in hydrogen, as well as in wind turbines and batteries. Aluminium is important across a wide range of clean technologies (IRP 2024b).

Many factors can contribute to supply risks around these commodities that can jeopardize immediate and scaled-up action for the energy transition: the time-lag from deposit identification to market; the competing needs for minerals from other development applications,[12] the concentration of material extraction and processing or production technologies; and commodity prices. The scale of current mining conflicts[13] is also seen as a further risk, which relates to the negative and social impacts of extractive activities.

One example is the socioenvironmental conflicts derived from the mining of gold, silver, copper, zinc or tin in territories owned or occupied[14] by indigenous communities in Amazonian countries (Villén-Pérez *et al.* 2022). A leaning towards prioritizing companies' interests has been observed in domestic laws and regulations (World Resource Institute 2020) by removing the judicial protection of indigenous communities, expropriating land, neglecting consultation during the project approval process (United Nations, Economic Commission for Latin America and the Caribbean [ECLAC] 2023) or even using armed forces to protect mining facilities (Bustos *et al.* 2023). These communities have also often been under threat in terms of the water quality impacts of mining operations (International Work Group for Indigenous Affairs [IWGIA] 2023).

Concerted action to decrease material requirements for transitions to renewable energy systems – including by applying sustainable consumption and production, resource efficiency and circular economy strategies – can help facilitate the transition to clean energy for all countries, while minimizing the socioeconomic impacts.

For those materials that are essential to meet the needs of the energy transition, promoting the use of the Sustainable Development Licence to Operate (SDLO)[15] could enhance the contribution of the mining sector to sustainable development (IRP 2020a).

Emerging trends, such as digitalization (United Nations Conference on Trade and Development [UNCTAD] 2020) and artificial intelligence, are also expected to change the way public and private actors operate. While this will be accompanied by increasing demand for specific materials, it remains unclear how this may impact the distribution of the benefits and environmental impacts of material use.

Increasing insecurity and conflicts (United Nations Development Programme [UNDP] 2022) and a sense of polarization have been observed globally, in a world defined by increased uncertainty. Uncertain or unpredictable events, such as those linked to climate change and geopolitical conflicts, are also on the rise. It often proves difficult to understand and assess the impacts of observed changes. This situation is referred to as "VUCA" world – "Volatile, Uncertain, Complex and Ambiguous".

11 The World Bank (Hund *et al.* 2020), the UN International Resource Panel (IRP, 2020a), the European Commission (Moss *et al.* 2013; Bobba *et al.* 2020), the International Energy Agency (IEA 2021IEA 2022 a, b and c), the International renewable Energy Agency (Gielen 2021), the German Raw Materials Agency (Marscheider-Weidemann *et al.* 2021), the Finnish Geological Survey (Michaux 2021) and various academics, including Grandell (2016); Watari *et al.* (2018), Elshkaki and Shen (2019), Moreau *et al.* (2019), Habib *et al.* (2020), Heijilen *et al.* (2021), Watari *et al.* (2021) and Christmann *et al.* (2022)

12 Due to population increase and changes in lifestyle, world average per capita production for cement, aluminium and steel grew by 3000% and over 4000% and 1100%, respectively, over that period (USGS Historical Data series, Kelly and Matos 2022).

13 The Environmental Justice Atlas (15 April 2023) identifies extraction of mineral ores and building materials (both categories appear aggregated) as one of the largest categories of environmental conflicts, out of 3,861 conflicts. The concentration of mining conflicts in the Andes in South America is particularly high.

14 The United Nations Declaration on the Rights of Indigenous Peoples (Article 25) and the ILO Convention 169 (Articles 7, 13, 15.1, and 32) recognize the rights of indigenous peoples to own, occupy and use their territories, as well as access natural resources and participate in development processes (Agybay *et al.* 2020).

15 A holistic multi-level and multi-stakeholder governance framework aimed at enhancing the contribution of the mining sector to sustainable development (IRP 2020a).

In a context of continuous change with recurrent and interconnected crises (resource supply, climate, biodiversity and pollution), improving resource use management can play a decisive role in increasing human security while meeting human needs for all. The resource agenda is not just an environmental agenda. It refers to the long-term capacity of natural systems to deliver secure well-being to all, which is essential for humanity to thrive in peace.

Box 1.4. Integrating a resource perspective across multilateral environmental agreements and the importance of science-based targets

Resource use and management are key to meeting the global goals on human development, climate, biodiversity, pollution and land degradation. The need to address the drivers of unsustainable resource use is increasingly recognized by other important scientific panels such as the Intergovernmental Panel on Climate Change (IPCC), the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES), the Word Health Organization (WHO) and the Global Environmental Outlook (GEO 6). For the first time, the IPCC (2022) has highlighted the importance of the use of materials, land and water for climate agendas, including scientific assessment on materials and on demand-side changes (changes in the demand for goods and/or services). In addition, IPCC's Sixth Assessment Report (AR6) identifies circular economy as a relevant strategy for GHG mitigation. According to IPBES-IPCC (2021), there are many synergies between actions for climate mitigation and biodiversity and material use, and that potential trade-offs depend on policy design. In a similar way, the IPBES assessment makes the link between the biodiversity crisis and resource use, and WHO links pollution and health outcomes to the use of resources — particularly in low-income countries.

Science-based targets for resource use — as with GHG emission and biodiversity targets — could guide actions to help implement global sustainability agendas within planetary boundaries and the Earth's carrying capacity. Some studies, such as Bringezu (2015; 2019), have highlighted the need for science-based targets for resources. By way of example, Watari *et al.* (2020) developed global targets for metal flows, stocks and use intensity that are consistent with emissions pathways to achieve a 2 degrees Celsius climate goal. This report makes an attempt to benchmark climate and biodiversity impacts to scientific targets in Chapter 3.

1.4. It is not enough to identify pathways for achieving sustainability global agendas. Concrete and immediate action at scale is required

Since the dawn of the sustainability and environmental intergovernmental agenda at the 1972 Stockholm Conference on the Environment, governments have failed to deliver on many environmental and sustainability commitments, and the actions taken so far do not meet the scale of the challenge (UNEP 2021b; IPBES-IPCC 2021; Fuller *et al.* 2022). The 2019 edition of this report showed that the extraction and initial processing of materials were responsible for 90% of land-based biodiversity loss and water stress and 50% of climate impacts. Moreover, the current resource use model leads to a highly unequal distribution of socioeconomic benefits and environmental impacts. It is therefore critical to explicitly acknowledge the resource perspective to meet the global goals on human development, climate, biodiversity, pollution and land degradation and to develop systemic actions that address common drivers of climate change, biodiversity loss and unsustainable resource use (see Box 1.4). Despite this, resource use and management are currently underrepresented in global, regional and national climate and biodiversity strategies (International Resource Panel 2022), and there is a dearth of targets for guiding and evaluating how improved natural resource use and management can contribute to meeting global sustainability goals (see Box 1.4).

Global agreements, based on the best available science, have set targets and goals for sustainable development, capping climate change to 1.5 degrees Celsius and halting biodiversity loss and land degradation. However, countries' commitments to resolving the climate crisis as presented through Nationally Determined Contributions (NDCs) under the United Nations Framework Convention on Climate Change's Paris Agreement are projected to lead to 2.8 degrees of warming by the end of the century (UNEP 2022b) — with estimates of 1.5 degrees of warming already within the next five years (World Meteorological Organization [WMO] 2022). While progress has been made on certain issues, for example the historic adoption of the Loss and Damage Fund for vulnerable countries at the UNFCCC COP27, the mitigation ambition expressed through the outcomes of the COP27 remained a concern (Harris 2023), as the world recorded its hottest July on record in 2023.

On the back of failures to achieve the Convention on Biological Diversity's (CBD) Aichi Targets[16] — only 14% of countries have met the target of halving or reducing natural habitat loss as 1 million species are threatened with extinction — the CBD has agreed to a new framework of goals to halt biodiversity loss and regenerate ecosystems (CBD 2022a). Nations must now demonstrate commitment through action.

16 Aichi targets, https://www.cbd.int/aichi-targets/

The world is not on track for the land degradation neutrality goal for 2030 from the UN Convention to Combat Desertification,[17] which estimates that 70% of all ice-free land has already been altered by human activity – changes that have impacted 3.2 billion people.[18]

While progress has been made towards the achievement of the SDGs, "the limited success in implementing the 2030 Agenda should raise strong concerns, and even sound the alarm for the international community" (UN 2019). Importantly, failures to protect ecosystems and biodiversity disproportionally impact the poor and most vulnerable, including women and children. In India, for example, it has been estimated that forest ecosystems directly contribute around 7% of national GDP, but represent 57% of the income of the poorest people (Sukhdev 2009). The International Labour Organization estimates that 1.2 billion jobs, or 40% of the global labour force, are at serious risk due to environmental degradation since they depend on ecosystem services (ILO 2022).[19]

The lack of effective action to deliver on intergovernmental commitments to environmental sustainability is increasingly resulting in the crossing of thresholds in global environmental systems, known as planetary boundaries. Transgressing these planetary boundaries puts humanity at risk in an existential way (IRP 2019; other research on planetary boundaries[20]).

The global community's historical failure to act on multilateral environmental agreements based on solidarity and justice has impacts on the options now available to address these crises. Solution pathways that were possible 50 years ago are now narrower, and the rate of change required far faster (UNEP 2022b; IPCC-IPBES 2021).

1.5. Rather than despair, determination to change and innovate can lead to just transition pathways and new opportunities for long-term sustainability

In a context of continuous change and recurrent and interconnected crises, improving how natural resources are used and managed can play a decisive role in more securely meeting human needs for all.

There have been strong signs that such change is possible since the last edition of the Global Resource Outlook 2019. Particularly in terms of natural resource use, there have been positive developments. One example is the adoption of a resolution at the Resumed Fifth Session of the United Nations Environment Assembly to develop a legally binding instrument on plastic pollution, including the maritime environment. The renewed focus on circular economy and the sustainability of supply chains at the United Nations Environment Assembly (UNEA) and in the Group of Seven (G7) also puts resource use on the global political agenda. For example, at UNEA-5.2, Member States adopted Resolution 5/12, which aims to improve environmental aspects of metals and minerals management along entire supply chains.

The challenge in the coming decade will be to speed up and scale up more integrated solutions to address the structural unsustainability of current resource use. This will require technological breakthroughs, new economic models, strong governance approaches, but above all the willingness and determination of political and economic leaders to make choices. This GRO aims to contribute to the understanding of why this determination is necessary (Chapters 2 and 3), what steps are essential to take and why this is essential to delivering on the overall goals of the SDGs, namely a decent life for all within the limits of the planet (Chapters 4 and 5).

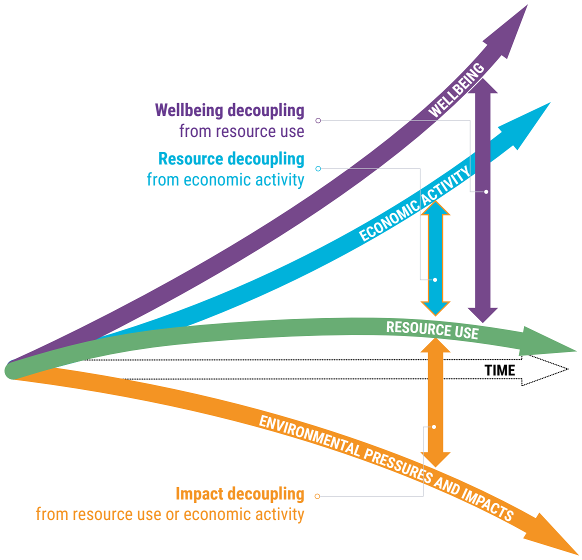
1.6. Decoupling natural resource use and environmental impacts from human well-being is essential and necessary for the transition to a sustainable future

Targeted and coordinated sustainability actions can decrease the amount of resources used and related environmental impacts, while delivering on continued socioeconomic well-being for all (IRP 2019a). This refers to the concept of decoupling human well-being from resource use, as well as decoupling resource use from environmental impacts (Figure 1.2).

This concept is not a one-size-fits-all approach. For the parts of the population with the highest resource consumption footprints (countries or fractions in a national population), actions must lead to absolute decoupling (reduction of resource use). In this this regard, IPCC (2022) reports that consumption (demand-side) measures such as diets with less animal protein, compact cities and more public transport can reduce GHG emissions by between 40% and 70% by 2050.

17 https://www.unccd.int/
18 https://www.unccd.int/land-and-life/land-degradation-neutrality/overview
19 Including jobs in "farming, fishing and forestry, and all those that rely on natural processes, such as air and water purification, soil renewal and fertilization, pollination, pest control, the moderation of extreme temperatures, and the protection provided by natural infrastructure (such as forests) against storms, floods and strong winds" (pg 8).
20 https://www.stockholmresilience.org/research/planetary-boundaries.html

Figure 1.2: Concept of decoupling.



Source: Revised from IRP (2019b).

For the contexts where resource use is expected to grow to enable dignified living,[21] the aim should be relative decoupling (where resource use increases more slowly than human well-being outcomes). For all contexts, impact decoupling is a precondition for any resource use trajectory to be considered sustainable (limiting environmental and health impacts to levels agreed in MEAs).

These differential paths for resource use and decoupling are linked to the concept of sufficiency, which is gaining traction in the policy agenda. Similarly, UNEP refers to a "fair consumption space", that is the "need to curb overconsumption while ensuring consumption opportunities needed for meeting basic needs, decent living standards, and human dignity" (UNEP 2022b). To enable such an increase, consumption levels in those parts of the population who live well above[22] the capacity of the planet should be decreased (Fanning *et al.* 2022; IPCC 2022).

Even sustainable socioeconomic systems will continue to rely on natural resources for the goods and services they need. Moreover, a global transition to more sustainable systems is expected to require significant amounts of resources (Schaffartzik *et al.* 2021; IEA 2021a; IEA 2022a; IEA 2022b and IEA 2022c) (see Box 1.3). In this context, institutions and infrastructure must be geared towards steering consumption patterns toward less resource-intensive modes while meeting human needs. According to Millward-Hopkins *et al.* (2020), adhering to sufficiency levels, combined with massive technological advances, could provide decent living standards for everyone and reduce total energy needs to the level of the 1960s by 2050, despite projected population growth.

In a context of increasing complexity and uncertainty, it is more critical than ever to manage and govern natural resources to enable the decoupling of human well-being from resource use and environmental impacts.

1.7. Decoupling will not happen spontaneously and will require systemic transformation

To deliver on decoupling, unsustainable patterns of resource use need to be reconfigured or replaced by sustainable modes of producing and consuming that respect the capacity of the planet, meet people's needs and improve human dignity (see Figure 1.3). This calls for a process of structural transformation. While transformation refers to the overall change or outcome of large-scale shifts in technological, economic and social systems, transition refers to the process towards the transformation.

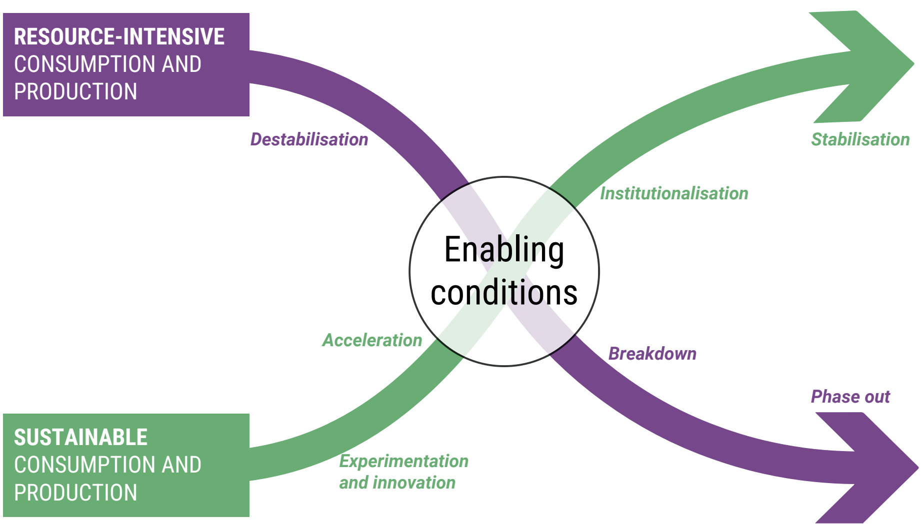


Figure 1.3: Strategies for the transition towards sustainable resource use.

Source: Adapted from Loorbach *et al.* 2017.

21 This concept goes back to the UNCHE Conference in 1972 in Stockholm, which takes human dignity as a central concept and explicitly links it to the use of natural resources and the state of the environment.

22 In terms of consumption-based environmental impact per capita.

Transitions are hugely complex and uncertain processes of change that can take decades to unfold (IRP 2024a). A successful transformation needs to overcome different barriers and lock-ins ranging from economic to behavioural, institutional and vested power dynamics, as well as skills, information and knowledge constraints (Table 1.1). For instance, transitioning can require large investment and can be technically challenging for many economic sectors. This also applies to public institutions and households. Transitioning can also lead to changes in the economic structure that can be perceived as disrupting, and challenge prevalent lifestyles and power structures.

Table 1.1: Examples of barriers and lock-ins to a transition to sustainable resource use.

Category	Examples
ECONOMIC LOCK-INS	• Markets failing to capture environmental costs of production and thereby incentivizing unsustainable consumption and production patterns. • Harmful subsidies being the norm. • Financialization of the commodity markets, which drives unsustainable resource extraction. • Business models do not account for resource use-related risks. • Concentration of decision-making power in business conglomerates. • Existing investments in machinery and infrastructure locking-in behaviours or resource needs. • New investment requirements by actors at all levels.
LIFESTYLES AND CONSUMPTION	• Resource-intensive aspirational consumption models, promoted by targeted marketing strategies and even by national policies. • Missing infrastructure to deliver sustainable mobility, housing, energy use and so on. • Lack of access to affordable sustainable products. • Gaps in education for sustainable development across school and higher learning curricula.
FRAGMENTED GOVERNANCE	• Geographical and sectoral fragmentation of resource management strategies that inhibit systematic and integrated responses. • Complex supply chains whose associated impacts are difficult to track, often with specific actors determining the functioning of the market.
QUALITY OF INSTITUTIONS	• Institutional inertia. • Poor quality of institutions, which can hinder action in society's collective interest. This can be due to the inherent challenges of organizational governance, lack of resources, focus on short-term benefits and corruption. • Lack of consideration for local communities, small-scale producers and the scientific community.
SKILLS	• Current skills not fully suited to the transition needs. • Current educational programmes do not develop the skills or business models that the transition will demand.
INFORMATION AND KNOWLEDGE CONSTRAINTS	• Lack of targets translating global sustainability agendas into resource-use targets. • Lack of transparent and easily actionable information across the value chain of consumption and production. • Increasingly complex information and complex solutions. • Citizens overwhelmingly receive information that promotes consumption and reinforces unattainable aspirational consumption patterns.
REBOUND EFFECTS	• Efficiency improvements are often outweighed by increasing consumption due to rebound effects.

Source: Adapted from IRP (2024a) and EEA (2022a).

To overcome these barriers, policy must drive change and ensure the necessary conditions for promoting the much-needed systemic change in our systems of consumption and production. This includes *inter alia* improved institutions and governance mechanisms that consider regulations, incentives and market-based instruments that can be developed inclusively and equitably on the basis of scientific evidence. Other major elements for success include alignment around common strategic goals across sectors and levels of governance, plus international coordination – for example through financial, knowledge, technological and capacity exchange (IRP 2024a). Suited metrics are essential to monitor and guide the transition (Box 1.5).

Equally important is actively phasing out unsustainable practices and overcoming lock-ins and barriers. For several decades, international organizations, scientists and civil society actors have pleaded for the phasing out of environmentally harmful taxes and subsidies, unsustainable spatial planning practices and so on. However, much capital has been poured into property and fossil fuels, while relatively small amounts of capital have been dedicated to sustainable resource use (UNEP 2009). This applies to public finance, where it is still the norm to subsidize unsustainable practices (Dasgupta *et al.* 2021) and private finance. Indeed, fossil fuels benefited from record subsidies in 2022 (International Energy Agency [IEA] 2023); (International Monetary Fund ([IMF] 2023).[23] This GRO report includes specific recommendations on this crucial aspect.

Box 1.5. Metrics and methodologies to guide a sustainability transition

A global transition towards sustainable resource use needs to be guided by suited metrics, namely metrics that also consider environmental and well-being outcomes, and metrics that can inform relevant decision-making processes (such as those involving key pressures, impacts, policy responses and so forth). This includes metrics that go beyond traditional measures of success (usually economic indicators and specifically Gross Domestic Product).

Gross Domestic Product (GDP) is compiled by virtually all countries based on their System of National Accounts as a summary figure for economic activity. Over time, GDP has also been used as a measure of overall well-being and welfare, despite its exclusion of environmental factors (natural capital) and many social factors (social capital). In *Our Common Agenda*,[24] the United Nations Secretary-General highlights the urgent need for countries to move beyond GDP as their main measure of progress, "advancing discussions on a methodology for measuring sustainability transformation in a way that integrates human well-being, natural capital and sustainable economic development" as a core priority for the 2023 UN General Assembly. Along these lines, this GRO report complements the GDP metrics used in the assessments with metrics on human well-being. For that, the Human Development Index (HDI) is used as a proxy for well-being related to three basic components of human development: life expectancy, education and income.

To inform and guide a sustainable transition, robust, complete, transparent and regularly updated data on the costs and benefits of resource use are also needed. This will make it possible to monitor the ability and efficiency of provisioning systems (see section 1.8) in delivering human well-being. The SDG indicator framework provides a comprehensive starting point,[25] including indicators on the performance of the provisioning systems that provide us with food, housing, and energy for example.

Given the critical role of actions on consumption, improved data on consumption hotspots and their related impacts (consumption environmental footprint) are also crucial. This GRO report assesses pressures and impacts from a consumption perspective in order to identify impact hotspots.

23 Although subsidy amounts vary according to the method through which they are estimated, most sources indicate that 2022 was a record year for fossil fuel subsidies. According to IEA estimates, USD 1 trillion spent on fossil fuel subsidies. Subsidy estimates from IMF also include social and environmental costs, and are therefore higher: IMF estimated USD 7 trillion was spent on subsidizing fossil fuels in 2022. However, the fact that more was spent during 2022 than any other year was constant across both methods.

24 https://www.un.org/en/common-agenda

25 While the aim of this report was to assess how resources deliver nutrition, energy, housing and at what environmental cost, data limitations prevented the use of such metrics throughout the report.

1.8. For solutions that go beyond incremental or isolated changes, the "provisioning systems" concept facilitates an integrated and systemic approach to decision-making

The lack of systemic approaches and approaches that include consumption considerations — also called demand side as they address the demand for goods and/or services — is a major impediment to current policy approaches towards complex and interrelated sustainability challenges. The 2030 Agenda for Sustainable Development[26] reflects an understanding that sustainability challenges (the 17 SDGs) should be addressed holistically. Assessments based on modelling and policy evaluation have shown that policies designed with a narrow scope can hinder progress elsewhere and negatively impact overall goals of sustainable human well-being.[27] In particular, strategies based on policy interventions that do not account for modes of resource use in a systemic way can have major unintended consequences.[28] It remains difficult to translate such system change visions into concrete policies and plans for action.

"Provisioning system" is a recent and increasingly relevant concept that groups together ecological, technological, institutional and social elements that interact to transform natural resources to satisfy human needs (Fanning *et al.* 2020). The concept enables an integrated consideration of how material and political-economic dimensions interact to shape resource use to deliver social outcomes (Schaffartzik *et al.* 2021). Figure 1.4 depicts how provisioning systems rely on the extraction of natural resources to deliver human well-being, while also impacting the environment and therefore people.

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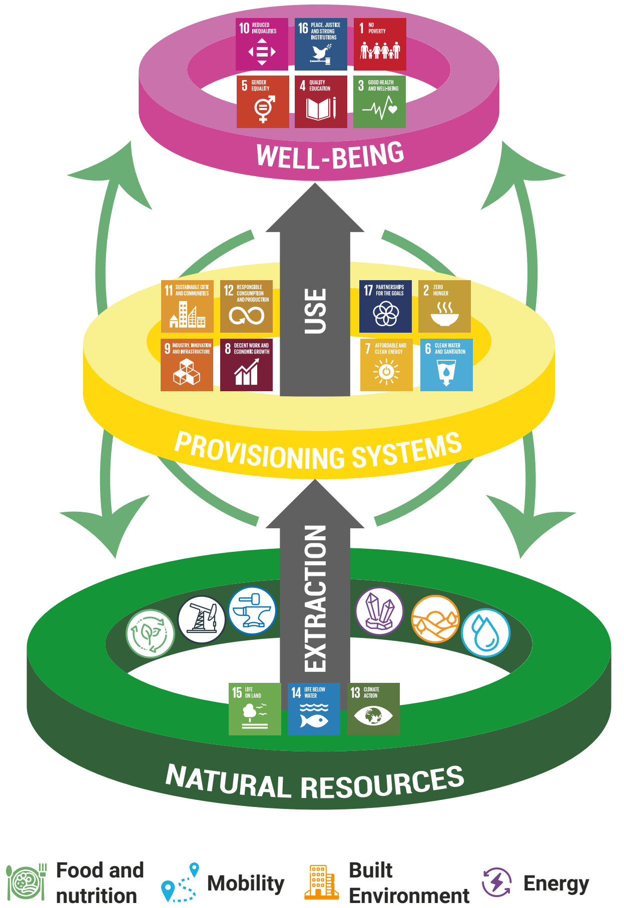
Figure 1.4: From natural resources to provisioning systems and societal well-being.



Source: Adapted from UNEP (2021b – Figure ES.1) and O'Neil et al. (2018 – Figure 1). Design concept by: Namita Sharma and Iris Lassus.

A provisioning-systems perspective is potentially useful for understanding and identifying solutions that transform the way human needs are met while also achieving sustainability goals (Schaffartzik *et al.* 2021). Such a perspective opens up possibilities beyond sector-specific solutions that may have unintended consequences. It can point to much less resource-intensive ways of providing solutions, rather than relying on what initially looks like a sustainable solution. For example, expanding or electrifying the car fleet may seem the optimal solution for transitioning to more efficient mobility systems. However, the massive upscaling of electric vehicles will be highly material intensive (Carrara *et al.* 2023; UNCTAD 2020), as would the additional road infrastructure work. Using a provisioning-systems perspective could promote solutions such as improving public transport or reducing the need for transport by designing and developing more condensed urban centres or enabling telework and telehealth services.

26 Transforming our world: the 2030 Agenda for Sustainable Development https://sdgs.un.org/2030agenda
27 See references at IRP Policy Coherence of the Sustainable Development Goals, https://resourcepanel.org/reports/policy-coherence-sustainable-development-goals
28 See references at IRP Policy Coherence of the Sustainable Development Goals, https://resourcepanel.org/reports/policy-coherence-sustainable-development-goals

The assessments within this GRO focus on the following four provisioning systems that are resource-intensive and central to human well-being: energy, food, built environment and mobility systems. These systems provide the goods and services that relate to basic development indicators, as reflected in the SDG monitoring framework. Some chapters of the GRO refer also to other provisioning systems to complement the assessments. For example, Chapter 3 refers to water and sanitation, education and clothing, while Chapter 2 refers to communication. Although other provisioning systems, such as specific consumer goods (electronics, textiles and the like), can play a critical role in delivering well-being, they are not explicitly assessed in the report but have been considered under other categories. Box 1.6 describes the boundaries of the main four provisioning systems considered by this report and Annex 2 (available at www.resourcepanel.org) outlines the underlying mapping from economic sectors[29] to provisioning systems. For this mapping, the use of resources and environmental impacts of each economic sector have been allocated to the provisioning systems where final consumption takes place. This means, for example, that materials used to generate electricity for crop irrigation or fuels for energy used by the food industry will be assigned to the food-provisioning system. This differs from the classifications used in climate mitigation reporting, for instance, where the energy sector includes most activities producing energy, and these are not assigned to final consumption sectors. This exercise is not without its methodological challenges.[30]

Box 1.6. Provisioning systems: key facts and figures

FOOD AND NUTRITION

Resource use and corresponding supply chains that contribute to human nutrition, including each step in the food supply chain from production to distribution, retail and consumption.

Actors: Farmers, food processors, retailers, food services, financial/trading actors and final consumers

Value added: 12%

Jobs: 33%

Demand of materials: 23.5 billion tonnes (84% biomass, 9% non-metallic minerals, 6% fossil fuels and 1% metallic minerals)

Highest material footprint in: Upper middle-income countries (10 billion tonnes; 79% biomass, 12% non-metallic minerals, 7% fossil fuels and 2% metallic minerals)

Highest material footprint per capita: High income countries (4.6 tonnes per capita; 82% biomass, 9% non-metallic minerals, 8% fossil fuels and 2% metallic minerals)

Main challenges: Unsustainable diets, food loss and waste, impact on ecosystems, carbon-intensive supply chains and competition with other potential applications of biomass (such as for energy)

MOBILITY

Land, sea, and air mobility, and associated infrastructure for transporting people and goods.

Actors: Land use/urban planners, vehicle manufacturers, travel services, national governments[31], citizens and entities

Value added: 9%

Jobs: 7%

Demand of materials: 28.6 billion tonnes (64% non-metallic minerals, 19% fossil fuels, 13% metallic minerals and 4% biomass)

Highest material footprint in: Upper middle-income countries (16.7 billion tonnes; 71% non-metallic minerals, 14% fossil fuels, 12% metallic minerals and 3% biomass)

Highest material footprint per capita: Upper middle-income countries (6.4 tonnes per capita; 71% non-metallic minerals, 14% fossil fuels, 12% metallic minerals and 3% biomass)

Main challenges: New lock ins in motorized mobility, long travel distances and high travel frequency and carbon-intensive vehicles

29 Such as those used for climate mitigation reporting or economic sector classifications such as the International Standard Industrial Classification of All Economic Activities (ISIC).
30 Economic sector classifications are not built and broken down in a way that assigns resource use to the final provisioning system. Assumptions need to be made that may introduce uncertainty into the results.
31 As developers of national plans for mobility infrastructure.

BUILT ENVIRONMENT

Constructed spaces for human activity, where people live and work (built infrastructure used by other systems would not come under this system).[32]

Actors: Land use/urban planners, the construction sector, citizens and entities

Value added: 13%

Jobs: 15%

Demand of materials: 30.6 billion tonnes (76% non-metallic minerals, 9% fossil fuels, 8% metallic minerals and 7% biomass)

Highest material footprint in: Upper middle-income countries (16.5 billion tonnes; 79% non-metallic minerals, 9% fossil fuels, 8% metallic minerals and 4% biomass)

Highest material footprint per capita: High-income countries (7.1 tonnes per capita; 71% non-metallic minerals, 11% metallic minerals, 10% fossil fuels and 8% biomass)

Main challenges: Lock-ins in buildings with high energy demand, high floor area and energy demand per capita, high emissions embodied in construction and competition with other users of biomass

ENERGY

Production, conversion and supply of energy for end consumers, and its associated infrastructure.

Actors: energy providers, energy producers, investors, citizens, national entities and State governments[33]

Value added: 3%

Jobs: 2%

Demand of materials: 6.1 billion tonnes (65% fossil fuels, 21% metallic minerals, 9% non-metallic minerals and 5% biomass)

Highest material footprint in: High-income countries (2.7 billion tonnes; 72% fossil fuels, 18% metallic minerals, 7% non-metallic minerals and 3% biomass)

Highest material footprint per capita: High-income countries (2.2 tonnes per capita; 72% fossil fuels, 18% metallic minerals, 7% non-metallic minerals and 3% biomass)

Main challenges: Carbon lock-ins in industries and infrastructure, high energy demand from other provisioning systems, limited supply of decarbonized electricity supply and low-carbon fuels, high demand of materials for the low-carbon transition, challenges of storing electricity (such as from photovoltaics) and competition for the use of biomass

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32 Rail infrastructure and roads form part of the mobility system.
33 As possible developers of energy projects.

1.9. Actions for the sustainable use and management of natural resources must place justice and sufficiency at the core

An environmentally sustainable economy with decent work and social justice is essential to the well-being of current and future generations. This is acknowledged in the context of climate change mitigation and adaptation under the UNFCCC (ILO 2022), where just transitions have become "increasingly fundamental to the transition to a low-carbon economy" (Katowice Committee of Experts on the Impacts of the Implementation of Response Measures [KCI] 2022)).

While definitions of a just transition vary, the International Labour Organization's (ILO) *Guidelines for a just transition towards environmentally sustainable economies and societies for all* (ILO 2015) presents an agreed policy framework and implementation reference. Again, with a focus on climate action, a just transition involves "maximizing the social and economic opportunities of climate action while minimizing and carefully managing any challenges related to the impacts on the world of work, including gendered impacts, in an effort to facilitate decent work outcomes, ensuring social dialogue and respect for international labour standards in the process" (ILO 2022).

The just transition goes beyond work-related impacts. The ILO principles to guide transitions to sustainable societies and economies include: reaching strong social consensus through consultation with all relevant stakeholders on the end point and pathways to sustainability; coherent policies across all sustainability dimensions and including focus on education, training and labour portfolios, as well as centralizing gender considerations; the creation of decent jobs; and the consideration of specific country circumstances when developing solutions, among others (ILO 2015).

Based on the inequalities in the use and benefits of natural resources highlighted in the 2019 report, this edition upholds the fundamental tenet of just transitions as central to any policy proposals. Indeed, the concepts of absolute and relative decoupling, as well as the decoupling of well-being from negative impacts, already consider differing country and consumption contexts and the need to redefine the structurally unequal distribution of cost and benefits within the current model of resource use. The up-to-date data and analysis of this report serve to better understand the inequalities of resource use and inform policy proposals for just transitions across country contexts.

Furthermore, the concept of sufficiency links the principles for just transitions to the use of resources. This concept is gaining traction on the policy agenda and refers to the need to increase resource use in low-development contexts to enable dignified living[34] for all, while reducing resource use in contexts of higher consumption footprints (see section 1.6. above). The concept applies to differential resource-use levels between countries but also between different fractions of the population within countries. The latter is becoming increasingly important since research shows that inequality has narrowed between countries but is rising within countries.[35]

Further research and conceptualizations are required into how to practically account for justice and sufficiency considerations in sustainability and environmental agendas. Without necessarily offering any empirical or policy conclusions, the insights from this report contribute to this by: (1) shedding light on the fundamental inequalities around resource use; and (2) identifying policy measures that ensure just outcomes as a core element of analysis.

1.10. 2024 Global Resources Outlook expands on earlier reports

This report builds on and extends the conversation started in 2019[36] by incorporating a transitions logic, a provisioning-systems perspective and centralizing considerations of just transitions and sufficiency in its analysis and recommendations. It provides assessments up to the present year of how resources are extracted and consumed throughout the global economy, as represented by metrics including those measuring domestic material extraction (as per SDG indicator 12.2.1), domestic material consumption (SDG indicator 8.4.2) and material footprints (SDG indicator 8.4.1) (see Chapter 2).

Material use trends are coupled with life-cycle impact assessment methodologies that consider upstream and downstream resource use and disposal in order to identify the environmental impacts of resource use (Chapter 3).

Based on a state-of-the art multi-model scenario framework that projects the environmental impacts of resource use for the first time, two possible trajectories are mapped. The first continues along historical trend lines, while the second explores what could be achieved with ambitious and far-reaching actions to curb resource use and its impacts (Chapter 4).

34 This concept goes back to the UNCHE Conference in 1972 in Stockholm, which takes human dignity as a central concept and explicitly links it to the use of natural resources and the state of the environment.
35 https://datatopics.worldbank.org/sdgatlas/goal-10-reduced-inequalities?lang=en
36 The first edition of the Global Resources Outlook was released in 2019 at UNEA-4.

Finally, based on the insights provided by the previous chapters, proposals for action that operationalize a transition to sustainable resource use are put forward (Chapter 5). Such proposals go beyond incremental improvements and consider the multiple barriers to large-scale action. These considerations can lead to outcomes that are science based, just and balanced to support far-reaching and multi-beneficial outcomes that can break through traditional barriers to change. Such actions and their outcomes will help in: holistically resolving the triple planetary crisis; moving from inequality to more equality, from overshoot to meeting global sustainability agendas' targets; and moving from focusing on efficiency to sufficiency – in other words, confronting the fundamentally unsustainable nature of our consumption and production systems.

While this report focuses on long-term trends, it nonetheless acknowledges that the world is concerned by shorter term issues, and that efforts towards resolving these crises can sometimes induce structural change. Furthermore, the improvements to the report include among others variations in the absolute and relative GDP change figures vis-à-vis those reported in 2019, since the GDP metrics have been aligned to GDP at constant prices in US dollars.

1.11. Concluding remarks

The current picture shows that countries tend to transgress planetary boundaries more quickly than they achieve social development outcomes (Fanning *et al.* 2022), and that no country achieves high societal outcomes without transgressing the limits of the planet (O'Neil *et al.* 2018). This sobering empirical fact and the sense of urgency have prompted the authors to propose ambitious systemic solutions for action at the global level in terms of sustainable resource use. The repositioning of the IRP from knowledge provider to a provider of action-oriented solutions will be critical in the next decade.[37]

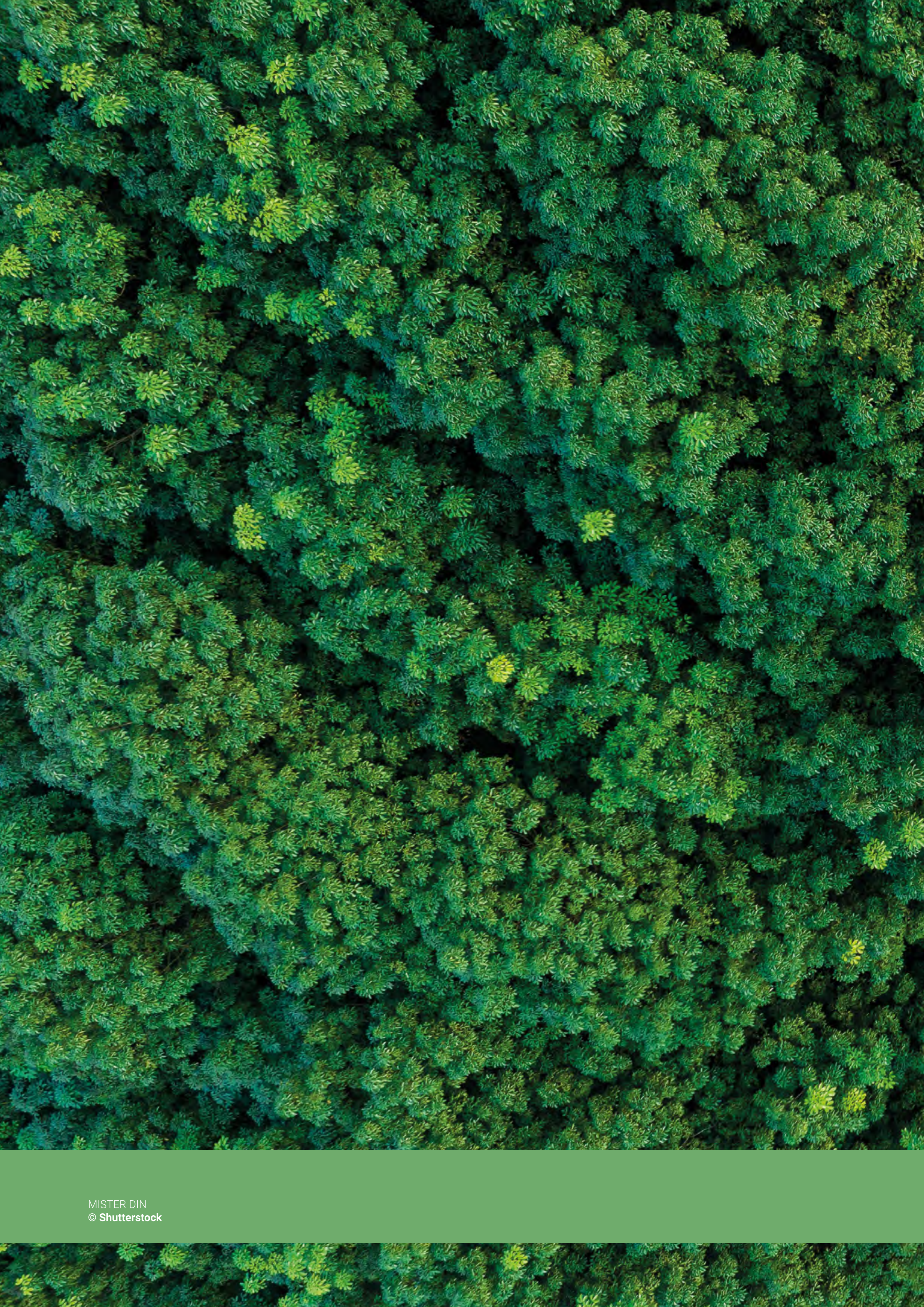
Some of the proposed solutions have been tried and tested, whereas others are innovative and not yet attempted. Pre-existing strategies are insufficient and, while further assessment of intervention effectiveness is needed, the urgent nature of the triple planetary crisis calls for action based on the precautionary principle of best available science. In a context of increasing uncertainty (UNDP 2022), strategies and actions might struggle to yield the desired results immediately. However, using science-based assessments can help steer the course, and actors must leverage the tools at their disposal to learn and make any adjustments to implementation strategies.

While the knowledge base for such comprehensive action needs to be strengthened, since the 2019 edition of the GRO the work of the IRP and the broader research communities on resource use and its fundamental linkages to sustainable development has developed strongly. More specifically, understanding has deepened on the linkages of resource use with the agendas and agreements around climate, biodiversity, land degradation and human health.

For UNEA-6, these findings are expected to inform countries and spur action for a strong resolution based on systemic plans and pledges with a central focus on resource use.

> ***This GRO is clear: it will be impossible to reach the goals without a much stronger focus on sustainable resource use in sustainability and multilateral environmental agreements.***

37 As stated in the IRP 2022-2025 Work Programme, https://www.resourcepanel.org/sites/default/files/documents/document/media/2022-2025_irp_work_programme_0.pdf



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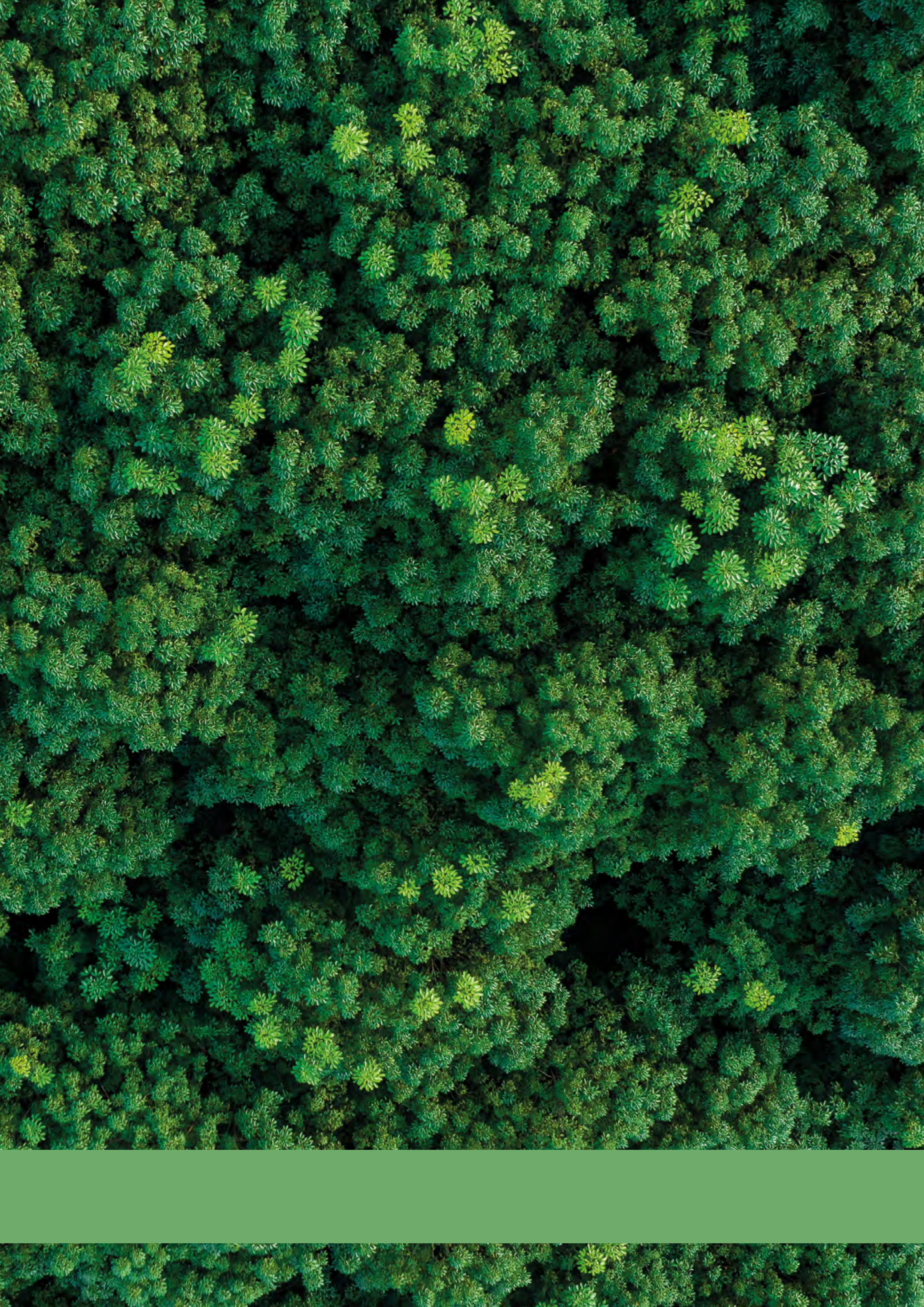


02

Drivers, pressures, and natural resource use trends

Authors: Heinz Schandl, Raymundo Marcos-Martinez, Jim West, Yingying Lu, Alessio Miatto, Stephan Lutter, Stefan Giljum, Manfred Lenzen, Mengyu Li, Livia Cabernard and Marina Fischer-Kowalski

Main findings

Rising living standards have come at the cost of rapidly increasing extraction and trade of materials, plus escalating waste and emissions. This includes lifting people out of poverty. Global material extraction surged from 30 billion tonnes in 1970 to 106.6 billion tonnes in 2024, an average annual growth of 2.3%. Consequently, the global average per capita demand for materials rose from 8.4 tonnes in 1970 to 13.2 tonnes in 2024.

Patterns of domestic material consumption have undergone significant shifts. In 1970, Asia and the Pacific, Europe and North America consumed roughly equal shares of primary materials, each accounting for about a quarter of the global total. By 2017, however, Asia and the Pacific's share had ballooned to almost 60% of global consumption.

The material footprint has remained static in high-income countries since the 2008-2009 Global Financial Crisis, while upper middle-income countries have experienced substantial growth. Lower middle-income and, to a lesser extent, low-income countries have seen modest enhancements in their consumption patterns. High-income countries continue to consume materials at a rate six times greater than that of low-income countries.

Built environment and mobility stand as the leading drivers of the rising global material demand, closely followed by food and energy. These sectors combined account for approximately 90% of global material demand.

Global material productivity, which measures the economic efficiency of material use, has grown at a notably slower rate compared to labour, energy and GHG productivity. After an extended period of decline, material productivity began to see improvements from around 2012, and these gains have since plateaued.

Waste and emissions have risen in tandem with the surge in material use. The shift towards a minerals-based economy has further exacerbated the challenges, leading to problematic waste streams and a rise in emissions and pollution.

Increased agricultural production has led to a rise in water consumption. The expansion of crop fields, pastures and plantation forests has further encroached on natural habitats, exerting additional pressure on ecosystem health and biodiversity.

To ensure continued progress, the integration of economic and environmental policies must continue. There is an urgent need for improved resource productivity and sustainable production and consumption systems that efficiently deliver essential services—such as built environment, mobility, food, and energy — with significantly reduced material and energy inputs and diminished emissions.

2.1 Introduction

The growing global population, expanding economy, rapid urbanization and a growing middle class have increased the demand for resources such as materials, water and land, putting pressure on these natural resources. This chapter delves into the effects of these factors, including economic and population growth, as well as urbanization and industrialization, by evaluating global trends in the demand for materials, water and land.

The data and analysis provided seek to define the level of commitment required to steer the global economy towards sustainable resource utilization (as per SDG 12.2) and to curb wasteful material consumption (as advocated by SDG 12.5) (Gasper *et al.* 2019).

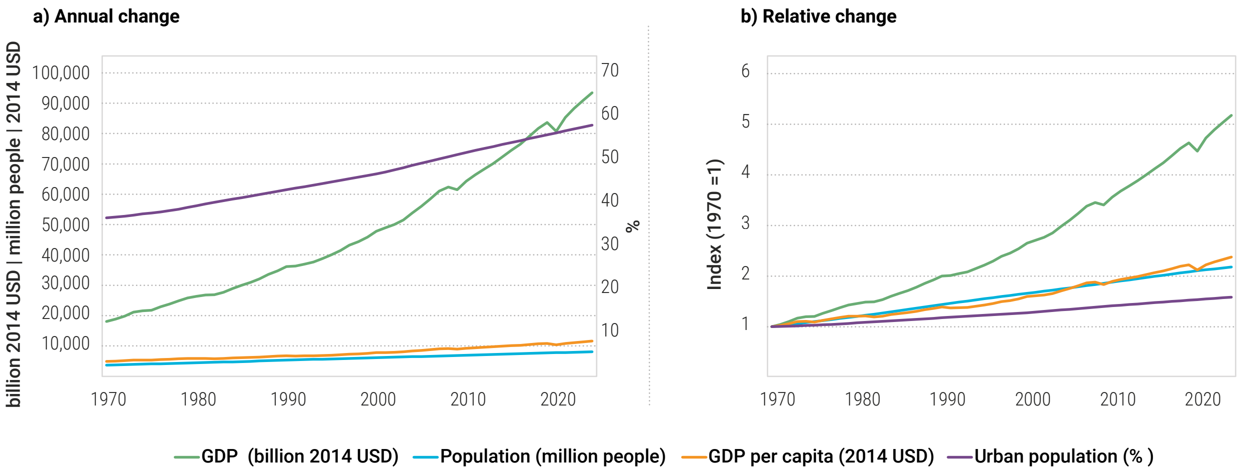
This chapter's core analysis uses established data on the extraction, trade and use of materials, as well as the resulting waste and emissions. The chapter attributes environmental pressures to final demand using the GLORIA global multi-regional input-output tool (Lenzen *et al.* 2022). The records are formulated using the widely recognized material flow accounting methodology (UNEP 2021) and strictly follow the guidelines set by the System of Integrated Environmental-Economic Accounts (SEEA) (Pedersen and de Haan 2006).

Most of the datasets used cover up to the year 2022. However, data have been modelled for up to 2024 using the IRP integrated modelling framework when applicable, as explained in the chapter. The calculations cover over 180 countries and are further grouped into seven world regions and four country income groups. The material flow accounts are grounded in international datasets that document the extraction and trade of materials, the generation of waste and emissions, energy usage and land and water consumption. Significantly, this is the first instance where the supply of materials has been linked to provision systems, as discussed in section 2.3.4.

2.2. What drives global resource use trends?

Over the past 50 years, there have been notable changes in economic output, population trends (KC and Lutz 2017; Lenzen *et al.* 2022), individual income (Dellink *et al.* 2017), and urbanization patterns (Jiang and O'Neill 2017). In 1970, global GDP stood at approximately 18 trillion US dollars (based on 2014 prices). This figure is projected to surge by over five times, reaching USD 93 trillion by 2024, as shown in Figure 2.1. By comparison, global population rose from 3.7 billion to 8.1 billion during this time frame. These shifts in economy and population led to an increase in GDP per capita from USD 4,882 in 1970 to USD 11,591 by 2024. This economic growth significantly enhanced the material well-being and quality of life for millions, especially in the Global South. As the world further urbanizes and industrializes, the strain on environmental systems intensifies, leading to exacerbated environmental consequences. Between 1970 and 2024, the proportion of the global population residing in cities is projected to rise from 37% to 58%, as depicted in Figure 2.1. Such trends imply profound consequences for the consumption of natural resources and environmental transformations, both on a global and regional scale.

Figure 2.1: Global changes in population, GDP, GDP per capita and urban population.



Source: United Nations Department of Economic and Social Affairs (UN DESA World Population Prospects 2022; UN DESA National Accounts 2022).

2.2.1 Population growth

Since the 1970s, the global population has been growing at an average rate of over 1.5% annually, reaching approximately 8 billion people today. Throughout this period, Asia and the Pacific has consistently been the most populous region. However, the swift growth of Africa's population stands out, as depicted in Figure 2.2, with significant implications for future distribution of natural resource use. The percentage of people living in high-income countries decreased from 23% of the global total in 1970 to 16% in 2020, as illustrated in Figure 2.3. Over the past 50 years, countries with higher per capita incomes have generally seen lower population growth rates. In contrast, the low-income group has witnessed the fastest population growth, averaging 2.6% annually. On a global scale, population growth rates have steadily dropped from an average of 1.9% per year in the 1970s to an estimated 0.8% annually between 2020 to 2024 (UN 2022).

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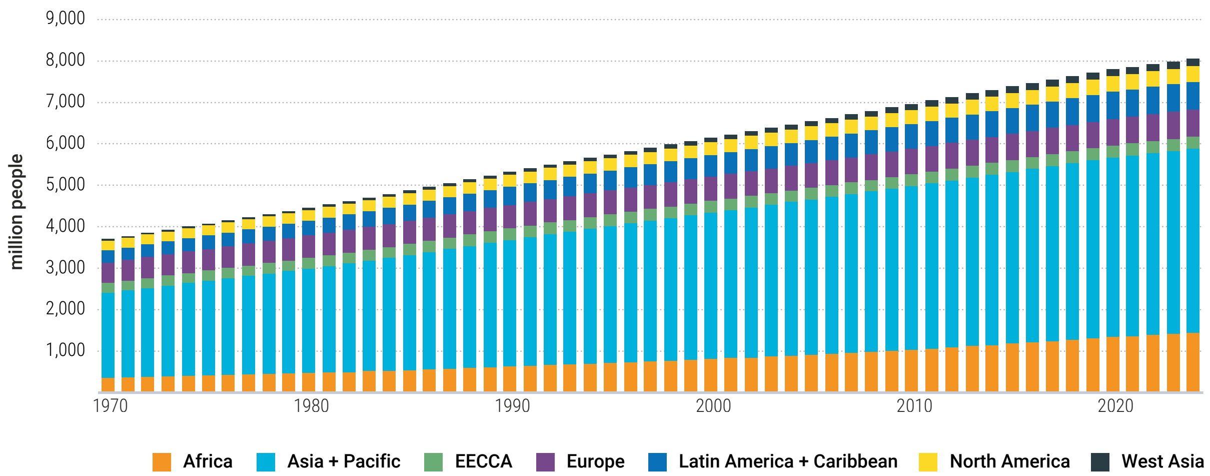
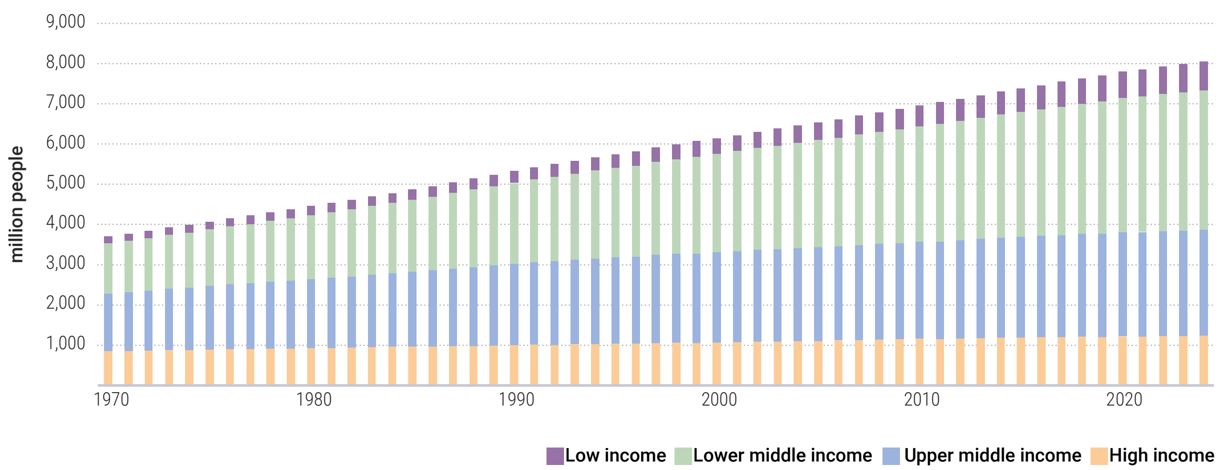
Figure 2.2: Distribution of population among seven world regions, 1970 – 2024, million people.



Source: UN DESA World Population Prospects 2022.

Figure 2.3: Distribution of global population among four income bands, 1970 – 2024, million people.



Source: UN DESA World Population Prospects 2022.

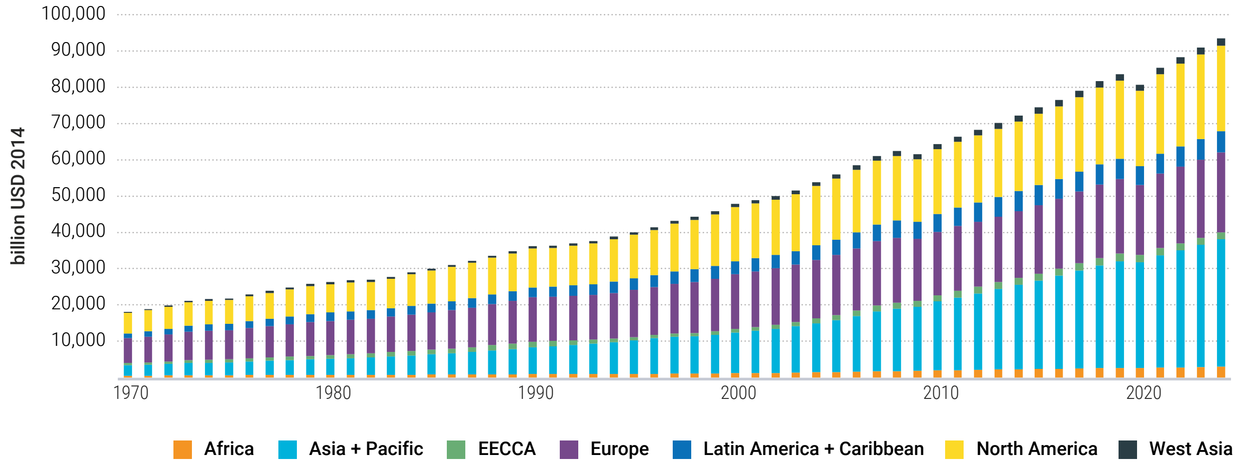
2.2.2 Gross Domestic Product

Global Gross Domestic Product (GDP) expanded much faster than global population at an average yearly rate of 3% between 1970 and 2020 (Figure 2.4). The economic slowdown generated by the COVID-19 pandemic reduced the world's GDP by around USD 5 trillion in 2020 and USD 3 trillion in 2021.

Between 1970 and 2020, Asia and the Pacific experienced the most significant GDP growth, averaging 4.8% annually. This led the region to account for the largest portion of global GDP, growing from 16% in 1970 to 36% in 2020. During this time, West Asia and Africa saw annual GDP growth of about 3.5%. North America, as well as Latin America and the Caribbean, had an average annual growth rate of 2.7%. Europe and Eastern Europe, Caucasus and Central Asia (EECCA) regions grew at a rate of over 2.1% annually. However, their contributions to global GDP declined: Europe's share went from 38% to 24%, and EECCA's from 4% to 2% (see Figure 2.4). By 2020, the GDP of Africa and West Asia were five and six times their values in 1970, respectively. However, their global GDP shares remained relatively stable at around 2.5%. Between 2019 and 2020, Latin America and the Caribbean witnessed the largest percentage drop in GDP at 7%, followed by West Asia at 6%.

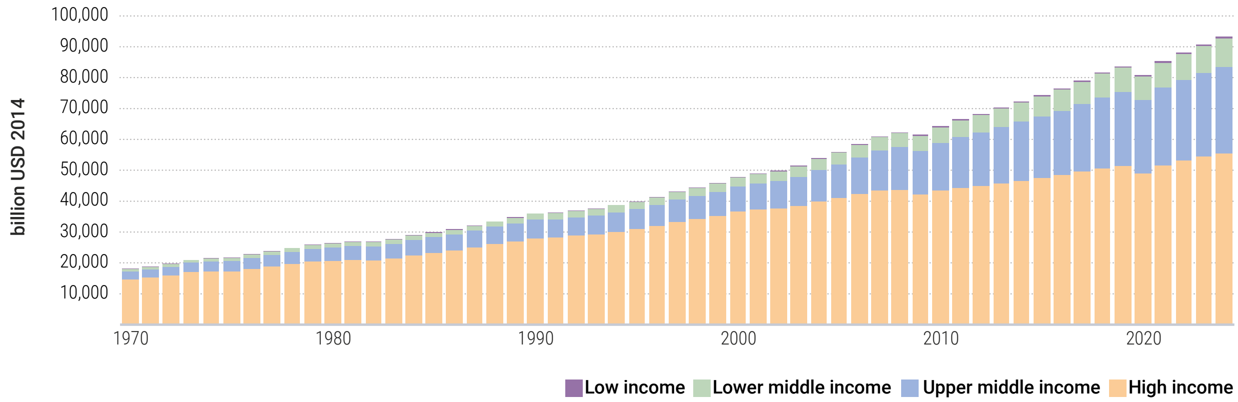
In 1970, high-income economies contributed 81% to global GDP and, by 2020, they still represented 61%, even though they had the most modest average annual growth rate of 2.7% (as shown in Figure 2.5). The reduction in high-income countries' global GDP share has been primarily offset by the growth in upper middle-income countries. These countries increased their contribution from 14% in 1970 to 29% in 2020. Meanwhile, lower middle-income economies saw their 1970 share of 5% double by 2020. On the other hand, low-income countries consistently represented around 0.6% of global GDP throughout this period (UN DESA 2023).

Figure 2.4: Distribution of global GDP among seven world regions, 1970 – 2024, billion USD (constant 2014 prices).



Source: UN DESA National Accounts 2022.

Figure 2.5: Distribution of global GDP among four income bands, 1970 – 2024, billion USD (constant 2014 prices).



Source: UN DESA National Accounts 2022.

2.2.3 Per capita GDP

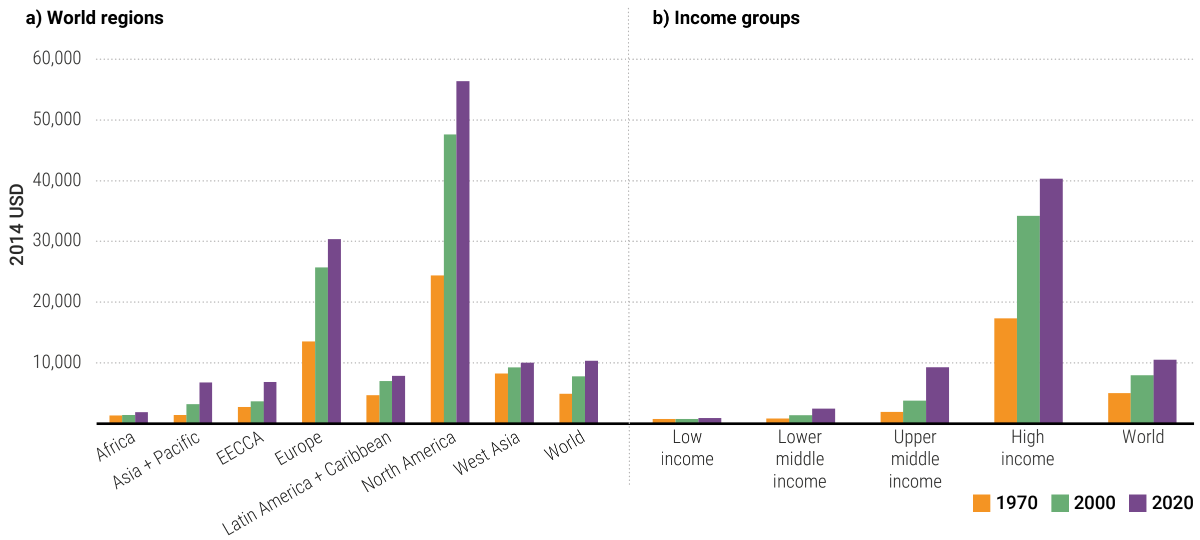
Per capita GDP provides a more accurate representation of material living standards compared to total GDP. Between 1970 and 2024, it is estimated that global per capita GDP will have increased by 2.4 times, reaching approximately USD 11,600 (as indicated in Figure 2.6). However, substantial disparities persist across regions, individual countries and different income groups. In 1970, both Africa and Asia and the Pacific had per capita GDP of around USD 1,350. However, their growth trajectories diverged significantly. Africa saw a modest annual growth rate in per capita income of 0.8%, whereas Asia and the Pacific witnessed a substantial rise, averaging 3.3% yearly growth in GDP per capita.

While overall per capita GDP has grown in all world regions since the 1970s, there have been periods of decline in per capita income following major historical events. In West Asia for instance, GDP per capita has not returned to the level of the late 1970s and early 1980s, due to sustained drops in real oil prices and the highest population growth rate of any region (with an annual average growth of 3.1%).

The EECCA region also experienced a decline in GDP per capita following the dissolution of the former Soviet Union. The global financial crisis and the COVID-19 pandemic negatively impacted per capita income growth in all regions.

Per capita income in non-high-income countries has been consistently lower than the world average (Figure 2.6). In 1970, the per capita income in high-income countries was 28 and 25 times higher than in low and lower middle-income countries, respectively. By 2024, the ratio of high-income countries' per capita GDP to low-income countries' GDP per capita is expected to double, while the corresponding ratio for lower middle-income countries is expected to fall to 17. While the gap between GDP per capita in upper middle-income and high-income countries has been narrowing, the difference in income between the two types of region was around USD 31,000 in 2020. The GDP per capita in low-income countries in 2020 was just 21% higher than the 1970 value. Upper middle-income regions had the largest increase from USD 1,700 in 1970 to USD 9,200 in 2020 (UN 2022; United Nations Department of Economic and Social Affairs [UNDESA] 2023).

Figure 2.6: Per capita GDP for (a) world regions and b) income groups, 1970, 2000, 2020, USD per capita (constant 2014 prices).



Source: UN DESA National Accounts 2022.

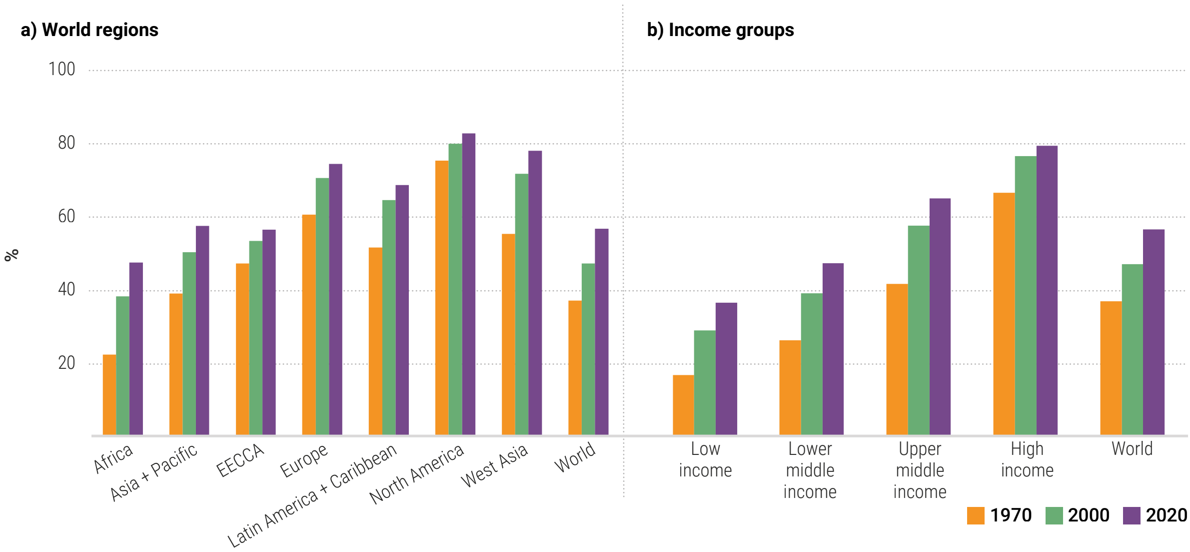
2.2.4 Urbanization

Urbanization has important implications for material use, as urban areas tend to consume more resources per capita compared with rural areas (Schiller and Roscher 2023). For example, urban residents typically have higher levels of consumption and use more energy, water and land than rural residents. They also tend to generate more waste and pollution. Additionally, urbanization can lead to increased demand for housing, infrastructure and transportation, which can place pressure on natural resources and contribute to environmental degradation. On the other hand, well-planned cities may offer resource-efficiency gains.

The proportion of the world population living in cities increased from 37% in 1970 to 56% in 2020, which represents an average annual growth rate of 0.8% (Figure 2.7). Urbanization is most advanced in developed regions such as North America and Europe, where around 80% of the population live in cities. However, urbanization has also increased rapidly in developing countries, particularly in Africa and Asia. Many Asian countries experienced a massive infrastructure build-up and rapid urban growth, as in China (Wang *et al.* 2016) but with some signs of pollution reduction and efficiency improvements (Yu 2021), as well as in India (Taubenbock *et al.* 2009) and other parts of the region. Africa had the largest annual urbanization growth rate of 1.4%, which led to an increase from an urban population of 22% in 1970 to 47% in 2020. This rapid growth dynamic has generated new challenges for resource use and environmental conservation, while opportunities for sustainable urbanism have remained mainly unexplored (Guneralp *et al.* 2018). North America appears to have reached a saturation point in terms of urbanization, as it posts the lowest annualized growth rate of all regions at 0.2%. The percentage of urban population in the ECCA regions had remained around 52% since 1980. Among income groups, low- and lower middle-income countries had the highest annual rates of urbanization betwee3n 1970 to 2020, at 1.5% and 1.1%, respectively (Figure 2.7). Urbanization in high-income countries increased by 0.3% per year. In all income groups, urbanization rates slowed after 1990.

Although the difference in material living standards and consumption between urban and rural areas may be negligible in high-income countries, there remain stark differences between urban and regional areas in all other country income groups. In low- and middle-income countries, rural areas are still often based on agroforestry activities and traditional resource use patterns that are being steadily transformed to modern resource-use patterns, thereby resulting in significant growth in overall use. Transitioning to sustainable material management and dematerializing the global economy need to be achieved against the backdrop of ongoing urban and industrial transformations in many countries of the South (Krausmann *et al.* 2008).

Figure 2.7: Urbanization rate for (a) World regions and (b) Income groups, 1970, 2000 and 2020.



Source: UN DESA World Population Prospects 2022.

2.3 Historical analysis of material resource use

Material resources are biomass, fossil fuels, metals and non-metallic minerals used in the economy (Fischer-Kowalski *et al.* 2011). It is important to report and analyse trends in material resource use for several reasons:

- Resource depletion: Analysing trends in resource use can help identify patterns of depletion and overuse, which can inform conservation and management strategies (Klinglmair *et al.* 2014).
- Environmental impacts: Material resource extraction and use can have significant environmental impacts, such as land degradation, water pollution and greenhouse gas emissions. Understanding trends in resource use can help identify areas where these impacts are most severe and where interventions are most urgently needed (Hellweg and Canals 2014).
- Economic growth: Material resources are essential for economic growth and development, and trends in resource use can indicate how economies are performing and where opportunities for growth may exist (Krausmann *et al.* 2009).
- Social well-being: Material resources are also essential for human well-being, and trends in resource use can provide insights into how access to resources is affecting different populations and how to ensure that resources are distributed equitably (Roberts *et al.* 2020).
- Decoupling: Analysing trends in resource use can also help identify if there is a trend of decoupling economic growth and human well-being from the demand for material resources. This is about whether the economy and well-being of people can be improved without increasing the use of resources. That is important because it can help to identify sustainable development pathways (Schandl *et al.* 2016).

A key deliverable of this report is the analysis of materials flow both from a production perspective (territorial) and a consumption perspective (final demand), involving the most recent material flow accounting methodology. The following sections outline a set of standard indicators. Table 2.1 provides an overview of the indicators. All material flow data presented in this report are available from the Global Material Flows Database (UNEP 2023a).

Table 2.1: Key indicators used in the assessment of material flows.

Acronym	Indicator	Coverage and data sources
DE	Domestic extraction of materials (biomass, fossil fuels, metal ores and non-metallic minerals)	Material harvested (agriculture, forestry and fisheries) or extracted (mining and quarrying) domestically; primary production statistics
IMP	Imports of primary materials and consumer goods	Materials and consumer goods produced abroad and imported; trade statistics
EXP	Exports of primary materials and consumer goods	Materials and consumer goods produced domestically and exported; trade statistics
PTB	Physical Trade Balance [IMP – EXP]	Imports minus exports of materials and consumer goods; calculated
DMC	Domestic Material Consumption [DMC = DE + PTB]	Materials that are managed and processed in the domestic economy; calculated
RME_{IMP}	Raw Material Equivalents of Imports	Raw materials required to produce imports; modelled using MRIO (Multi Regional Input Output) analytical tools
RME_{EXP}	Raw Material Equivalents of Exports	Raw materials required to produce exports; modelled using MRIO analytical tools
RTB	Raw Material Trade Balance [RTB = RME_{IMP} – RME_{EXP}]	Import minus exports of raw materials required to produce materials and consumer goods; calculated
MF	Material Footprint [MF = DE + RTB]	Primary materials associated with final demand independently of where they are sourced (domestically or abroad); modelled using MRIO analytical tools
DPO	Domestic Processed Output [DPO = Waste + GHG Emissions + dissipative use]	End-of-life materials, GHG emissions and dissipative use of materials; waste and emission statistics and agricultural statistics

Source: Krausmann et al. 2017a; UNEP 2021.

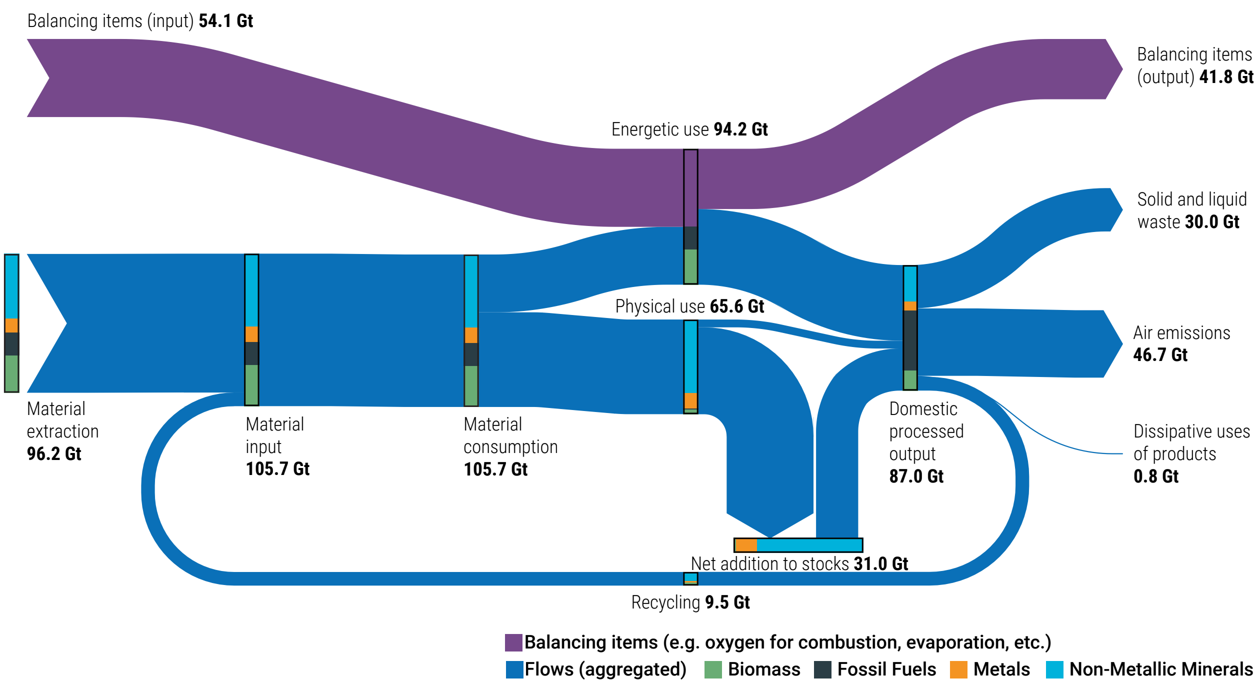
This methodology provides a comprehensive framework that encompasses the stages of material extraction, usage and end-of-life processing. It therefore serves as a valuable guide for multiple public policy areas such as sustainable materials management, waste management, resource recovery strategies, circular economy initiatives, policies targeting emission reductions and the achievement of net-zero goals. Figure 2.8 outlines the entire material movement within the global economy for 2019. It also offers a deeper understanding of the accounting system used in this report, highlighting the fundamental dynamics and complexities of global materials management.

In 2019, a total of 105.7 billion tonnes of materials were consumed by the global economy. Most of this total (91% or 96.2 billion tonnes) was derived from harvesting and extraction. Recycled and recovered resources accounted for 9.5 billion tonnes, which is approximately 9% of the total. Energy requirements, especially for electricity generation and biomass used for human food and animal feed, made up 40% of total material consumption. The other 60% was used as structural and technical materials. Notably, half of this was incorporated into durable assets like buildings, transportation and communication infrastructures, productive assets and consumer products.

In the material flow accounting framework for 2019, the tally for waste and emissions is significant. It involved 30 billion tonnes of both solid and liquid waste, combined with 46.7 billion tonnes of greenhouse gas emissions. Additionally, there was a dissipative use of 800 million tonnes. There has also been a net addition of 31 billion tonnes to material stocks. Notably, material stocks have seen a substantial increase since the 1970s (Krausmann *et al.* 2017).

It is worth noting that, as of 2019, the percentage of secondary materials used in manufacturing and construction activities was approximately 9% (Krausmann *et al.* 2018; Schandl and Miatto 2018). However, even if the technical potential for resource recovery is fully harnessed, the current economic structure only allows for an estimated circularity of between 30% and 40% (Haas *et al.* 2015). This highlights the gap between current levels and the maximum potential within the existing framework. To push the circularity rate beyond its current potential, there must be a fundamental restructuring of the global production and consumption system. This would require significant changes in industries such as consumer goods, built environment, mobility, food and energy (Fanning *et al.* 2020) (see Chapter 4). The redesign of production and consumption systems is increasingly viewed as a crucial aspect of the circular economy because it encompasses more than just resource recovery and recycling.

Figure 2.8: Global material flows, waste and emissions, 2019, billion tonnes.



Note: Balancing items calculate 54.1 billion tonnes on the input side and 41.8 billion tonnes on the output side.
This accounts for, e.g. oxygen for combustion, evaporation, etc. These elements are needed for the system to be balanced (inputs, outputs).
Source: Global Material Flows Database (UNEP 2023a).

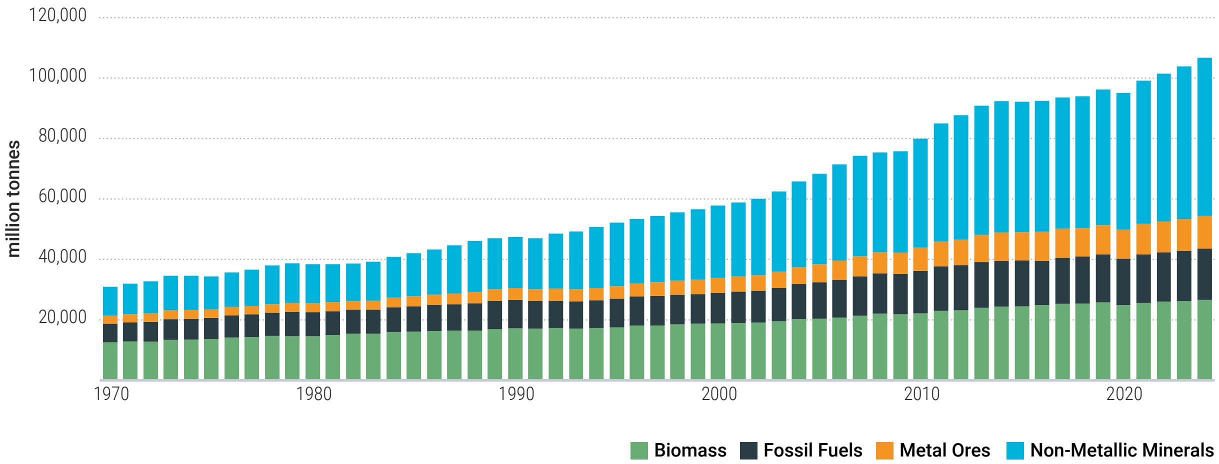
2.3.1 Global trends in material extraction

Economic activity, infrastructure and material living standards all rely on the supply of materials to fuel the economy and support social well-being (Schandl *et al.* 2018). Materials are extracted, traded and transformed into goods, or used to provide services, and are eventually disposed of as waste or emissions. Environmental impacts occur at all stages of the supply chain, and they have been intensifying in proportion with the growing global demand for materials.

The global demand for material use has seen prolonged growth over the past five decades. The annual global extraction of materials has grown from 30.9 billion tonnes in 1970 to 95.1 billion tonnes in 2020, and is expected to reach 106.6 billion tonnes in 2024 following an annual average growth rate of 2.3% (Figure 2.9). The first decade of the new millennium ushered in a major increase in global material demand, which grew at 2.1% per year between 1970 and 2000 before accelerating to 3.5% between 2000 and 2012. This acceleration was driven by large infrastructure investments and growing material living standards in middle-income countries, especially in Asia. Between 2012 and 2020, global material demand plateaued in the aftermath of the 2008 to 2009 global financial crisis of and the economic slowdown cause by the global pandemic. The average growth rate shrank to 1% per year but has since recovered to reach 2.9% average annual growth.

The global average of material demand per capita was 8.4 tonnes in 1970 and grew to 12.2 tonnes per capita in 2020. Material demand grew in line with GDP but rose significantly faster than population. This has resulted in stagnant material efficiency in the global economy and a rise in consumption and material living standards. It is worth noting that the acceleration of global material extraction since 2000 has coincided with a slowdown in GDP and population growth. One driver of this phenomenon is likely to be the disproportionate concentration of GDP growth in economies that are transitioning from an agrarian-based to an urban-industrial economic mode, which is particularly intensive in material and energy use (Krausmann *et al.* 2008).

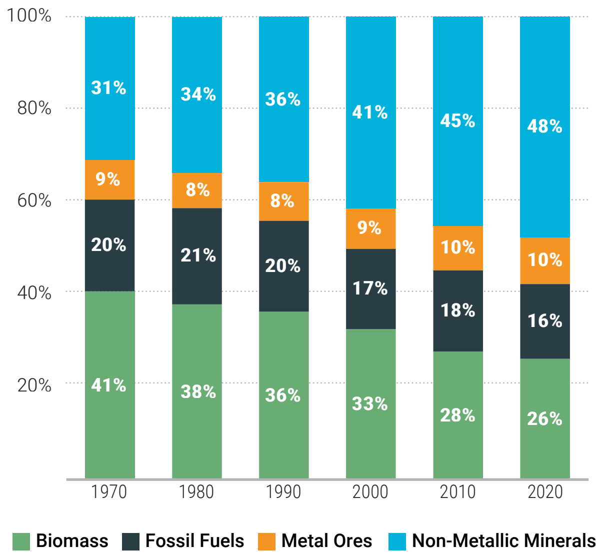
Figure 2.9: Global material extraction, four main material categories, 1970 – 2024, million tonnes.



Source: Global Material Flows Database (UNEP 2023a).

The composition of material use has also changed significantly over the last five decades (Figure 2.10). In 1970 biomass was the largest category of material use at 41% but its share decreased to 33% in 2000 and 26% in 2020. Non-metallic minerals have become the largest category at 48% up from 31% in 1970, signalling a transition from biomass-based agrarian metabolism to a mineral-based industrial metabolism.

Figure 2.10: Global material extraction, four main material categories, 1970-2020, shares.



Source: Global Material Flows Database (UNEP 2023a).

Biomass – The use of biomass, including crops, crop residues, grazed biomass, timber and wild-caught fish, made up 41% of all materials extracted in 1970, but by 2020 this proportion dropped to slightly over a quarter (Figure 2.10). This is because countries in early stages of economic development tend to rely more on biomass-based materials and energy systems. As more people worldwide transitioned to higher levels of industrialization in the last five decades, the demand for materials began to reflect the higher demand for minerals-based materials and energy systems that are typical of industrialized nations. While the proportion of biomass usage tends to decrease in industrialized countries, individual consumption often rises. As a result, even though the proportion of biomass used decreased, the total tonnage of biomass demand increased from 12.6 to 24.8 billion tonnes between 1970 and 2020, an average increase of around 1.3% per year (Figure 2.9). Crop harvest grew at an annual rate of 2.2% over the last five decades and was the largest component of biomass extraction in 2020, making up around 40% of the total. Grazed biomass for livestock animals grew at a similar rate, reflecting the increasing popularity of animal and dairy-based diets among an expanding middle class in many parts of the world. The growth rate was slowest in biomass sub-categories for which non-biomass alternatives are easily available, such as wood for fuel and building material, and for sub-categories with hard limits on yields that cannot be easily overcome with advancing technology, such as wild-caught fish.

There has been an increase in crop consumption over the past few decades. This is due to a growing global population, as well as a shift towards more meat-based diets that require more crops for animal feed. Additionally, the expansion of biofuel production has also contributed to rising crop consumption.

Historical trends in grazed biomass use are closely linked to the growth of livestock populations and the expansion of animal and dairy-based diets in many parts of the world. Grazed biomass, which refers to grass and other vegetation consumed by livestock animals, has grown at an average rate of 2.2% per year over the last five decades, reflecting the increasing importance of this type of biomass for meeting the food and energy needs of a growing global population. The growth of grazed biomass has been particularly significant in developing and transitioning countries, where rising incomes and changing dietary preferences have led to a growing demand for meat and dairy products. However, trends in grazed biomass use have also been influenced by advances in agricultural technology, changes in land use and environmental and policy-related constraints on livestock production.

Historically, timber use has increased over the last five decades. From 1970 to 2020, global timber extraction grew from around 1 billion cubic metres to 4 billion cubic metres, an annual average growth of 2%. The new millennium ushered in a major increase in global timber requirements, which grew at 2.0% per year between 1970 and 2000 but accelerated to 2.5% per year afterwards. The growth of global timber demand was largely driven by major investments in infrastructure and increased material living standards in developing and transitioning countries, especially in Asia. While there was a brief slowdown in the growth rate of demand for timber between 2008 and 2010 due to the global financial crisis, this had a marginal impact on the overall trajectory.

Fossil fuels – The use of fossil fuels, including coal, petroleum, natural gas, oil shale and tar sands, grew in absolute terms from 6.1 billion tonnes to 15.4 billion tonnes between 1970 and 2020 (Figure 2.9). However, their share of global extraction decreased from 20% to 16% during the same period (Figure 2.10). On average, they grew by 2.1% per year between 1970 and 2020. Natural gas posted a growth rate of 2.8% per year, while coal grew at a rate of 2.1%. Both materials displayed higher growth than petroleum, which grew by 1.3%. This is due to the expanded use of coal- and gas-fired power stations for electricity generation. In recent years, however, the use of coal has stagnated because of lower gas prices, an increase in renewable energy sources and improvements in energy efficiency. According to the International Energy Agency, this has contributed to a slowdown in global coal consumption (IEA 2017).

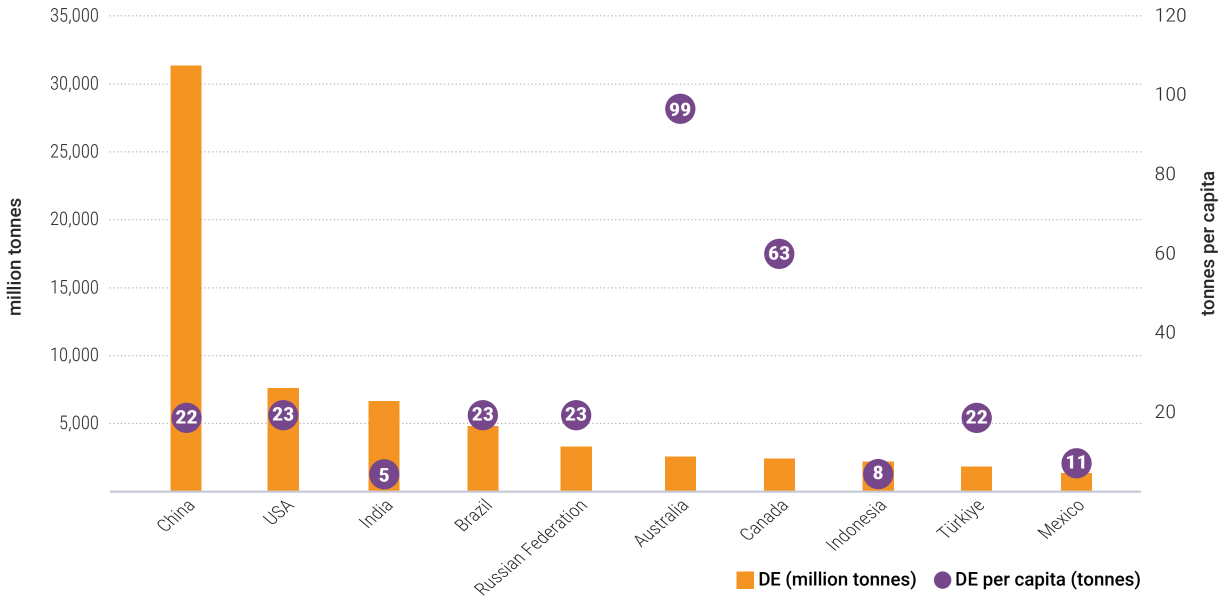
Metal ores – Iron, aluminium, copper and other non-ferrous metals accounted for around 9% of global material extraction (2.7 billion tonnes) in 1970, and this grew slightly to around 10% (9.6 billion tonnes) in 2020 (Figure 2.10). This represents a yearly average growth of 2.6% and reflects the importance of metals for the construction industry, energy and transport infrastructure, equipment, manufacturing and for many consumer goods. Iron ore was the fastest growing metal because of the rising demand for steel in construction activities and the second wave of urbanization in the Global South. Metals also play a key role for the energy transition to an intermittent renewable energy system that will rely on massively increased energy transmission infrastructure (mainly aluminium and copper) and energy storage capacity (cobalt, nickel and lithium). The electrification of transport and mobility will further add to global metal demand and will require the build-up of metal-recycling capability.

Non-metallic minerals – These include sand, gravel and clay for construction and industrial purposes and represent the largest component of material use. They accounted for the highest growth of 3.2% per year on average and extraction grew from 9.6 billion tonnes in 1970 to 45.3 billion tonnes in 2020 (Figure 2.9). This fivefold increase has been related to the massive build-up of infrastructure in many parts of the world. The increasing share of non-metallic minerals from 31% to almost 50% of overall global material extraction (Figure 2.10) reflects a major shift in global extraction from biomass to mineral-based natural resources.

The transition of the global economy's material composition from biomass and renewable minerals to non-renewable resources has changed the nature of major environmental pressures and impacts, which continue to move from the local to the global scale. The global extraction of materials has also become marginally more concentrated in the last five decades, with ten economies responsible for over 70% of global extraction in 2020 compared to around 64% in 1970. More than one third of all materials (around 31.3 billion tonnes) in 2020 were extracted in China, followed by 7.6 billion tonnes in the United States of America, 6.6 billion tonnes in India and 4.8 billion tonnes in Brazil (Figure 2.11). By comparison, Brazil, Russian Federation, India, China and South Africa (BRICS) sourced 46.9 billion tonnes of domestic materials. This represented 49.3% of global material supply, whereas the G7 countries (United States of America, Japan, Germany, France, United Kingdom, Italy and Canada) sourced 16.4 billion tonnes of materials domestically.

Of the top 10 extractors, Australia had by far the highest material extraction per capita at 99 tonnes, followed by Canada at 63 tonnes per capita (Figure 2.11). Many of the other top 10 extractors had an extraction rate of around 20 tonnes per capita, except for Indonesia and India, which displayed much lower rates. India's per capita domestic material extraction is only one fifth that of China or the United States of America and, if India follows a conventional pattern of historical industrialization, the impact on global materials extraction would be similarly profound.

Figure 2.11: Domestic extraction of materials – Top-ten largest extractors in 2020, million tonnes and tonnes per capita.



Source: Global Material Flows Database (UNEP 2023a).

Figure 2.12: Total and per capita domestic extraction of materials for a) seven world regions and b) four income bands.

Source: Global Material Flows Database (UNEP 2023a).

The Asia-Pacific region surpassed the rest of the world as the most dominant resource extractor in 2009. At this time, half of the global resources were extracted in Asia and Pacific. By 2020, 48.9 billion tonnes of natural resources, that is 51% of the global total, were extracted in the Asia and Pacific region (Figure 2.12). This level reflects the very large population, and the fact that biomass and non-metallic minerals taken together make up 75% of all material extraction and are mostly sourced domestically. This results in a domestic extraction rate only slightly lower than Europe (11 tonnes per capita compared to 12 tonnes per capita). North America has the highest per capita domestic extraction at 29 tonnes followed by Eastern Europe, Caucasus and Central Asia at 19 tonnes, West Asia at 16 tonnes and Latin America and the Caribbean at 15 tonnes (Figure 2.12).

The lion's share of global materials is extracted in upper middle-income countries that, in 2020, also had the highest per capita extraction rate (Figure 2.12). The group of upper middle-income countries, which includes the large economies of China, Brazil, Mexico and South Africa, extracted 55.8 billion tonnes of materials (equivalent to 21.3 tonnes per capita). This was slightly higher than the 20.8 tonnes per capita (25.7 billion tonnes) of material extraction in high-income countries. Per capita extraction rates in lower middle-income countries were 6 tonnes per capita in 1970 and 5 tonnes per capita in 2020. This reflects two major dynamics. The first is the demand for materials to build up infrastructure required for newly organizing and industrializing countries. The second driver is the outsourcing of material- and energy-intensive stages of production by higher income countries to the upper middle-income group of transitioning economies. The relocation of resource-intensive processes to middle-income countries is likely to have been driven by lower environmental standards and cheaper labour costs than in higher income regions.

2.3.2 Global trade in materials

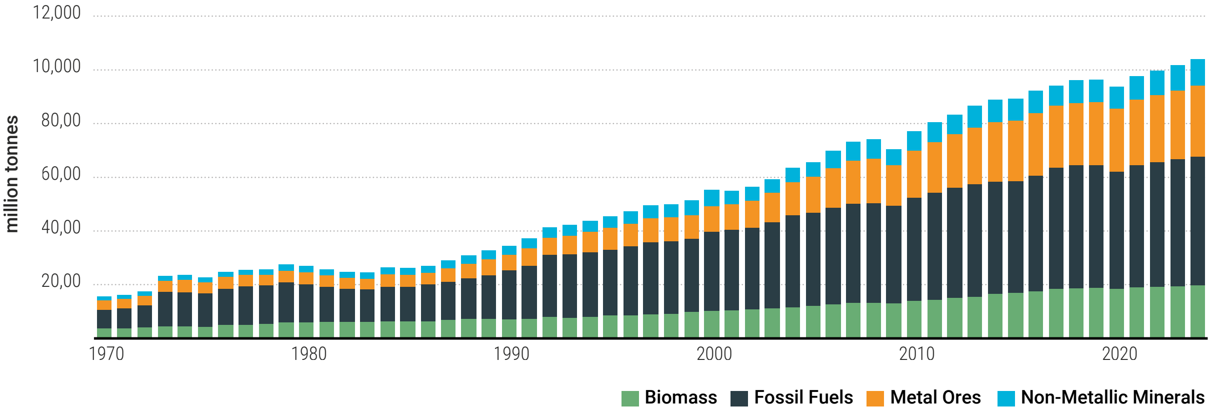
Global trade in primary materials corrects regional imbalances in material resource availability to support global systems of production and consumption (Dittrich and Bringezu 2010; Dittrich *et al.* 2012). While many materials such as biomass, sand and gravel tend to be locally sourced, others such as metal ores and fossil fuels are often disproportionally concentrated in some world regions and countries or else impractical to exploit in other locations. Fossil fuels are the most traded primary material, accounting for almost half of the 9.4 billion tonne global trade in materials in 2020 (Figure 2.13). Metal ores represent a quarter of the total. Markets and supply chains for many materials that are strategically important for production systems and essential service provision have become globalized. Total direct trade of materials in 2020 was around six times the 1.6 billion tonnes recorded in 1970.

The growing reliance of many countries on the supply of virgin materials for trade has several consequences. Firstly, the environmental repercussions of resource extraction fall on the countries endowed with these natural resources (Muradian and Martinez-Alier 2001). The prices for these commodities are largely influenced by global events, reflecting the fluctuations and volatility of the international market. Importing nations face risks to their supply chain resilience. Furthermore, consumers in the countries of origin often pay the high global market prices. This undermines the benefits or compensation that communities in resource-rich countries might receive from the extractive sector of their economy (Sprecher *et al.* 2015).

The physical trade balance (PTB) is an indicator of whether a country or region is a net importer or exporter of primary materials and helps determine a country's position and role in global supply chains. This is calculated as direct physical imports minus direct physical exports. During the last five decades the Asia and the Pacific region has become the largest net importer of primary materials followed by Europe (Figure 2.14). All other world regions are net exporters including, more recently, North America. Between 1993 and 2010 this region has relied primary on imported materials. However, with the build-up of domestic extraction capacity this has changed, and North America now supplies primary materials, mostly fossil fuels (oil and liquefied gas), to the global market. By 2024, Latin America and the Caribbean, West Asia and Eastern Europe Caucasus and Central Asia are projected to be net contributors of resources (Figure 2.14).

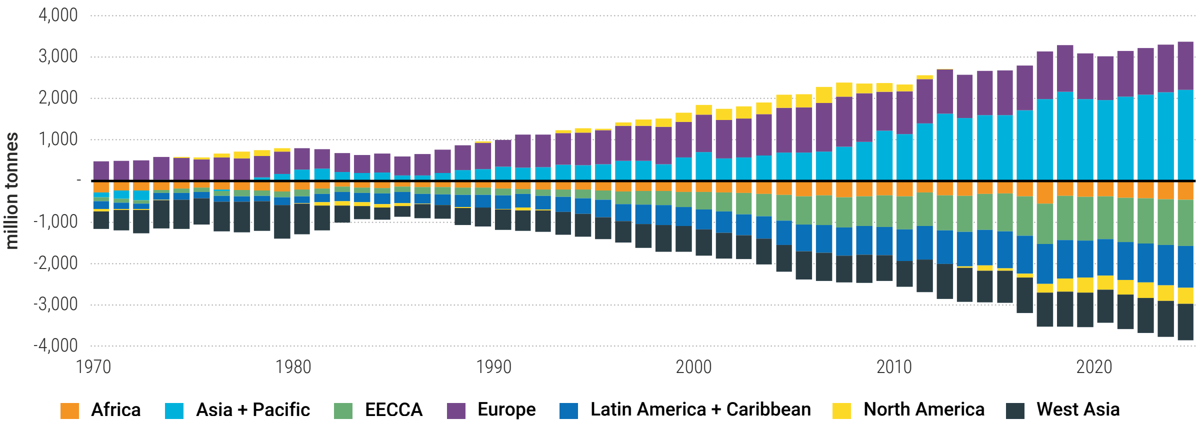
When the physical trade balance is categorized into wealth bands, it becomes evident that low-income and lower middle-income countries have consistently supplied material resources to higher-income nations (Figure 2.15). Up until around 2014, upper middle-income countries were net suppliers of materials. However, that year marked a notable trend shift, with the upper middle-income group beginning to rely on imported materials. Concurrently, high-income countries, which had depended on a net material supply from other groups from 1970 to 2010, started to supply materials themselves, essentially swapping roles with the upper middle-income group. Since the early 2010s, upper middle-income countries have been net importers of materials, signalling a change from a manufacturing focus to a growth paradigm led by domestic consumption in those countries. The cause of these trends lies mainly in the rapid industrialization of some countries in the upper middle-income group and the shift of global production to this group, especially the wake of the global financial crisis, which disproportionally affected high-income countries. This resulted in the reallocation of domestically extracted resources in the upper middle-income to local production and consumption, as well as ultimately drawing in primary materials from all other groups. These shifts in the global economy drove up commodity prices and made the export of primary products a more economically attractive activity even among some members of the high-income group. For Australia alone, the increase in total exports of fossil fuels and metal ores combined between 2005 and 2015 could account for around half or the increase in PTB of the high-income group and the shift of the group to become a net exporter of materials.

Figure 2.13: Global trade of materials, four main material categories, 1970 – 2024, million tonnes.



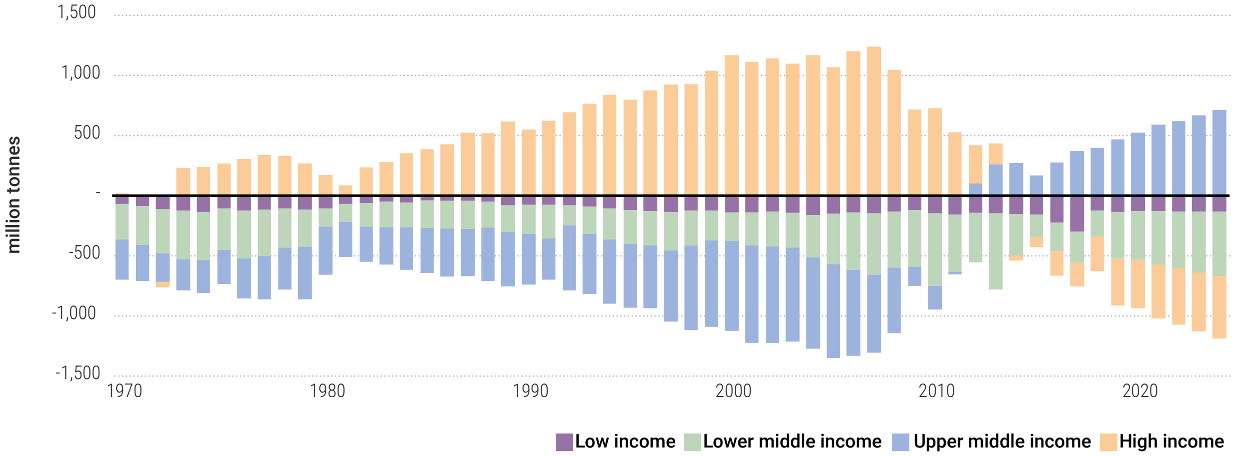
Source: Global Material Flows Database (UNEP 2023a).

Figure 2.14: Physical trade balance by seven world regions in 1970-2024, million tonnes.



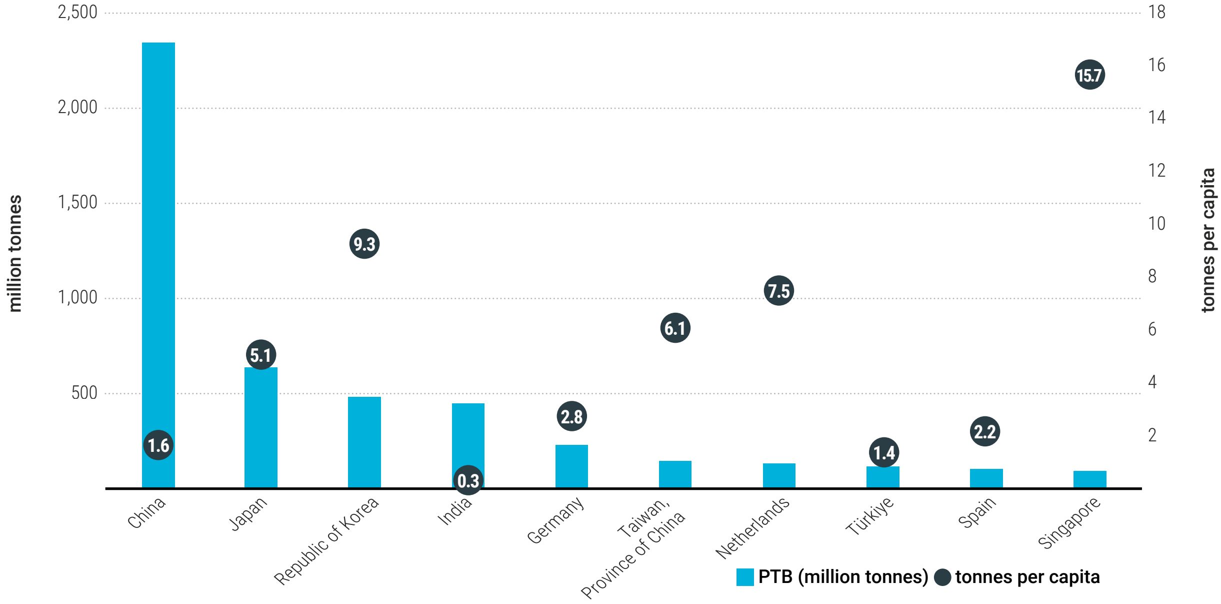
Source: Global Material Flows Database (UNEP 2023a).

Figure 2.15: **Physical trade balance by four income bands in 1970-2024, million tonnes.**



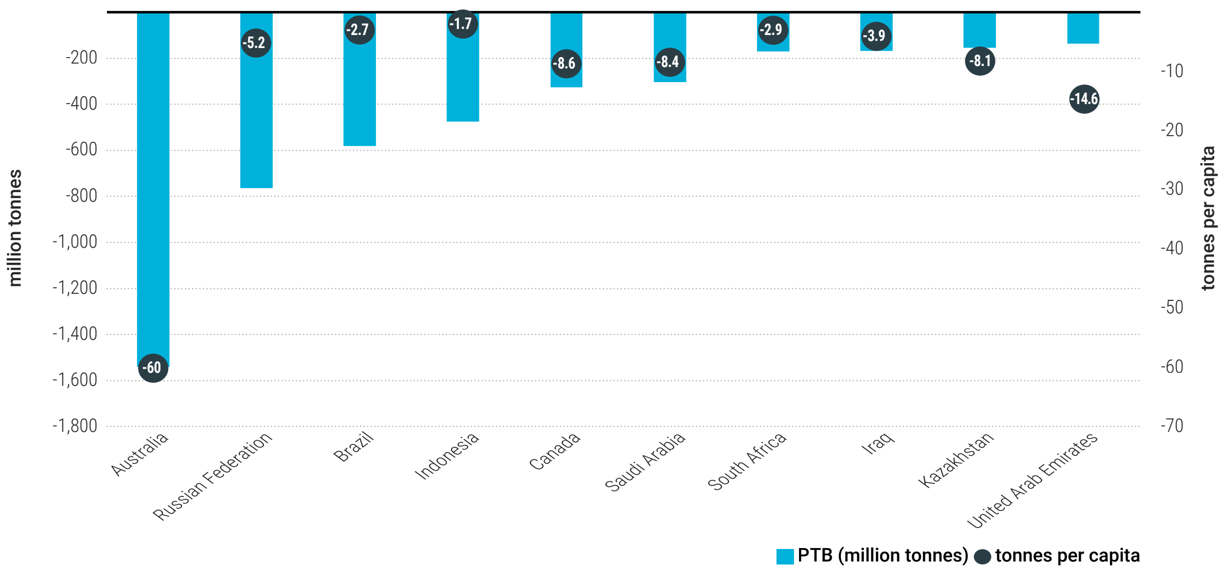
Source: Global Material Flows Database (UNEP 2023a).

Figure 2.16: **Top ten net importers of materials, 2020, million tonnes and tonnes per capita.**



Source: Global Material Flows Database (UNEP 2023a).

Figure 2.17: **Top ten net exporters of materials, 2020, million tonnes and tonnes per capita.**



Source: Global Material Flows Database (UNEP 2023a).

An assessment at the country level shows that, despite China's dominance of net imports in total tonnage terms, and the fact that it drives the trend for physical trade balance in the upper middle-income group of countries, its per capita net import levels of 1.6 tonnes remains comparably low (Figure 2.16). This is less than a third of Asia's second largest economy, Japan, and less than a fifth of Republic of Korea. Singapore recorded the highest per capita level for net imports at around 16 tonnes per capita.

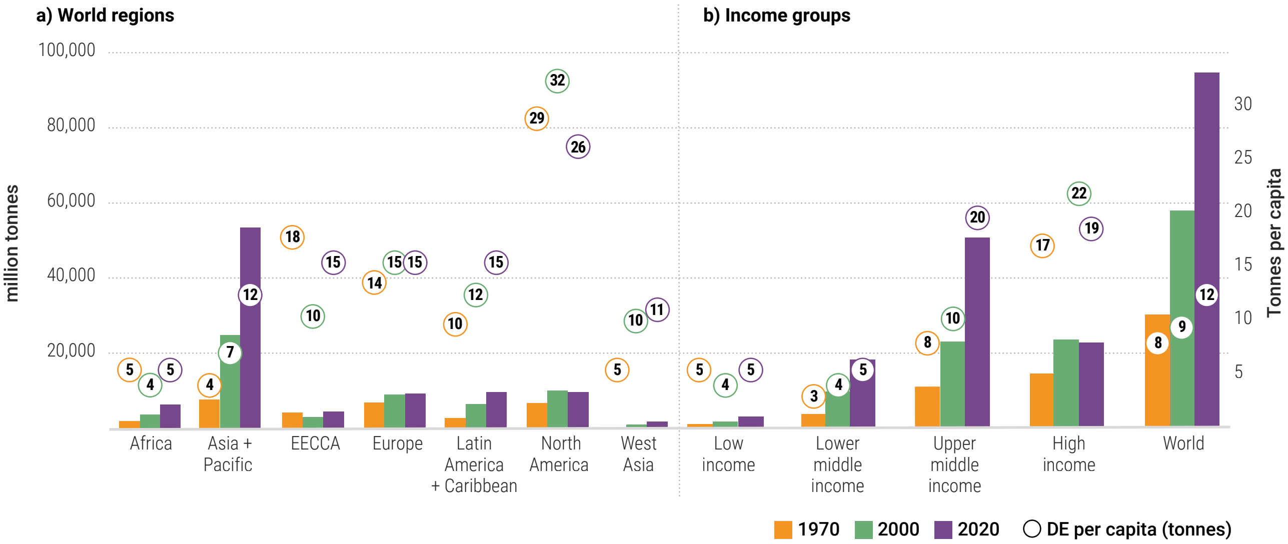
The largest net exporter of materials in 2020 was Australia followed by the Russian Federation, Brazil and Saudi Arabia (Figure 2.17). Australia's extremely high levels of net exports are dominated by just two categories – ferrous ores and coal – the bulk of which is destined to other countries in the Asia Pacific region. Brazil's exports are also dominated by ferrous ores, while those of the Russian Federation and Saudi Arabia are the result of petroleum and natural gas exports. On a per capita basis, Australia is three times the level of the next major exporter Saudi Arabia. The presence Australia and Brazil as the two large international players in ferrous ores, while dominant exporters of metals notably Chile regarding copper are absent, simply reflects the fact that most non-ferrous metals are traded in highly concentrated or refined forms.

2.3.3 Domestic Material Consumption

Domestic material consumption (DMC) is another direct measure of the materials managed in an economy. This is calculated as domestic extraction plus physical trade balance. It directly measures the physical quantity of materials extracted or imported into a territory (minus any physical exports). These materials may be consumed over the short term, such as most biomass and fossil fuels, and so turned into waste and emissions. Other materials such as metals or construction materials remain in national stocks for prolonged periods of time. Ultimately, however, all materials accounted for in DMC will need to be disposed into the environment as some form of waste and emissions. Therefore, DMC can be thought of as an indicator for sustainable materials waste management and as an indicator for the long-term waste potential of a national economy.

In the West Asia region, DMC was 10.4 times larger in 2020 than in 1970 (Figure 2.18). However, the Asia and Pacific region increased its DMC from 7.7 billion to 53.5 billion in the same period, accounting for 57% of global DMC in 2020. Europe and North America had similar shares of DMC to Asia and the Pacific in 1970 (around 24%) and the share of both regions have since declined to 10% of global DMC. They are now equal to Latin America and the Caribbean, whose share has mostly remained unchanged since the 1970s.

Figure 2.18: Total and per capita domestic material consumption (DMC) by (a) seven world regions and (b) income groups.



Source: Global Material Flows Database (UNEP 2023a).

The share of DMC of high-income countries decreased from 48% in 1970 to 24% in 2020 (Figure 2.18). This is because of the rapid rise of DMC in the upper middle-income group from 36% in 1970 to 54% in 2020. The lower middle-income group also increased its share, while the low-income group of countries has remained steady at 3% of global DMC for the last five decades. Virtually none of the growth in materials consumption has been associated with the wealthiest countries but neither has much of it gone to the poorest countries, despite the latter being in most urgent need of improved material living standards.

The trajectory of per capita domestic material consumption for the seven world regions reflects and occasionally magnifies the features and events of regional material consumption. Rapid increase in per capita DMC in Asia and the Pacific has been a major factor. In 1970, Asia and the Pacific had the lowest per capita DMC of all world regions (3.75 tonnes), which was even below Africa and West Asia (which both posted about 5 tonnes per capita in 1970) (Figure 2.18). In 2020 Asia and the Pacific posted per capita DMC of 12 tonnes, which was around the world average but slightly lower than in Latin America and the Caribbean and Europe, and around half that of North America.

The decreasing significance of the high-income group of countries for global DMC is also reflected by DMC per capita in terms of the ratio between high-income countries and worldwide levels. More importantly, per capita levels of DMC in the upper middle-income group surpassed those of the high-income group in 2012, and this trend has been confirmed as a stable feature of the global economy. The large and ongoing transfer of global production shares from high-income countries to upper middle-income countries calls into question the reality of the mooted stabilization of DMC at higher income levels as a result of the transfer of material- and energy-intensive production stages, or whether it has simply been transferred to transitioning countries. This is a question of utmost importance for determining future global material demand and will be further addressed when investigating the material footprint and the outlook in Chapter 4.

Domestic Material Consumption has been selected by the Inter Agency Expert Group (IEAG) for Sustainable Development Goals indicators as the basis for monitoring progress towards SDG 12.2, which calls for the sustainable management of natural resources. In this role it has both strengths and weaknesses. Its role as an indicator of the total waste potential that must ultimately be sunk back into the environment within a nation's territory is valuable, and it cannot be replaced by consumption-based measures such as material footprint (see below). On the other hand, it is currently used for the SDGs in a highly aggregated form (typically one, or at the most four, individual material categories), lumping together materials that have radically different environmental impacts per tonne. Finally, it is crucial to use DMC in combination with a consumption-based measure. The strength of DMC in attributing environmental loads to a specific territory can be a major weakness in attributing responsibility for the mobilization of resources and emissions. An individual nation that simply outsources the most material- and energy-intensive processes in its production chains will score well on DMC-based SDG measures, regardless of the environmental load its consumption may represent at the global level.

2.3.4 Material Footprint

Material footprint (MF) is the other material flow indicator that has been selected to monitor progress in the context of the SDGs, and more specifically SDG 8.4 on resource efficiency (Lenzen *et al.* 2022). The material footprint is a demand-based, rather than a territorially based. indicator reflecting the material requirements of a country's household and government consumption and capital investment, independently of where the materials come from. In short, it attributes all the material resources mobilized globally to the final consumer, and so it traces embodied or virtual flows of materials associated with value, rather than simply territorially delineated physical flows (Wiedmann *et al.* 2015). In the context of the SDGs, material footprint complements DMC by ensuring that material flows that underpin a country's consumption while taking place in and impacting the environmental in other countries, are nonetheless attributed to an end consumer's account. The validity of footprint results depends on the choice of the global multiregional input-output model and, while the directionality of footprints across models is stable, there are significant differences between model results at a more detailed level (Giljum *et al.* 2019).

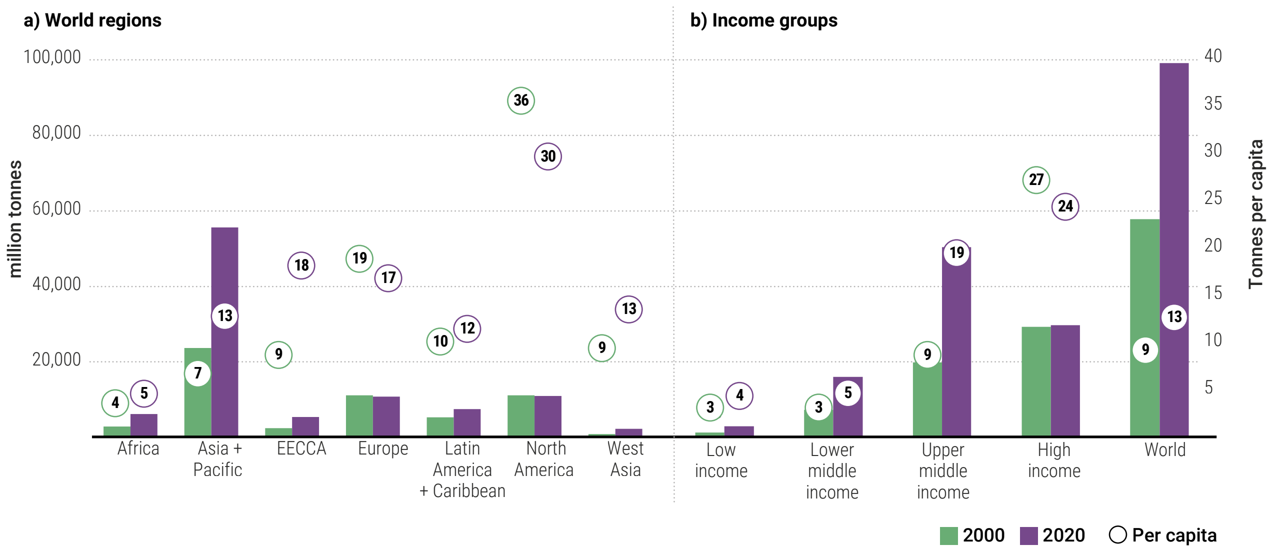
The Asia and Pacific region accounted for 41% of the global material footprint in 2000 and 56% in 2020 (Figure 2.19). The corresponding shares of Europe and North America changed from 19% to 11% in the same period. Despite reducing its per capita material footprint by 17% between 2000 and 2020, North America's per capita footprint was almost three times the world average. In 2000, high-income countries accounted for 51% of the global footprint and upper middle-income countries for 34%. By 2020, these numbers had practically reversed (Figure 2.19).

Essential services that satisfy human needs are delivered by provisioning systems. This includes six systems: the four systems that form the focus for this report (food, built environment, mobility and energy), as well as the other two that complement the analysis (communication plus waste management and resource recovery (WMRR)). Any provisioning system requires a specific physical infrastructure and materials to build, maintain and operate the infrastructure and supply the population with the service (Spangenberg and Lorek 2002). This chapter calculates the material requirements related to each provisioning system.

In 2020, 55% of all global material demand (59 billion tonnes) was related to built environment and mobility (including the construction and transport sector and its infrastructure) (Figure 2.20). There were 23.6 billion tonnes of materials required for the food system and 6.1 billion tonnes for the provision of energy (electricity, power and heat). The material needs for provision services (Tanikawa *et al*. 2021) show stark differences between regions and country income groupings. In high-income countries, built environment and mobility dominate material requirements, while the shares of material footprint for energy (9%) and communication (3%) are also significant contributors (Figure 2.20). Upper middle-income countries have the highest share of material demand for built environment and mobility at 68% of overall material footprint.

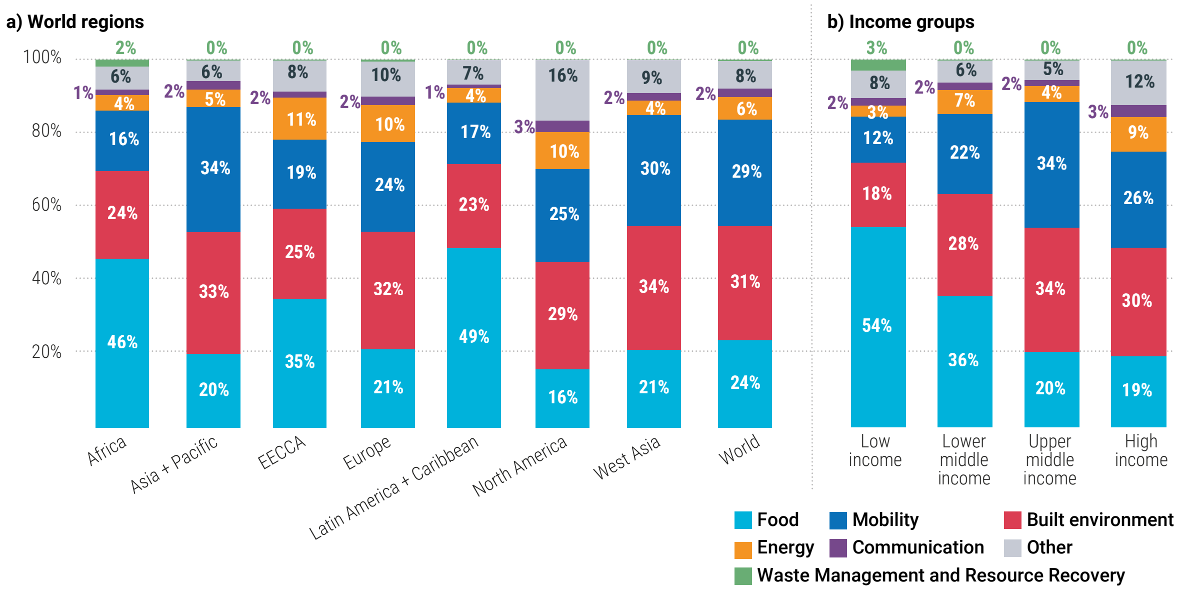
In the lower middle-income and low-income groups, food and built environment are the dominant provisions for material demand. In the low-income group, supplying food contributes 54% of the overall material footprint. This picture is replicated at the regional level where Asia and the Pacific has the highest share of material demand for built environment and mobility, whereas food and built environment are the dominant provisions in Africa; Eastern Europe, Caucasus and Central Asia; and Latin America and the Caribbean. Provision systems are closely related to social practices and consumer behaviour, and high-income groups need to engage with sufficiency strategies to complement more eco-efficient production systems and green infrastructure (Spangenberg and Lorek 2019).

Figure 2.19: Material footprint by (a) seven world regions and (b) income groups.



Source: Global Material Flows Database (UNEP 2023a).

Figure 2.20: Shares of material footprint by five provision systems and regions and country income groups, 2020, percentage.



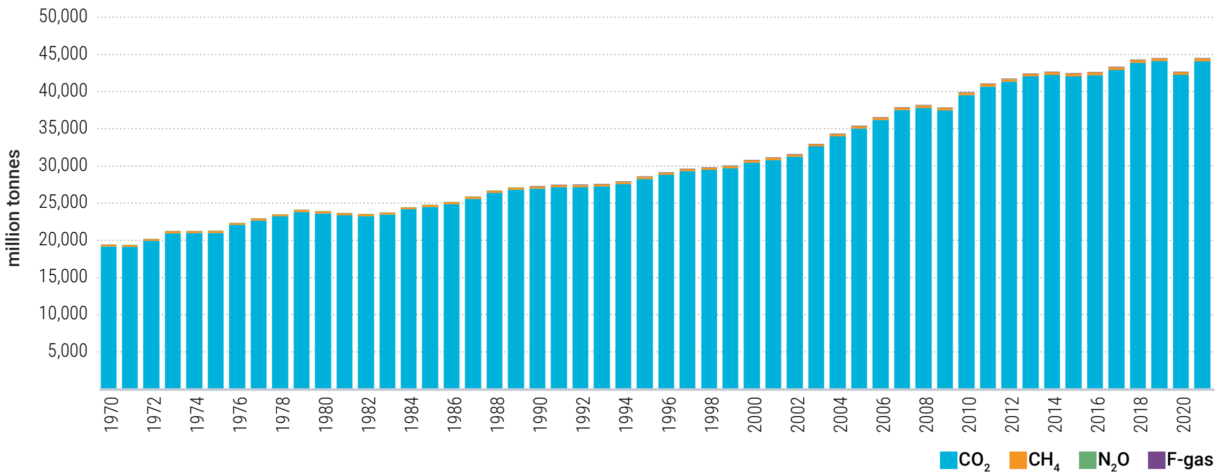
Source: Global Material Flows Database (UNEP 2023a).

2.3.5 Waste and emissions

Global greenhouse gas emissions have increased significantly since 1970 due to increasing use of energy carriers and carbon-intensive materials such as iron, steel and cement. Over the last half century, greenhouse gas emissions have more than doubled from around 20 billion tonnes in 1970 to around 43 billion tonnes in 2020 (Figure 2.21). Measured in tonnes, and not transformed with their global warming potential, CO_2 emissions represented the largest proportion of greenhouse gases.

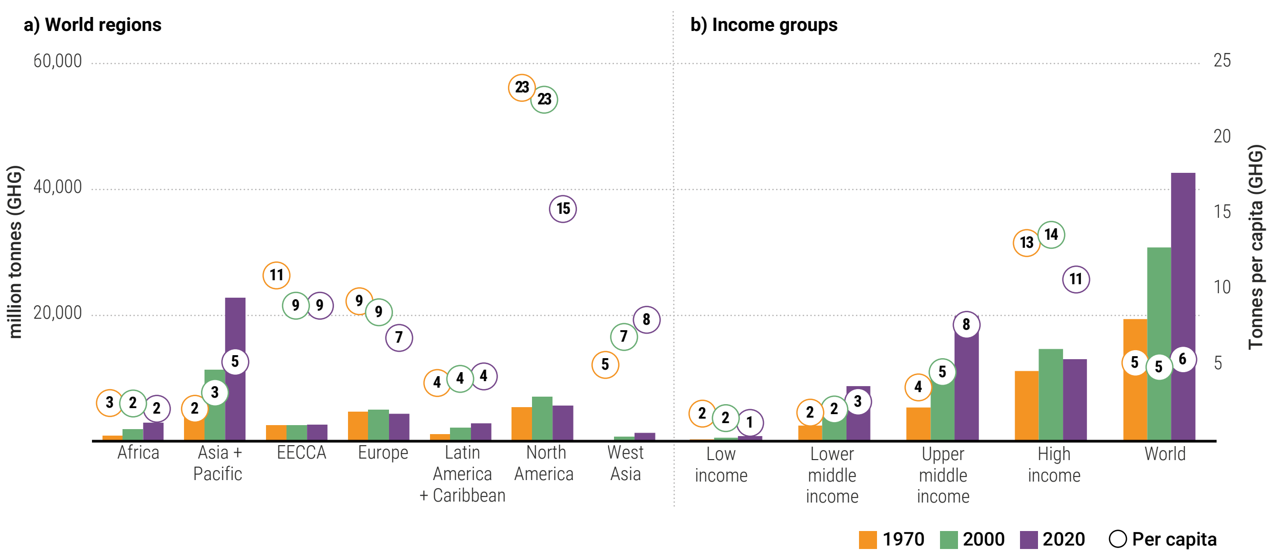
In recent years, the Asia Pacific region has been responsible for more than half of global greenhouse gas emissions, and upper middle-income countries have replaced high-income countries as the largest emitter (Figure 2.22). This reflects a change in the global energy system, a much higher saturation of electrification in the Global South, urbanization and increasing living standards in the middle-income group of countries. However, on a per capita basis, high-income countries still account for the highest level of emissions, and per capita emissions in high-income countries have remained around seven times higher than those in low-income economies since 1970.

Figure 2.21: Global GHG emissions by gas, 1970 – 2021, million tonnes.



Source: Emissions Database for Global Atmospheric Research (EDGAR) 2023.

Figure 2.22: Total and per capita GHG emissions by seven world regions and income groups, 1970, 2000 and 2020. Production-based emissions.



Source: Emissions Database for Global Atmospheric Research (EDGAR) 2023.

In a similar fashion, global waste flows have expanded between the 1970s and today and reached 19.9 billion tonnes in 2020. That means that one fifth of the 95.1 billion tonnes of materials end up as solid waste. Around 30% (6.1 billion tonnes) of end-of-life waste was recycled globally in 2020, resulting in a circularity rate of around 7% (Haas *et al.* 2015).

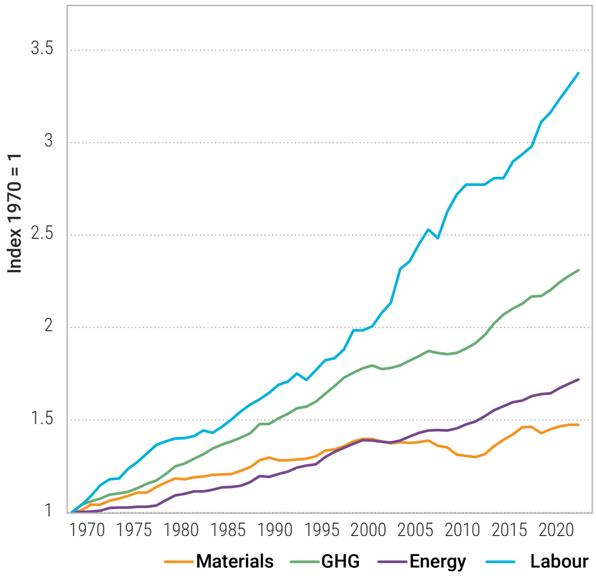
About 40 billion tonnes remain in the economy and add to the stock of buildings, infrastructure and consumer goods. Stock has dramatically grown since the 1970s (Krausmann *et al.* 2017). It is worth noting that, in the current economic structure, the circularity potential of the global economy sits between 30% and 40% circularity if all technical potential for resource recovery is utilized. That puts the circularity rate in perspective. Increasing the circularity potential beyond its current value requires a fundamental restructuring of the global system of production and consumption and large shifts in industry and consumer goods, built environment and mobility, food and energy. Redesigning production and consumption systems is increasingly seen as an important feature of the circular economy to go beyond resource recovery and recycling.

2.3.6 Resource productivity

Global material productivity, defined as the ratio of GDP to domestic material consumption, increased at an average annual rate of 0.7% between 1970 and 2020 (Figure 2. 23). Improvements in resource productivity can have many causes including structural change in the economy away from resource-intensive primary and manufacturing sectors to service-sector activities or outsourcing of material-intensive processes to countries abroad. Some gains in material productivity can be attributed to successful environmental and industry policy, as is the case in Japan (Takiguchi and Takemoto 2008). In 1970, EECCA countries had a material productivity of 0.15 USD/kg (Figure 2.24). However, between 1970 and 2010 the index grew by 2.9% per annum, then stabilized at around USD 0.45 per kg of domestic material consumption. Historically, Europe and North America have had the highest material productivity among all regions. Both regions experienced similar rates of growth from 1970 to 1998. Subsequently, North America's material productivity increased at a higher rate than Europe and, by 2010, the gap between the two regions had practically closed. West Asia had the largest material productivity between 1970 and 1980, primarily due to high fossil fuel prices. However, since 1983 the region's material productivity has been around USD 0.87 per kg of domestic material consumption. Material productivity growth in other regions has stagnated, resulting in an increasing regional gap in terms of Europe and North America.

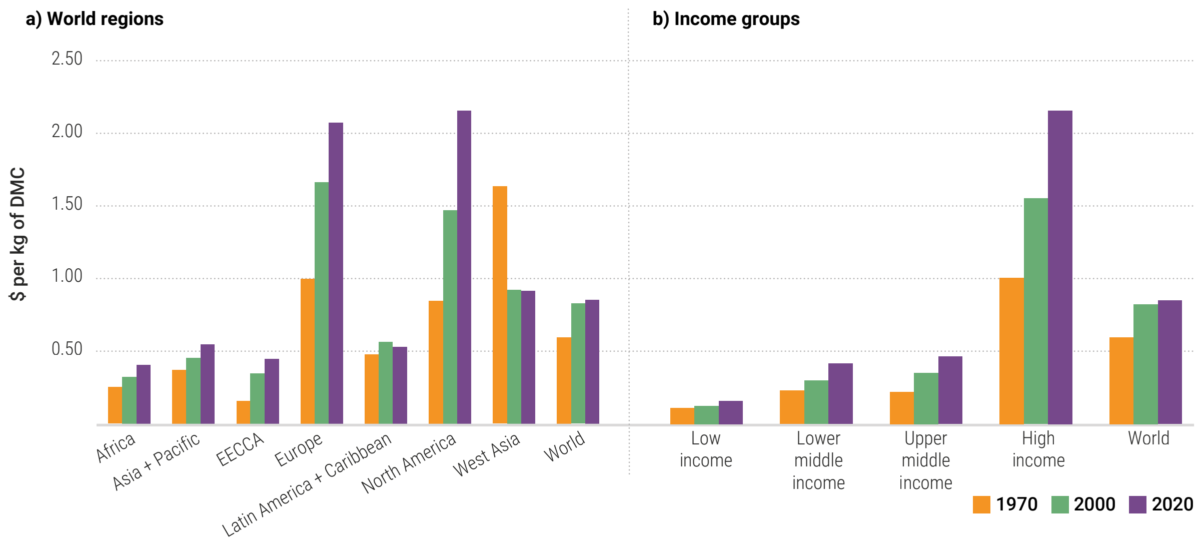
The material productivity gap is more evident when looking at income groups. In 1970, high-income countries had nine times the material productivity of low-income countries (Figure 2.24). By 2024, the ratio is projected to be thirteen times. The average material productivity of lower and upper middle-income countries has remained around 20% of the average in high-income countries.

Figure 2.23: Global resource productivity of materials, GHG emissions, energy and labour productivity, 1970 – 2024, index.



Source: Global Material Flows Database (UNEP 2023a); Emissions Database for Global Atmospheric Research (EDGAR); IEA World Energy Database; Penn World Table version 10.01.

Figure 2.24: Material productivity by seven world regions and four income band regions, 1970, 2000 and 2020, USD per kg.



Source: Global Material Flows Database (UNEP 2023a).

2.3.7 Drivers of material use

The Impact Population Affluence and Technology (IPAT) formula, introduced by Ehrlich and Holdren (1971), considers environmental pressure and impact to be determined by changes in population size, affluence and technological development related to resource-use intensity. It is important to note that the T in IPAT is not strictly speaking about technology but reflects all drivers other than population and per capita income combined. The IPAT framework is used to examine the significance of overarching drivers of material demand at an economy-wide level. To estimate associations between changes in impacts and drivers, Herendeen's (1998) logarithmic version of the IPAT formula was applied:

Here *I* is domestic material extraction, material footprint, waste or emissions, depending on the subsection; *P* is population; *A* is measured as *GDP/Population*; and *T* is estimated as the ration of any impact variable to GDP such as *domestic extraction/GDP*.

Domestic Material Extraction

From 1970 to 2000, global increases in material extraction were equally influenced by population and affluence growth (Figure 2.25).[38] However, technological development offset around one third of such an increase. In Africa, West Asia and Latin America and the Caribbean, population growth was a major determinant of domestic extraction. Technological changes fully offset material extraction increases from population and affluence growth only in EECCA countries. Technology offset around 60% and 69% of the additional domestic material extraction in North America and Europe, respectively. This variable had the lowest influence in West Asia and Latin America and the Caribbean.

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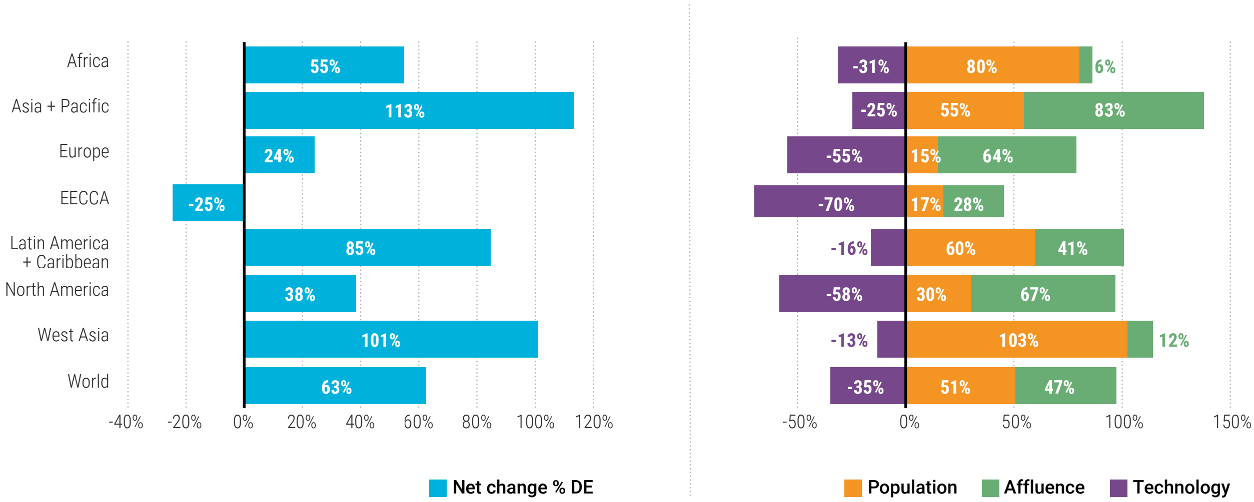
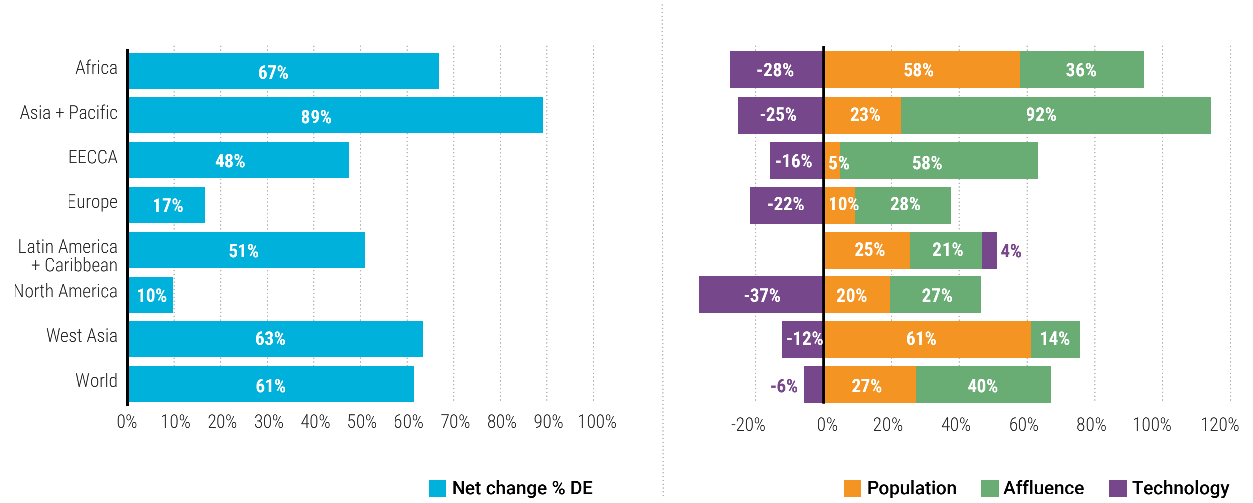
38 IPAT estimates for the period 1970-2000 differ from the Global Resource Outlook 2019 due to changes in IRP database methodology.

Figure 2.25: **Drivers of domestic extraction, 1970 – 2000, percentage.**



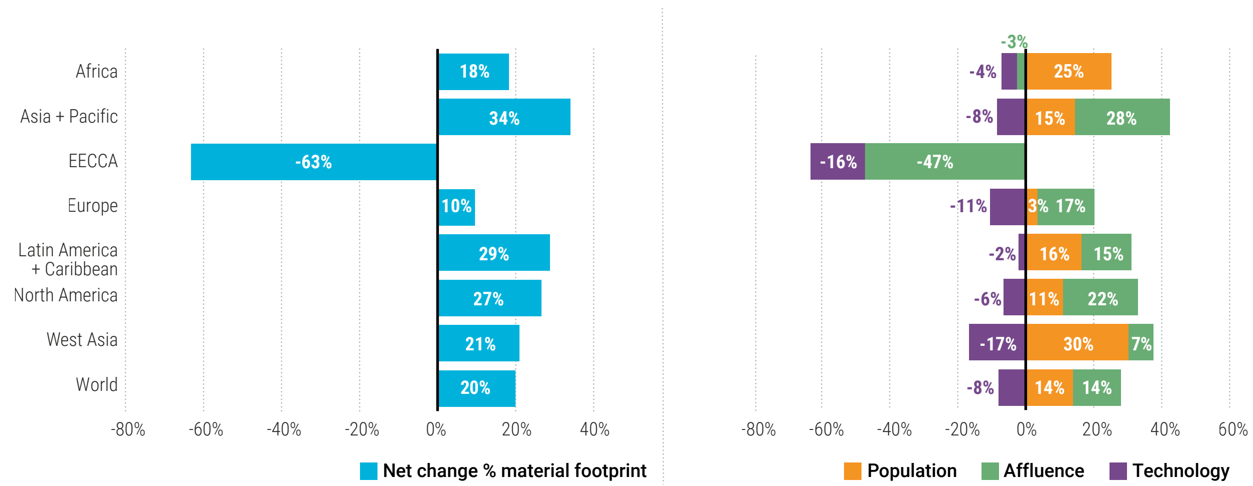
Note: Net changes might vary from the sum of the impacts of population, affluence, and technology due to rounding.
Source: Authors' own calculation.

Figure 2.26: **Drivers of domestic extraction, 2000 – 2024, percentage.**



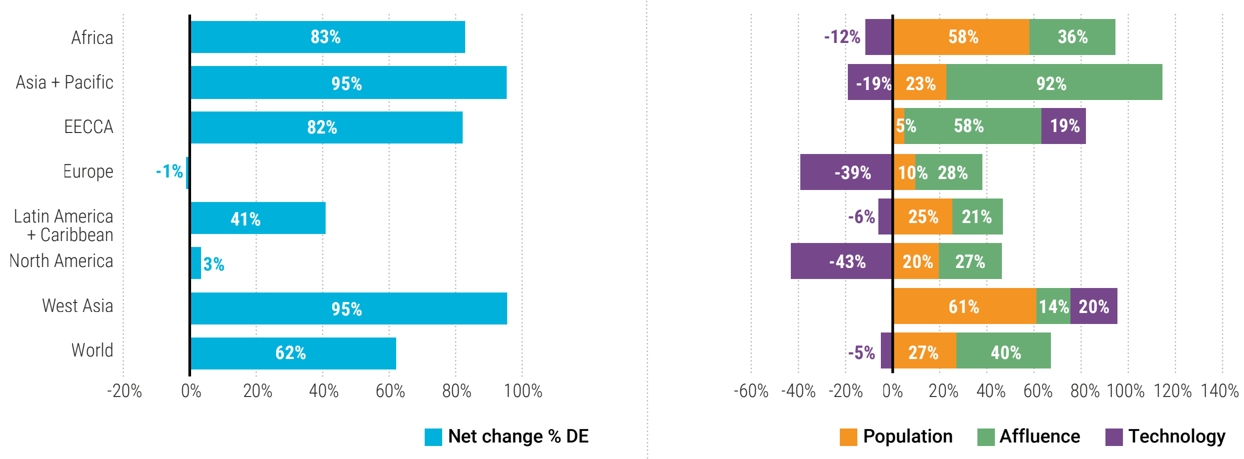
Note: Net changes might vary from the sum of the impacts of population, affluence, and technology due to rounding.
Source: Authors' own calculation.

Figure 2.27: **Drivers of material footprint, 1990 – 2000, percentage.**



Note: Net changes might vary from the sum of the impacts of population, affluence, and technology due to rounding.
Source: Authors' own calculation.

Figure 2.28: Drivers of material footprint, 2000 – 2022, percentage.



Note: Net changes might vary from the sum of the impacts of population, affluence, and technology due to rounding.
Source: Authors' own calculation.

Between 2000 and 2024, technological changes are not expected to fully offset increases in domestic material extraction driven by population and affluence in any region (Figure 2.26). Such a variable is estimated to have contributed to an increase in material extraction in Latin American and Caribbean countries. Affluence was the primary driver of increases in domestic extraction in all regions except Africa, West Asia and Latin American and Caribbean countries.

Material Footprint

The IPAT analysis of material footprint from 1990 to 2000 shows a marked difference from that of domestic extraction (Figure 2.27). However, this is largely due to the shorter time frame analysed for material footprints. The biggest deviation occurs in the EECCA region, which is attributable to the Soviet Union's dissolution and the subsequent economic turmoil in the region from 1990 to 2000. This region provides a unique case where a drop in prosperity led to a substantial and prolonged decrease in material footprint at the regional level. Globally, population and affluence growth had a similar impact on material demand with population being the stronger driver in Africa, West Asia and Latin American and Caribbean countries. Changes in technological efficiency appear to have intensified the growth of material footprint in all regions, rather than mitigating it.

During the period 2000 to 2024, a closer association has been observed between the results of domestic extraction and material footprint (Figure 2.28). At the global level, the contribution is practically the same for both, which is to be expected as MF equals DE globally.[39] The proportion between population and affluence remains consistent, but the absolute percentages generally shift.

2.4 Water use

Water withdrawal is influenced by changes in purchasing power impacting total consumption, consumption patterns, climate and water use efficiency (Hoekstra and Chapagain 2005). This concept allows the estimation of water use through supply chains, water use efficiency and allocations and sustainability of water consumption within river basins (Hoekstra 2016)

While the impact of water withdrawals on the long-term global water balance is marginal, anthropogenic impacts are considerable in some river basins (Haddeland *et al.* 2014). According to some estimates, in 201 river basins with 2.67 billion people there was severe water scarcity at least one month per year between 1996 and 2005 (Hoekstra *et al.* 2012). Climate change, urbanization, population changes and increasing average per capita income are expected to exert more pressure on scarce water resources (Florke *et al.* 2018).

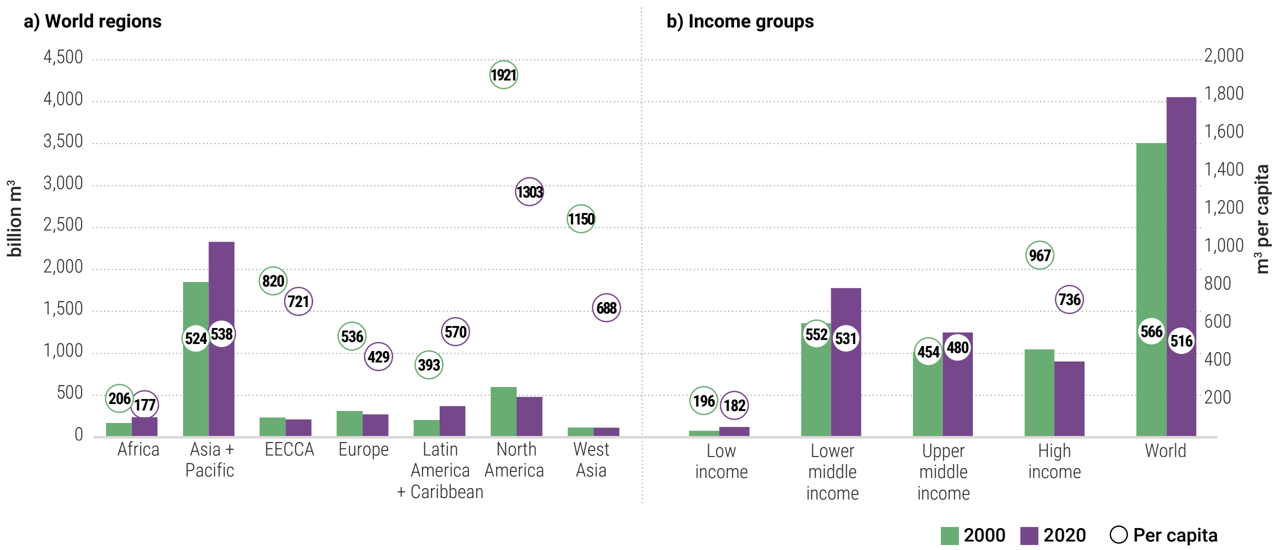
According to the AQUASTAT database of the Food and Agriculture Organization of the United Nations (FAO), global water withdrawal (fresh water removed from surface and groundwater) increased from around 3.5 trillion m^3 in 2000 to 4 trillion m^3 in 2020 (Figure 2.29). On a per capita basis, water withdrawal reduced from 566 m^3 in 2000 to 516 m^3in 2020, with the largest reduction occurring in high-income countries, particularly in North America (Figure 2.29). In 2000, 67% of global water withdrawal was due to agricultural activities, 22% for industrial use and 11% for municipal use (meaning water used for domestic, household purposes or public services). This is consistent with studies indicating that demand for cereal products accounted for 27% of the average global water footprint per capita between 1996 and 2005, followed by meat (22%) and dairy products (7%) (Hoekstra and Mekonnen 2012). By 2020, the share of water withdrawal accounted for by the agricultural and municipal sector increased to 72% and 13%, respectively, while the share of the industrial sector decreased to 15%.

39 Small differences between MF and DE indicators are due to rounding. The different impact and technological coefficient are a result of the reallocation of global direct material extraction among countries during the material footprinting process.

In 2000, the Asia and Pacific region accounted for 53% of global water withdrawal, followed by North America (17%) and Europe (9%) (Figure 2.29). By 2020, this share increased to 58% for Asia and Pacific countries but decreased to 12% in North America and 7% in Europe. The highest average yearly increase in water withdrawal from 2000 to 2020 occurred in Latin America and Caribbean countries (3%), Africa (2%) and Asia and Pacific countries (1%). In that period, the annual rate of water withdrawal decreased around 1% per year in EECCA, North American and European countries. Agriculture accounted for the largest share of water withdrawal in all regions except in Europe and North America where industries were the major water consumer. The share of total water withdrawal for municipal use increased in all world regions, which is consistent with urbanization trends. On a per capita basis, North America and West Asia had the two largest volumes of water withdrawal in 2000: 1,921 $m^3$and 1,150 m^3, respectively (Figure 2.29). Both regions reduced their per capita water use around one third by 2020. On the other hand, Asia Pacific and Latin American and Caribbean countries increased their per capita water withdrawal by 3% and 45% during the same period.

Since 2000, low-income countries have accounted for only around 2% of global water withdrawal (Figure 2.29). Water withdrawals in high-income countries have dropped from 30% of global consumption in 2000 to 22% in 2020. The higher the regional income, the lower the share of water withdrawal for agricultural uses and the larger the share for industrial uses. For example, in 2020, around 90% of total water withdrawals in low-income countries were for agricultural use compared with around 40% in high-income countries. Water withdrawal per capita only increased in the upper middle-income region (Figure 2.29). High-income countries posted the largest reduction (24%) in per capita water withdrawal between 2000 and 2020. However, by 2020, per capita water withdrawal in such a region was still around 2.6 times the per capita withdrawal in low-income countries.

Figure 2.29: Total and per capita water withdrawal by seven world regions and income groups, 2000 and 2020.



Source FAO AQUASTAT 2023.

2.5 Land use

In the last half century, afforestation and cropland abandonment have been the predominant land use change processes in the global North, while deforestation and agricultural expansion dominate in the Global South (Winkler *et al.* 2021). Shifts from deforestation to net forest gains have been driven by interacting factors such as large-scale forest restoration policies, agricultural intensification, rural-urban migration, economic development and improvements in international trade (Rudel *et al.* 2009). In addition, agricultural expansion has been linked to rising international demand for commodities such as timber, soy, palm oil and beef (Gibbs *et al.* 2010) that has driven large scale commercial farming of monoculture crops or livestock production. These processes have been more intense in areas with inefficient enforcement of land use regulations, corruption and unclear land tenure systems that result in unsustainable land use practices (Marcos-Martinez *et al.* 2018)

Land use change can affect biodiversity, water resources, air and soil quality, carbon sequestration and the provision of other ecosystem services (Winkler *et al.* 2021). Land use decisions also impact the livelihoods of local communities, food security and international trade (Lambin and Meyfroidt 2011). Understanding trends and drivers of land use could help develop effective policies and management strategies to mitigate negative impacts and promote sustainable land use.

2.5.1 Global and regional land use trends

Land in intensive use, namely land substantially modified or utilized without accounting for levels of management intensity,[40] increased from 44.5 million km^2 in 1970 to 49.8 million km^2 in 2022 — an average annual increase of 0.2% (Figure 2.30). In 1970, pasture land accounted for 68% of the intensively used land, while crops covered 30% and urban and forestry each accounted for around 1%. By 2022, pastures covered 63%, cropland 31%, forestry 4% and urban land 2%. However, intensive land use per capita almost halved from 1.2 ha in 1970 to 0.63 ha in 2022. Per capita crop and pasture lands reduced by 54% and 49% in that period. Forestry land doubled from 113 m^2 per capita in 1970 to 226 m^2 per capita in 2022, while urban land use per capita increased from 78 m^2 to 98 m^2.

In 2020, the Asia and Pacific region accounted for 30% of total intensive land use, followed by Africa (24%) and Latin America and the Caribbean (15%) (Figure 2.31). The latter posted the largest increase in intensive land use (up 38%) between 1970 and 2020 due to the expansion of pasture (1.20 million km^2) and crop land (0.72 million km^2). Africa expanded its intensive land use by around 2.1 million km^2 between 1970 and 2020. Around 47% of such an increase was for crop production, 32% for forestry and 18% for pasture land. The Asia and Pacific region saw increases in: its crop area by around 1.1 million km^2, forestry land by 0.4 million km^2 and its urban land by 0.1 million km^2, whereas pasture land decreased by 0.1 million km^2. During the same period, Europe decreased its intensive land use by around 0.12 million km^2, despite expanding its forestry area 3.3 times over and multiplying its urban footprint 1.6 times. A similar process occurred in North America, which reduced intensive land use by around 0.22 million km^2 despite increasing its forestry area by 60% and its urban cover by 140%. Only the EECCA region registered a decrease in forestry between 1970 and 2020 (a loss of around 4,000 km^2).

The largest per capita decrease in intensive land use was observed in West Asia, going from 5.2 ha per capita in 1970 to 1.1 ha in 2020 (Figure 2.31). Africa reduced its per capita intensive land use from 2.8 ha to 0.9 ha during the same period. The smallest decrease in per capita intensive land use occurred in Europe: a 24% reduction between 1970 and 2020.

Intensive land use in low-income countries increased by 1.2 million km^2 between 1970 and 2020 (Figure 2.31), with most of that change occurring after 1990. Half of such land expansion was for crop production, followed by forestry (28%), pasture (19%) and urban land (2%). Despite its small land share, urban land increased 6.5 times during that period. Pasture land area in lower middle-income countries remained unchanged, but crop and forestry cover increased by 0.9 million km^2 and 0.7 million km^2, respectively. Urban land in that group of countries more than quadrupled, going from 31,000 km^2 in 1970 to 130,000 km^2 in 2020. From 1970 to 1990, upper middle-income regions increased pasture land by 1.9 million km^2 and crop land 0.6 million km^2. Forestry and urban land increased by 25% (16,000 km^2) and 47% (33,000 km^2) in the same period. Subsequently, crops and pasture each increased by around 0.6 million km^2, forestry by 20,000 km^2 and urban land by 117,000 km^2. High-income countries reduced their total intensive land use from 13.6 million km^2 in 1970 to 12.4 million km^2 in 2020. Such a decrease was due to 1.3 million km^2 reductions in pasture land and 0.4 million km^2 decreases in crop land.

Low- and lower middle-income groups had the largest percentage reduction in per capita land use relative to 1970 values, with decreases of around 70% and 50%, respectively. Low-income countries decreased their land use per capita consumption by 2 ha between 1970 and 2020. This was mostly due to a decline in pasture land area. In other regions, reductions in per capita land use ranged from 0.3 ha to 0.6 ha (Figure 2.31). Declining trends in per capita pasture or crop land area and expanding urban areas were observed in all income groups. Forestry land per capita only decreased in upper middle-income countries.

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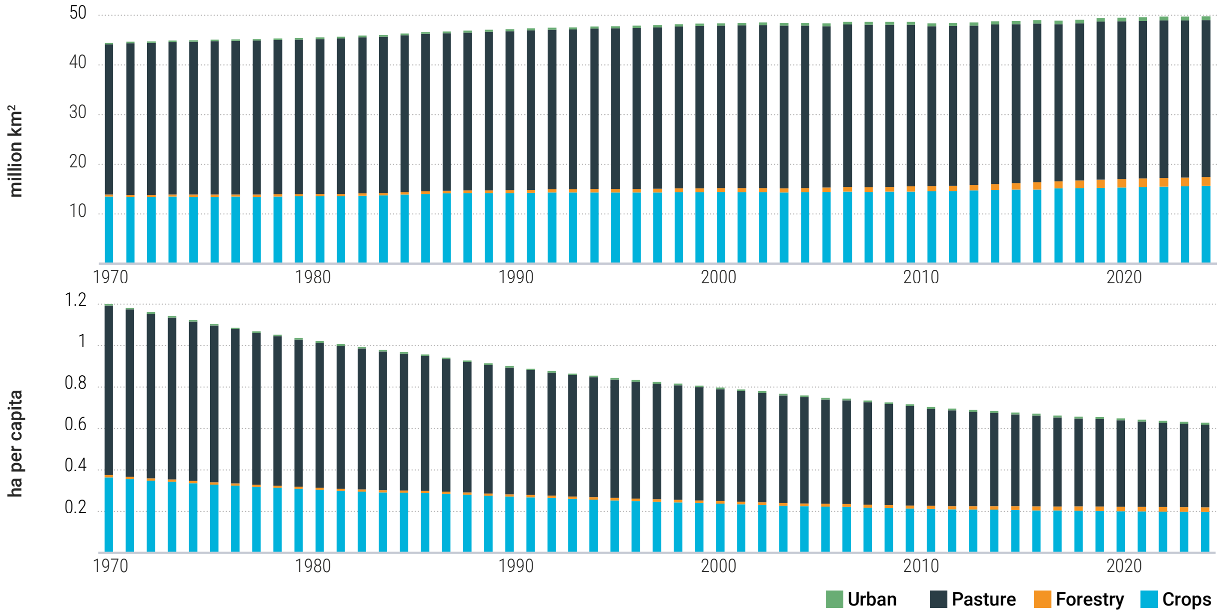
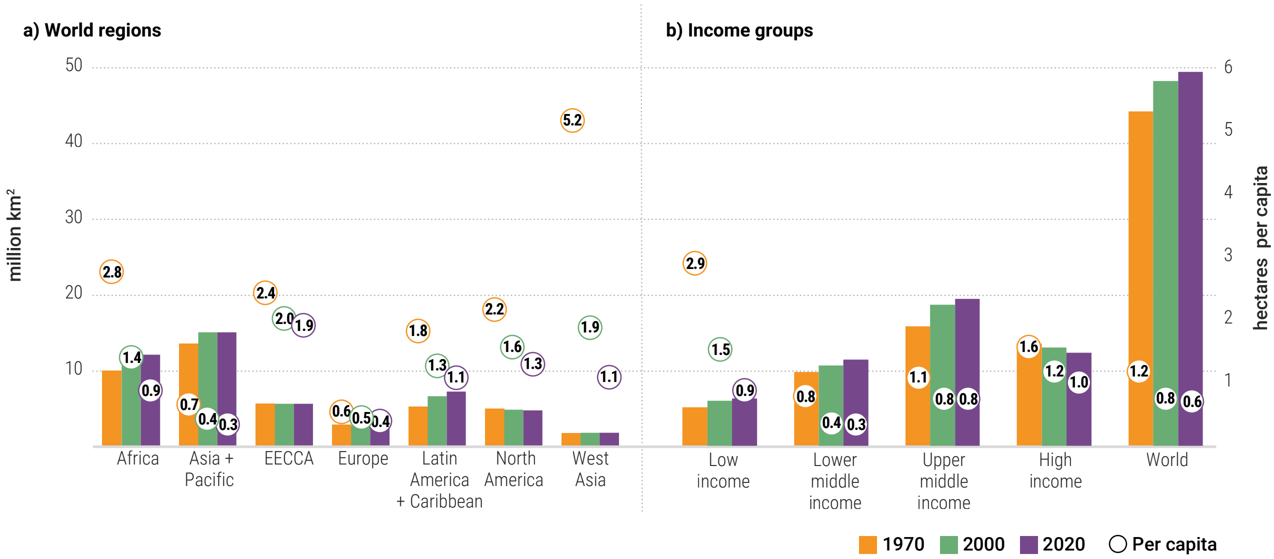
40 Changes in land use due to variations in input productivity that result in intensification or extensification processes are not considered in this section.

Figure 2.30: Global intensive use of land, 1970 – 2022, million square kilometres.



Data source: Land-Use Harmonization project (LUH2), *University of Maryland.*

Figure 2.31: Total and per capita land use by seven world regions and income groups, 1970, 2000 and 2020.



Source: LUH 2.

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2.6 Conclusions

This chapter delves into the primary economic, population and urbanization drivers that underlie the environmental pressures associated with material use, waste and emissions, as well as land and water consumption. The core emphasis is on materials management, which aligns with the main mandate of the International Resource Panel, and the crucial task of decoupling material consumption from economic growth. To achieve this, the chapter employs material flow accounting methodology, bolstered by supplementary environmental accounts concerning water and land use.

The pressure indicators introduced in this chapter complement economic accounts. They can be promptly generated at a national level without incurring exorbitant costs. These indicators serve as a proactive alert system for impending environmental challenges, thereby facilitating the establishment of specific targets and the monitoring of progress towards achieving the environmental goals of the 2030 Sustainable Development Agenda.

The foundation for material flow accounts comes from international datasets detailing the harvest and extraction of materials, waste and emissions, energy consumption and land and water use. Analyses rooted in national datasets might align more closely with national statistical sources. Nevertheless, the overarching results presented here are regarded as both robust and credible, given the extensive literature on material flows and resource productivity. Notably, this is the first instance where material supply has been attributed to provision systems. This effort can be further refined with a detailed life-cycle assessment to address certain limitations resulting from the generalized assumptions of the environmentally extended input-output methodology.

The core insights of this chapter largely echo the conclusions of the 2019 Global Resources Outlook: global material demand is still on the rise, material use productivity remains stagnant and the benefits of material use are unevenly distributed across nations and populations. This translates into an unsustainable scale of global material use. Furthermore, the optimal utilization of materials is not consistently achieved, and the distribution of economic, social and environmental advantages is suboptimal.

As nations continue their industrialization and the global middle class expands, there is a corresponding uptick in material use, waste and emissions, as well as water and land consumption. This intensifies the strain on environmental systems, both in terms of generating essential resources and accommodating waste. As indicated in Figure 2.8, the majority of harvested and extracted materials are used just once, underscoring the underutilized potential for increased circularity and loop-closure in our systems.

While this report notes a temporary slowdown in the growth of global material demand between 2014 and 2020, forecasts suggest a resurgence in accelerated growth in the coming years. Every phase of the material life cycle — from extraction to disposal, encompassing what can be termed as the industrial metabolism — incurs environmental impacts. Chapter 3 of this report delves deeper into the connection between resource use pressures and their resulting environmental ramifications.

A monumental push towards sustainable materials management and enhancements in resource productivity is imperative. This must go hand in hand with responsible consumption, facilitated by strategic infrastructure investments, to guide the global economy towards sustainable and equitable natural resource use that caters to the needs of an expanding population. The potential for decoupling resource consumption from economic activity and human well-being, backed by ambitious policy initiatives, is further explored in Chapter 4 of this report.

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03

Given that resource use is driving the triple planetary crisis, sustainable resource management is urgently needed

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Main findings

Biomass growing and harvesting; mineral and fossil resource extraction; and processing of materials, fuels and food accounted for more than 55% of global greenhouse gas emissions in 2022 and more than 60% if land-use change impacts are considered. This is a further increase compared to 2015 (reference year GRO 2019), demonstrating that climate mitigation efforts have neglected material-resource related impacts.

Growing and harvesting biomass (agricultural crops and forestry) contributed over 90% to total global biodiversity loss and water stress. Relatively few industrial sectors – food related sectors (agriculture, retailers, and food services), wood related industries (forestry, construction) and increasingly biochemicals – are responsible for the bulk of biodiversity loss and should be primarily targeted by policy.

The extraction of resources and processing for food, materials and fuels emitted many times more CO_2 emissions than the target would allow for all human activities combined, and greatly exceeds targets for biodiversity loss.

A transition to a circular and sustainable bioeconomy is critical given the growing environmental impacts of biomass resources for all impacts. Reducing overconsumption of food, animal-based food and food waste would bring co-benefits for all environmental impacts. Conversion (and strong intensification) of biodiversity- and carbon-rich natural systems should be avoided and reversed. Since the availability of sustainable biomass is limited, biomass should be used in cascades and in long-term applications with biogenic carbon storage effects replacing materials with large impacts.

Decarbonization of the energy system and material production is urgently needed to mitigate climate change and pollution-related health impacts. In some parts of South and North-East Asia, people lose about a month of life every year due to particulate matter pollution from industrial sources. Implementing state-of-the-art flue gas cleaning everywhere would more than halve the current worldwide health impacts from industrial particulate matter emissions.

Per capita environmental and socioeconomic footprints continue to vary greatly in different regions and income country groups. High-income countries cause ten times more climate impacts through consumption than low-income countries.

Provisioning systems contribute to total global climate change impacts as follows: energy and mobility jointly 29%, food 23% and the built environment 17%. The climate impact of energy, mobility and built environment is ten times higher in high-income regions than in low- and lower middle-income regions. Biodiversity loss and water stress are primarily related to food provisioning in all regions.

Countries with high and very high well-being (measured by the Human Development Index) still show increasing environmental impacts on average and should work on absolute decoupling. Provisioning systems of education and sanitation have minimal environmental impacts and can hence be improved to increase well-being without compromising the environment.

3.1 Introduction

3.1.1 Relevance

The triple planetary crisis of climate change, biodiversity loss and pollution increasingly threatens the future of society. Climate change impacts are already evident worldwide, but national pledges for greenhouse gas reductions still fall short of meeting the required level to maintain the Paris target (UNEP 2021b). Similarly, species extinction rates are tens to hundreds of times higher than the average rate over the past 10 million years, and the pace is accelerating (IPBES 2019a). Resource extraction, processing and use make a significant contribution to these and other environmental impacts.

This chapter provides an update of the development of resource-related impacts up to 2022 and shows the gap in terms of reaching targets for climate change and biodiversity loss impacts. It also shows which impacts are caused by provisioning systems. This helps to understand the status quo, historic trajectories, environmental hotspots, improvement potential and the need for action for sustainable global resource management, with the goal of achieving a high level of well-being while keeping impacts to an acceptable level and in line with global environmental goals.

3.1.2 Content

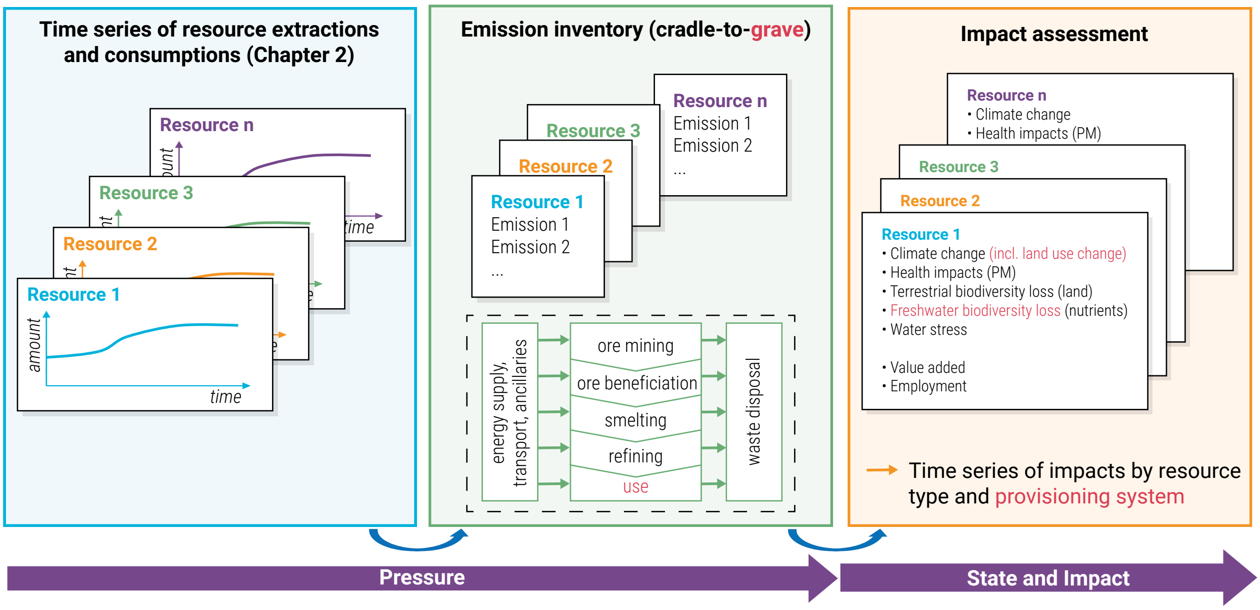
Based on the quantification of resource extraction and consumption amounts provided by Chapter 2, this chapter focuses on their environmental consequences.

As in GRO 2019, the extraction of minerals, fossils and biomass, and the processing thereof for materials, fuels, fibres and food, are all included (Figure 3.1). The matching of economic sectors to these resource types and the remaining economy is documented in Cabernard *et al.* (2019), with a few deviations (see Annex 2). In a new development, if resources are used for the production of others, the impacts are allocated to the resource where the impacts are caused (and not to the resource that is supplied, as was the case in the GRO 2019). This means, for example, that if coke is used for steel production, the impacts of that coke are counted in the coke sector (and not in the steel sector, as was carried out for the GRO 2019). This procedure is more consistent with the material footprint assessment of Chapter 2 and IPCC emission accounting rules. Biofuels and biochemicals are now accounted as biomass resources (and not as fossils as in GRO 2019). Moreover, impacts of the downstream use and disposal of materials, fuels, fibres and food are included in this edition of GRO (following the approach of Cabernard *et al.* (2022), which means the applications, the industrial sectors consuming the resources and the possible impacts in the downstream value chain are all discussed (Figure 3.1).

Based on the analysis of impacts along the value chain, potential for improvement is identified and recommendations are generated for sustainable resource management. Furthermore, the chapter also assigns downstream uses of material resources to provisioning systems. This includes the four systems that form the focus of the whole report (see Chapter 1, section 1.8), as well as additional systems for which results can illuminate impact hotspots. Provisioning systems were defined on the level of end-sectors and products. This means, for instance, that the use of a car or public mobility service by a household would be counted within the provisioning system “mobility”, while transport of materials to a building site would be counted within the provisioning system “built environment”. Similarly, a household’s use of electricity would be counted as “energy”, while the use of electricity for a building site would be counted within the provisioning system “built environment”. These system boundaries were chosen to consider the entire supply chain of provisioning systems and avoid double counting, but they deviate from previous definitions.

The base data for the assessments in this chapter come from Exiobase v3.8 (Stadler *et al.* 2021), complemented with trade data from Eora (Lenzen *et al.* 2013), production data from FAOSTAT (Food and Agriculture Organization of the United Nations) and British Geological Survey (Minerals UK), land-use data from (Hurtt *et al.* 2020) and (Chini *et al.* 2021), greenhouse gas emissions from land use change from the Blue model (Hansis *et al.* 2015) and impact assessment methods from Table 3.1 (see also Cabernard and Pfister 2021).

Figure 3.1: Overview of the methodological procedure to assess selected health, environmental and socioeconomic impacts of resource extraction, processing and downstream use. New elements compared to GRO 2019 are marked in red.



PreciousPhotos

Impacts assessed in this chapter

In addition to considering the complete life cycle of resource use in this new edition of the GRO, the list of impacts assessed has been extended by freshwater eutrophication impacts (leading to aquatic biodiversity loss). Moreover, impacts of land-use change on climate change, neglected in GRO 2019, are now included (Hansis *et al.* 2015; Friedlingstein *et al.* 2022).

Furthermore, the modelling was improved. In particular, regionalization in the background data was enhanced to increase the accuracy of the impact assessment such as for land-use related biodiversity loss and water stress (Cabernard and Pfister 2021), as well as particulate matter-related health impacts (Oberschelp *et al.* 2020). Moreover, biodiversity loss impacts related specifically to land use of mining activities and temporal trends for global biodiversity loss have been added (Hurtt *et al.* 2020; Cabernard and Pfister 2022). These improvements have improved accuracy and made it possible to zoom in to more spatial detail (such as displaying geographical maps of where impacts occur in Section 3.5).

Table 3.1: List of impact indicators assessed in GRO 2024 and changes compared to GRO 2019. Climate change and biodiversity loss have been defined as core planetary boundaries (Steffen et al. 2015) and are critical elements of the triple planetary crisis.

Impact category	Unit	References	Changes compared to GRO 2019
Climate change (also called GHG or carbon footprint)*	Tonnes of CO_2-equivalents (t CO_2-eq)	(UNEP SETAC 2016), LUC emissions of agriculture and forestry: (Hansis et al. 2015; Friedlingstein et al. 2022); LUC emissions of industry and urban infrastructure: (Müller-Wenk and Brandão 2010)	Same as GRO 2019 with an extension for greenhouse gas emissions for land-use change (LUC).
Land-related biodiversity loss (from land occupation and land use change)	Fraction of global species at risk of extinction (global PDF**)	(UNEP SETAC 2016)	Impact assessment method unchanged, assessing species loss per ecoregion and weighting it with an endemism-based risk factor. Increased regionalization of agricultural and mining processes (Cabernard and Pfister 2022) in the background data improve the assessment results compared to GRO 2019.
Water stress	m^3-e	(UNEP SETAC 2016)	Impact assessment method unchanged, but increased regionalization of agricultural and mining processes in the background data improves the assessment results.
Health impacts from particulate matter (PM), including impacts from primary emissions of PM as well as secondary formation from precursor gases SO_x, NO_x and ammonia	DALY**(amount of life years lost or lived with health impairment)	(UNEP SETAC 2016); (Oberschelp et al. 2020)	Unchanged in the main analysis, but improved impact assessment and regionalization of emissions and assessment of environmental fate and effects in Section 3.5 (bottom-up analysis); assessment of outdoor fine primary ($PM_{2.5}$) and secondary particulate-matter emissions (not including indoor emissions).
Freshwater biodiversity loss through eutrophication	Fraction of ecoregion species at risk of extinction (regional PDF***)	(Scherer and Pfister 2015); fate: (Helmes et al. 2012); effects: (Azevedo et al. 2013)	Newly implemented for this report.
Ecotoxicity	CTU****	(Rosenbaum et al. 2008)	Only applied case study on copper tailings (Box 3.3); same method as GRO 2019; the method considers the fate of emissions in the environment (degradation and partitioning between environmental compartments) and substance-specific toxic effects.
Value added	Euro	(Stadler et al. 2018)	Same as GRO 2019; value added indicates the value created through the production of goods and services. It is calculated by subtracting the cost of intermediate consumption from the total output value. Value added serves as a measure of the income available for the contributions of labour and capital to the production process.
Workforce	Full time equivalents	(Stadler et al. 2018)	Same as GRO 2019

* GHG emissions are not a pressure, but a measure of climate impact. To convert the units of all greenhouse gas emissions from 1 kg of the original emission to the unit of 1 kg CO2-equivalents, emissions were weighted according to the concentration change they produce in the atmosphere (considering persistence and chemical transformations) and multiplied by the radiative forcing of the respective gas: a substance property describing how much energy the substance can absorb. This effect of altering the energy balance (and hence the climate) of the earth is accumulated over 100 years. The impacts are called climate change impacts but are also known as the carbon footprint or GHG emissions.
**DALY: disability adjusted life years (World Health Organization 2019).
***PDF: potentially disappeared fraction of species.
****CTU: comparative toxic units (Rosenbaum et al. 2008).

Identification of drivers of impacts

The drivers of environmental impacts are estimated using the IPAT equation, a formula that describes the relationship between human activity and environmental degradation. The IPAT equation, which stands for Impact = Population x Affluence x Technology, suggests that the total environmental impact (I) is a product of three primary factors: the size of the human population (P), the level of affluence or consumption per person (A) and the environmental impact per unit of consumption, often influenced by technology and processes (T) (Chertow 2000). Understanding and analysing these components can help identify key areas of intervention to mitigate negative environmental impacts.

Targets

This report posits possible science-based targets (henceforth referred to simply as targets) derived from intergovernmental agreements to benchmark the state of climate and biodiversity impacts. These targets are indicative and seek to demonstrate the extent to which environmental impacts from resource use could derail commitments to global climate and biodiversity agreements. The IRP research in the area of science-based targets is ongoing.

For climate change, the remaining 2020 CO_2 budget for a 50% success probability of reaching the 1.5 degree target was taken from Table SPM.2 in IPCC (2021), amounting to 500 Gt CO_2. For the years prior to 2020, the cumulative CO_2 emissions were added to this budget, while the global CO_2 emissions from 2020 and 2021 were subtracted to calculate the remaining budget for the years 2021 and 2022. This remaining budget (410 GT CO_2 for 2022) was then divided by the years to go until 2100 (78 years as of 2022). Current CO_2 emissions were then benchmarked against this annual budget. This target is to approximate the current position compared to where the situation should be. However, this figure is uncertain. For example, the linearity assumption of distributing the budget equally until the year 2100 could be challenged. The overall budget of 500 Gt CO_2 depends on assumptions about the release of non-CO_2 GHG. Furthermore, an initial overshoot of the target would lead to a lower net budget because of permafrost thaw (Gasser *et al.* 2018). For example, in the event of an overshoot followed by compensating with negative emissions, the non-linearity of the permafrost response implies that the budget is actually lower. In other words, more capture will be needed to compensate for non-linear permafrost carbon release. Recently, a lower CO_2 budget of 280 GT after the year 2022 was proposed (Lamboll *et al.* 2023). Using this budget instead of the IPCC-derived budget would have led to similar results, reinforcing the conclusions from Section 3.2.3.

The impact target for biodiversity loss is split into a short-term target for land-use change (newly induced biodiversity loss additional to historical loss) and a long-term target for land occupation (including historic biodiversity loss due to total land occupation). The short-term target considers a limit of 0.001% additional global species extinction per year (Steffen *et al.* 2015). The long-term target for land occupation was set to limit global species loss to 1.5% (see Annex 3) (Nathani *et al.* 2019).. Beyond land use (land use change and land occupation), other sources of biodiversity loss include climate change, terrestrial acidification and water stress. Climate change and water stress were assessed as standalone indicators in this edition of the GRO (Table 3.1), and their implications on biodiversity loss were not additionally addressed to avoid double counting. Other biodiversity impact-pathways (e.g. acidification) were omitted as consensus within the UNEP Life Cycle Initiative (Frischknecht and Jolliet 2017; Frischknecht and Jolliet 2019) has not yet been achieved about how to model these effects.

Decoupling of well-being from environmental impacts

This chapter assesses the links between the environmental impacts and human development indicators, which in turn facilitates an assessment of well-being decoupling. This is based on the inequality-adjusted Human Development Index (IHDI) and its three components (gross national income per capita, education and life expectancy). The upper cut-off threshold, which was applied by the original IHDI calculation, was removed. This was because a comparison of a capped well-being indicator with uncapped impact indicators would make it impossible to analyse the decoupling of human well-being from resource use over time. For example, the IHDI education component was reconverted to units of years of schooling (instead of an index between 0 and 1), and then weighted with the inequality factors from the IHDI (the larger the inequality the smaller are the values of these factors multiplied to the raw HDI values of income, education duration and life expectancy). Since the well-being quality gain may be different for countries with low IHDI versus countries with high IHDI, this analysis was subdivided into the four groups proposed by the HDI framework (very high, high, medium and low).[41]

41 While IHDI is used as a well-being indicator, the grouping of countries follows the classification of the United Nations Development Programme (UNDP), which relates to HDI values.

3.1.3 Further information

In order to facilitate a deep-dive analysis into specific resources, sectors or regions, an open-access tool has been developed to downscale the GRO results of this chapter: https://public.tableau.com/app/profile/livia.cabernard

Examples for applying this tool to derive country-specific information are included in the country profile annex.

3.2 Growing impact of global resource-related impacts and missed targets

3.2.1 Resource management is the key to environmental policy

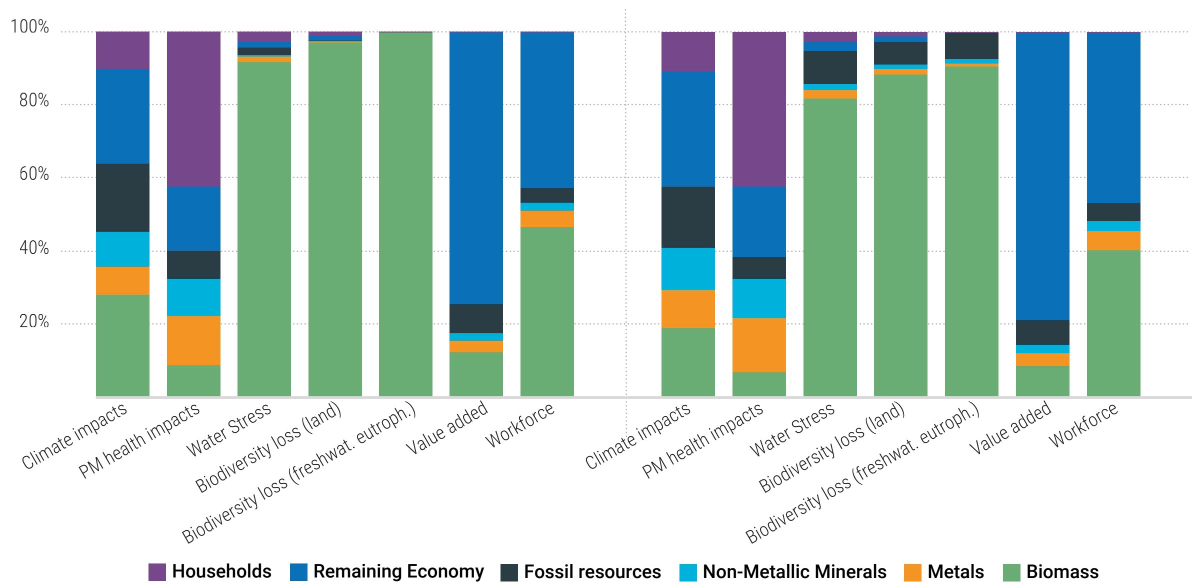
Growing and harvesting biomass continued to be the dominating driver of land-related biodiversity loss, global water stress – and newly assessed freshwater biodiversity loss due to eutrophication (Figure 3.2). Most of these biomass impacts came from agricultural processes (for food and textile production).

Biomass cultivation, mineral and fossil resource extraction and processing for materials, fuels and food accounted for more than 55% of global greenhouse gas (GHG) emissions in 2022 and more than 60% if greenhouse gas emissions from land-use change are taken into account (Figure 3.2). This is a further increase compared to 2015 (reference year for GRO 2019), continuing the upward trend. Climate mitigation efforts have so far focused too little on agriculture, resource extraction and processing and urgently need to be directed to this issue. Otherwise, the Paris Agreement goals cannot be achieved. This includes creating a circular economy to decrease the impacts of resources, whereby attention needs to be paid to sustainability and clean cycles (see Box 3.1).

In contrast to the other environmental impacts, health impacts occur primarily in the downstream combustion of fuels and biomass resources, and only 40% relate to extraction and processing. The downstream impacts would be even larger if indoor particulate matter (PM) exposure effects had been included in the analysis.

Although resource cultivation/extraction and processing contribute between 40% and > 95% to all environmental impacts and employment, they only created 25% of the global value added. About 50% of the global workforce is employed in the resource sector, particularly in agriculture (Figure 3.2). Most of this employment takes the form of low-paid jobs.

Figure 3.2: Relative contribution of different types of resources (extraction and processing), the remaining economy (downstream use of resources in the economy after extraction and processing) and households (impacts of direct emissions and resource consumption) to global environmental and socioeconomic impacts for 2022. Left: Application of the updated methodology (considering land-use change climate impacts plus land occupation and emissions, minor changes in the sector classification – see Annex 2 – and new allocation to resource types as documented in Section 3.1.2). Right: Application of GRO 2019 methodology (no climate land use change impacts, previous sector classification – see Annex 2 – and different allocation to resource types).



Box 3.1. Plastics management

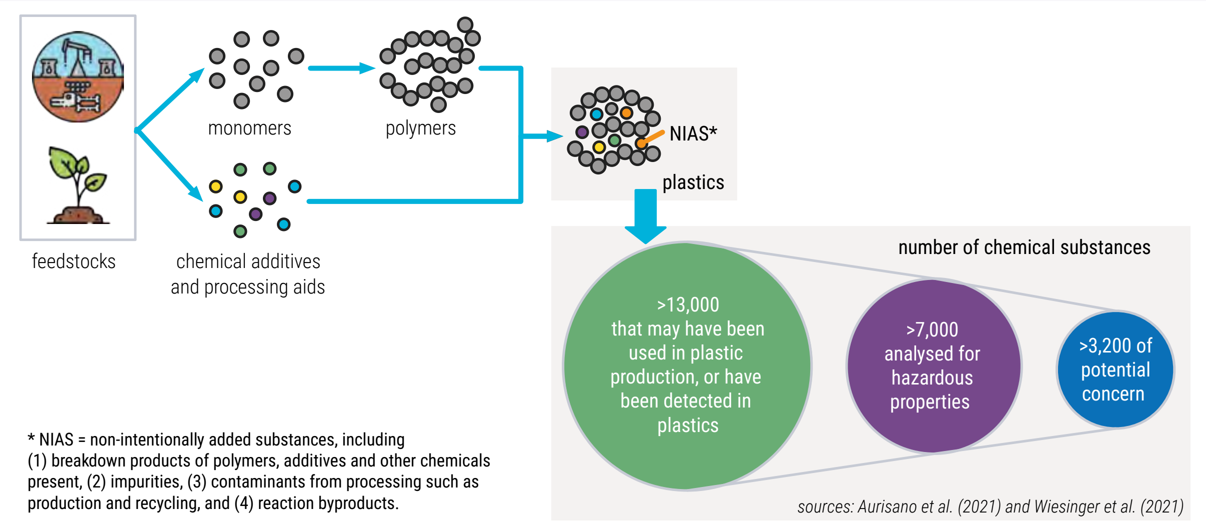
(Helene Wiesinger, Zhanyun Wang, Magdalena Klotz and Stefanie Hellweg)

Alleviating the environmental impacts of plastics needs both upstream and downstream solutions. Plastics contribute 4.5% of the global climate impacts, with fossil energy and feedstocks in production being the main drivers (particularly coal) (Cabernard *et al.* 2021; Huo *et al.* 2022; UNEP 2023c). Meanwhile, mechanical recycling has been suggested as a key solution as it can reduce demand for primary plastics while offering the strongest environmental benefits among current waste-management options (Laurent *et al.* 2014; Meys *et al.* 2021; Schwarz *et al.* 2021; OECD 2022; UNEP 2023c). Proper waste management also decreases plastic leakage into the environment (Jambeck *et al.* 2015), which endangers wildlife and human health at great social costs in terms of externalities (UNEP 2023).

Upscaling mechanical recycling is challenging. Climate-neutral plastics require an effective recycling rate of over 70% according to Meys *et al.* (2021) (global estimate). However, barriers such as diversity, contamination and inaccessibility of waste plastics hamper achievement of this target (Klotz *et al.* 2022; Klotz *et al.* 2023). Various waste plastics are typically recycled together, resulting in lower-quality secondary plastics with reduced usability. Even with considerable systemic changes (including maximum collection rates, design for recycling and improved sorting), a maximal overall mechanical recycling rate is projected to be 30% (Klotz *et al.* 2022; Klotz *et al.* 2023).

Chemicals in plastics are another overlooked barrier. Plastics are complex materials composed of diverse chemical components (Figure 3.3). While bringing benefits such as improved plastic properties and processability, chemicals in plastics pose the following challenges for increased circularity: (1) the sheer number of hazardous chemicals associated with plastics, and lack of transparency about their presence, impedes safe (re)use or recycling of plastics. Out of the 13,000 chemicals identified, around a quarter are known to be highly hazardous, possibly posing great risks to human and ecosystem health (Figure 3.3). This may still be an underestimate, as nearly half of the chemicals identified lack basic hazard and risk data for the analysis (Aurisano *et al.* 2021; UNEP 2023d; Wiesinger *et al.* 2021). Also, many hazardous chemicals can be recycled into new products, resulting in unforeseen exposure and risk (Brosché *et al.* 2021; Pivnenko *et al.* 2016, 2017; Strangl *et al.* 2018; Zennegg *et al.* 2014); (2) many chemicals can impede mechanical and chemical recycling processes, including hindering optical sorting (Turner 2018), accelerating degradation of the polymers during recycling (Day *et al.* 1995), causing corrosion of equipment (Ozturk and Grubb 2012) or hampering the utilization of chemical recycling products (Kusenberg *et al.* 2022). For more details, see Wang and Praetorius (2022).

Figure 3.3: Overview of chemicals in plastics (adapted from UNEP and the Secretariat of the Basel, Rotterdam and Stockholm Conventions 2023).



Multiple systemic changes are needed, including: reducing overall demand, using renewables in production, phasing out hazardous chemicals, streamlining and harmonizing composition (including through standards), enhancing transparency across use cycles (such as digital markers linked with the composition information) and improving collection, sorting and waste management. Currently, intergovernmental negotiations are taking place to develop a global plastics treaty, thereby providing a unique opportunity for systemic changes. Some recent studies have outlined how these objectives may be achieved, including under such a treaty (Klotz *et al*. 2022; Klotz *et al*. 2023; Wang and Praetorius 2022; UNEP 2023c).

3.2.2 Lack of global absolute decoupling - environmental impacts continue to increase

Between 2015 (reference year of (IRP 2019a)) and 2020, there was no absolute decoupling of economic activity from any environmental impacts on the global scale (Figure 3.4). All impacts increased in absolute terms, with only a few temporary reductions.

A key driver for rising GHG was the increasing reliance on coal energy to process materials, especially metals (Figure 3.5), construction materials and chemicals. More than half of global coal use was for the production of these materials (Cabernard *et al.* 2022).

3.2.3 Targets for climate and biodiversity impacts have been dramatically missed

Comparing the global CO_2-emissions to the climate target shows that society is increasingly falling short of the target, depleting the CO_2 budget rapidly. In 2022, the extraction of resources and processing for food, materials and fuels emitted multiple times more CO_2-emissions than the target would allow for all human activities together (Figure 3.5). Therefore, immediate and decisive action is required to lower the GHG emissions, paying attention to the crucial role of material resources.

Also, the two targets for biodiversity loss have been missed. The long-term target (related to land occupation) was exceeded 6 times in 2022 (Figure 3.5), while the short-term target (related to land-use change) was exceeded by around 35 times (Figure 3.5). The short-term target considers the annual species loss due to land-use change. The longer-term perspective indicates that, even if impacts from land conversion cease, land use impacts would still have to be reduced in order to meet suggested targets. In conclusion, net impacts of land-use change should be stopped immediately, and ecosystems should be restored to meet both the short-term and long-term targets. This would also benefit climate impacts, since land use change contributes 10% to global GHG.

Figure 3.4: Temporal development of environmental impacts and socioeconomic indicators compared to drivers of population and GDP growth from 1995 to 2022. Left: total worldwide impacts (see Figure 3.1); right: from resource extraction and processing up to "ready-to-be-used" materials, food or fuels (as in GRO 2019). Dashed lines are partially based on nowcasted data after 2012 (Tukker 2016) and are therefore uncertain. In contrast to GRO 2019, the GDP is now based on constant 2015 prices.

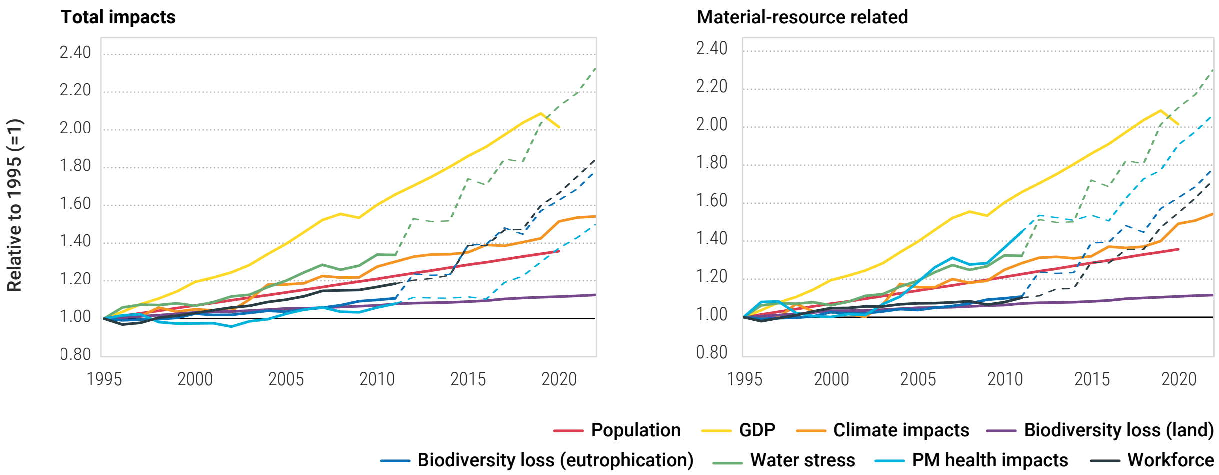
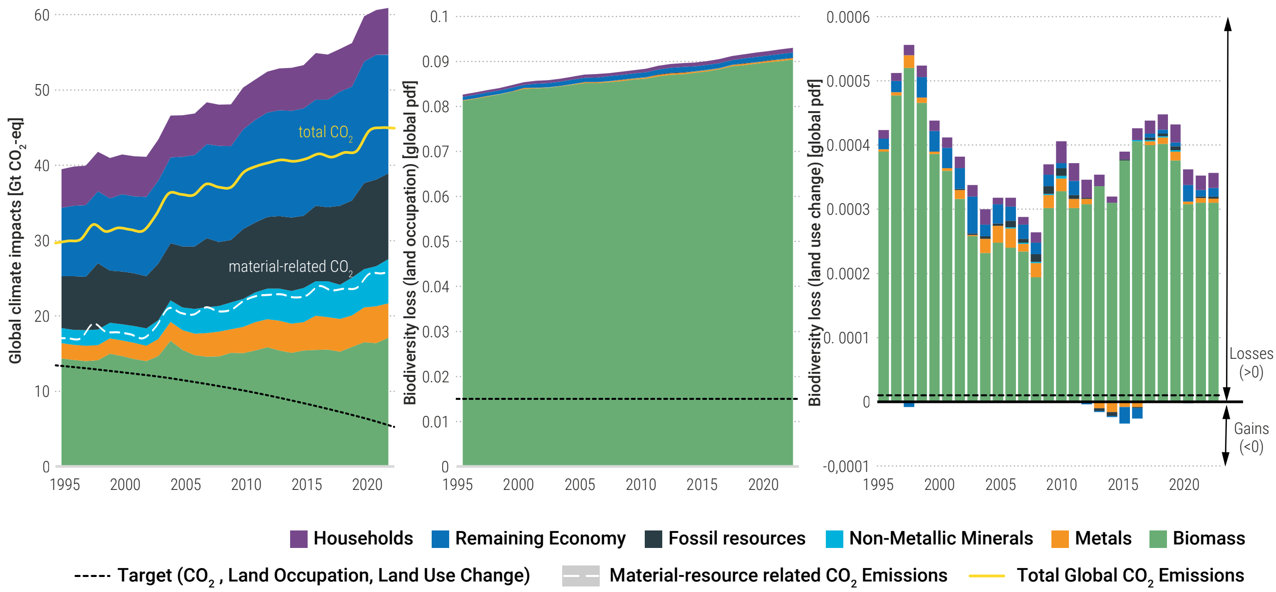


Figure 3.5: Time series of climate change (left) and land-related biodiversity loss (middle and right) split by material resource group (including cultivation/extraction and processing) and downstream use (remaining economy and households). Moving averages over five years are used for land use change (right figure). The black dashed lines show the targets (see section 3.1.2). For climate change, this curve is declining, as the target is a CO_2-budget, which decreases every year due to overshoot of annual targets. In addition to GHG (coloured areas), also the total (purple curve) and the total material-resource related CO_2 emissions (white curve) are shown to enable a comparison with the target (which does not comprise GHG other than CO_2).



3.2.4 Provisioning systems of food, energy, mobility and built environment are main contributors to environmental impacts

Provisioning systems of energy and mobility, food and built environment contributed 70% to total global climate change impacts, with shares of 29%, 23% and 17%, respectively (2022) (Figure 3.6). However, less than half of global value added is related to these provisioning systems. Land-related biodiversity loss, water stress and eutrophication are primarily related to food provisioning (between 55% and 75% of all impacts), followed by the built environment and energy for land-related biodiversity loss (including through wood use and related forestry activities).

The built environment, as well as "water, sewage and health", has seen a particularly large increase in climate impacts between 1995 and 2022 (factor 2.5), but also clothing and "other" services (often non-essential) have increased by more than 60% in this period (Figure 3.7). The increase of impacts from the built environment was mainly due to infrastructure build-up in Asia, and is likely to be followed in other developing regions in the future. Sustainable construction and urbanization strategies are therefore urgently needed to avoid a further massive increase in climate impacts. This includes sufficiency strategies (such as limiting floor area per person to a minimum that allows for decent living), material- and energy-efficient building design, use of materials that store (biogenic) carbon over long periods of time, material circularity and urban design with distributed centres (to limit mobility needs).

Figure 3.6: Relative contribution of provisioning systems to global environmental and socioeconomic impacts for 2022. For each provisioning system, impacts cover the whole life cycle including extraction, production, transport, use and end-of life. The provisioning systems energy and mobility are represented in the graph by public mobility (dark blue), energy (orange, including electricity, hot water supply and the production of fuels) and household fuel use (yellow, including direct emissions from private mobility and heating). Energy and mobility used by the other provisioning systems (such as for food) are allocated to these provisioning systems.

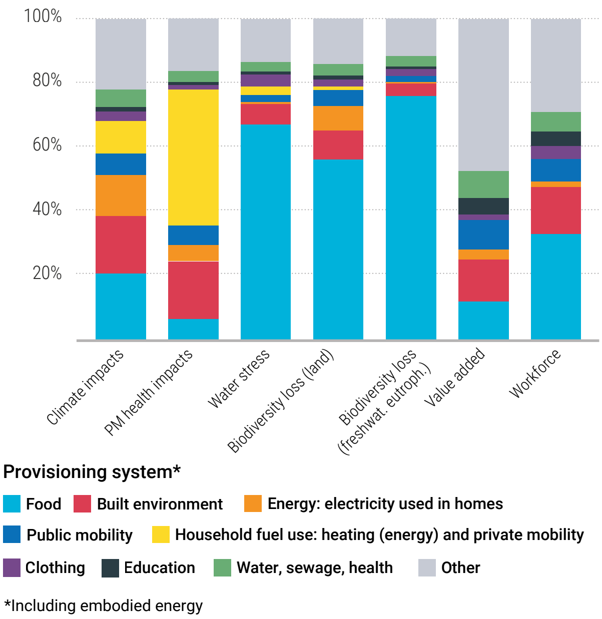
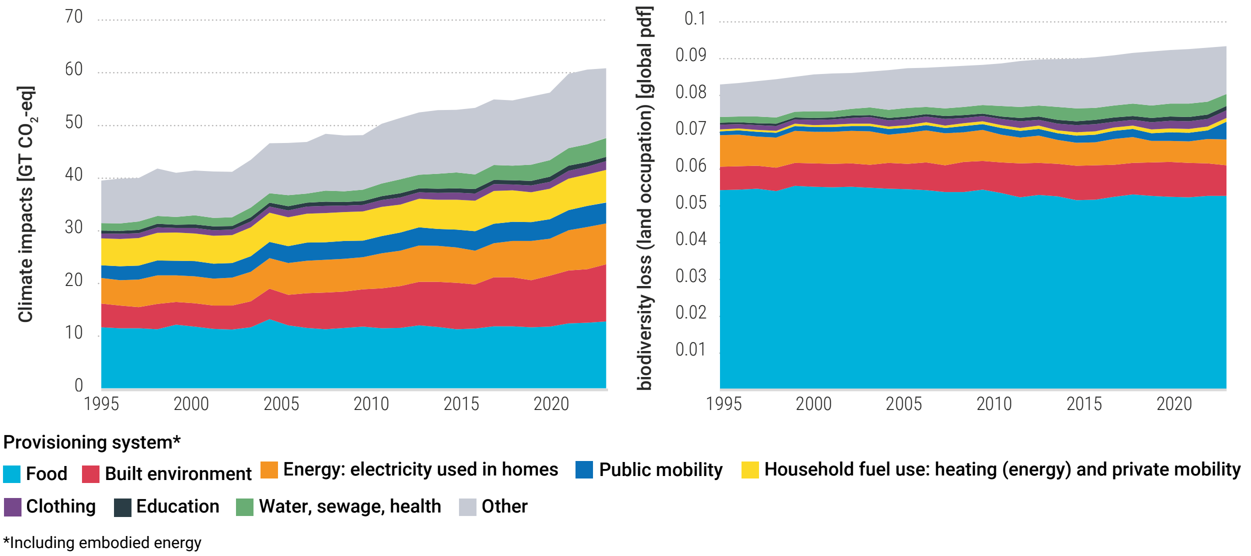


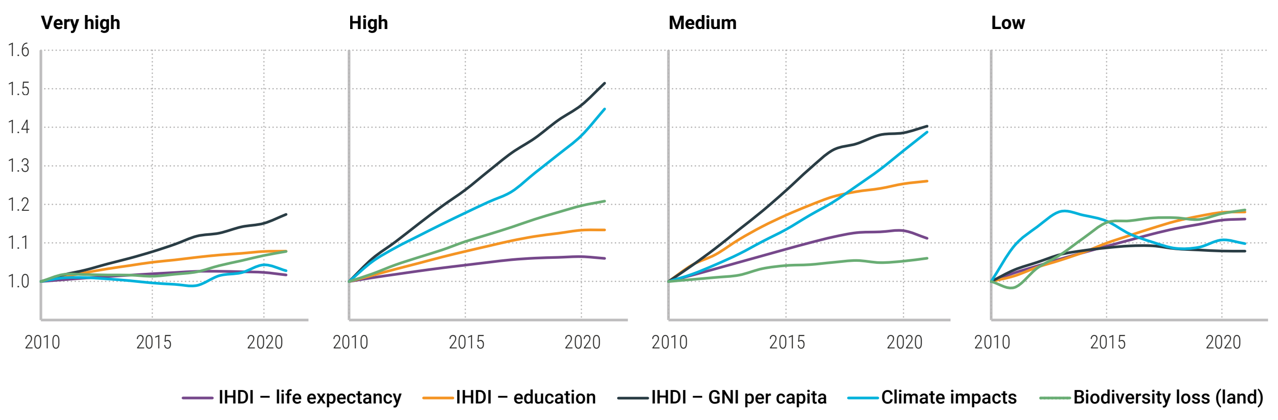
Figure 3.7: Time series of climate change (left) and land-related biodiversity loss (right) impacts split by provisioning system. The provisioning systems energy and mobility are represented in the graph by public mobility (dark blue), energy (orange, including electricity, hot water supply and the production of fuels) and household fuel use (yellow, including direct emissions from private mobility and heating).



3.2.5 Well-being increased but without absolute decoupling in any IHDI county groups

Between 2010 and 2022, average IHDI increased for all HDI country groups,[42] and environmental impacts continue growing. This means that no absolute decoupling of IHDI from environmental impacts was observed for any of the groups. In terms of relative decoupling, a diverse picture was observed among HDI country groups. For instance, for countries with very high HDI levels, the income component posted the highest growth in relative terms, with moderate increases in environmental impacts. High and medium HDI countries showed the biggest relative increase in the IHDI income component, with high relative increases in environmental impacts. Both medium and low HDI countries show remarkable increases in the IHDI education component, especially the former.

Figure 3.8: Temporal development of inequality-weighted human development metrics (average of the three components of inequality adjusted HDI in countries with HDI level from very high to low) and selected environmental impacts (climate change and biodiversity loss as core planetary boundaries) between 2010 and 2022 (availability range of inequality adjusted HDI). Data were smoothed (moving-average method). Raw data for well-being downloaded in August 2022 from UNDP (https://hdr.undp.org/data-center/documentation-and-downloads) and processed as documented in Section 3.1.



42 While IHDI is used as a well-being indicator, the grouping of countries follows the classification of the United Nations Development Programme (UNDP), which relates to HDI values.

3.3 Environmental impacts are unevenly distributed

3.3.1 Environmental impact footprints differ greatly between income country groups

On a per capita level, there remain major differences in the environmental impacts of consumption between various income group countries (ranging between a factor of 2 and 10). For example, high-income countries caused 10 times more climate impacts through consumption than low-income countries. Trade reenforces this inequality (Figure 3.9, right): High-income countries displace environmental impacts to all other income country groups, which means they import resources and materials that cause environmental impacts in the exporting regions.

All impact categories other than climate change are mainly attributed to nutrition (similar to land-related biodiversity loss shown in the lower graph of Figure 3.10). The differences in impacts for food provisioning systems between high and low/middle-income countries is a multiplication factor of approximately 3 and 2, for climate change and land-related biodiversity impacts, respectively, while high-income regions cause more than 10 times more climate impacts to obtain provisioning systems of energy, mobility and built environment than low- and lower middle-income regions (Figure 3.10). "Other" provisioning systems make up one third of the climate impacts in high-income regions and are also increasing in upper middle-income regions, while they are less important in lower income regions. Main contributors to these other provisioning systems include machinery production (>20%), public services and social security (17%), consumer products like furniture and consumer electronics (13%) and recreation (6%) (see Annex 4). The largest increase of climate impacts took place in upper middle-income regions, mainly due to built environment.

Figure 3.9: Left: Per capita environmental impact footprints (climate change, PM health, water stress, land-use related biodiversity and biodiversity loss from freshwater eutrophication) and socioeconomic benefits (value added, employment) by income group (consumption perspective). Right: Global net trade impacts per capita ordered by income group countries, represented as a share of global per capita impact. Reference year 2022.

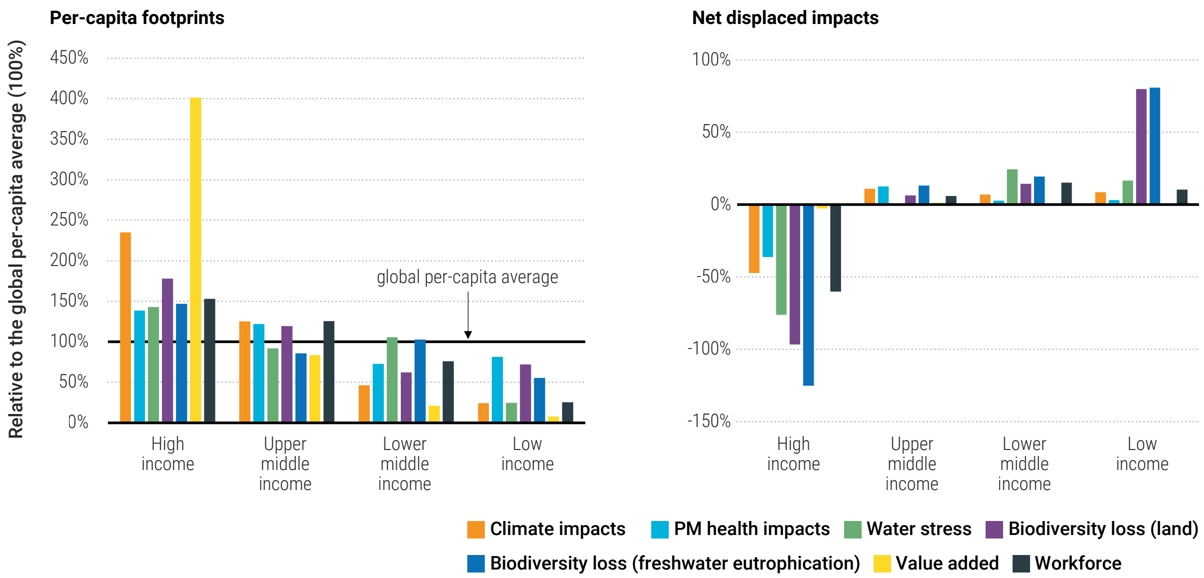
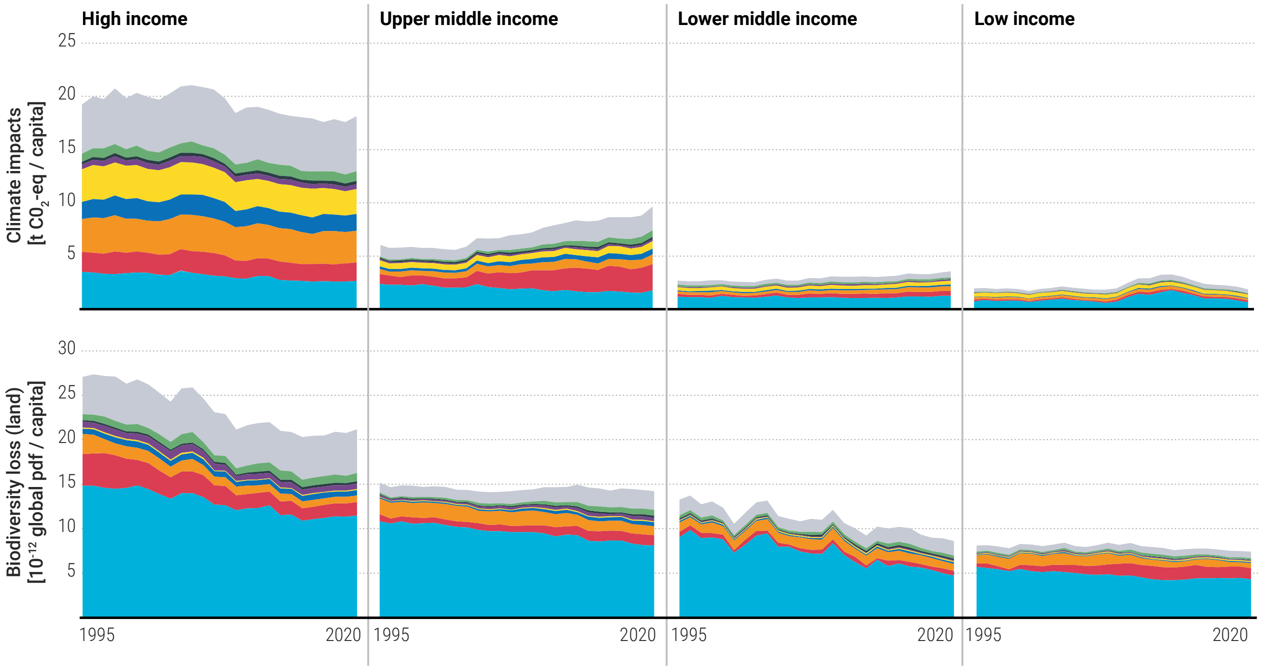


Figure 3.10: **Environmental footprints (consumption perspective) on a per capita basis allocated to provisioning systems from 1995 to 2020 by income group.**



3.3.2 Regional variations in the environmental impacts of provisioning systems

Per capita climate footprints (consumption perspective) have decreased in North America and Europe, but increased in all the other regions (Figure 3.11). Nevertheless, per capita climate footprints are still distinctly higher in North America compared to all the other regions. A similar pattern is observed for water stress footprints, which increased the most in Asia and the Pacific and Africa, but which are still highest in North America and Europe, as well as West Asia. Biodiversity loss footprints are twice as high in Latin America and the Caribbean compared to all the other areas, due to the region's unique ecosystems with many endemic species. It should be noted that the decreasing trend of impacts in this region is only valid for the consumption perspective, but not the production perspective (see Figure 3.13).

The importance of provisioning systems in determining impacts varies regionally. For example, in Africa food plays a more dominant role compared to other provisioning systems, while in North America energy and other services are more important (Figure 3.11 and Box 3.2). For most other impacts (water stress, land- and eutrophication related biodiversity loss), most impacts are connected to food provisioning systems (Figure 3.11).

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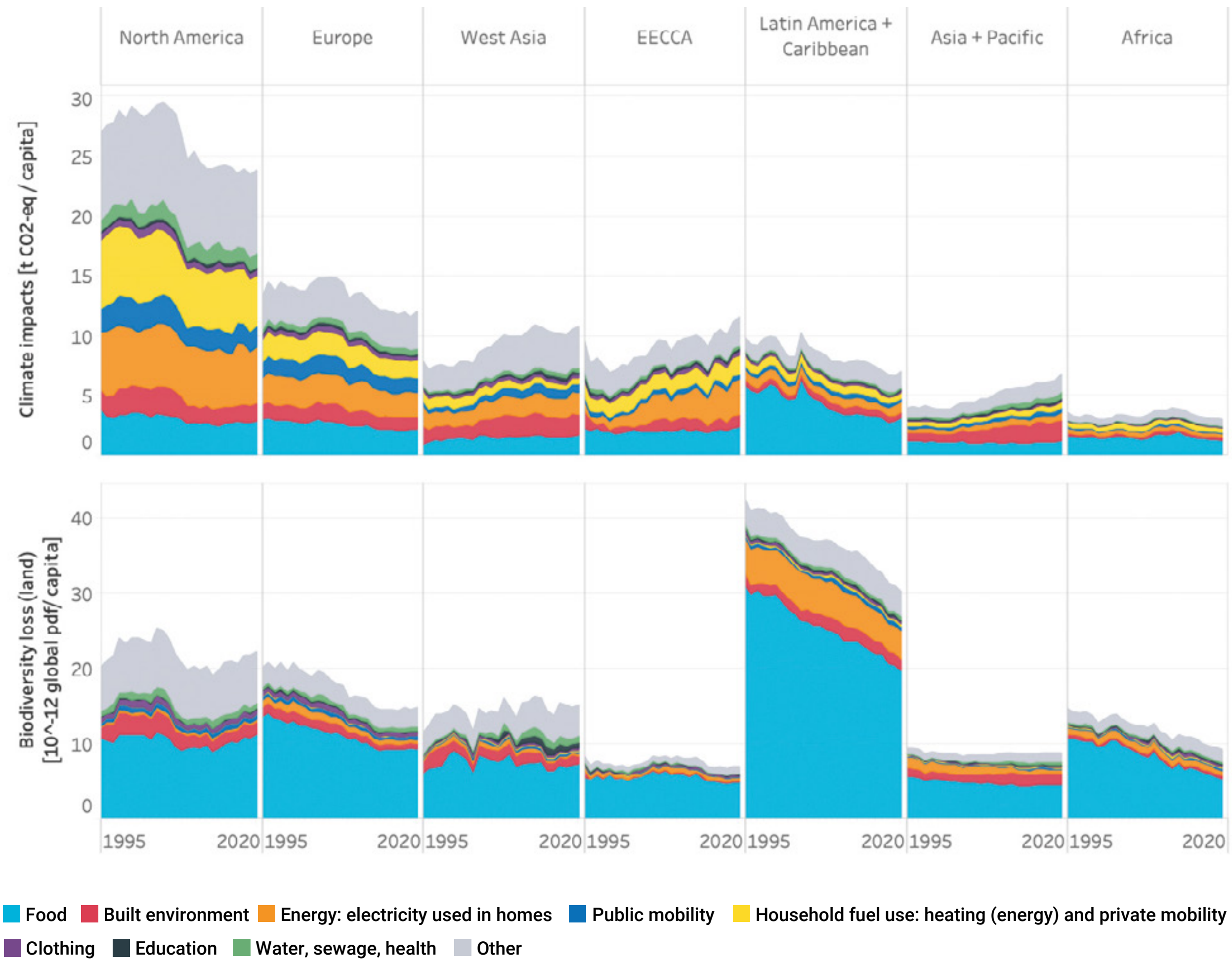
Figure 3.11: **Environmental footprints (consumption perspective) per region on a per capita basis allocated to provisioning systems from 1995 to 2020.**



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Box 3.2. Sustainable and healthy nutrition

(Christie Walker, Livia Cabernard and Stefanie Hellweg)

Food is essential for human health and currently a main cause of environmental and social impacts. Food is related to many SDGs, including SDG 3 (good health and well-being), SDG 13 (climate) and SDGs 14 and 15 (protecting life in water and on land, respectively). Furthermore, food systems contribute to the transgression of many planetary boundaries (Willett *et al.* 2019), causing more than 20% of the global impacts of climate change and more than 60% of land-related biodiversity loss (Figure 3.6). Food waste alone causes between 8% and 10% of global climate impacts (Mbow *et al.* 2019), with yearly per capita food waste amounts of 79 kg, 71 kg and 91 kg in high, upper middle and lower middle-income countries, respectively (UNEP 2021d). In addition to environmental impacts, the type of food consumed can have substantial effects on human health and hence well-being. On the one hand, there is a worldwide trend towards increased intake of detrimental nutrients, such as sugar, salt and certain types of fats (Baroni *et al.* 2007; Westhoek *et al.* 2014), along with an increase in calorie consumption and obesity rates. The average intake of detrimental nutrients is between two and seven times greater in high-income countries than in low-income countries (*Chaudhary et al.* 2018, based on data from the FAO Statistical Database (FAOSTAT)). On the other hand, there are hidden hunger and vitamin deficiencies (Bendik *et al.* 2014), particularly in lower income countries. Therefore, health and environmental impacts of diets are of crucial importance and should be optimized to simultaneously achieve healthy diets that can contribute to well-being while also having low environmental impacts.

An analysis of diets in Europe (full reporting of daily intake of 162 food items during one month of >1400 individuals (Celis-Morales *et al.* 2016)) showed a large variation in both healthiness and environmental impacts (Walker *et al.* 2018; Walker *et al.* 2019). Individuals with a high intake of food consumed too many harmful nutrients and also tended to have higher environmental food-related impacts, which illustrates the need to avoid overconsumption of food. A healthy diet did not necessarily indicate lower or higher environmental impacts, but the study showed a large variation (sometimes in orders of magnitude) of impacts for diets that were healthful. This indicates that there is room for reducing impacts without trade-offs for healthiness. Low-impact healthy diets included higher than average consumption of vegetables and lower consumption of meat. Vegetarians tended to have lower impacts and, despite some underconsumption of beneficial nutrients, a lower disease risk compared to the average population (see also Springmann *et al*. 2016; Springmann *et al.* 2018; Willett *et al.* 2019). Overconsumption of (red and processed) meat is associated with increased disease risk (Gakidou *et al.* 2017), but a strictly plant-based diet needs to be well planned to avoid deficiencies in certain nutrients (McEvoy *et al.* 2012; Springmann *et al.* 2018).

The composition of a healthy and environmental diet can change from person to person due to different energy requirements (activity level), nutrient demands (age, gender and life stage) or genetic makeup (Otten *et al.* 2006). To determine a personalized, healthful and low-impact diet depending on location, season, food preferences and nutrient and energy requirements, a diet-optimizing tool was developed (Walker *et al.* 2021). The diet had to (1) meet the nutrient and calorie needs of the user (considering age, gender and activity level), and (2) meet all dietary recommendations of the Global Burden of Disease (GBD) to reduce dietary disease risk. Optimal diets derived with this tool differ in types of vegetables and fruits depending on location and season, but are otherwise rather similar even between individuals with different needs. An optimized diet that is considered healthy and minimal impact did not include meat, but did include fish (from a sustainable fishery) to meet nutrient needs, assuming no nutritional supplements are being consumed. Diet compositions are similar whether optimizing for climate change or biodiversity impacts, but climate-friendly diets include more legume consumption while biodiversity-friendly diets rely on more energy from fats, oils and eggs. Healthy diets are possible with per capita climate impacts as low as 0.5 t CO_2-eq/year (Walker *et al.* 2021), compared to the current global average of 1.5 t CO_2-eq/year. This could be lowered further by reducing dairy consumption. Milk is considered by the GBD to be vital for a low-disease-risk diet and was therefore a necessary component of the diets, but climate impacts could be significantly reduced if this requirement were lifted. Entirely vegan diets with realistic portion sizes required supplements to cover all minimum nutrient recommendations. The lowest impact diets typically contain a combination of local and imported food products, but mainly from neighbouring or nearby countries.

In summary, very low impact and healthy diets are possible with some planning. Governments should include both healthiness and sustainability in their national food-based dietary guidelines. There are several easily achievable goals for reducing food-related impacts, such as reducing food waste, avoiding overconsumption of food and reducing red and processed meat consumption (Westhoek *et al.* 2016). The latter two create co-benefits in terms of health and environment. An environmentally optimal diet that meets all health requirements is nearly entirely plant based, while also including some dairy products and small amounts of (fatty, low impact) fish.

3.3.3 Environmental impacts embodied in international trade

Regional distributions of environmental impacts differ between the production and consumption perspectives (Figure 3.12 and Figure 3.13). The production perspective allocates the impacts to the location where they physically occur, while the consumption perspective allocates impacts throughout the supply chain to the region where the goods and services are consumed. The difference between the two perspectives indicates environmental impacts embodied in international trade. Substantial environmental impacts are embodied in global trade, meaning that environmental impacts are caused by the production of goods that are exported for consumption elsewhere. This highlights the importance of supply-chain management of consumer countries, in addition to the need for producers to reduce impacts.

In 2022, more than half of global land-related biodiversity loss occurred in Africa and Latin America, but less than 10% of global value added was generated in these regions. Conversely, almost half of global value added was generated in Europe and North America, although less than 10% of global water stress and biodiversity loss happened in these regions (Figure 3.12). This opposing pattern of lower domestic environmental impacts and higher value added is partially a sign of higher environmental standards, but also a consequence of impact displacement to other regions. Europe and North America import goods that cause climate, biodiversity and water stress impacts elsewhere (Figure 3.11 and Figure 3.13). For instance, land-related biodiversity impacts are more than twice as high from a consumption than production perspective (Figure 3.12). At the same time, Europe's value added through sales of exported goods was larger than the money spent on imported goods, due to exports of valuable manufactured commodities. The opposite is the case for Latin America and Africa, which bear large environmental impacts for exported goods but value added created through these goods is minimal (see Figure 3.13). Therefore, in addition to the net resource outflow of material resources, energy and land from lower income to higher income regions (see Chapter 2), there is also a transfer of associated environmental impacts from the high-income consuming regions to resource-extracting regions. This is a missed opportunity, as trade could theoretically help to mitigate environmental impacts by producing goods where they have the least impact.

In addition to environmental impacts, Figure 3.12 also shows trade in work-intensive goods: In West Asia, three times more labour is needed to meet West Asian consumption than is employed in West Asia itself, mainly due to biomass imports from Asia and Pacific and Africa.

Asia and the Pacific is the biggest of all regions (world population share of 56% in 2020), and also accounted for a similar share of all impacts except land-related biodiversity loss and value added (Figure 3.12). However, it is worth noting that environmental impacts within this region are also unevenly distributed. For example, hotspot countries for greenhouse gas emissions and particulate matter health impacts from industrial sources are China and India (Figure 3.19 and Figure 3.20), while land-related biodiversity impacts are particularly high in Indonesia and other South-East Asian and Pacific regions (Figure 3.22).

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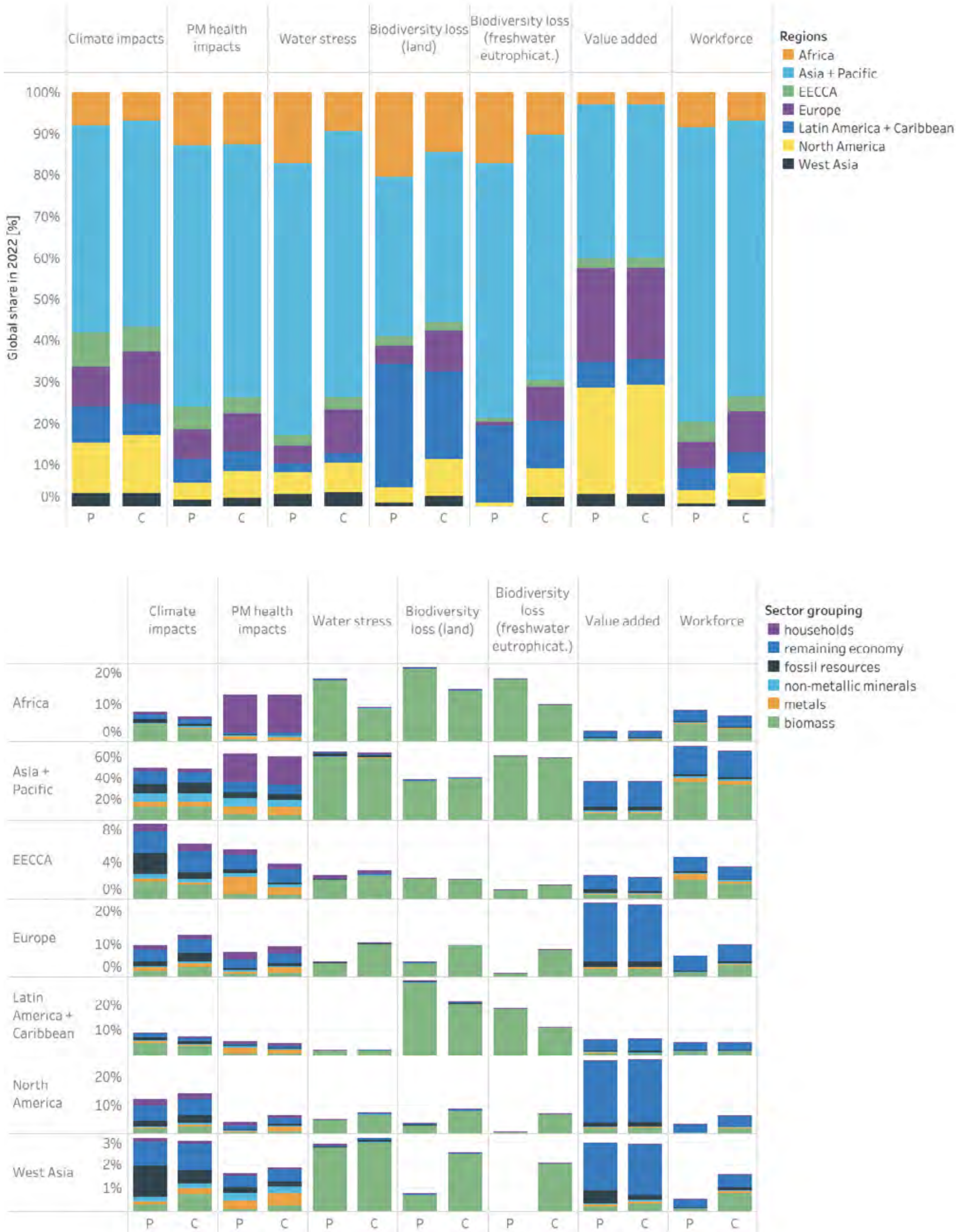
Figure 3.12: Relative contribution of different regions to global environmental and socioeconomic impacts from a production (P) and consumption (C) perspective (above), by resource type (extraction and processing), the remaining economy (downstream chain of resource extraction and resource processing) and households for 2022 (below). Note the difference in scale of the y-axis in the figure.

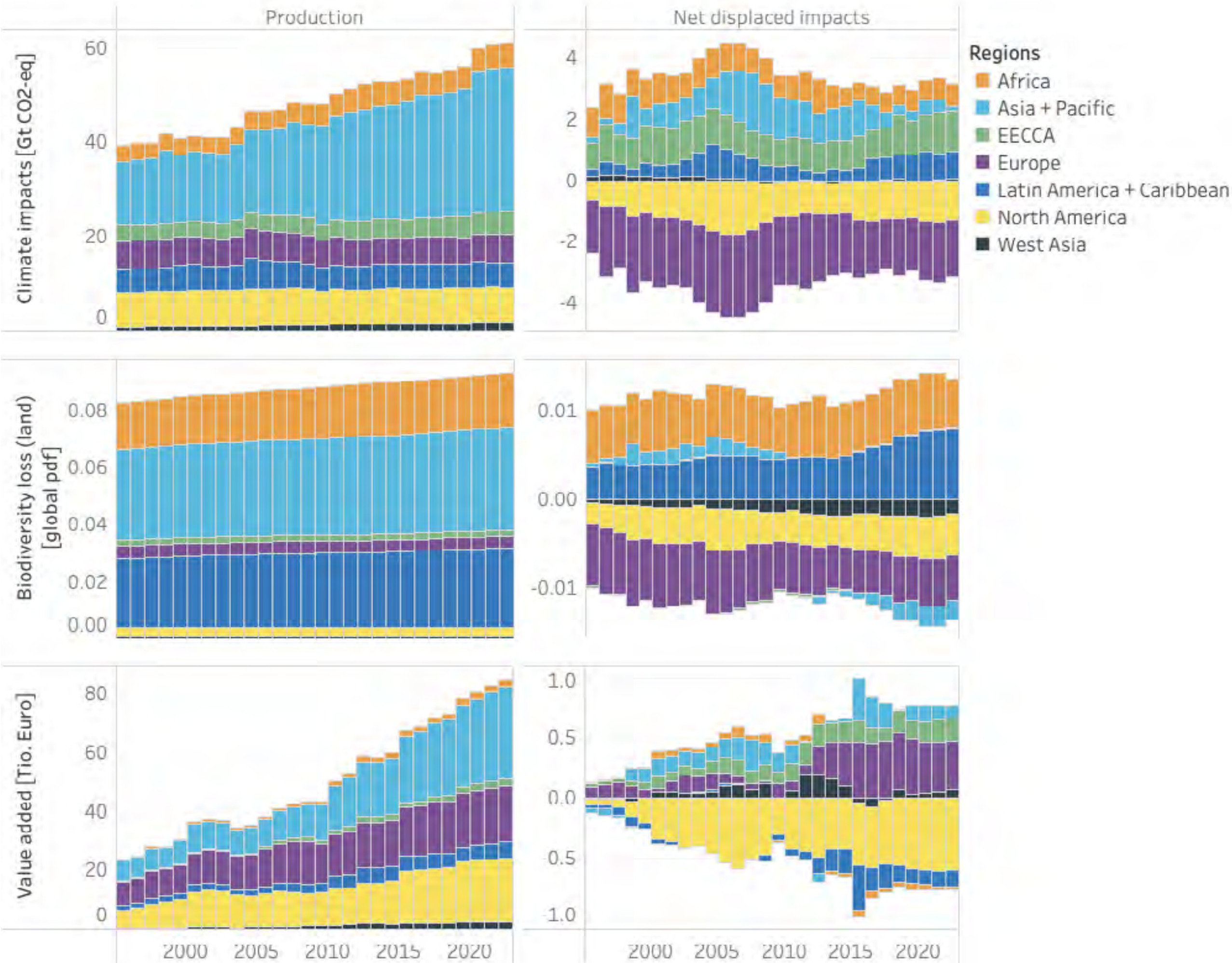


3.3.4 Temporal trends of domestic impacts and trade differ among regions

Climate change impacts particularly increased in the Asia and the Pacific region (mainly due to build-up of infrastructure), while land-related biodiversity loss increased primarily in Latin America and Africa (Figure 3.13). Almost half of the impacts in Latin America and Africa are connected to producing food and other biomass products for export (compare scales of y-axis of left and right graphs in Figure 3.13), with an increasing trend in Latin America. Asia and the Pacific changed from an initial exporter of goods causing biodiversity loss to an importer (with the trend increasing). Net value added attached to trade is less than 1% of the global value added.

amdadphoto

Figure 3.13: Time series of climate change (above), land-related biodiversity loss (middle) and value added (below) split by region; left: production perspective; right: net trade impacts (positive values indicate that impacts occur in these locations for producing exported goods, negative values indicate that goods are imported to these regions causing impacts and value added elsewhere). Note that the scales on the y-axis vary.



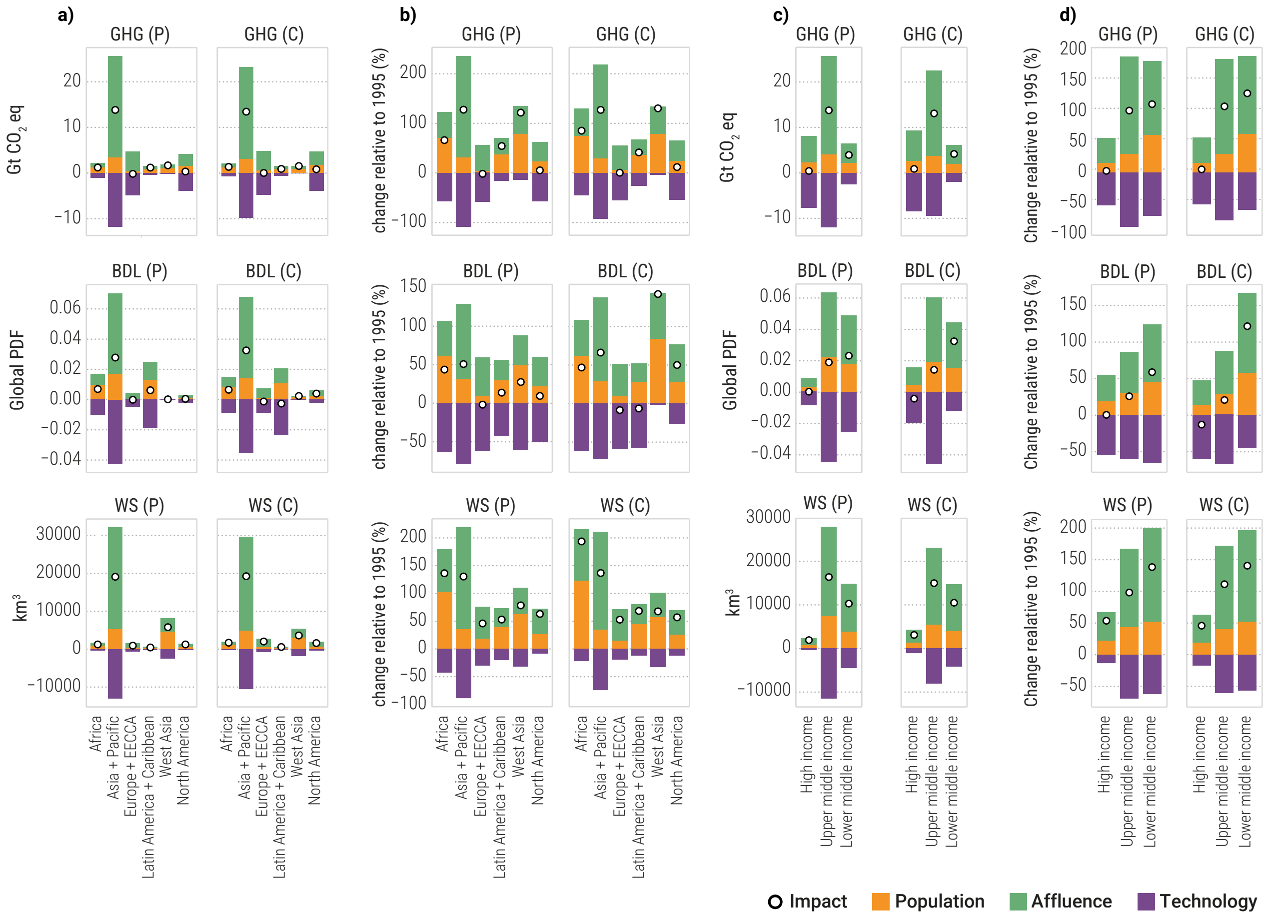
3.3.5 Affluence is the main global driver of environmental impacts

Different regions display various environmental impacts (Figure 3.14, Panel a and b). The Asia and Pacific region dominates in absolute environmental impacts across all impact categories. Given the presence of populous and rapidly developing nations like China and India, this region's influence on global environmental impacts is substantial. Africa's impacts are considerably smaller than Asia and the Pacific. Africa's increasing population and emerging economies increasingly contribute to water stress and biodiversity loss. West Asia, with its reliance on fossil fuels and arid conditions, faces severe water stress and rising GHG emissions. In Europe and North America, GHG emissions have stabilized, while biodiversity and water stress impacts have grown.

Climate change, water stress and land-related biodiversity impacts increased most in upper middle-income regions, and particularly in the Asia Pacific region. The primary driver was affluence (per capita income), which was only partially mitigated by technological changes (Figure 3.14). Population was a main driver in Africa and West Asia.

The findings on impacts show some similarities with those presented in Chapter 2. A closer look at the figures in section 2.3.7 (similar to the decomposition period from Chapter 3's Figure 3.14) reveals that regions like Asia Pacific, Africa and East Asia have seen striking growth in their material footprint. This trend is consistent with Figure 3.14 (with dots in Panel b). Conversely, Europe and North America show a stabilizing material footprint, a pattern also evident for environmental impacts in Figure 3.14. The underlying drivers are also broadly consistent. For instance, in China, the rise in material footprint is predominantly attributed to affluence. In contrast, Africa's impacts are largely influenced by its growing population. Meanwhile, Europe's material footprint is minimally influenced by population growth, with technological changes being relevant as a significant counterbalance (see Annex 5 for details at country level). However, it is important to emphasize that these observations broadly match and a more granular examination of individual indicators might paint a slightly different view. For example, while Europe's results align for GHG and BDL impacts, they deviate when it comes to water stress.

Figure 3.14: Driver by region (a, b) and income country groups (c, d). Panels a, c in absolute terms and Panels b, d in relative terms (that is, change in impact relative to 1995, a value of 100 means that specific impact increased by 100% between 1995 and 2019).



WS - Water Stress, BDL - Biodiversity Loss, GHG - Greenhouse gases, P: production perspective; C: consumption perspective

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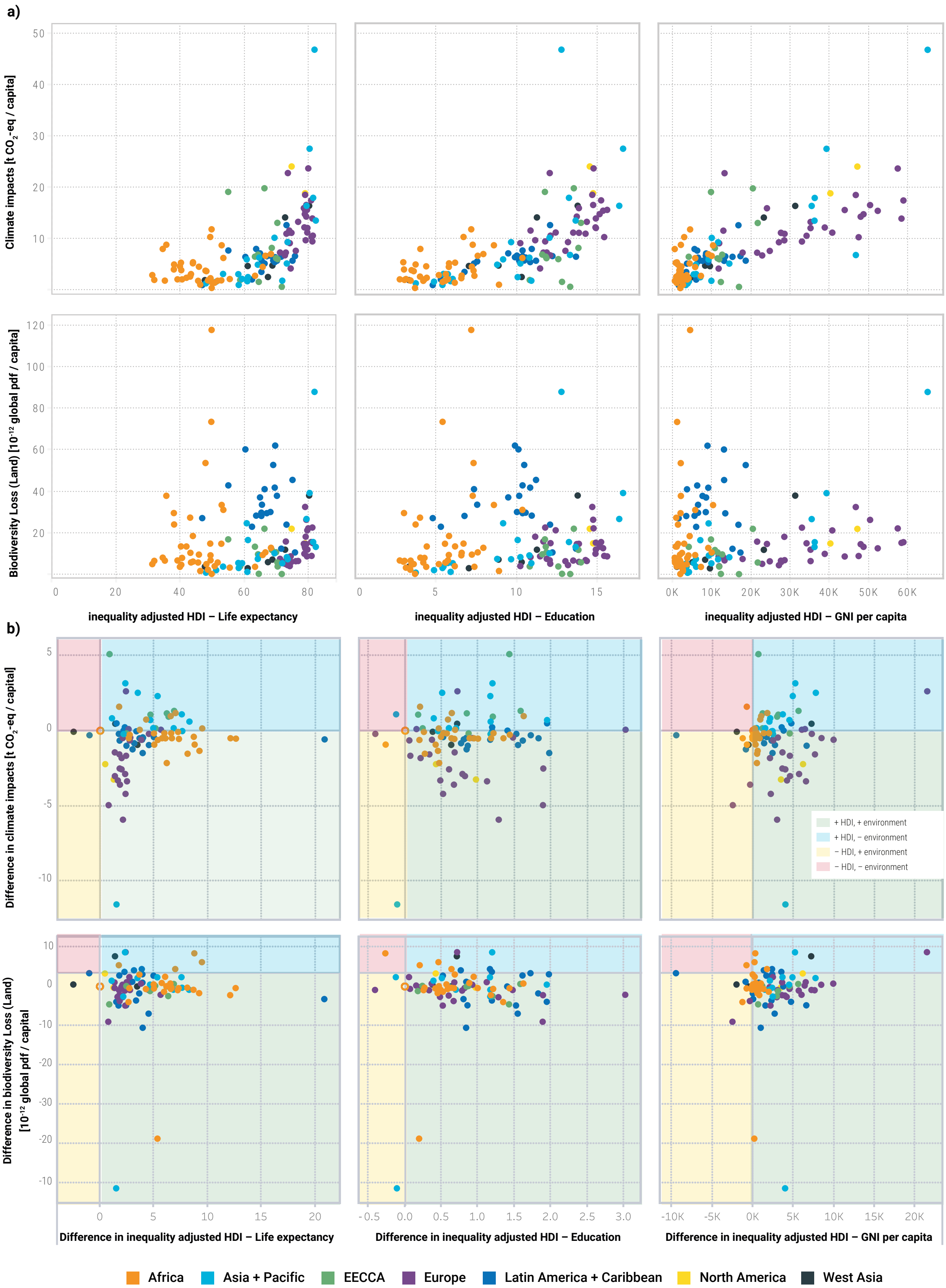
3.3.6 Well-being indicators can improve at little environmental cost

All three components of the IHDI positively correlate with climate change impacts for a given point in time (Figure 3.15a). For land-related biodiversity loss, the data are less straightforward than for climate change, as the phenomenon is heavily influenced by regional conditions such as vulnerability of ecosystems. The observed correlation between climate impacts and well-being indicators does not come as a surprise, as energy supply is based mainly on fossil fuels and facilitates economic growth. However, these correlations are not a given for the future. For example, Figure 3.7 shows that provisioning "sanitation, health and water", as well as "education", only causes minor environmental impacts and could be improved at low environmental costs. Therefore, an increase in the well-being dimensions of education and potentially life expectancy could be obtained without a large increase in environmental impacts.

Many countries, especially in Africa, managed to increase inequality-adjusted life expectancy between 2010 and 2019 without increasing per capita climate impacts (see Figure 3.15). However, most African countries remained on a rather low level in inequality-adjusted life expectancy and education despite this increase (generally below 60 years and 8 years, respectively). By contrast, most Latin American countries achieved a higher level in inequality-adjusted life expectancy and education (generally more than 60 years and 9 years, respectively). Especially Chile, Argentina, Costa Rica and Ecuador achieved a high inequality-adjusted life expectancy (more than 70 years) and education (more than 10 years) while keeping climate impacts comparably low (below 6.5 t CO_2-eq / capita). In contrast, most countries in Europe and North America with only slightly higher inequality-adjusted life expectancy and education duration have distinctly higher climate impacts (generally more than 10 t CO_2-eq / capita). In Europe, North America and Asia and the Pacific, a high inequality-adjusted life expectancy above 70 years is associated with almost exponentially increasing climate impacts.

Most countries improved over time in terms of well-being and/or environmental impacts (Figure 3.15b). While the aggregated results showed no absolute decoupling of impacts for any of the HDI country groups (Figure 3.8), 29 out of 189 countries did improve climate change and biodiversity loss while still enhancing well-being in all three dimensions (Figure 3.15b).

Figure 3.15: Per capita impacts (consumption perspective) against well-being measured as inequality-adjusted HDI (each pair of dots represents one country; colours of dots indicate the region).(A) absolute values for 2019; (B) difference between 2019 and 2010 values where the background colours indicate whether both well-being and impacts improved (green), both worsened (red) or only one of the two components improved (yellow/blue). Raw data for well-being downloaded in August 2022 from UNDP (https://hdr.undp.org/data-center/documentation-and-downloads) and processed as outlined in section 3.1.



3.4 Supply-chain analysis

3.4.1 Climate impacts are caused by many actors and sectors throughout the value chain

Figure 3.16 shows the supply chain mapping of global climate impacts. It depicts the link of provisioning systems (c) to the use of material resources (d) and the emissions released in the upstream, midstream and downstream chain (e) split by emission source (f) for the Group of 20 and non-G20 members from a consumption perspective (b) and a production perspective (g) and the regional aggregation applied otherwise in this report (a) and (h). The G20 members account for 75% and 80% of global climate impacts from a production and consumption perspective, respectively.

According to the analysis of provisioning system use of materials, half of the climate footprint of the built environment is attributed to cement, bricks and other concrete elements, while the remainder is attributed to metals (15%), fossil resources (29%) and biomass – mostly wood and rubber (10%, Figure 3.16 c–d). More than half of the climate footprint of the built-environment provisioning system is related to China's consumption (Figure 3.16 b–c; see also Cabernard *et al.* 2022)).

The split of the four material groups by upstream, midstream and downstream emissions shows that 12% of global climate impacts were emitted in the upstream chain, 35% and 18% were released by extraction (including also crop cultivation and forestry) and processing, respectively, and 41% were released in the downstream chain (Figure 3.16 c–d).

The link to the emission sources shows that upstream emissions were mainly released by coal energy (Figure 3.16 e–f). The emissions from the extraction stage were mostly attributed to biomass production due to cultivation of crops, animal farming and forestry, which lead to land use change and biogenic emissions (such as methane, see Figure 3.16 d–f). Most emissions from the processing stage were related to metals and non-metallic minerals, whose emissions were released by calcification and fossil fuel combustion for material production (Figure 3.16 d–f). This implies that climate policy should focus more on using less materials and lowering the CO_2-intensity of material production. In the downstream chain of materials, fossil fuel combustion, for purposes such as energy for mobility and heating, caused most of the GHG emissions (Figure 3.16 c–e).[43]

Figure 3.16 also shows that greenhouse gas releases are distributed across whole value chains, resource types, provisioning systems, industrial sectors (Cabernard *et al.* 2022) and households. Climate policies therefore need to target a wide variety of actors in multiple sectors across the whole value chain.

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43 Note that biogenic CO_2 emissions were not included in the assessment and, hence, combustion emissions from biomass combustion (including wood) for heating and cooking are not shown in Figure 3.16. This is because regrowing biomass will sequester CO_2 from the atmosphere again. However, this omission of biogenic CO_2-emissions is being debated in the literature (see Cherubini ***et al.*** 2011), as there typically is a time lag between emission and resequestration. Direct incineration of biomass, especially wood, is therefore to be avoided. Instead, use of biomass in long-term applications (such as construction), and energetic valorization (preferably with carbon capture and storage (CCS)) at the end of several use cascades, is recommended.

Figure 3.16: Supply chain mapping of global climate impacts in 2022 (total 55 Gt CO_2-equivalents, 100%). Each bar adds up to 100% and shows the global climate impacts from different perspectives in the global supply chain such as

(a) the world regions of final consumption,

(b) the G20 and non-G20 of consumption (all G20 members with a contribution of more than 5% individually shown and the others aggregated),

(c) the provisioning systems where material resources are finally used for supplying final consumption,

(d) the four material groups,

(e) the split by upstream, midstream and downstream impacts,

(f) the processes that release greenhouse gas emissions,

(g) the G20 and the non-G20 countries where GHGs are released (all G20 members with a contribution of more than 5% individually shown and the others aggregated) and

(h) the world regions where greenhouse gas emissions are released.

3.4.2 Biodiversity impacts mainly occur at the start of the value chain

Figure 3.17 shows the supply chain mapping of global land-related biodiversity loss impacts. It depicts the links between land use types, regions of production and consumption, produced goods and consuming sectors for land-related biodiversity impacts.

Figure 3.17: **Supply chain mapping of global land-related biodiversity loss impacts in 2022. Each bar adds up to 100% and shows the global biodiversity impacts from different perspectives in the global supply chain, such as**

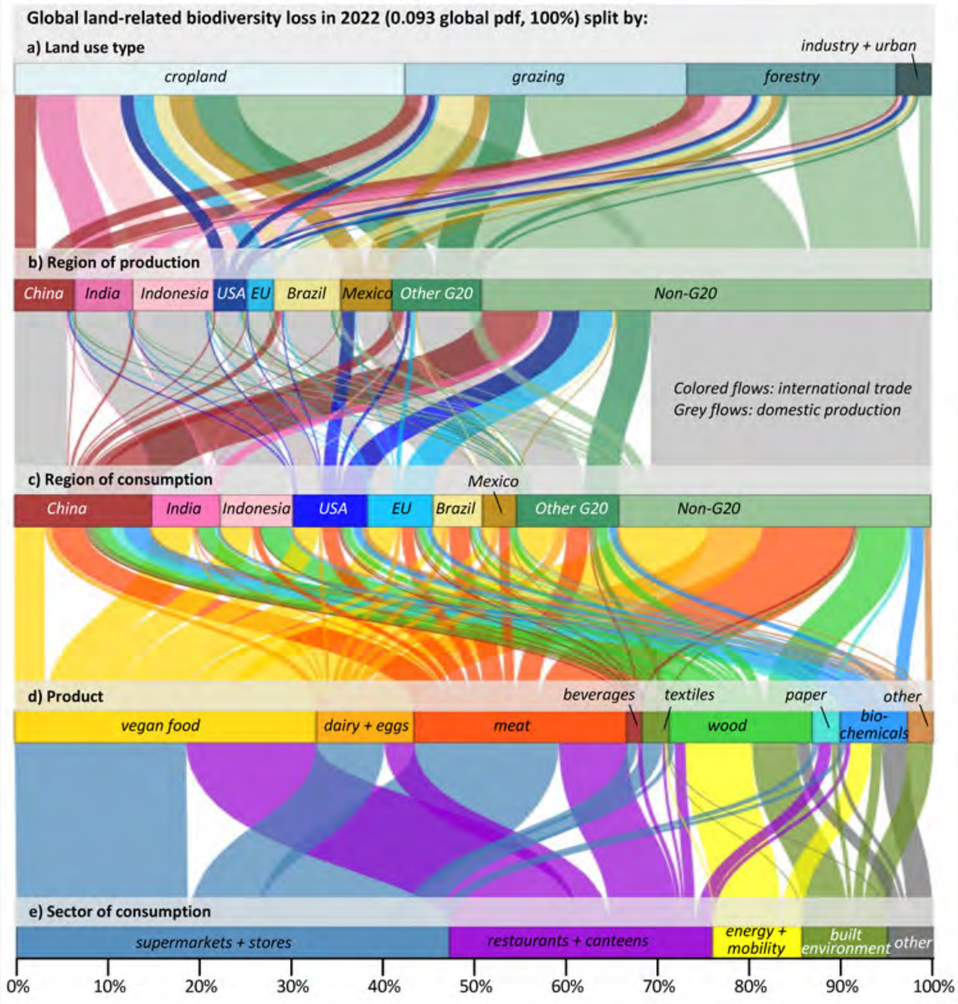
(a) land-use type,

(b) regions of production (G20 members individually shown if contribution was >5%),

(c) regions of consumption,

(d) produced goods

(e) sector of consumption.



Almost 75% of land-related biodiversity impacts come from agriculture, while forestry accounts for 23% (Figure 3.17a). Most impacts occur in Latin America, Africa and South-East Asia and the Pacific (Figure 3.22). The biodiversity footprint of the European Union (EU), United States of America (USA) and China is two times higher from a consumption perspective than a production perspective. This is attributed to imports of food and other biomass products, mostly from the non-G20 countries. More than two thirds of the global land-related biodiversity impacts are caused by food production, followed by wood, paper, biochemicals and textile production. Animal-derived food products cause more biodiversity impacts than the entire remaining food production. End-consuming sectors refer especially to products purchased at supermarkets and shops (about half of total impacts), restaurants (29%) and energy, mobility and built environment. Since the vast majority of biodiversity impacts occur at the beginning of the value chain (agriculture and forestry) and only a few end sectors are concerned, policies may focus on these intervention points in constructing a circular and sustainable bioeconomy.

This is a challenging task, as biomass production accounts for 97% of total global biodiversity impacts, but generates only 12% of global value added (note that agriculture is often subsidized). This means that there are limited financial means for improvement measures, unless downstream users of biomass or political actors contribute a share to these measures.

3.5 In-depth regionalized assessment of resource-related environmental and health impacts (production perspective)

This section summarizes where impacts of resource extraction, processing and use are occurring, along with the causal resources/processes. There are environmental impacts that cannot be addressed by the type of methods used in this chapter, since they are very specific to the material and to local practice and context. An example for this is described in Box 3.3, which outlines the ecotoxic impacts of copper tailing disposal.

Box 3.3. Ecotoxic impacts from copper tailing disposal

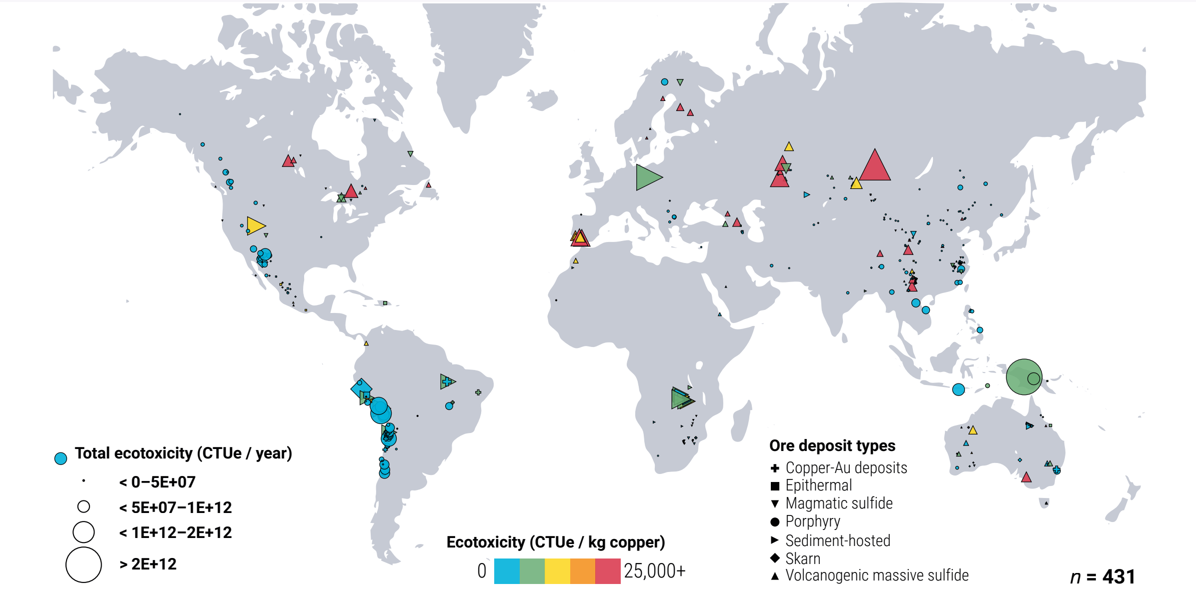
(Lugas Raka Adrianto)

The environmental impact of mine waste disposal creates a large footprint in terms of scale and long-term hazards. Large volumes of tailings are currently disposed of by dumping them into engineered impoundments. Although these facilities are designed for long-term storage, there is a risk of dam failure and heavy metal pollution. Recognizing these vast waste implications is crucial, given rising mineral demands (Franks *et al.* 2021).

Copper tailings account for roughly half of worldwide tailing volumes (Oberle *et al.* 2020). Other metals are often extracted as by-products together with copper (for simplicity only copper is referred to here). Prior studies have quantified the environmental impacts of copper extraction and processing, with findings concluding that copper has the largest ecotoxicity impacts of all metals mined (IRP 2019a). The main challenges encompass site-specific factors (such as local environmental conditions), ore processing and tailing properties. Copper is extracted from different types of deposits that determine how it is processed and ultimately, the characteristics of the discharged tailings (Mudd and Jowitt 2018). Therefore, a comprehensive approach is required to capture such factors while improving the geographical coverage of the global copper tailings inventory and useful technical representativity (Adrianto *et al.* 2022).

Figure 3.18 shows a total of 431 copper sites in 49 countries (80% of the world share) in the global evaluation, from which environmental hotspots can be derived. Copper tailings generated from the processing of porphyry, sediment-hosted and volcanogenic massive sulfide ore deposits account for more than three quarters of the global freshwater ecotoxicity impacts of copper tailings. Toxicity varies among and within countries.

Figure 3.18: Ecotoxic impacts caused by individual copper tailings deposits from a global perspective. Reprinted with permission from Adrianto et al. 2022. Copyright © 2022 American Chemical Society.



In response to recurring dam failures and tailing storage problems, international stakeholders are rapidly building consensus to prevent devastating environmental disasters. Regulations prohibit poor tailing handling like river discharge and submarine disposal. Nevertheless, countries like Indonesia, Papua New Guinea and Norway still practise these methods (Vogt 2013), posing economic gains but risking environmental damage and community distress. Inadequate understanding of submarine disposal risks underscores the need for thorough research into establishing optimal mine waste management practices.

The UNEP Global Resource Information Database in Norway (UN-GRID Arendal) recently launched a portal to monitor and global information on various metal tailings at 1,862 sites (GRID-Arendal 2020). This global system enhances oversight of tailing storage facilities, promoting responsible mining with better transparency. Repurposing mine waste may offer an alternative way to address environmental issues linked to conventional disposal (IRP 2020; Kinnunen *et al.* 2022) and produce useful materials from tailings.

3.5.1 Health impact and climate change analysis relating to industrial-plant specific fine particulate matter ($PM_{2.5}$)

Every year more than 200 million life years are lost (disability-adjusted life years (DALYs)) due to fine particulate matter (Lozano *et al.* 2020). Fine particulate matter causes by far the greatest health impacts across all types of environmental pollution. About 120 million DALYs are lost due to outdoor air pollution and 80 million DALYs due to indoor air pollution. Indoor air pollution is mostly related to cooking with solid fuels. Household mobility and heating demands are estimated to contribute more than 40% of the outdoor $PM_{2.5}$ health burdens, while the industrial activities supplying fossil energy, metal processing and non-metal mineral processing (such as cement-making) are responsible for more than 30% (Figure 3.2). The remainder is largely due to agriculture.

Fine particulate matter with a size smaller than 2.5 um ($PM_{2.5}$) may arise from the emission of several substances, including primary emissions of $PM_{2.5}$ as well as emissions of sulphur dioxide (SO_2), nitrogen oxides (NO_x) and ammonia (NH_3). Emission intensities depend on the type of pollutant, region and the season. While industrial emission sources may contribute year round and represent major sources of $PM_{2.5}$, SO_2 and NO_x, it is often cold winter days during which household heating can be a major contributor (especially for primary $PM_{2.5}$ emissions), whereas agricultural emissions of NH_3 are mostly related to fertilizer application. Traffic releases high NO_x and $PM_{2.5}$ emissions, and is closely related to personal mobility and hence population density. Natural emission sources such as volcanoes or wildfires may sporadically contribute substantial amounts of air pollutants and can further degrade the air quality.

The fate of these pollutants in the atmosphere is complex and the cooling effects of some of these pollutants in terms of climate change have been reported (Hansen *et al.* 2023). At the same time, constituents of PM such as black carbon are reported to contribute to global warming. Therefore, emission abatement may lead to complex connections and trade-offs in terms of human health and global warming. This section focuses on industrial emissions related to fine particulate matter and CO_2 as well as identifying pollution sources and hotspot regions. Human health and climate change impacts from industrial airborne emission sources are largely caused by the use of fossil resources, mostly as a combustion fuel. Globally, the greatest impacts are observed where population densities are highest, as manufacturing sites and energy demands are usually co-located with the necessary workforce and potential customers of the final products (Oberschelp *et al.* 2023).

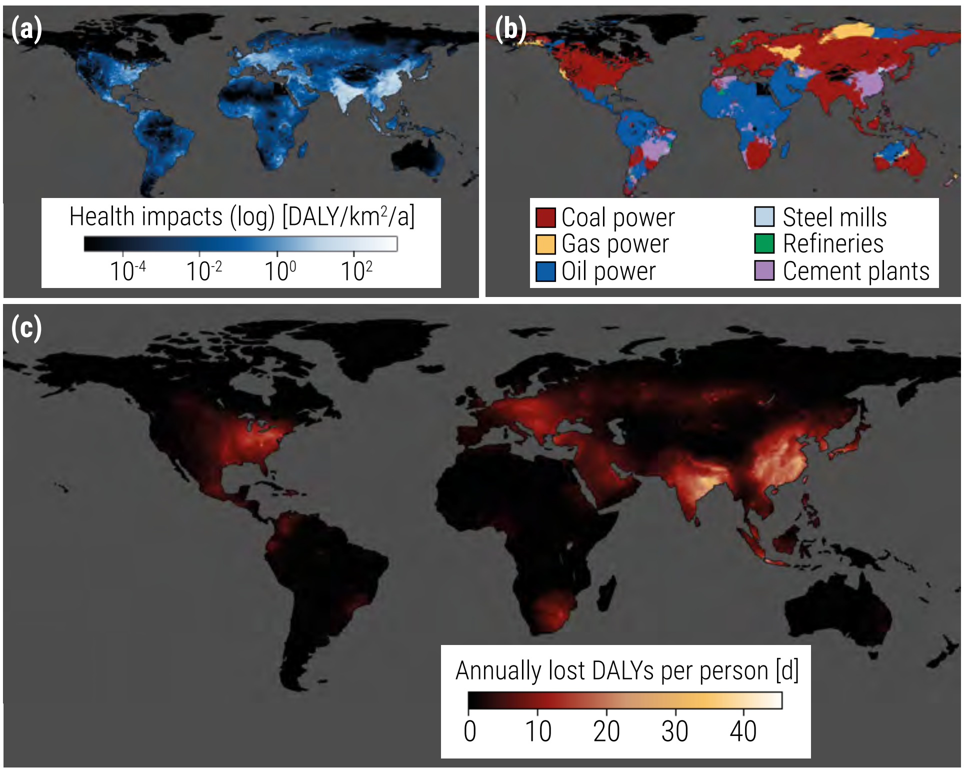
Several regions/countries stand out in terms of the related health impacts in their population: China, India, Indonesia, Europe and the United States (Figure 3.19a). These findings are in line with several earlier studies (GBD Risk Factors Collaborators 2019; Hu *et al.* 2023; Manisalidis *et al.* 2020; McDuffie *et al.* 2021; Nansai *et al.* 2021). While this is partially related to population density, individual health risks are also elevated in some of these regions. For example, in some parts of South and North-East Asia people lose about a month of life every year due to particulate matter pollution from industrial sources (Figure 3.19c).

Figure 3.19:

(a) Global human health impacts in Disability Adjusted Life Years (DALYs) from particulate matter in 2019 caused by six main types of industrial activities,

(b) the regionally most health-impacting of these six industrial activities (see key), and

(c) on average, how many DALYs are lost per year and per person due to industrial emissions in each region.



Deployment of emission abatement technologies is still deficient in some regions and would enable the mitigation of human health impacts. China, for example, has invested heavily in end-of-pipe emission reduction measures, as well as the monitoring and enforcement of up-to-date emission limits based on the Action Plan on Prevention and Control of Air Pollution and the Three-year Action Plan to Fight Air Pollution. These measures have shown a strong positive effect on health, although the magnitude of industrial activities and the large exposed and vulnerable population are still having significant impacts on human health (McDuffie *et al.* 2021). In India and Indonesia, in contrast, emission standards for the main drivers of health impacts are still less enforced (Mills 2021). India, for example, tried to establish new and stricter emission standards for the power sector in 2015, but implementation is still largely incomplete due to several contributing factors including the necessary pre-requisites not being in place in time (such as sufficient measurements of emissions and expertise in flue-gas-cleaning technologies). The number of affected sites is so high that there is insufficient qualified domestic personnel to carry out all the projects at once (India, Ministry of Environment, Forest and Climate Change [MoEFCC] 2021).

Even when state-of-the-art technologies are implemented, continuous proper operation of the equipment remains a challenge (Franco and Diaz 2009). Also, running costs and market constraints need to be taken into account in the technology choice because, in addition to capital costs, it might be challenging to: obtain a continuous supply of reactants on the local market; and find a proper way to dispose of partly hazardous wastes. That is an issue across all main pollutants. For instance, selective non-catalytic reduction (SNCR) or selective catalytic reduction (SCR) for NO_x emission reduction requires continuous ammonia, wet flue gas desulphurization needs limestone or lime, while fabric filters for PM abatement need a recurring replacement of filters. The latter case is especially telling as economic considerations in middle-income countries often lead to the use of low-quality fuels despite growing energy demands. This, in turn, accelerates the degradation of abatement equipment. In such cases, more robust abatement technologies like electrostatic precipitators (ESPs) can be a better choice, as they do not require replacement of degraded filters. The drawback, though, is a lower performance in abating the most harmful fraction of PM with a diameter below 2.5 um ($PM_{2.5}$), which can enter deep into the human lungs.

The correlation of income inequality and health inequality due to industrial emission sources is substantially more pronounced in lower income regions, and is mutually amplifying by nature. In lower middle-income countries, people with heavy manual, outdoor jobs are routinely exposed to particulate matter air pollution (Kulkarni and Patil 1999). The increased breathing rate leads to an elevated intake of pollutants and health impacts. In addition, heavily polluted areas are often less expensive to live in, so families with low incomes are generally more likely to live in polluted areas and be exposed to air pollution (Adamkiewicz *et al.* 2011), while also possibly lacking the financial resources for proper health care that could help treat or cure diseases from pollutant exposure. Although such patterns also appear in high-income countries (Tessum *et al.* 2019) the impacts there are reduced due to lower absolute levels of pollution (Figure 3.19) and better general health care.

In low- and middle-income countries, for example in Central/Northern Africa and in South America, industrial activities are much smaller in scale, and have not turned into main causes for particulate matter-related health impacts at a large scale. This is also relevant to the main causes of industrial health impacts. While coal power generation is very prominent in most industrialized or developing countries, it is more the small-scale fuel oil or diesel combustion for power generation that drives the impacts in low-income countries (Figure 3.19b). That is because such installations can be smaller and more spread out, while also being less demanding in terms of infrastructure and up-front capital cost. Likewise, steady natural gas supply usually relies on pipeline infrastructure, and does not represent an alternative, despite lower health impacts.

Petroleum refining and steel-making have health impacts but only at the regional level (like in San Francisco or Seattle for refining, or in Northern China for steel-making (Figure 3.19b)). The patterns of CO_2 emission intensities for these industries reveals emission patterns that are spread out (Figure 3.20). In the case of refining, this usually relates to the locations of main fuel consumers (such as the United States). In the case of steel mills, it relates to the availability of the raw materials, mainly iron ore (Figure 3.19b).

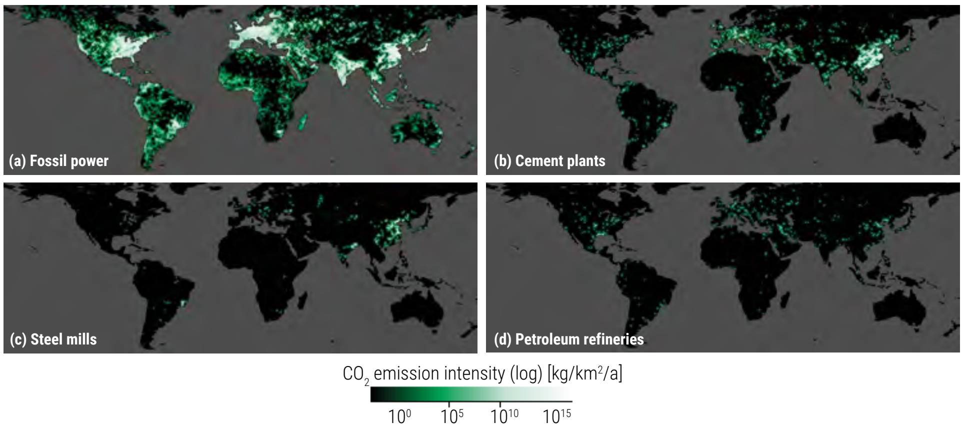
Although greenhouse gas emission patterns (Figure 3.20) generally show some similarities to the health impact patterns (Figure 3.19), there are also notable differences. For example, the emission levels of fossil power plants in Europe and the Eastern half of North America are comparable to China and India due to high local power demands and a large share of fossil power generation. In contrast, steel making tends to produce high GHG emissions in China (Shen *et al.* 2021), where the economic focus is both on steel-consuming infrastructure build-up, as well as the manufacturing of steel for domestic and export use.

Cement making by clinker plants is different, as it is a prerequisite for infrastructure build-up and has a crucial role in CO_2 emission patterns of China, India, West Asia and Europe (Zhang *et al.* 2018) (Figure 3.20). Clinker kilns are often less stringently regulated than other types of industrial facilities, for instance in the context of NO_x emissions (Edwards 2014). This has even pushed up its contribution to health impacts in parts of Viet Nam and China beyond those of coal power generation (Figure 3.19b). In some regions of Europe, GHG emission intensity is especially high per amount of cement clinker output due to older cement plant designs that lack proper heat recovery and thus need more fuel than modern plants.

In terms of industrial technological development, there are various relevant pathways being explored. In higher income countries, the focus is on bringing down greenhouse gas emissions and avoiding fossil fuels across industries. The deployment of end-of-pipe carbon capture and storage (CCS) technologies is an option for reducing emissions of hard-to-abate GHGs, and can lead to a further improvement of $PM_{2.5}$-related emissions as this technology has high requirements in terms of flue gas contaminants. For example, it requires further reductions of flue gas SO_2 contents and will consequently bring down health impacts from $PM_{2.5}$. At the same time, however, there will be higher energy demands for CCS that may offset some share of the emission reductions (Huo *et al.* 2022), besides the high infrastructure requirements and costs, which limit the applicability of CCS.

A larger change is likely to take place for petroleum refining, as a decline in gasoline and diesel demands is anticipated in industrialized countries (IEA 2021b). This makes refiners consider a shift in production to chemical feedstocks or high-value specialty products like Sustainable Aviation Fuels (SAFs). If sourced from biogenic raw materials instead of fossil raw materials, these could contribute to lower global warming impacts. However, the use of such raw materials may induce higher energy requirements (Zhang *et al.* 2020; Ng *et al.* 2021; Gonzalez-Garay *et al.* 2022) and have complex consequences for the carbon stored in the biomass around the globe (Cherubini *et al.* 2011), as well as for biodiversity loss. Therefore, not all biogenic raw materials are better than fossil alternatives and a thorough assessment is needed in each individual case.

Figure 3.20: CO_2 emission intensity maps for various industries. In contrast to Figure 3.19a, here the emissions sources are shown and not the locations that are affected by the impacts. Fossil power generation represents the sum of coal, gas and oil power generation. Coastlines and country boundaries are shown in grey.



3.5.2 Impacts of land use (land use change and occupation)

Land use has multiple environmental impacts (IPBES 2019a). Destruction of natural habitats is the main driver of biodiversity loss. Deforestation causes the vast majority of global climate change impacts due to land use change (10% of global GHG) and poor land management leads to soil degradation (including loss in productivity) (see Box 3.4) and loss of ecosystem services. This section examines the land-related biodiversity loss results presented in the previous sections, and places them in their geographical context.

Box 3.4. Decoupling agricultural production from land degradation and improving soil health by matching land use and potential

(Jeff Herrick and Stephan Pfister)

Each year, 24 billion tonnes of fertile soils are. lost, costing the economy around USD 40 billion. One third of all soils are thought to be moderately to highly degraded by erosion, nutrient depletion, chemical pollution, acidification, salinization and compaction (IRP 2016). Matching land use with land potential is the simplest and most straightforward strategy for decoupling agricultural production from land degradation and improving soil health.

Land potential is defined as the "potential of the land to sustainably generate ecosystem services" (IRP 2016). The long-term land potential depends on soil type, climate and topography (Bouma 2014). Soil health reflects the current status of the land relative to its long-term potential and determines the land's current or short-term potential. Attempting to exceed long-term land potential through unsustainable land use degrades soil health and can result in irreversible degradation of land potential (see Figure 3.21). Recent modelling studies, (Sonderegger and Pfister 2021) clearly demonstrate both types of impacts on agricultural productivity.

Figure 3.21: **Left: A degraded landscape in south-central Kenya where erosion has exposed a clay-rich subsoil, reducing water infiltration to the point where grassland restoration is difficult or impossible. Additionally, this type of degradation results in increased rates of run-off, causing flooding. Right: Landscape in southern Mexico where simple changes in land use could result in significant increases in crop production while reducing soil erosion: intensifying the more productive lower and flat areas on existing cropland could allow restoration of the rapidly degrading steeper areas to pasture or forest (photographs: J. Herrick).**

Matching land use with its sustainable potential can simultaneously increase production, and maintain and improve soil health. Changes in the spatial distribution of land uses within a farm, landscape or region, such as simply intensifying production of annual crops on less steeply sloping land can result in multigenerational benefits (see Figure 3.21).

Land use planning tools are available through FAO's Land Resources Planning Toolbox44 and the Toolbox of The Land Degradation Neutrality Flagship of the Group on Earth Observations (GEO LDN).45 However, new tools are needed to make the process simpler, faster, more transparent and more clearly based on biophysical realities while supporting broad participation in land use decision-making. More specifically, tools are needed to simplify access to relevant knowledge and information. More information on land potential is provided by IRP 2016.

44 https://www.fao.org/land-water/land/land-governance/land-resources-planning-toolbox/en/
45 https://geo-ldn.org/resources/analytical-tools/

Biodiversity loss

According to this chapter's approach to estimating land-use related biodiversity loss, impacts are mainly caused by agriculture and forestry in vulnerable ecosystems (Figure 3.22). Tropical regions and islands in particular are home to many endemic species, leading to high biodiversity loss when natural habitats are lost. Biodiversity loss is particularly substantial in Madagascar, Central America, North-Western parts of South America and parts of Brazil, South-East Asia, the Indian subcontinent, various parts of sub-Saharan Africa, South-Western Australia and the Northern shore of the Mediterranean Sea and the Iberian Peninsula (Figure 3.22). In many tropical regions the situation has worsened in recent decades as a result of further conversion of natural land for human usage (see Figure 3.22). This additional land conversion should be urgently avoided, particularly in areas of high ecosystem value where targets are greatly exceeded (Figure 3.4). On a more positive note, re-naturalization has improved the situation in Southern Europe, Iran and some parts of China (see blue areas in Figure 3.22).

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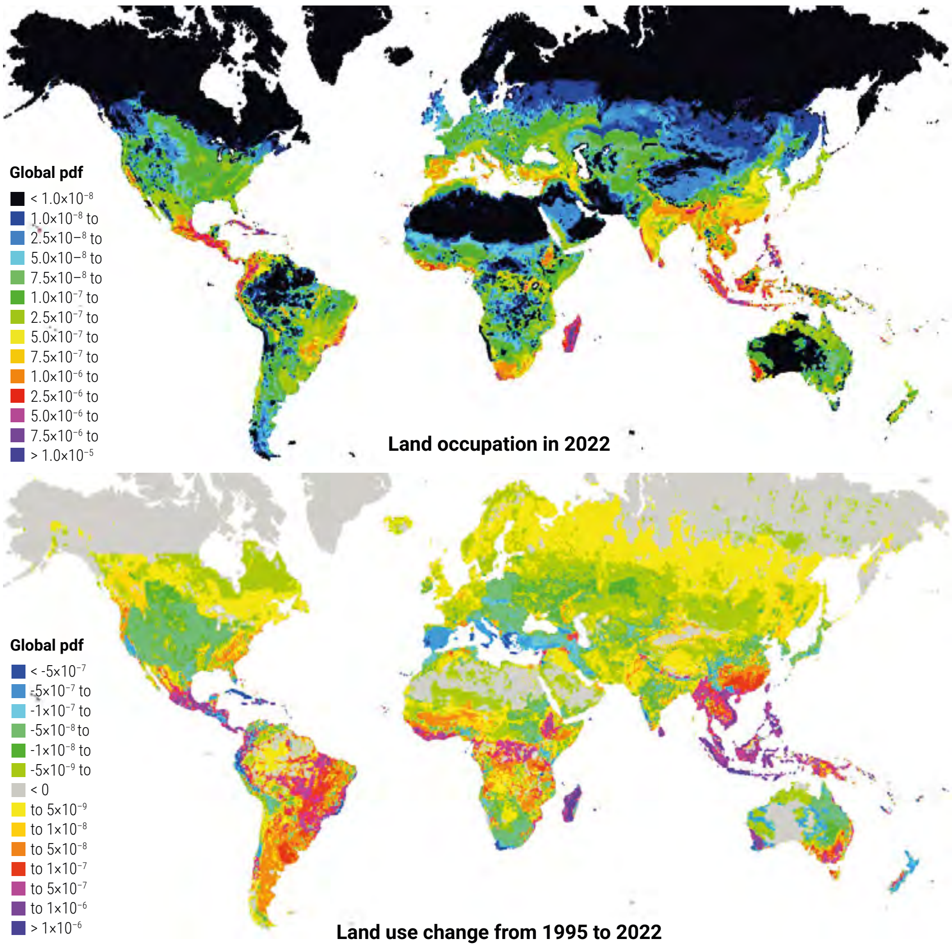

Figure 3.22: Land-use related biodiversity impacts; land-use data from Hurtt et al. 2020 and the impact methodologies of UNEP and the Society of Environmental Toxicology and Chemistry (UNEP SETAC 2016).

above: land occupation impacts in 2022

below: land use change (1995–2022) impacts; negative numbers (blue to green colors) indicate biodiversity recovery, while positive numbers (yellow, red to purple colours) indicate biodiversity loss through land-use change.

When reconverting land to natural habitats, care must be taken to avoid simply shifting regional impacts: Recent research has shown that extensification and renaturalization of land in Europe lowers biodiversity impacts within Europe, but would increase imports to meet domestic demand for biomass, including those from biodiversity-vulnerable regions, to compensate for the decrease in domestic yields (Rosa *et al.* 2023). Therefore, in addition to reconverting land and extensification to restore biodiversity, proper supply-chain management for biomass is needed. If, for example, biomass yields are decreasing as a result of land reconversion or extensification, imports to meet the supply-gap should come from areas where biodiversity impacts are low. Reduction of food overconsumption, animal derived food and food waste can lower the overall pressure on land-resources and biodiversity impacts. Similarly, avoiding direct wood use for energy (especially when not equipped with carbon capture and sequestration (CCS)) and instead using the available wood from sustainable forestry in long-term applications (such as construction) can help limit biodiversity impacts and climate change. Biomass should be used in cascades, since sustainably produced biomass is a scarce resource. This means a circular use of biomass which gives priority to higher value and minimal impact uses.

Mining is globally less relevant for global land-related biodiversity impacts (<1% of total global land-related biodiversity impacts), but can be locally significant (Cabernard and Pfister 2022). Mines with particularly high biodiversity impact include coal mines in Indonesia, nickel mines in New Caledonia, gold mines in Ghana, bauxite mines in Australia, iron mines in Brazil, copper and lithium mines in Chile and diamond mines in South Africa (Annex 6). Per unit of electricity generated, coal power causes an average of ten times more mining-related biodiversity impacts than all renewable energy technologies per unit of electricity generated (Cabernard and Pfister 2022). This, however, neglects potential non-mining biodiversity impacts of renewable technologies, such as land-use effects of biomass energy technologies, which can be significant (Rosa *et al.* 2023) or, at some locations, bird collision with wind turbines (May *et al.* 2021). Overall, synergies exist in fostering solar and wind power to meet global climate and local biodiversity targets.

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3.6 Conclusions

This chapter describes trajectories of environmental impacts, with the goal of assessing the status quo and trends of resource-related impacts and identifying potential urgency for action. Moreover, this chapter identifies environmental hotspots of resources and suggests intervention points for resource management with high environmental leverage. Finally, it analyses the downstream uses of resources, and points to key industrial sectors, provisioning systems and consuming entities. This can be useful for the design of effective resource-management strategies, responsible sourcing strategies and targeted policies.

The underlying analysis is based on a model with unique detail (163 industry sectors, 189 countries, regionalized impact assessment based on UNEP-SETAC 2016) and also facilitates the downscaling of results to country level (available at https://public.tableau.com/app/profile/livia.cabernard). However, simplifying assumptions had to be made to achieve global coverage. For example, industrial sectors are assumed to be homogeneous, and within-country variations of income and consumption could not therefore be analysed. Moreover, while the impact assessment follows state-of-the-art practice, some impact categories are missing, as appropriate methods are still under development (such as for marine biodiversity loss). Also, despite the regionalized approach, global assessments always carry uncertainties and cannot consider all relevant local factors. Furthermore, data after 2012 are nowcasted for water stress, eutrophication and PM health impacts, and this technique involves major uncertainties. Finally, the assessment of well-being was restricted to the IHDI components (income, education and life expectancy) because matching more specific well-being indicators with provisioning systems (such as comparing the impacts from food provisioning systems to malnutrition indicators) did not lead to meaningful results due to poor quality of existing well-being data. Improvement of such data is encouraged, so that this type of analysis will become feasible in the future.

This chapter shows that all environmental impacts are globally increasing and that targets for climate change and biodiversity loss are dramatically missed. This shows the need for immediate and decisive action. Agriculture and forestry (biomass resources) are the main contributors to biodiversity loss from land use and eutrophication, as well as water stress. They also have a major impact on climate change (Figure 3.2). At the same time, increased use of biomass is central to many climate strategies, which may intensify biomass-related impacts even more. This leads to the conclusion that the transition to a sustainable circular bioeconomy is key to mitigating climate change, biodiversity loss and water stress.

Another key finding is the large importance of coal as a fuel to process materials – half of global coal is used for material production, causing climate change and health impacts due to PM emissions. This illustrates that material efficiency and the decarbonization of the supply chain of materials should be at the heart of climate policy.

Finally, all inequality-adjusted HDI-dimensions (income, education and life expectancy) correlate with climate impacts (and, to a lesser extent, biodiversity ones). However, the analysis of provisioning systems showed that, education causes very few impacts, for example. This suggests that improvements in well-being are possible without major increases in impacts.

Opportunities for addressing key environmental hotspots of resource use include:

- Stopping (net) impacts of land use change and land use intensification, especially in areas with high biodiversity value and carbon storage,
- Reducing overconsumption of food, animal-based food and food waste,
- Decarbonization of material production and energy systems,
- Sourcing wood only from sustainable forestry for producing long-term goods with cascade use (and only at the very end for energy recovery in plants equipped with CCS),
- Sustainable construction and urbanization strategies, including sufficiency strategies (such as considerations of floor area per person)
- Mainstreaming sustainable consumption (including sufficiency strategies and avoiding rebound effects – see also Box 5.5),
- Creating a sustainable circular economy, which needs to face challenges such as the availability of safe materials.

Chapter 4 examines some of these opportunities and assesses their potential contribution to a sustainable resource future.

04

Scenario outlook

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Main findings

Decisive and timely action can decouple human well-being from resource use and environmental impacts, as illustrated by the Sustainability Transition scenario, in order to accelerate human development and dignified living for all, moderate resource use and pressures, and decrease environmental impacts.

For the first time, the analysis demonstrates the potential for integrated policy action to decouple pressures and impacts across multiple energy- and resource-use domains, while improving well-being outcomes and reducing economic and resource-use inequalities. Crucially, the analysis finds that an integrated approach, combining action on resource efficiency, energy and climate plus food and land, achieves significantly greater positive effects than any one of these policy packages would in isolation. This builds on previous findings suggesting that resource efficiency increases the effectiveness of actions to reduce greenhouse emissions while reducing economic costs.

Both the Historical Trends and Sustainability Transition scenarios see strong growth in the value of economic activity and per capita incomes, along with a more than 20% increase in global population by 2060. This drives short-term increases in global resource extraction up to 2030, after which the scenarios diverge.

The Historical Trends scenario sees all key pressure and impact indicators increase in absolute terms, driving increasing damage and risks. Global resource use grows strongly up to 2050 before stabilizing. Key pressure indicators include resource extraction up around 60% from 2020 levels by 2060, primary energy up 50%, food and fibre biomass extraction up 80% and the area of agricultural land up 5% – displacing native habitat and increasing biodiversity risks. Key impact indicators include net greenhouse gas emissions up more than 20% and increasing biodiversity losses.

In contrast to the Historical Trends scenario, the Sustainability Transition scenario envisions stronger economic growth, moderating resource pressures, significant reductions in environmental impacts to below current levels and reduced global inequalities.

In the Sustainability Transition scenario, aggregate global resource use stabilizes in around 2030 and then begins to decline from around 2045. Per capita resource use declines globally from around 2040 to become lower than current levels by 2060. This reflects declines in per capita resource extraction and use in upper middle-income and high-income countries that outweigh, in aggregate, increases in per capita resource use in low and lower middle-income countries.

In the Sustainability Transition scenario, key impact indicators are projected to fall below current levels by 2060, representing absolute decoupling, along with slower growth in resource-based pressures, representing relative decoupling. Greenhouse gas emissions fall by around 80% by 2060 compared with 2020 levels. The area of crop and pasture land both fall, with agricultural land area contracting by 5% by 2060. Energy-related pressures fall to 25% below 2020 levels by 2060. Global resource extractions slow from 2030 to peak in 2045, and then settle at around 20% above 2020 levels by 2060. The mix of resource use shifts towards renewables, with food and fibre biomass extraction increasing by 40% to 2060.

The Sustainability Transition scenario indicates globally stronger economic growth and human development outcomes, primarily as result of resource-efficiency measures, with the global economy 3% larger in 2060 than under Historical Trends. Services improve across all provisioning systems, with larger gains in low and lower middle-income countries. Provisioning systems also become more resource efficient, particularly for built environment, mobility and energy. Low and lower middle-income countries benefit more from policy interventions and the uplift in economic growth, helping to narrow economic inequalities.

Moreover, in new analysis (not undertaken for the 2019 GRO edition), the Sustainability Transition also assesses impacts on Human Development Index (HDI) and finds higher HDI values for all income groups: up 5.8% and 6.8%, respectively, for upper and lower middle-income nations, and up 11.5% for low-income nations in 2060, relative to Historical Trends.

The Sustainability Transition scenario projects a narrowing of inequalities in resource use and related environmental impacts across countries. Per capita resource use in lower income countries rises to around 7 tonnes per capita, consistent with estimates of requirements for decent living standards. This convergence reflects slower growth or absolute reductions in per capita resource extraction and use in high and upper middle-income countries along with larger, more rapid reductions in impacts (particularly greenhouse gas emissions), relative to low and lower middle-income countries. However, significant inequalities remain. The ratio of resource use between high- and low-income countries falls from 4.0 times in 2020 to 2.3 times in 2060 for tonnes of domestic extraction per capita, and from 4.7 times to 2.9 times when measured on a material footprint basis.

It is important to note that the modelling does not account for likely negative feedback effects from environmental impacts to economic activity and well-being, such as climate impacts, air and water pollution or the risk of ecosystem collapse. Improved representation of these feedback effects is a priority for future IRP analysis.

4.1. Introduction: Two contrasting scenarios

Resource use is fundamental to human well-being, and a major driver of environmental impact. Past advances in living standards and human development came at the cost of rapid increases in environmental pressures (see Chapter 2) and associated environmental impacts (see Chapter 3). Problems associated with natural resource depletion, climate change, water shortages, biodiversity loss and environmental degradation are increasing, and are increasingly intertwined and reinforcing – as recognized by the triple planetary crisis of climate change, biodiversity loss and pollution. Many of these problems are subject to thresholds, or tipping points, where impacts accelerate and where repair or restoration become much more difficult (Stefan *et al.* 2018).

This chapter contrasts two outlooks for resource use to 2060. A Historical Trends scenario explores the consequences of established patterns of resource use continuing. The analysis finds that, under business-as-usual assumptions, rising populations, incomes and resource use together drive increases in environmental pressures at a scale that risks potentially catastrophic impacts on the earth systems and ecological processes that underpin human well-being and the diversity of life on our planet. The second scenario, an illustrative Sustainability Transition, demonstrates that this does not need to be the case.

Results in this chapter are based on projections for the country and regional groups used in the underpinning models, in contrast to results in Chapters 2 and 3 that were based on best available granular country-level data. The aggregation of some countries into combined regions affects results reported for income-level groups (see section 8.4 in the annex).

4.1.1. Assumptions and narrative for the Sustainability Transition scenario

The Sustainability Transition assesses the impact of implementing socially and technologically feasible shifts: resource efficiency and more sustainable buildings and settlements; climate and energy; food and land; and a just and equitable transition. Section 4.3 provides more details.

These shifts and measures are modelled and assessed using the IRP's integrated assessment framework, involving a suite of linked models of the global economy; resource extraction, transformation and use; land use (focused on agriculture and forestry); and energy and provisioning systems. Results and projections apply up to 2060, as important global trends continue to evolve after 2050. More details are provided in Annex 7.

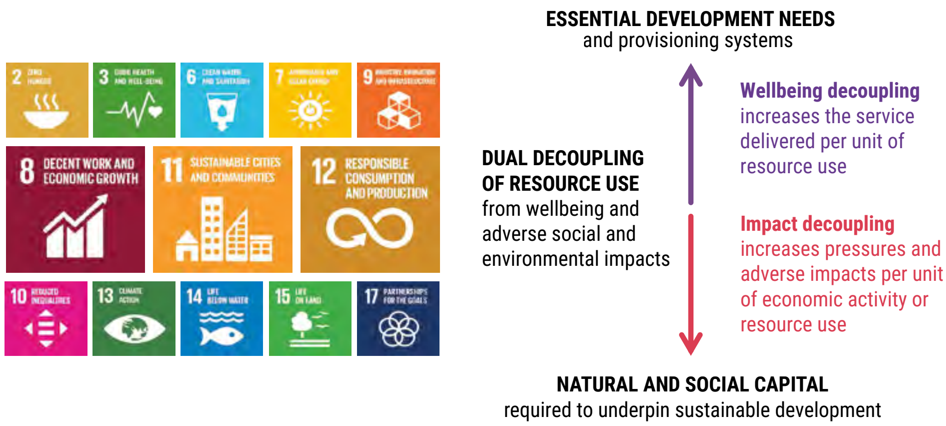
According to the analysis, the four elements of the Sustainability Transition scenario lift global economic performance and boost economic growth and well-being, while decoupling growth in incomes and resource use from environmental impacts and damage. Income and well-being improve, while the most urgent pressures and impacts fall significantly, and other pressures stabilize or moderate.

4.1.2. Scenario analysis assesses decoupling potential

The analysis builds on the notion of dual decoupling, introduced in GRO19. This focuses on the potential to increase well-being contributions per unit of resource use, and decrease impacts and damage per unit of economic activity and resource use (Figure 4.1).

The chapter reports a range of indicators, as shown in Table 4.1 reflecting the variables available from the multi-model framework.

Figure 4.1: Dual decoupling to promote sustainable development.



Source: Adapted from GRO19 (IRP 2019a).

Table 4.1: Key indicators used to assess decoupling in the scenario modelling

Domain	Underlying drivers	Well-being or provisioning system indicator	Pressure indicator	Impact indicator
Resource use	Population growth Consumption demand Economic growth (GDP)	Human Development Index (HDI, HDI*) GDP per capita	Resource use (DE, DMC, MF)	No key indicator identified
	Shelter needs	Building floor space (m^2)** (stock)	Resource use, buildings (DMC) (flow)	No key indicator identified
Energy and climate	Energy needs, including for mobility	Household energy use	Total primary energy Final energy	GHG, total GHG, energy
	Mobility needs	Passenger transport (pkm/y)**	Final energy use, transport Resource use, transport (DMC)**	GHG, transport
Food and land	Healthy and sufficient food	Calories per capita	Land use change (agricultural land) Biomass extraction (DE. Food and fibre biomass) Water extraction from stressed catchments*	Biodiversity (species extinction)

Notes: * The modelling calculates HDI based on Global Trade and Environment Model (GTEM) results for national income per capita, along with education and life expectancy projections for SSP1 and SSP2. Results are presented for HDI weighted for population growth (denoted HDI*) where comparing to aggregate indicators, such as GDP or DE. ** supplementary indicator, not reported in main chapter. Source: GRO24 scenario modelling team.

According to the analysis, both scenarios project strong economic growth, with the value of global economic activity increasing at least 150% between 2020 and 2060 (in real terms, above inflation), along with a 23% increase in global population.

However, resource use, pressures and environmental impacts are very different across the two scenarios, with no absolute decoupling in the Historical Trends scenario and substantial decoupling in the Sustainable Transition scenario.

Don Landwehrle

4.1.3 Innovations

The scenario modelling and analysis includes several developments that are new to GRO24:

- The Global Trade and Environment Model (GTEM) and the Global Biosphere Management Model (GLOBIOM) used in GRO19 are now coupled with an Integrated Model to Assess the Global Environment (IMAGE), which includes a new materials stock and flow module (IMAGE-MAT). This strengthens the modelling framework and provides new insights into how different pathways for key stocks (such as buildings and vehicles) shape future resource and energy requirements, alongside associated impacts.
- Supply chain analysis calculates physical material footprints (MF) that allocate resource use to final consumption by provisioning system and country, thereby complementing previous reporting of resource extraction (DE), trade (PTB) and use (DMC) of raw materials. This provides new insights into underlying drivers and the distribution of benefits from resource transformation and use.
- Scenario treatments build on GRO19 to include new detail and treatments for energy use, the built environment (including buildings and mobility within settlements), sufficient and healthy diets plus measures to support a more just transition.
- The modelling and analysis provide new well-being indicators, including the calculation of Human Development Index (HDI) outcomes, along with indicators for services provided by resource and energy use (see Table 4.1).

4.1.4. Contents

This chapter presents key results from the IRP's integrated scenario modelling, with a particular focus on assessing the potential to decouple economic growth and human well-being from resource use and adverse economic impacts.

Section 4.1 introduces the scenarios; sets out the key indicators used to assess decoupling economic growth, pressures and impacts; and outlines key innovations in the analysis. Section 4.2 provides a brief overview of outcomes under Historical Trends. Section 4.3 reports outcomes, findings and insights for the Sustainability Transition scenario. This includes:

- Summary of the scenario assumptions (Section 4.3.1)
- Overview of key decoupling outcomes (Section 4.3.2)
- Key results for the resource efficiency element of the scenario (Section 4.3.3), including an in-depth study of materials and energy use in buildings
- Key results for the climate and energy element of the scenario (Section 4.3.4), including in-depth examination of the transport and electricity sectors
- Key results for the food and land element of the scenario (Section 4.3.5)
- Key results for the just transition element of the scenario (Section 4.3.6)

Additional details on the modelling framework and implementation are provided in Annex 7.

4.2. High environmental damage and inequality under the Historical Trends scenario

The Historical Trends scenario shows the impact of current trends and policies in patterns of economic activity and associated resource use. This includes detailed representation of energy system outcomes under current policies, taking account of announced policies and specific climate commitments.

4.2.1. Historical Trends assumes economic growth consistent with institutional projections driving significant growth in resource use

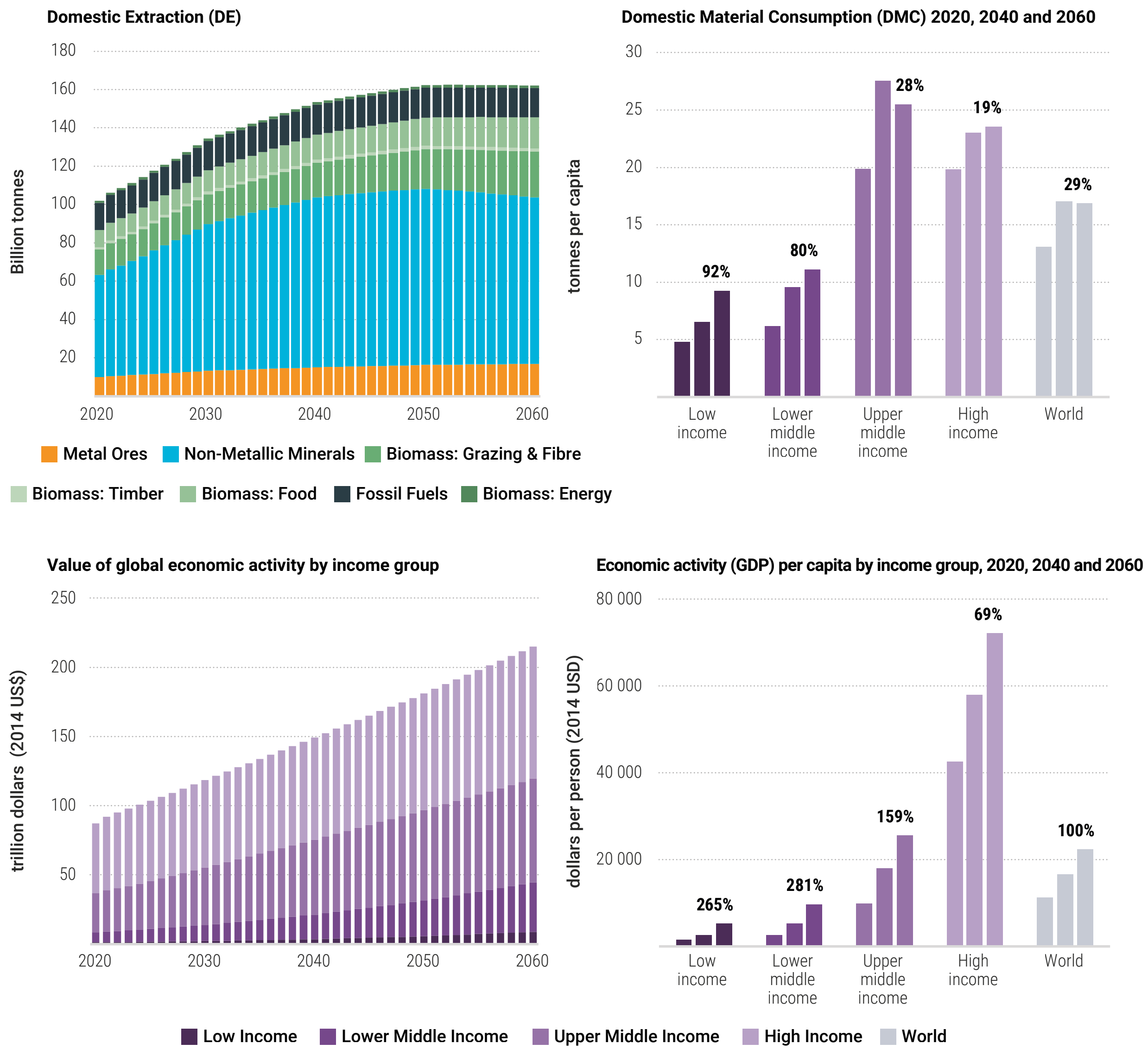
The Historical Trends scenario is calibrated to established benchmark economic outlooks. These involve long-term economic growth driven by trend improvements in total factor productivity, underpinned by capital deepening, improved human capital (particularly skills and knowledge) and technological advances.

It is important to note that the scenario modelling does not fully account for negative feedback effects from environmental impacts on economic activity and well-being. Examples include reduced labour productivity due to illness or premature death (from air and water pollution), costs of resource degradation (increasing resource extraction and processing costs), loss of ecosystem functions and services (such as clean air and water, healthy and productive soils and climate regulation), direct and indirect effects of climate change (such as impacts on agricultural production) or risk of ecosystem or earth system collapse. While these feedbacks are likely to have negative impacts on economic growth and productivity, the specific magnitude, timing and geographic distribution of likely impacts are highly uncertain. Improved representation of these feedback effects is a priority for future IRP analysis.

Consistent with other economic outlooks, the scenario estimates more rapid percentage growth in GDP per capita in low and lower middle-income countries (relative to other income groups). However, GDP per capita measured in absolute values (real United States dollars, adjusted for inflation) rises more slowly in these countries due to substantial differences in base levels. Most or all upper-income countries qualify as high-income well before 2060 on the basis of today's real GDP per capita threshold (World Bank 2023). Faster percentage GDP growth in low and lower middle-income countries helps narrow existing economic inequalities, thereby reducing the difference in GDP per capita across low and high-income countries by around a third by 2060. However the distribution of income and wealth remains vastly unequal.

As outlined above and shown in Figure 4.2, global resource use grows strongly to around 2050 and then stabilizes, as non-renewable resource use peaks just before 2050 and begins to decline, with modest continuing growth in biomass extraction. This is largely driven by upper middle-income economies moving from a resource-intensive growth phase into more value-added activity. Results indicate substantial global relative decoupling of resource use (up around 60%) from economic growth (up around 150%), as shown in Figure 4.19 below (section 4.3.6). The modelling finds this is primarily driven by changes in economic structure and consumption patterns, rather than by technological change within individual economic sectors. Rising incomes (reflected in GDP per capita doubling over 40 years) see more than half the world's population shift into the high and upper middle-income group by 2060. This drives major changes in in consumption patterns, moving away from more energy and resource-intensive basic needs and infrastructure development towards higher value-added goods and services with lower embodied energy and resources per dollar.

Figure 4.2: The outlook for resource use and economic activity under Historical Trends.



Source: GRO24 scenario modelling.

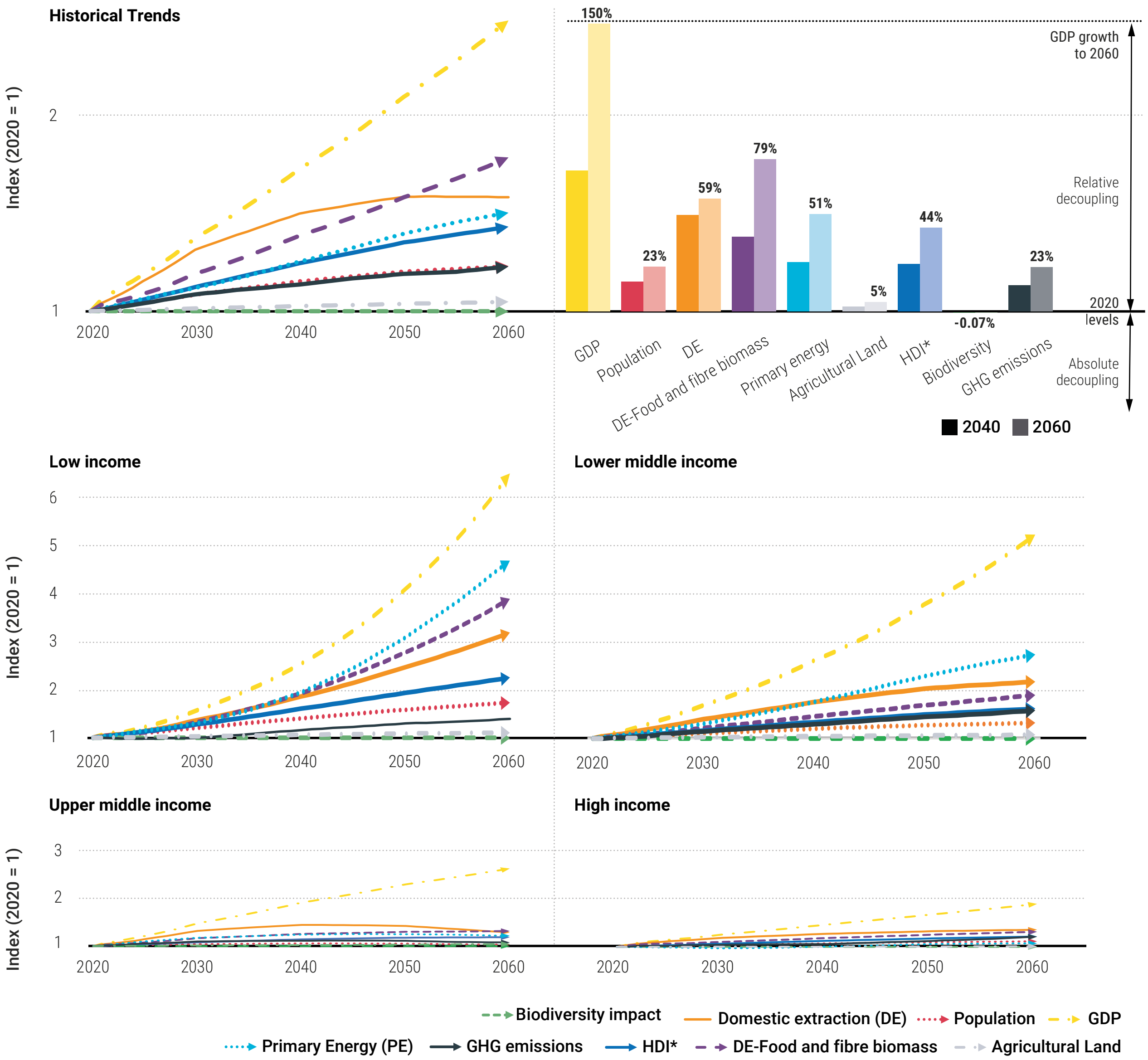
4.2.2. No absolute decoupling projected under Historical Trends

Against this backdrop, under Historical Trends each of the key pressure and impact indicators increases, without decoupling well-being from resource use (see Figure 4.3):

- Key pressures include resource extraction (DE) increasing by 59% between 2020 and 2060, primary energy up 51%, food and fibre biomass extraction up 79% and the area of agricultural land up 5% (displacing native habitat).
- Key impacts include a 23% increase in greenhouse gas emissions and continuing loss of biodiversity (indicated by total number of species), noting the modelling does not fully account for the impacts of climate change impacts on biodiversity.
- The key well-being indicator, the population-weighted Human Development Index (HDI), improves – largely as a result of increasing national income per capita. However, the analysis finds no evidence of impact decoupling, with the HDI rising less than total resource extraction globally and for all four income groups.

Figure 4.3 provides an overview of the drivers, pressures, well-being indicators and impacts under the Historical Trends scenario up to 2060. The panels at the bottom of the figure show how trends differ across different income-level regions.

Figure 4.3: The Historical Trends scenario sees pressures and impacts continue to rise, despite some relative decoupling. All figures refer to absolute values.



Source: GRO24 scenario modelling (PE from IMAGE, Biodiversity impact and change in agricultural land from GLOBIOM, all others from GTEM).

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4.3. Sustainability Transition increases well-being and income while decreasing pressures and environmental impacts

4.3.1. Key elements of the Sustainability Transition scenario

The analysis models a scenario involving multiple shifts towards a more sustainable and just world, using the IRP's multi-model integrated assessment framework.

Responsible and sustainable production and consumption (SDG 12) is interpreted broadly, going beyond resource efficiency (SGD 8.4) to include improved management and outcomes for food (SDG 2), water (SDG 6), energy (SDG 7), economic performance (SDG 8), settlements and built environment (SDG 9 and 11), climate (SDG 13) and life on land (SDG 15). The scenario also incorporates measures to reduce inequalities (SDG 10) and support a just transition.

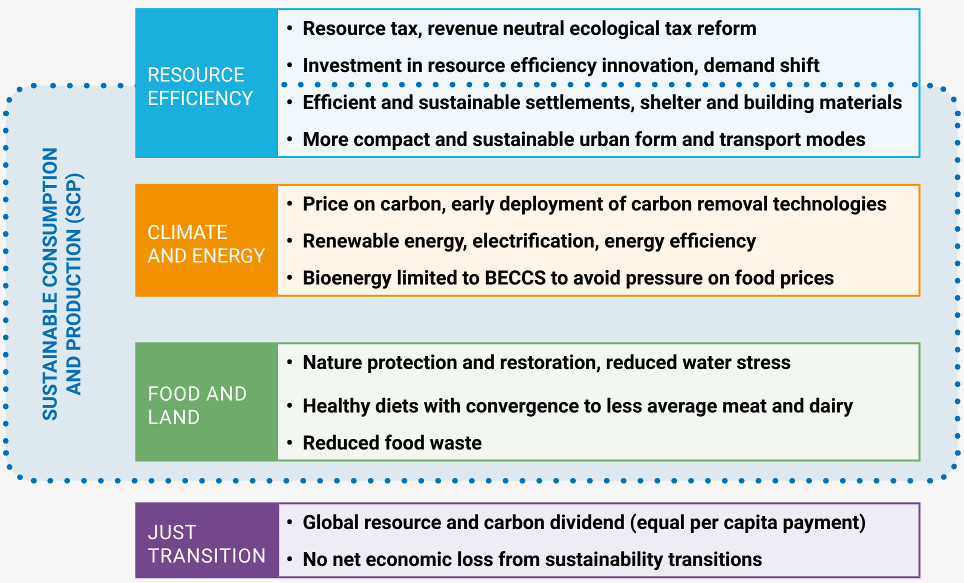
The Sustainability Transition scenario is made up of four shifts, each involving an evidence-based package of measures designed to maintain or improve human well-being while limiting environmental pressures and reducing adverse impacts.

- Resource efficiency shift broadly consistent with SDGs 8, 11 and 12, including new analysis for this GRO of shifts in favour of more sustainable built environment (including buildings and settlements) and mobility;
- Climate and energy shift broadly consistent with SDGs 7 and 13, updated to be consistent with the most recent IPPC reviews;
- Food and land shift broadly consistent with SDGs 2, 3, 14 and 15, with new analysis of a shift to healthy diets for this GRO; and
- Measures to address inequalities and support a just and equitable transition, reflecting multiple SDGs including Goal 10.

Together, these four shifts account for the differences in scenario outcomes relative to Historical Trends.

Figure 4.4 provides an overview of these elements, which are each explained in more detail below.

Figure 4.4: Summary of policy packages and social shifts in the Sustainability Transition scenario for GRO24.



Note: The no net economic loss measure is not fully implemented in the modelling.

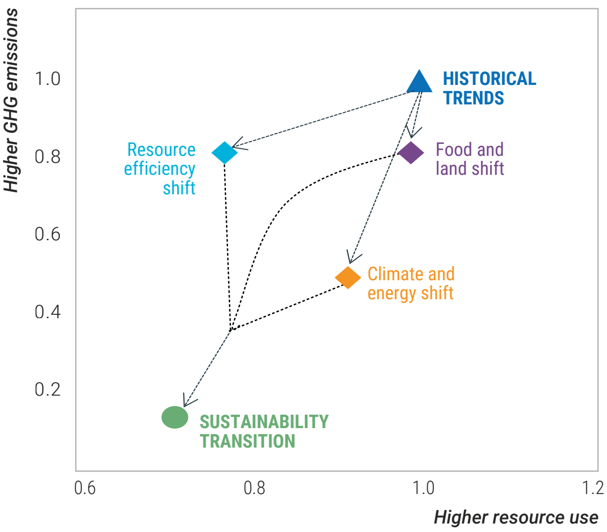
Source: GRO24 scenario modelling team.

The purpose of the Sustainability Transition scenario is to provide a robust, evidence-based illustration of one potential pathway to a more sustainable world. It does not attempt to identify the best or optimal pathway nor provide a detailed assessment of each component of the total package. Rather, the chapter seeks to assess the tensions and synergies between the different sustainability aspects by reporting the relative contributions of each shift across a range of indicators.

Each of the four shifts has a differential effect on multiple aspects of resource use and economic activity, and related pressures and impacts. Figure 4.5 shows the contribution of each shift, if implemented on a stand-alone basis, along with the combined effect of the Sustainability Transition measures on global resource use (DE) (horizontal axis) and in greenhouse gas emissions (CO_2eq) (vertical axis), relative to Historical Trends in 2060.

Crucially, the modelling finds that an integrated approach, combining action on resource efficiency, energy and climate plus food and land together, achieves significantly larger positive effects than any one of these shifts in isolation. The combined effect of the measures that make up the Sustainability Transition scenario reduces global resource use by around 30% and greenhouse emissions by around 90% relative to Historical Trends in 2060. In addition, the analysis finds that each of the first three shifts maintain or improve well-being while reducing environmental pressures and impacts, and that the fourth shift improves well-being without undermining environmental performance or having large impacts on aggregate global resource use or greenhouse emissions.

Figure 4.5: Overview of effects of scenario elements on resource use and greenhouse gas emissions in 2060.



Index: Historical Trends in 2060 = 1.0.
Source: GRO24 scenario modelling.

While the suite of measures in the Sustainability Transition scenario addresses all three dimensions of the triple planetary crisis – climate change, biodiversity and pollution – the underlying causal processes and structure of the multi-model framework allow more robust projections for greenhouse gas emissions and land use change, and less robust projections for climate impacts, biodiversity outcomes and pollution. Notwithstanding these gaps in the indicator framework from the model, there are good reasons to be confident that measures of the kind included in the Sustainability Transition scenario would make strong positive contributions across all three dimensions of the triple planetary crisis.

Summary of resource efficiency policy measures

The modelling builds on previous IRP analysis of resource efficiency (Hatfield-Dodds *et al.* 2017; IRP 2019a). The first component promotes resource efficiency innovation, representing Research and Development funding, incentives and support for technology demonstration and deployment. This reduced unit supply cost could drive a significant rebound effect if implemented in isolation, which could increase aggregate resource use. This potential rebound effect is avoided by a second component, which adjusts relative prices by gradually increasing the total supply costs of virgin resources. In the modelling this is represented as a resource levy, but it could be any policy that increases total costs (such as more stringent environmental standards) and encourages more efficient use of resources. The levy is uniform across regions, with a 30% higher rate per tonne for non-renewable resources. Revenue is assumed to be used to support resource efficiency innovation and reduce existing taxes on income and household consumption (such as wages, payroll and sales tax).

Consistent with previous analysis, the modelling finds that this set of resource-efficiency measures reduces or slows the growth of resource use by shifting expenditure to less resource-intensive consumption. The measures also boost long-term economic growth due to enhanced innovation, bolstered productivity and a small increase in investment as a share of GDP.

The second set of measures, new for GRO24, focuses on resource use in construction and renewal of buildings and settlements, and ongoing urban metabolism (discussed in more detail below). These measures assume a convergence in building area per person and more efficient use of the building stock, with housing area in lower income regions growing faster than in high-income regions. See Annex 7 for more detail.

Relative to the Historical Trends scenario, these changes result in:

- Reduced resource use through resource efficient production, and longer life cycles for products and buildings.
- More efficient construction and smaller average building area per person, particularly in regions with larger buildings relative to the global average.
- Higher density settlements with more shared green space and greater use of active transport (walking and cycling) and public transit systems.
- A higher share of timber and biomass-based construction materials in new buildings and infrastructure, and lower share of steel and concrete construction materials.

These shifts progressively lower the resource intensity of construction and related economic activity while maintaining or improving the services or amenity provided, such as the space and comfort provided by buildings. The shifts are implemented in the modelling primarily as efficiency shifts, reducing the demand for basic materials and associated raw resource inputs, without increasing overall demand for manufactured items and buildings.

For clarity, the current modelling does not explore the full potential of circular economy policies. Scenarios that add ambitious resource recovery and recycling to these policies would be expected to deliver larger improvements in resource efficiency. While the package of resource-efficiency measures implemented in the modelling boosts economic growth and provides net economic benefits, poorly designed and implemented strategies could also slow growth and result in net economic costs.

Summary of climate and energy measures

The climate policy package involves a uniform global carbon levy calibrated to achieve a global emissions trajectory well below 2°C; accelerated deployment of renewable electricity and electrification; support for energy efficiency; and early deployment of carbon removals technologies to minimize carbon overshoot. Net carbon revenues are used to provide a carbon dividend payment that supports reduced inequalities and a more just transition (see section 4.3.6).

Consistent with the climate scenario literature, the primary climate policy measure is a global carbon levy. For simplicity and transparency, the levy is modelled as an incentive price that is applied to carbon dioxide and other greenhouse emissions at a uniform rate across all countries and emissions sources, including emissions from land clearing. The incentive price increases over time, and is calibrated to achieve the target global emissions trajectory. Sequestration from plantings and reafforestation that contribute to biodiversity goals receive a subsidy at the same rate per tonne of carbon as the levy. Net carbon revenues are returned as climate protection dividends on an equal per capita basis globally each year, rather than being retained in the country where the emissions occur. While highly stylized, the levy and dividend approach scores well from an economic efficiency perspective (applying a comprehensive market-based incentive), while the tangible annual dividend payments to households would help ease some of the political challenges associated with implementing ambitious emissions reductions (see Klenert *et al.* 2018).

The climate and energy shift includes measures to accelerate uptake of renewable electricity, electrification (displacing fossil fuel energy with renewables) and a doubling of energy efficiency by 2030. This occurs endogenously in IMAGE, while GTEM energy demand is calibrated to be broadly consistent with the IEA Net Zero Emissions scenario (IEA 2022d). Energy system resource requirements, including for metals, are accounted for in the modelling framework.

The climate policy package also supports the deployment of carbon dioxide removal (CDR) technologies such as reforestation, bioelectricity with carbon capture and storage (BECSS) or Direct Air Capture (DAC). This recognizes the risk management benefits of early and rapid decarbonization action, limiting the extent of emissions overshoot (Obersteiner *et al.* 2018) and associated risks of reinforcing climate feedbacks, while avoiding the need for high volumes of carbon removals later in the century to achieve the same cumulative emissions budget.

These measures, combined with the resource efficiency (see section 4.3.3) and food and land shifts (section 4.3.5), result in lower total energy use than under the Historical Trends scenario and significant reductions in global greenhouse gas emissions consistent with the benchmark 1.5°C pathway (IPCC 2018b), with around a two thirds chance of limiting global warming to 1.5°C above pre-industrial levels in 2100.

Policy measures and social shifts for land use, ecosystems and healthy diets

The land and food shift adopts an integrated approach to protecting landscapes and biodiversity. This ensures climate, energy and resource use policies are aligned with land and food system goals, minimizing the additional actions required to achieve desired biodiversity outcomes. Applying the carbon levy (described in section 4.3.1) to emissions from land clearing helps to avoid deforestation, while payments for land sector sequestration are only provided where this contributes to improvements in biodiversity.

Additional conservation policies are implemented, as required, to ensure scientifically recommended levels of protection for each ecoregion are introduced and enforced by 2030 (see Annex 7.3.2). This is modelled by preventing loss of native vegetation in areas identified as key biodiversity areas (BirdLife International 2017) or wilderness (Watson *et al.* 2016), and providing any additional incentives required for land use change providing biodiversity benefits (Leclere *et al.* 2018). The package also supports higher agricultural productivity, particularly in low- and medium-income nations (which converge towards productivity levels in high-income nations), reduced agricultural waste and food system losses, reduced barriers to agricultural trade and lower meat consumption where this promotes healthier diets. Improvements in water use efficiency are harnessed and environmental flow protections are fully enforced by 2030 (Pastor *et al.* 2019), reducing total agricultural water use in catchments that are currently water stressed, and ensuring all irrigated production is consistent with maintaining environmental flows and watering requirements. This combination of measures reduces near-term biodiversity loss by around a third compared to historical levels, and improves biodiversity relative to Historical Trends by the end of the century (Leclere *et al.* 2020).

The land and food systems package also assumes a shift in societal behaviour towards healthy diets, consistent with international dietary guidelines (Springmann *et al.* 2017; Springmann *et al.* 2018, Box 3.2) and reduced food waste throughout the food supply chain. The shift towards healthy diets assumes an enabling approach to policy, such as regulation to make sustainable options available and affordable, enable informed choice and limit misinformation and abuse of market power – with the primary driver of change assumed to be consumers' and citizens' desire to live longer and healthier lives. This is consistent with, and supported by, rising average incomes, reduced poverty, evolving social norms and improved public understanding of the long-term benefits of a healthy diet and lifestyle. The modelling projects that average global per capita supply of calories and protein increase. Average per capita consumption of meat increases, but more slowly than under Historical Trends, with red meat consumption around 40% lower than under Historical Trends in 2060. Reduced food waste is supported by enabling policies and also motivated by financial savings to producers, processors and consumers, while also helping to increase food availability and reduce environmental pressures.

To reduce competition for land and avoid upward pressure on food prices, policy incentives for crop-based biofuels are phased out before 2025, and bioenergy for electricity generation is focused on BECCS (with carbon capture and storage), as this contributes to net negative emissions.

Together, these policies and societal changes limit the expansion of agricultural land and support improved biodiversity outcomes relative to Historical Trends. The smaller area of agricultural land in the GRO24 Sustainability Transition scenario is offset by higher yields per hectare, improved food system efficiency, changes in livestock mix (with fewer cattle and sheep and more pigs and chicken) and shifts in diet towards plant-based protein. More details are provided in Annex 7.

Measures to reduce inequalities and support a more just transition

The primary just transition measure is a global per capita dividend that returns the aggregate revenue raised through the carbon levy to households as a uniform global per capita carbon dividend payment (regardless of where the revenue is collected). This is consistent with views that the atmosphere is owned equally by all people. Differences in income across nations result in a uniform payment providing a much larger percentage increase in income to low and lower middle-income nations than to high-income nations. This approach addresses, in a stylized way, equity issues associated with the distribution of greenhouse emissions, resource extraction and land use, while providing a substantial net transfer of revenue to low- and lower middle-income nations.

A range of other just transition measures are embedded in other elements of the Sustainability Transition scenario. Examples include: ambitious action to address climate change that reduces adverse impacts on risks for vulnerable communities; restrictions on biofuel production that avoid upward pressure on food prices; ensuring healthy and sufficient food provides significant benefits to low-income nations and groups; and more sustainable urban mobility that improves urban air quality and the transport options for low-income groups.

The scenario design also includes an exploration of a no net loss measure, which would result in no region suffering an overall shortfall in national income per capita shortfall relative to the Historical Trends scenario. While it was not possible to implement this as a fully modelled treatment, only a small proportion of countries are projected to have net losses of GDP relative to Historical Trends, with a negative impact a little under 2% of GDP in 2060. These countries account for 18% of global population in 2060 and are predominantly in the upper middle-income group. Compensating these countries through cash transfers would require redistribution of around 12% of the GDP gains from the Sustainable Transition scenario.

It is important to note that poorly designed policies can negatively impact the desired outcomes from each intervention. For example, it is essential to recognize the critical role of women, youth, indigenous peoples and local communities alongside all constituents of civil society in sustainable and equitable natural resource management for meeting human global needs, by also prioritizing their inclusion in decision making process and their empowerment.

4.3.2. Decoupling outcomes

The analysis finds that the combined impact of the Sustainability Transition measures results in significant decoupling, offering a dramatic contrast to Historical Trends.

- All four key pressure indicators grow less than they do under Historical Trends.
    - Resource extraction and use grows more slowly than economic growth, representing relative decoupling. Total global resource extraction peaks in 2045 and falls slightly to 20% above 2020 levels in 2060, rather than 59% under Historical Trends. Food and fibre biomass extractions increases 40% rather than 79% by 2060.
    - Primary energy supply falls by 27% between 2020 and 2060, in contrast to the 41% increase seen in Historical Trends.
    - The area of agricultural land falls by 5% rather than rising by 5% by 2060.
- One key impact indicator – greenhouse gas emissions – improves, with emissions falling by 83% from current levels by 2060, representing absolute decoupling.
- The other key impact indicator shows relative decoupling, with Towards Sustainability avoiding 38% of the biodiversity loss projected under Historical Trends. However, past land conversion and land management practices continue to impact future biodiversity outcomes, which sees continuing negative biodiversity impacts despite net reductions in the area of agricultural land.
- The primary well-being indicator, the Human Development Index, grows 24% globally by 2060, with stronger growth in low- (up 38%) and lower middle-income nations (up 26%).

Decoupling outcomes and patterns vary systematically across income groups. High-income countries have lower population and lower per capita economic growth, and see stronger near-term decoupling outcomes for both aggregate and per capita pressures and impacts (as shown in Figure 4.3). Low-income nations have much higher population and per capita economic growth, and see higher growth in all three pressures and more moderate absolute decoupling.

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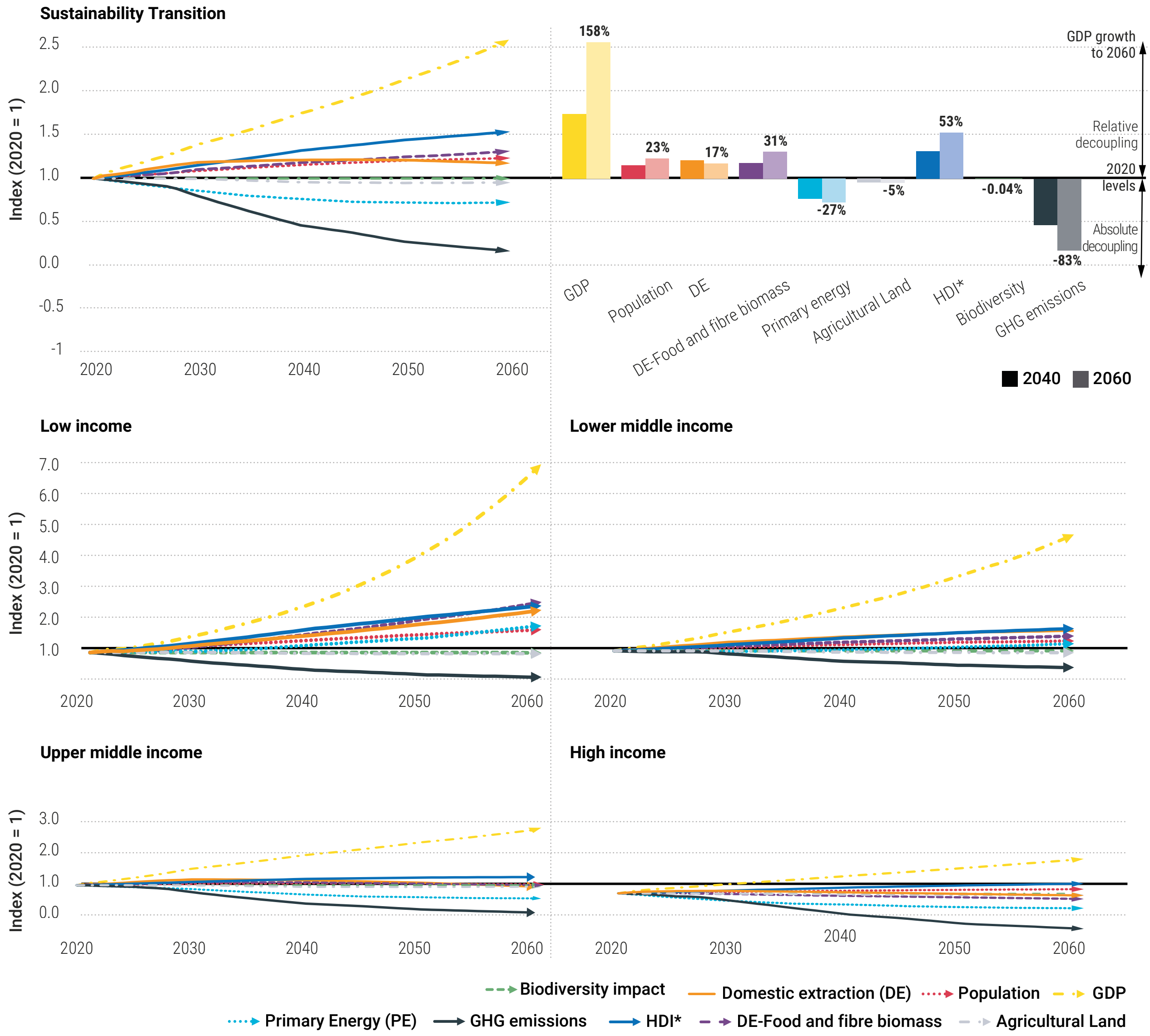
Figure 4.6: The Sustainability Transition scenario sees both absolute and relative decoupling, with key impacts falling from current levels, while pressures grow more slowly than well-being.



Note: HDI is calculated as population-weighted index. As HDI is a per capita measure, for comparability it is adjusted here for aggregate changes in population.
Source: GRO24 scenario modelling (PE from IMAGE, Agricultural land from GLOBIOM, all others from GTEM).

For the first time, the IRP's integrated multi-model assessment framework demonstrates the potential to decouple pressures and impacts across multiple domains, including resource use, climate and energy, food and nutrition and biodiversity and life on land – which are often considered separately rather than in an integrated way.

The following sections present results through the primary lens, or focal issue, associated with each of the four shifts (as set out in section 4.3.1):

- Resource efficiency, including an in-depth examination of buildings, and the contributions of different measures to resource use outcomes
- Climate and energy, including detailed studies into electricity, building energy use and transport, and the contributions of different measures to decoupling emissions from energy and economic growth
- Food and land, including the contributions of different measures for decoupling pressures on land and ecosystems from food and achieving healthy diets
- Supporting reduced inequalities and a just transition, including key results for income and well-being.

4.3.3. Key results for resource efficiency

The resource efficiency shift combines measures to promote resource efficiency; sustainable housing, building materials and urban design; improved urban mobility; and responsible consumption and production. These measures are aligned to SDGs 8, 9, 11 and 12. These shifts cut future growth in global resource extraction by two thirds, relative to the Historical Trends scenario.

The Sustainability Transition measures influence extraction of fossil fuel, timber and metal ores more strongly than food biomass, energy biomass and non-metallic ores (see Figure 4.7). This largely reflects limited substitutes for food, strong underlying demand for food and energy and more limited resource efficiency potential for these resource categories. Fossil fuel energy resources are affected most strongly, falling almost 60% from current levels (measured in tonnes), reflecting the combined effects of general resource efficiency measures and targeted climate policy measures.

As shown in Figure 4.7, global aggregate resource extraction is projected to peak around 2045, 23% above 2020 levels, and then falls slightly to be 20% above the 2020 level by 2060. This peak and decline are driven by improved resource efficiency globally, along with falling aggregate resource demand in upper middle- and high-income countries.

Global per capita resource use peaks earlier, around 2030, at 9% above 2020 levels before falling to 3% lower than 2020 levels in 2060. Per capita resource use in low and lower middle-income countries increases by between 40% and 50% by 2060 (7 to 9 tonnes per capita), which is consistent with available estimates of resource requirements for decent living standards (Vélex-Henao and Paulick 2023). In aggregate, this growth in lower income countries is more than offset by a peak and net decline in middle-income countries (where a substantial share of resource use is embodied in exports to other countries) and a steady decline in resource use per capita in high-income countries. This includes declines in per capita resource extraction (DE) and per capita material footprints (MF) in higher income countries (see Figure 4.7 and Figure 4.8 below).

Together, these shifts halve resource-use inequality, with the ratio of domestic extraction per capita between high- and low-income countries falling from 4.0 times the low-income per capita average in 2020 to 2.3 times in 2060.

The modelling thus finds sufficiency is a practical option (see section 1.9 above), with the Sustainability Transition scenario projecting increased resource use in lower income countries, enabling dignified living for all, along with reduced resource use in countries with high existing levels of resource use.

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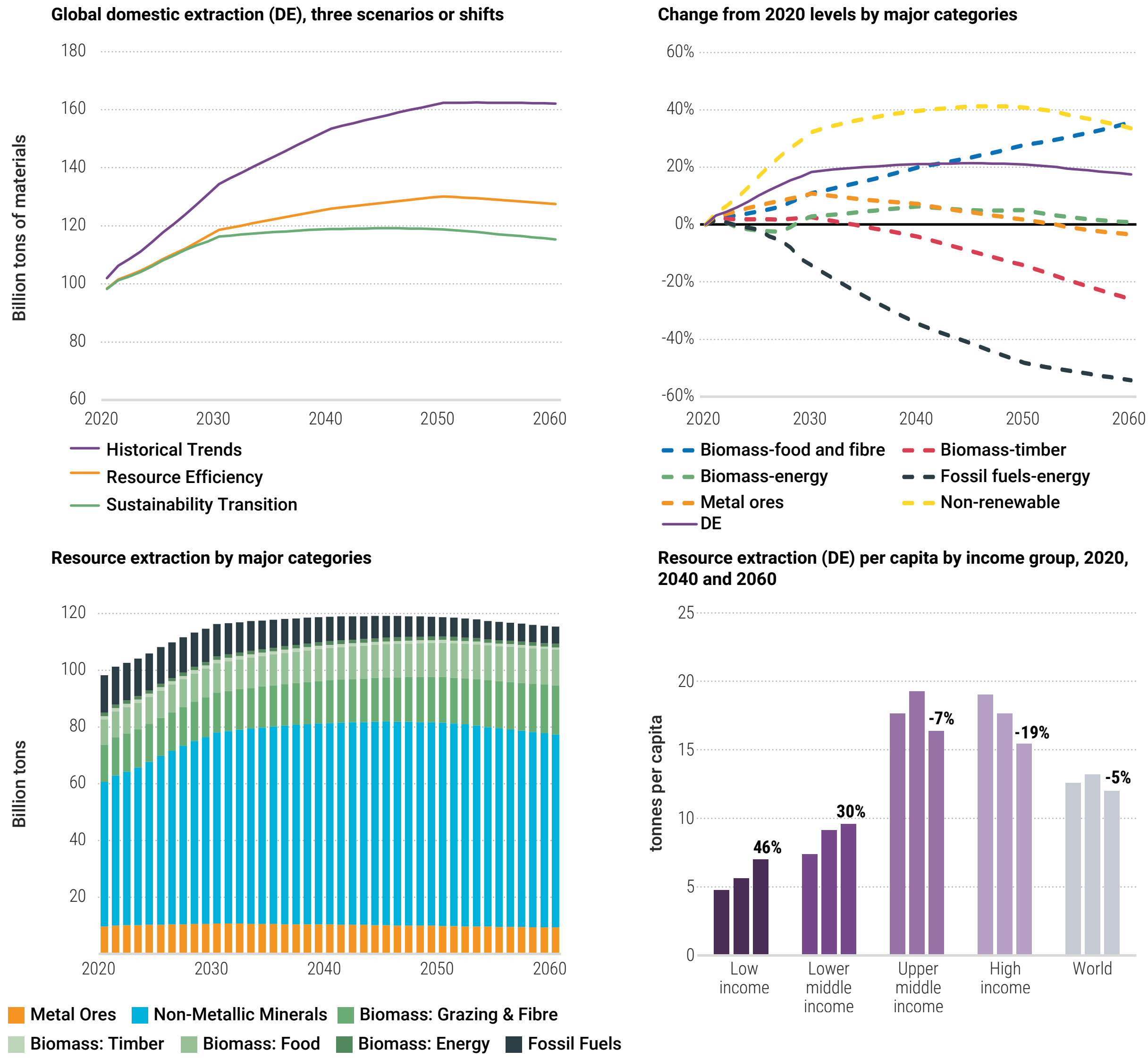
Figure 4.7: The outlook for resource extraction in the Sustainability Transition scenario.



Note: Bottom left panel – percentages shown are change in per capita resource extraction from 2020 to 2060 for each group.
Source: GRO24 scenario modelling.

Figure 4.8 provides an end-use perspective on resource use. This presents the material footprint of provisioning systems and country groups, using supply chain analysis to allocate resources to their final use and location. As in Chapter 2, results are provided for the four provisioning systems covered in the report, but also for other systems (communication and waste management and resource recovery (WMRR)). Overall, these show that all provisioning systems become more resource efficient, with aggregate resource use increasing only for the food system, reflecting healthier and more sufficient diets as well as global population growth. Built environment and food continue to account for the majority of resource use, increasing slightly from 67% to 70% over the period to 2060. Per capita material footprint levels and trends for material footprint for each income group are similar to those for domestic extraction, but vary more significantly when comparing net resource importers and exporters.

Figure 4.8: The outlook for material footprint (MF) resource use in the Sustainability Transition scenario.

Note: The MF analysis is based on GTEM results for the resource efficiency, climate and energy treatments, before accounting for just transition measures. Percentages shown are change in per capita material footprint from 2020 to 2060 for each group.

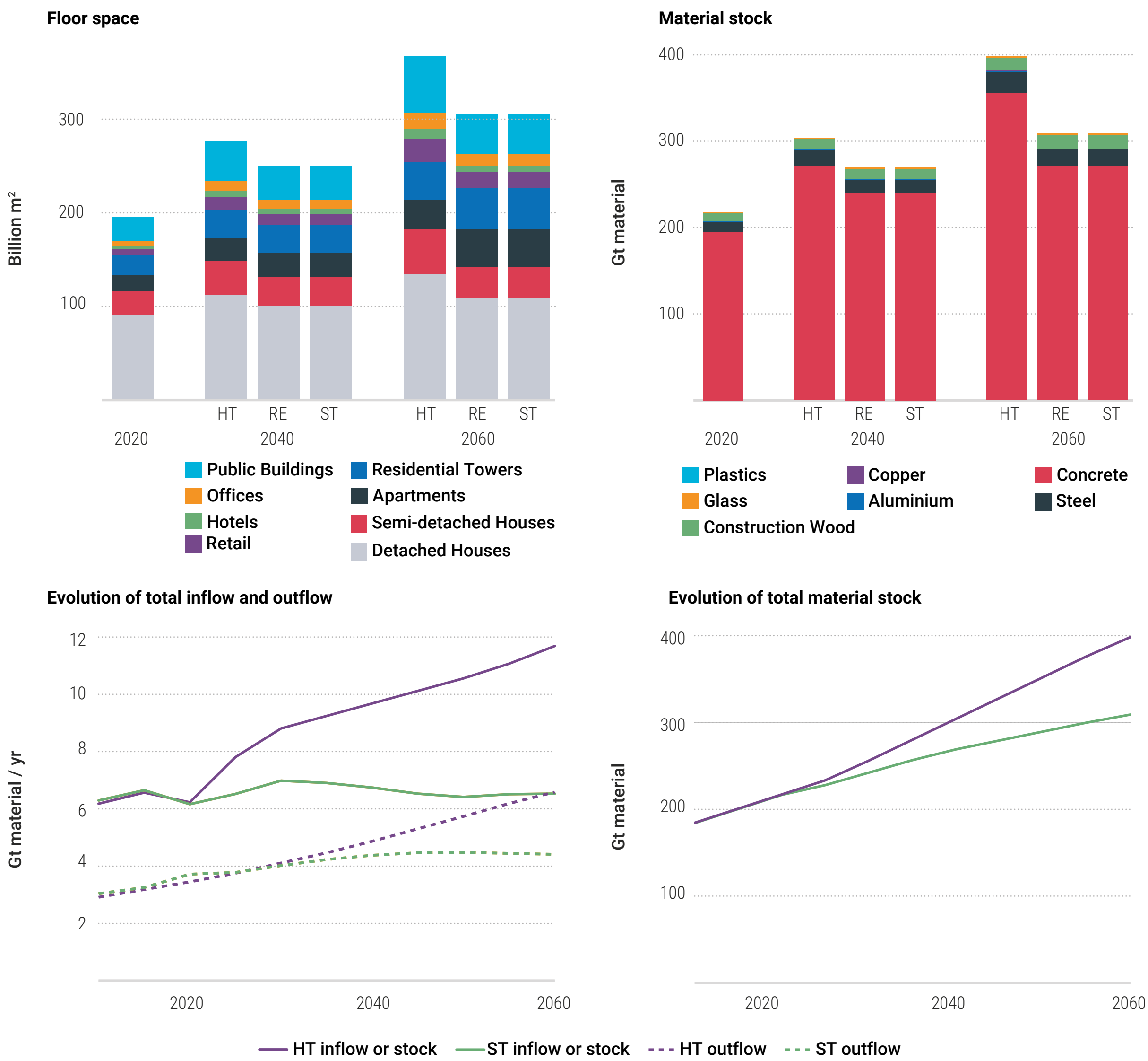
Source: GRO24 scenario modelling.

In-depth examination of resource use in buildings

It is useful to examine resource and energy use associated with the built environment, given that housing accounts for around half of all resource use (see Figure 4.8 above). According to the analysis, the stock of materials in the built environment at the global level will continue to grow until 2060 in all scenarios. The key reason is that, in many parts of the world, basic infrastructure still needs to be built up, given the expected economic and population growth. The most rapid increase is projected for service sector floor space, leading to mostly concrete demand.

The IMAGE-MAT model findings are contrasted with Historical Trends (HT), a stand-alone approach to resource efficiency (RE) and the Sustainability Transition (ST) scenario, which combines resource efficiency with climate and energy measures.

Figure 4.9: Resource use in buildings in the Sustainability Transition scenario.



Note: HT refers to Historical Trends. RE indicates resource efficiency assumptions only. ST includes both resource efficiency and climate and energy assumptions.
Source: GRO24 scenario modelling.

As part of the resource efficiency strategy, the analysis assumes lower commercial floor space, a shift in housing type, more use of lighter materials and lifetime extension of buildings (see Annex 7.3.3 for details). To some extent, this strategy can mitigate the increase in floor space per capita and thus the demand for new materials The need for new floor space area in developing countries, however, more than outweighs the efficiency assumption and globally there is still an increase in floor area (Figure 4.9a) and materials (Figure 4.9b). The reduction in material stock compared to the Historical Trends scenario is about 25%. The Sustainability Transition scenario also includes climate policy, but this does not have an additional impact on demand for floor space.

The inflow of materials into the building stock is significantly larger than the outflow for all scenarios over this period. The demand for construction materials doubles under the Historical Trends scenario but remains at roughly 6 Gt/year under resource efficiency assumptions (Figure 4.9 above). In the very long term, such stabilized demand will eventually lead to a stabilization of the stock. The dynamics imply that the outflow of demolition waste will remain lower than demand until 2060 even under resource efficiency assumptions, which means that an inflow of virgin materials will be needed over the period as a whole.

Contributions of different measures to resource use and impact decoupling

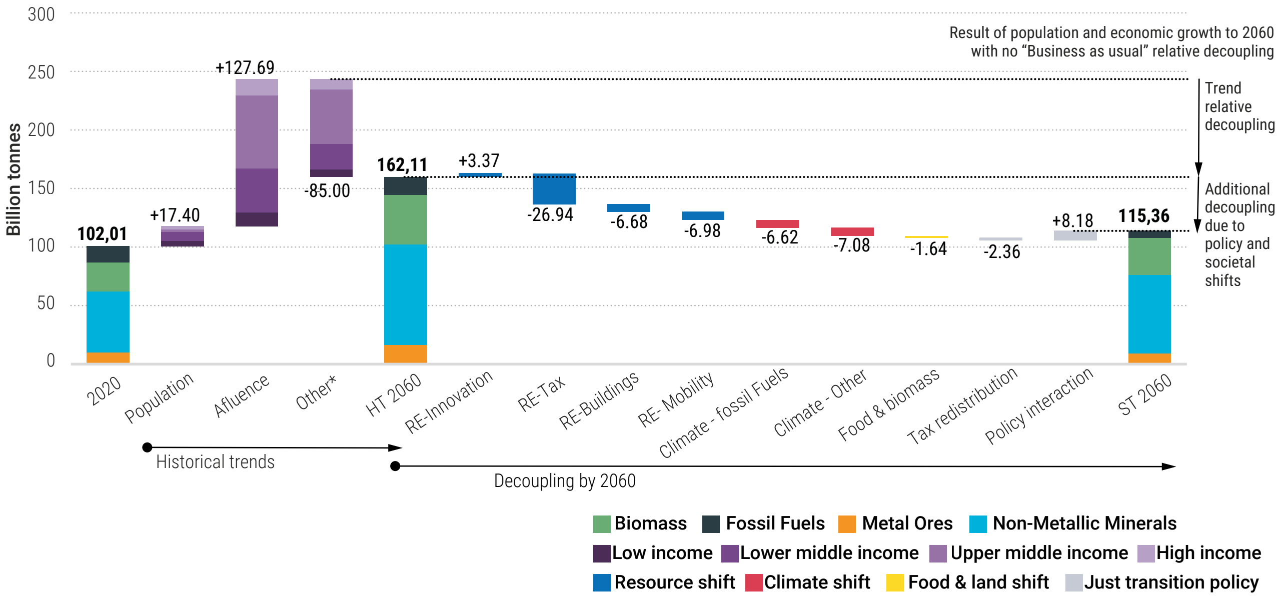
Although the Historical Trends scenario indicates relative decoupling of resource use, resource-related pressures and impacts increase significantly from current levels. Resource use increases 59% to 2060, while the value of global economic activity increases 150%, driven primarily by economic growth in upper middle-income countries.

These risks and pressures are significantly reduced under the Sustainability Transition scenario, which suggests aggregate and per capita global resource extraction peak and begin to decline around 2045 and 2030 respectively (see above).

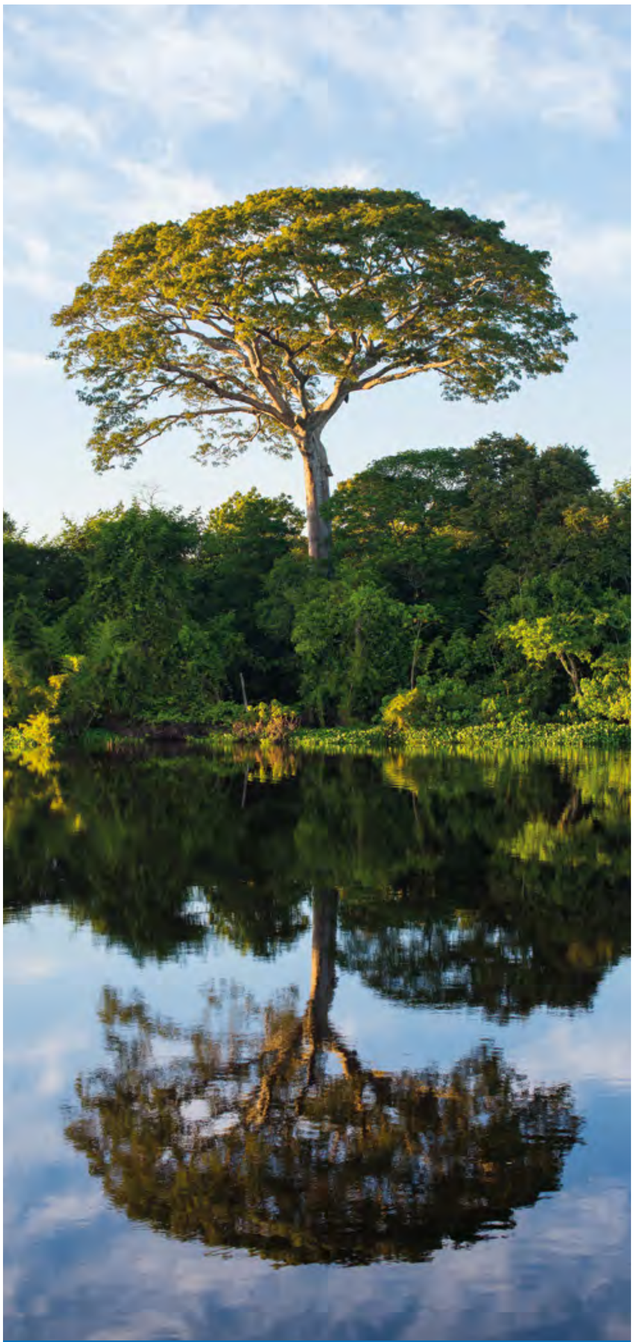
According to the modelling, the resource efficiency shift makes the largest contribution to this additional decoupling. These measures avoid an additional 37 billion tonnes of resource extraction by 2060, accounting for around two thirds of the gross reductions in resource use relative to Historical Trends. The climate shift makes an important but smaller contribution to decoupling resource use, avoiding 13 billion tonnes, while the food and land shift reduces aggregate biomass extraction by around 1.6 billion tonnes.

The analysis identifies two rebound effects, where scenario elements increase global resource use. The first is the innovation component of the resource efficiency treatment, which in isolation would add 3.4 billion tonnes (2.1%) to global resource use (see Hatfield-Dodds *et al.* 2017). The second arises from policy interactions, where improved diet and more equal global distribution of income result in improved productivity in lower income nations, boosting economic activity and resource use relative to Historical Trends. However, these rebound effects are relatively modest in aggregate, and are more than offset by reductions in resource use associated with other elements.

Figure 4.10: Contributions of different shifts and scenario assumptions to resource use decoupling.



Note: Bold numbers indicate net global domestic extraction (DE). Other includes changes in economic structure and trend technology change within economic sectors. The reduction in resource use for food and land treatment is the change in biomass extraction, not total resource use.
Source: GRO24 scenario modelling



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4.3.4. Key results for climate and energy

The climate and energy shift includes measures to reduce global greenhouse emissions including improved energy efficiency and productivity, energy decarbonization through increased renewable electricity and electrification (displacing fossil fuel use in other sectors) and carbon removals. These measures are aligned to SDGs 7 and 13, promoting affordable clean energy and action to achieve the Paris climate goals.

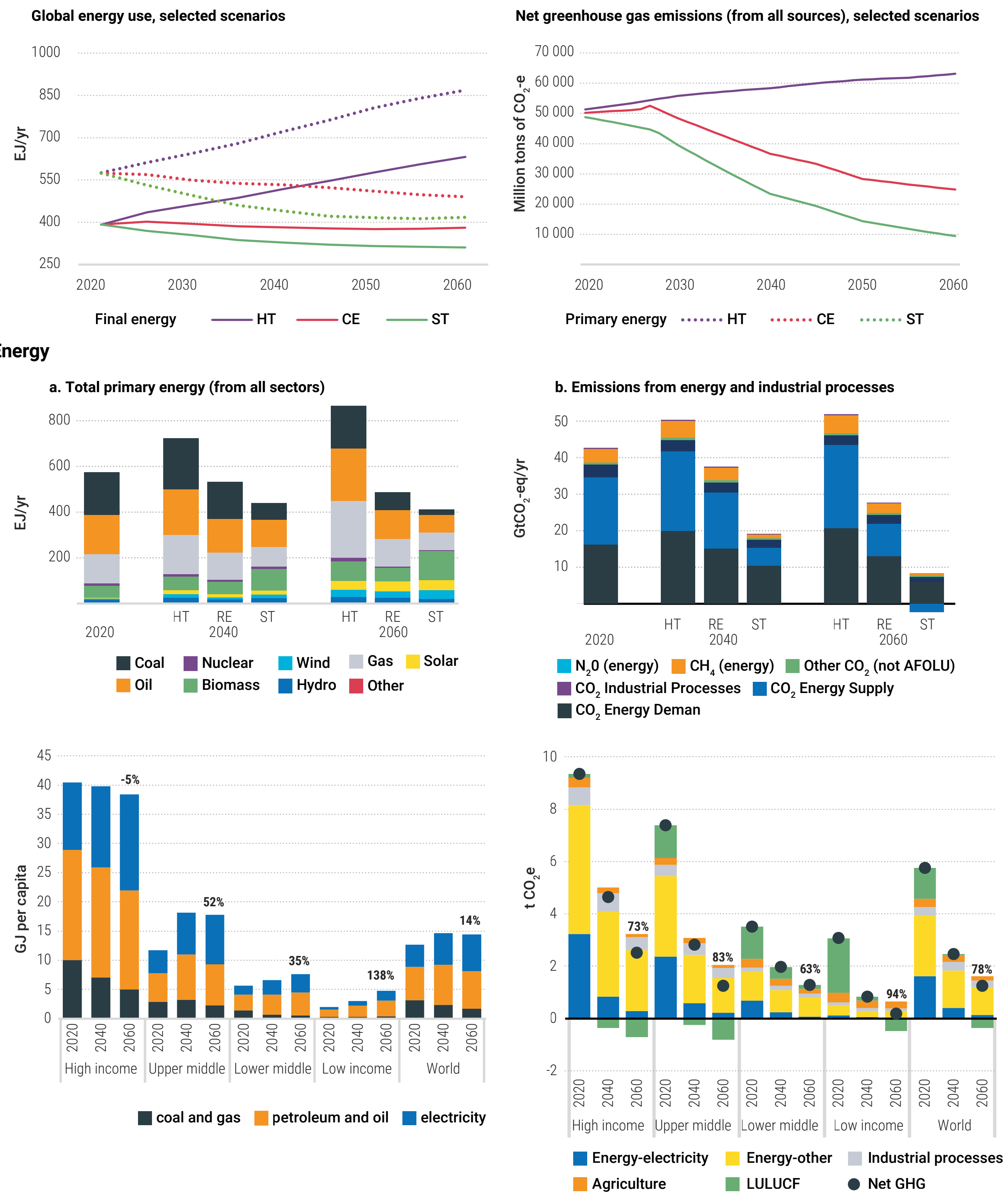
In contrast to the outlook for resource use, the Sustainability Transition scenario foresees energy efficiency measures driving down energy supply and use by 2040, followed by more gradual reductions by 2060. As shown in Figure 4.11, final energy consumption falls 16% by 2040 and a total of 21% by 2060. Total primary energy (measuring energy inputs before generation and system losses) falls 23% by 2040 and 27% by 2060.

Consistent with other climate scenario modelling, the analysis shows climate action as effective in driving substantial reductions in greenhouse gas emissions, with net emissions falling by around 50% from 2020 by 2040 and around 80% by 2060.

The analysis identifies strong decoupling of energy supply and use from greenhouse gas emissions, with the energy mix shifting decisively away from fossil fuels. The share of renewable energy rises from around one sixth of supply in 2020, to around a third in 2035 and then to two thirds in 2060.

In terms of per capita household energy use in high-income countries with elevated energy consumption, energy supply per person decreases 5% over the 40 years to 2060. Other income groups see rises by 2060, but the rate of increase varies significantly. Energy supply per person doubles in the lowest income group. Reductions in net emissions per person are more uniform across countries, falling 95% in high-income countries and by 84% for the world as a whole, largely driven by the decarbonization of national and global energy systems.

Figure 4.11: The outlook for energy and greenhouse gas emissions in the Sustainability Transition and other scenarios.



Note: CE indicates climate and energy shift only. ST includes both resource efficiency and climate and energy assumptions. Household energy consumption results subject to review.

Source: GRO24 scenario modelling.

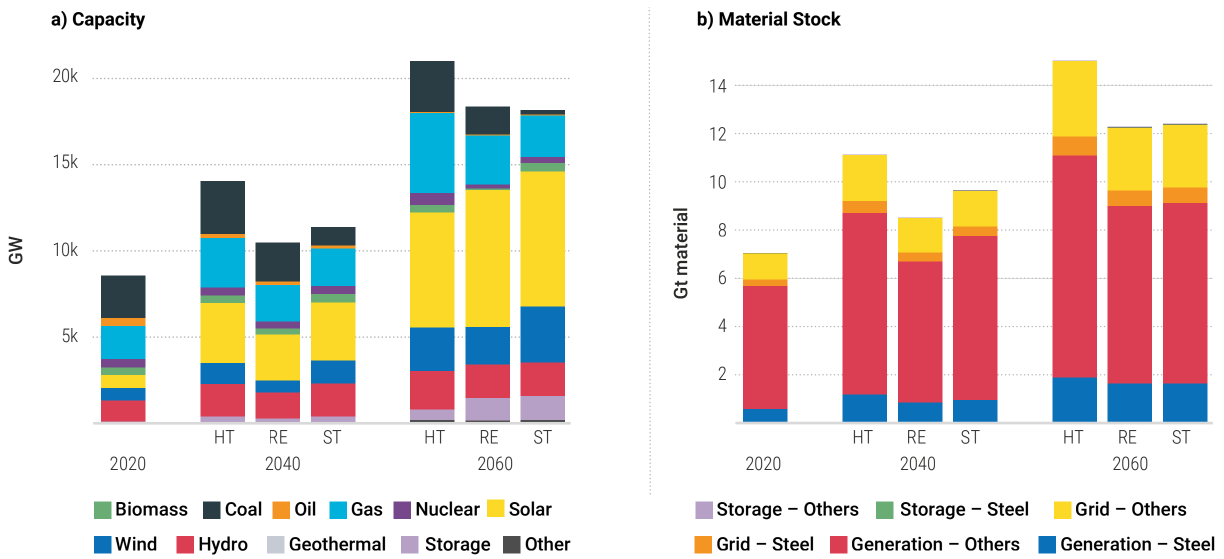
In-depth examination of electricity generation

Electricity plays a crucial role in the Sustainability Transition, both through decarbonizing existing electricity supply, and through enabling electrification of processes currently powered by fossil fuels. The Historical Trends scenario projects a rapid increase in electricity supply and use, and a shift away from fossil fuel generation to renewables (reflecting relative costs and currently implemented policies). Implemented in isolation, the analysis finds resource efficiency measures would reduce electricity demand, and therefore reduce the need for installed capacity. To some extent, in the medium term this is offset by climate policy measures accelerating electrification and the switch in energy mix, largely due to a greater move towards electric cars (see Annex 7.3.3 for details). Electricity system demand for materials reflects these trends. The Sustainability Transition sees higher material demand than the resource efficiency shift (in isolation) in 2040, driven by the medium-term building up of renewable electricity infrastructure.

In-depth examination of building energy use and greenhouse emissions

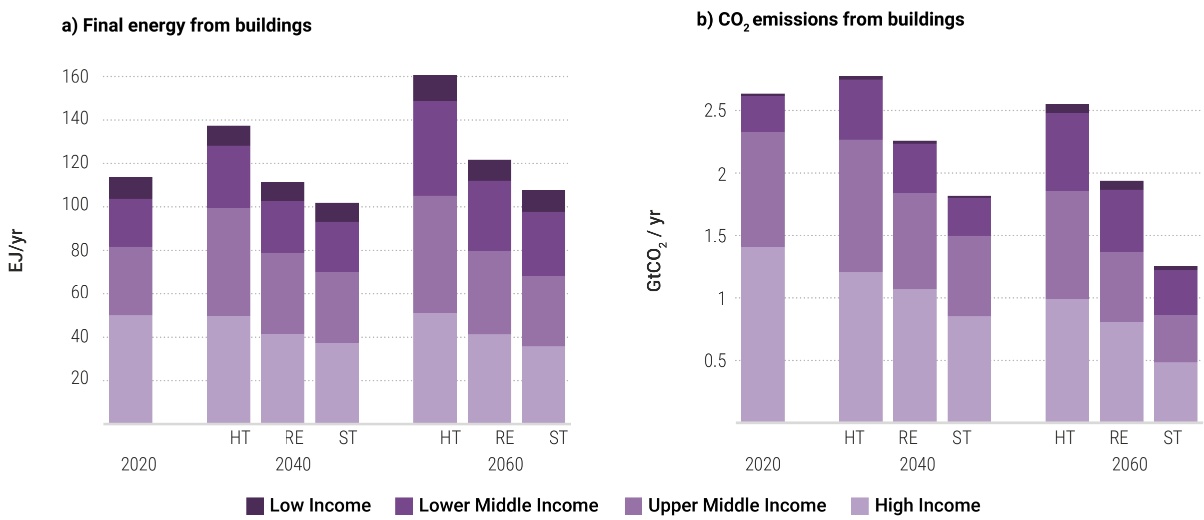
The diffusion of improved building standards globally also promotes more efficient energy use for heating, cooling, hot water, appliances and lighting, thereby reducing total energy use in the Sustainability Transition scenario. Resource efficiency measures account for around half of the reduction in greenhouse gas emissions from buildings in 2060, with climate and energy measures accounting for the other half, as shown below.

Figure 4.12: Electricity system capacity and resource use in the Sustainability Transition and other scenarios.



Note: CE indicates climate and energy shift only. ST includes both resource efficiency and climate and energy assumptions.
Source: GRO24 scenario modelling.

Figure 4.13: Energy use and greenhouse emissions from buildings in the Sustainability Transition scenario.



Note: RE indicates resource efficiency assumptions only. ST includes both resource efficiency and climate and energy assumptions.
Source: GRO24 scenario modelling.

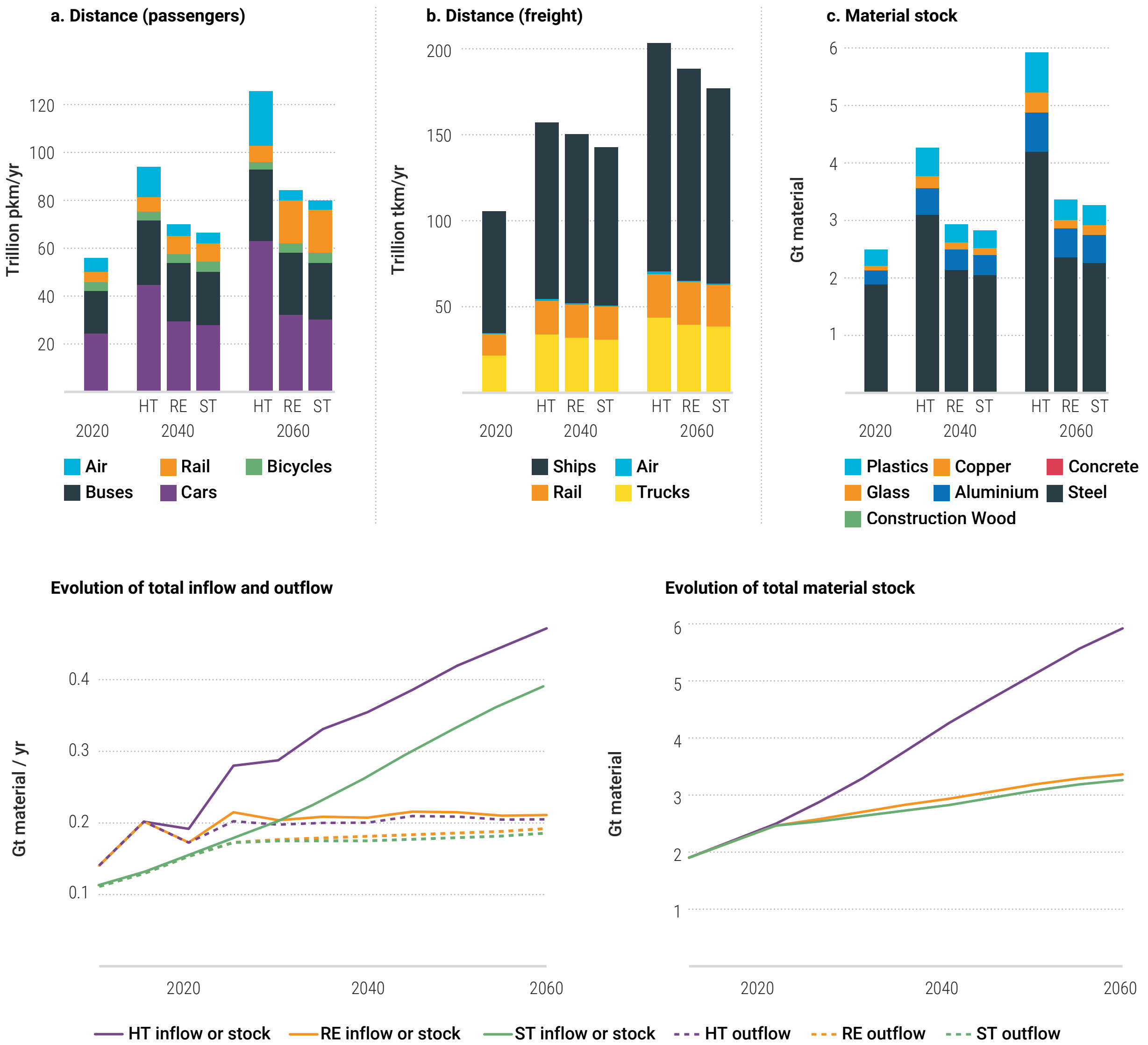
In-depth examination of mobility and transport

Transport accounts for more than one fifth of global GHG emissions, and the growth of road and air transport is a major driver of increasing emissions in the Historical Trends scenario.

The analysis finds that climate policies and especially resource efficiency measures slow the growth of transport demand for passengers and freight, as well as resource demand from the transport system. Specific measures include more intensive use of cars, longer asset life and some modal shifts (see Annex 7.3.3). This results in a gradual increase in the resources embodied in vehicles (with a larger increase in the number of vehicles). The analysis projects that total steel use will increase modestly from current levels, contrasting with much more dramatic growth seen under Historical Trends. The analysis also finds that resource efficiency measures have the largest effect on stock inflows and outflows. It is important to note that the current analysis does not fully account for potential to implement circular economy policies to reduce virgin material inputs to vehicle production.

Consistent with the whole-of-economy findings presented above, the analysis finds significant potential to improve transport energy efficiency (such as energy use per passenger kilometre) and to decouple emissions from transport energy use. More livable and compact design of settlements slows the growth of transport demand while meeting mobility needs, reducing travel time and energy consumption. Climate policies support shifts in the vehicle fleet to electric rather than fossil fuel based, reducing greenhouse emissions from current levels, and supporting improved air quality. As before, the analysis finds that the separate resource efficiency and climate policy options are highly complementary in promoting lower energy costs and reduced greenhouse gas emissions.

Figure 4.14: Transport task and resource stocks and flows in the Sustainability Transition and other scenarios.



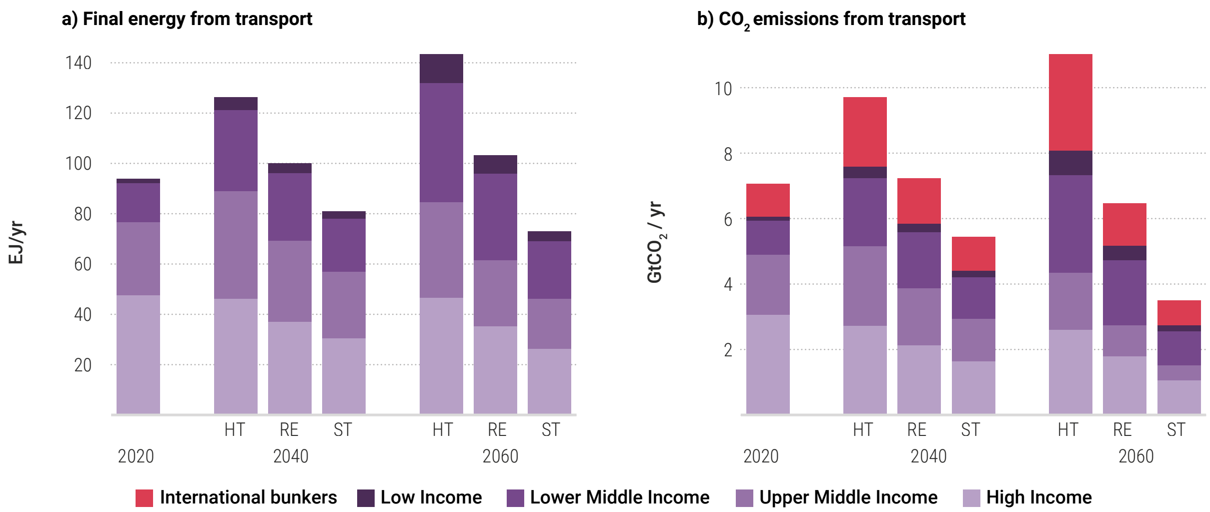
Note: RE indicates resource efficiency measures only. ST includes both resource efficiency and climate and energy assumptions.
Source: GRO24 scenario modelling.

Different measures for decoupling greenhouse emissions from energy and economic growth

A rising tide of global and national climate policies and action has already bent the curve for global emissions under current policies. Prior to 2010, emissions were projected to more than double by 2050, including by catalysing lower renewable energy costs, particularly for wind and solar power.

The Sustainability Transition scenario builds on this momentum, putting the world on track to achieve the more stringent end of Paris climate goals. The analysis finds that energy-system abatement accounts for around three fifths of overall global emissions reductions relative to Historical Trends, including improved energy efficiency and productivity (6.0 $GtCO_2eq$) and switching from fossil fuels to renewable energy (24.9 $GtCO_2eq$), including through electrification of transport and industry. Most of the other abatement in the scenario projections is achieved through reduced land sector emissions and deployment of CO_2-removals technologies. Emissions from land use, land use change and forestry (LULUCF) fall from 2020 levels, with gross emissions of 9.1 $GtCO_2eq$. Land sector emissions fall steadily, with the sector providing net sequestration shortly after 2040, rising to 3.5 $GtCO_2eq$ of sequestration in 2060. By contrast, gross emissions from LULUCF under Historical Trends remain above 7.3 $GtCO_2eq$ each year through to 2060. Reductions in non-CO_2 agricultural and industrial emissions make a relatively modest contribution to total abatement.

Figure 4.15: Transport energy use and greenhouse gas emissions in the Sustainability Transition and other scenarios.



Note: RE indicates resource efficiency measures only. ST includes both resource efficiency and climate and energy assumptions.
Source: GRO24 scenario modelling.

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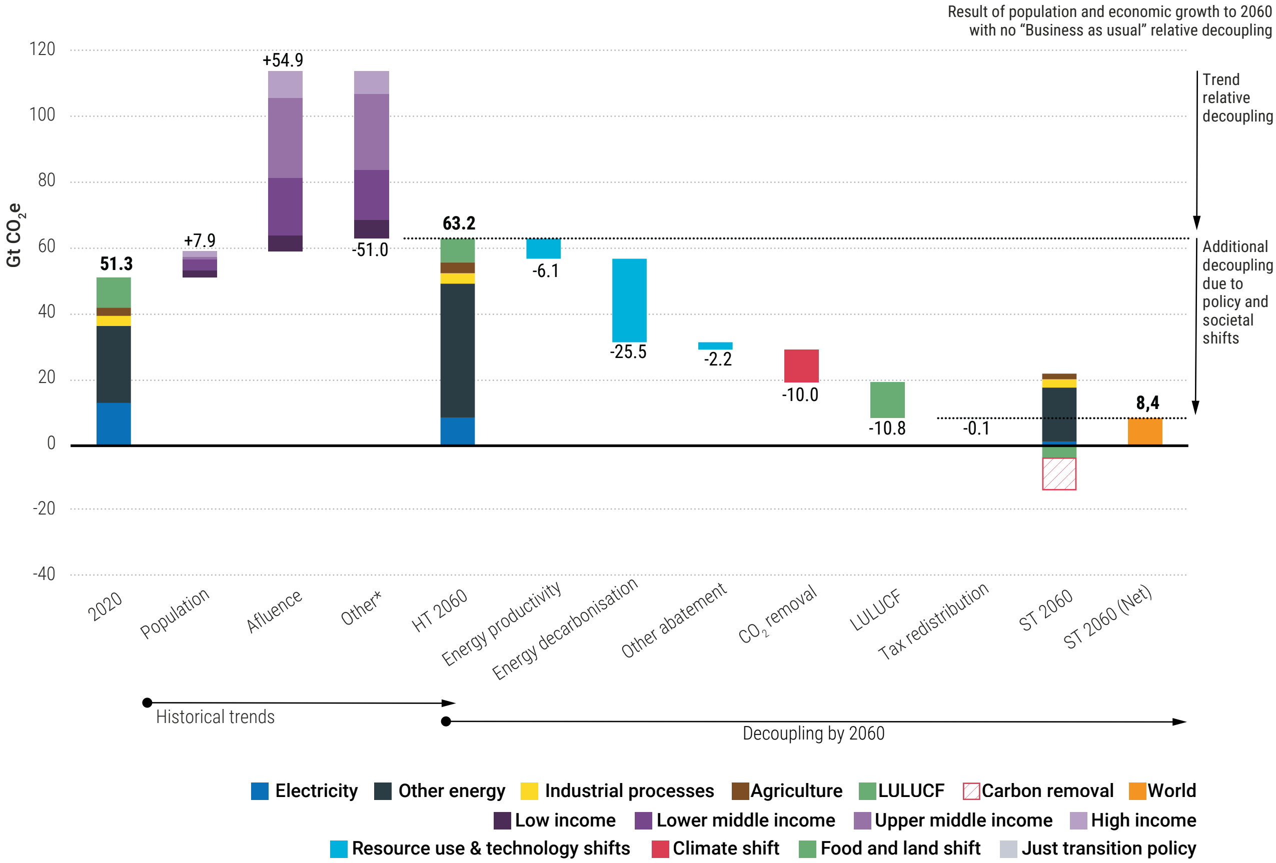
Figure 4.16: Contributions of key shifts and processes to decoupling greenhouse gas emissions from economic growth.



Note: Bold numbers indicate net global domestic extraction (DE). Other includes changes in economic structure and trend technology change within economic sectors.

Source: GRO24 scenario modelling.

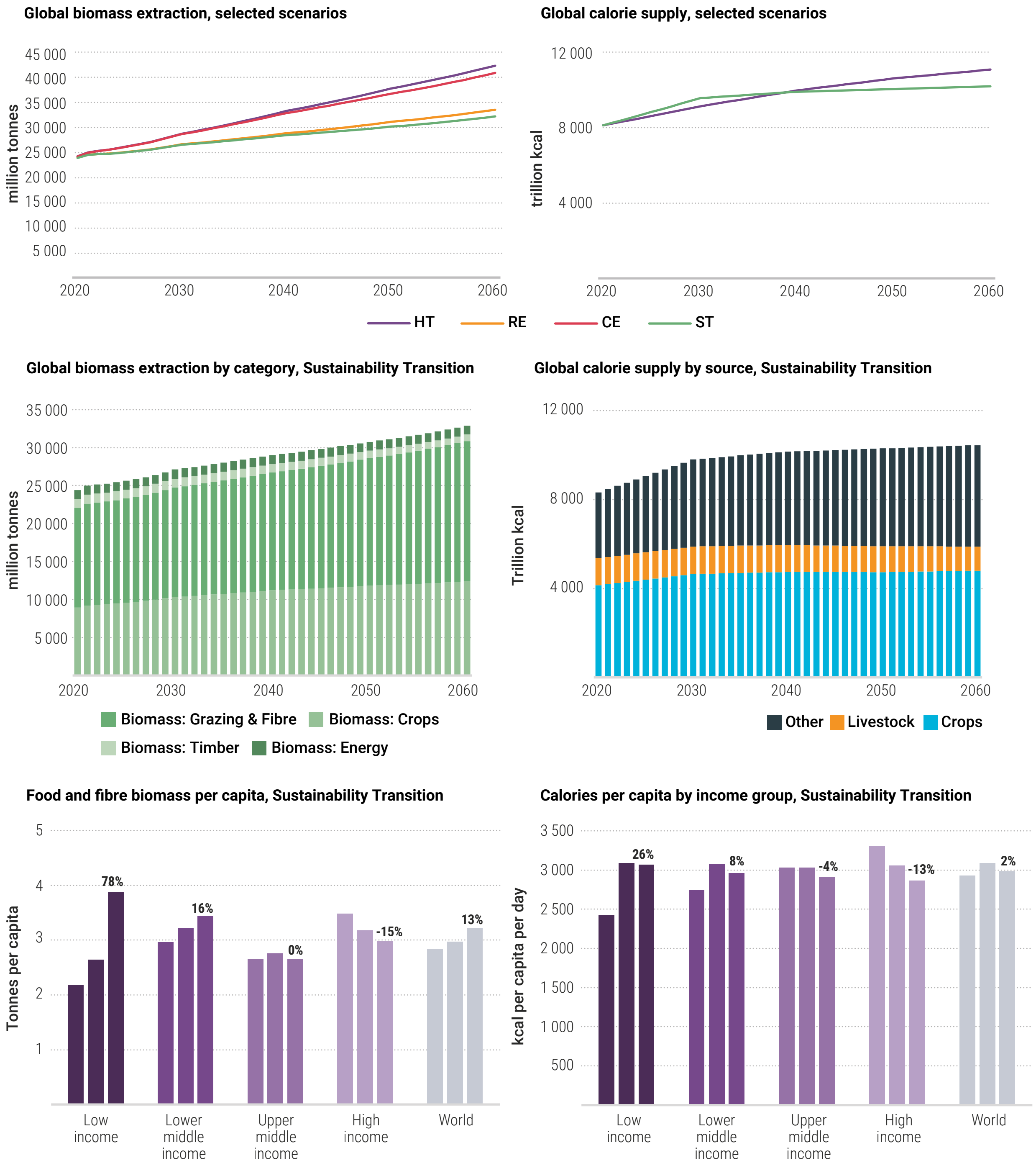
4.3.5. Key results for food and land

The food and land shift combines measures to promote healthy diets, reduce food system waste, promote protection of native habitat and ecosystems and limit water extraction in stressed water catchments. These measures are aligned to SDGs 2, 3, 14 and 15, promoting zero hunger, healthy diets, reduced food waste; and protecting landscapes, habitat and biodiversity, freshwater resources and marine resources and ecosystems.

Achieving healthy and sufficient diets requires a net increase in per capita food biomass extraction to 2030, even after accounting for decreased food system waste, with a more gradual rate of increase from 2030 to 2060 to balance population growth. This sees higher early growth in calorie supply and food and fibre biomass extraction in the Sustainability Transition scenario than projected for Historical Trends (as shown in Figure 4.17).

Achieving healthy and sufficient diets also sees a rebalancing of global per capita calorie intake, increasing by 26% and 8% by 2060 in low and lower middle-income countries, while decreasing by 15% over the same period in high-income countries. Changes in per capita food and fibre biomass reflect a similar pattern, with very strong growth in low and lower middle-income nations and corresponding decreases for upper middle and high-income countries. Higher agricultural productivity also increases self-sufficiency in food production in lower income countries, and contributes to faster growth in food and fibre biomass in these countries over the period.

Figure 4.17: The outlook for biomass, food, and calorie supply in the Sustainability Transition and other scenarios.



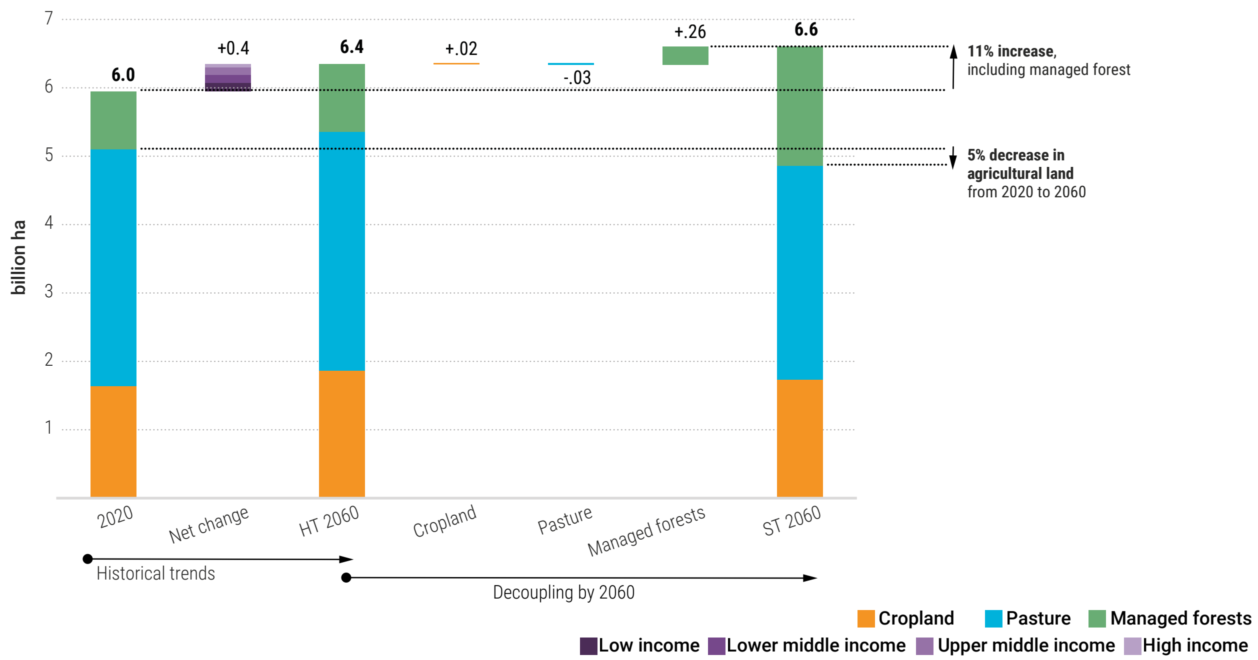
Note: HT = Historical Transition, RE = Resource Efficiency shift, CE = climate and energy shift, ST = Sustainability Transition. Columns in bottom left and bottom right show values for 2020, 2040 and 2060 for each income group.
Source: GRO24 scenario modelling.

Decoupling pressures on land and ecosystems from food and healthy diets

According to the modelling results, improved agricultural productivity can supply healthy and sufficient food for a larger global population while reducing the area of cropland and pastures by 5% by 2030 and maintaining this area up to 2060. However, the analysis also projects a shift of some natural forest area into forests managed for timber extraction.

As noted above, more sustainable food and land settings avoid around one third of the biodiversity loss projected under Historical Trends. This represents relative rather than absolute decoupling, with losses of biodiversity continuing as a lagged effect of past land conversion and land management, thereby affecting future biodiversity outcomes despite net reductions in the area of agricultural land.

Figure 4.18: Contributions to decoupling land use change from food supply.



Note: Bold numbers indicate net domestic extraction

Source: GRO24 scenario modelling.

4.3.6. Supporting reduced inequalities, sufficiency and a just transition

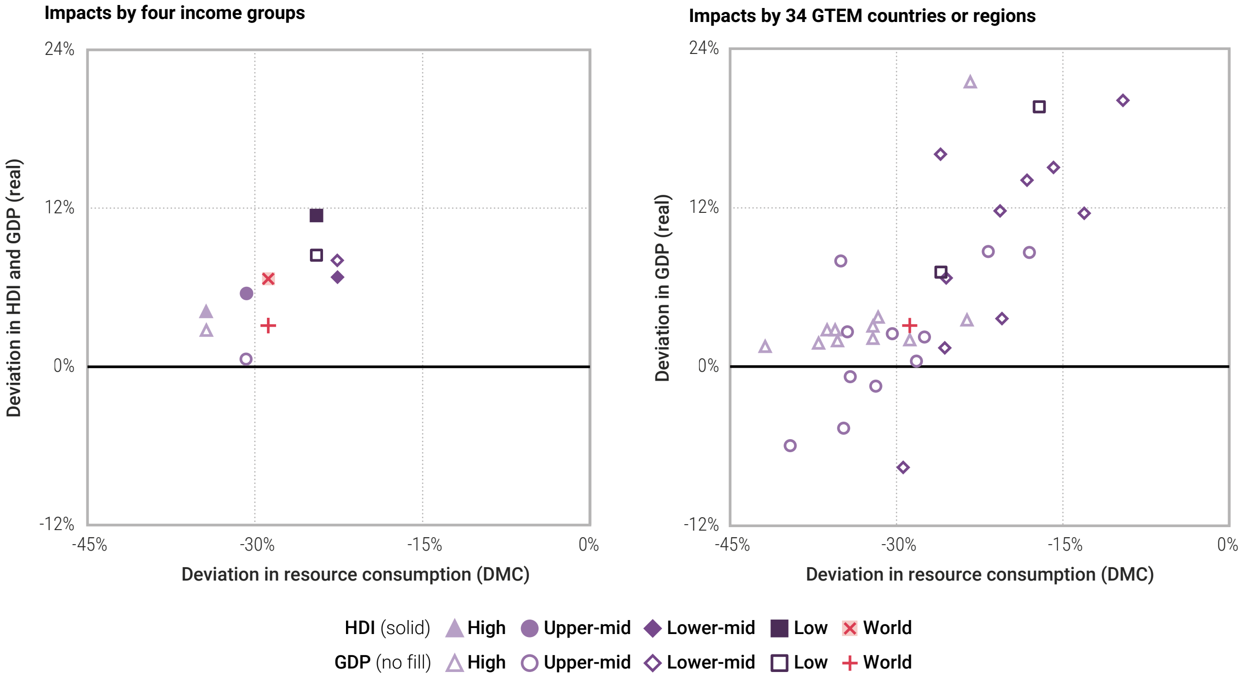
The Sustainability Transition scenario also includes several measures to support a more fair and equitable global development trajectory, and to ensure that measures to improve resource management and environmental outcomes do not impose a disproportionate or unreasonable burden on low-income or disadvantaged groups. The measures are aligned to multiple SDGs, particularly SDG 10 relating to reduced inequalities.

The modelling and scenario analysis finds that the world does not have to choose between economic growth and development or stronger environmental protection. Well-designed and well-implemented polices can deliver both at the same time, lifting economic growth and well-being while also moderating pressures and reducing environmental impacts.

The analysis finds that the value of economic activity (GDP) grows more dramatically than the comprehensive and balanced human development index (HDI) – with global GDP per capita up 109% to 2060 while the HDI grows 24%. However, it finds that the attention to distribution and supporting a more just transition results in larger impacts on HDI than on GDP per capita (as shown below), when comparing the Sustainability Transition scenario to Historical Trends.

The analysis also finds lower income countries enjoy larger gains in well-being from the Sustainability Transition, as indicated by larger improvements HDI and GDP gains (relative to Historical Trends), while high and upper middle-income nations typically achieve larger reductions in resource use.

Figure 4.19: Impacts of the Sustainability Transition on resource use (DMC), economic activity (GDP) and well-being (HDI) relative to Historical Trends in 2060. Results for world, income groups and 34 GTEM countries and regions.



Note: Results for ST versus HT in 2060. HDI is only calculated for income groups, not the individual 34 GTEM regions due to data availability. The HDI calculation for the Sustainability Transition scenario uses education and life expectancy projections for SSP1.

Source: GRO24 scenario modelling (GTEM results and SSP demographic projections).

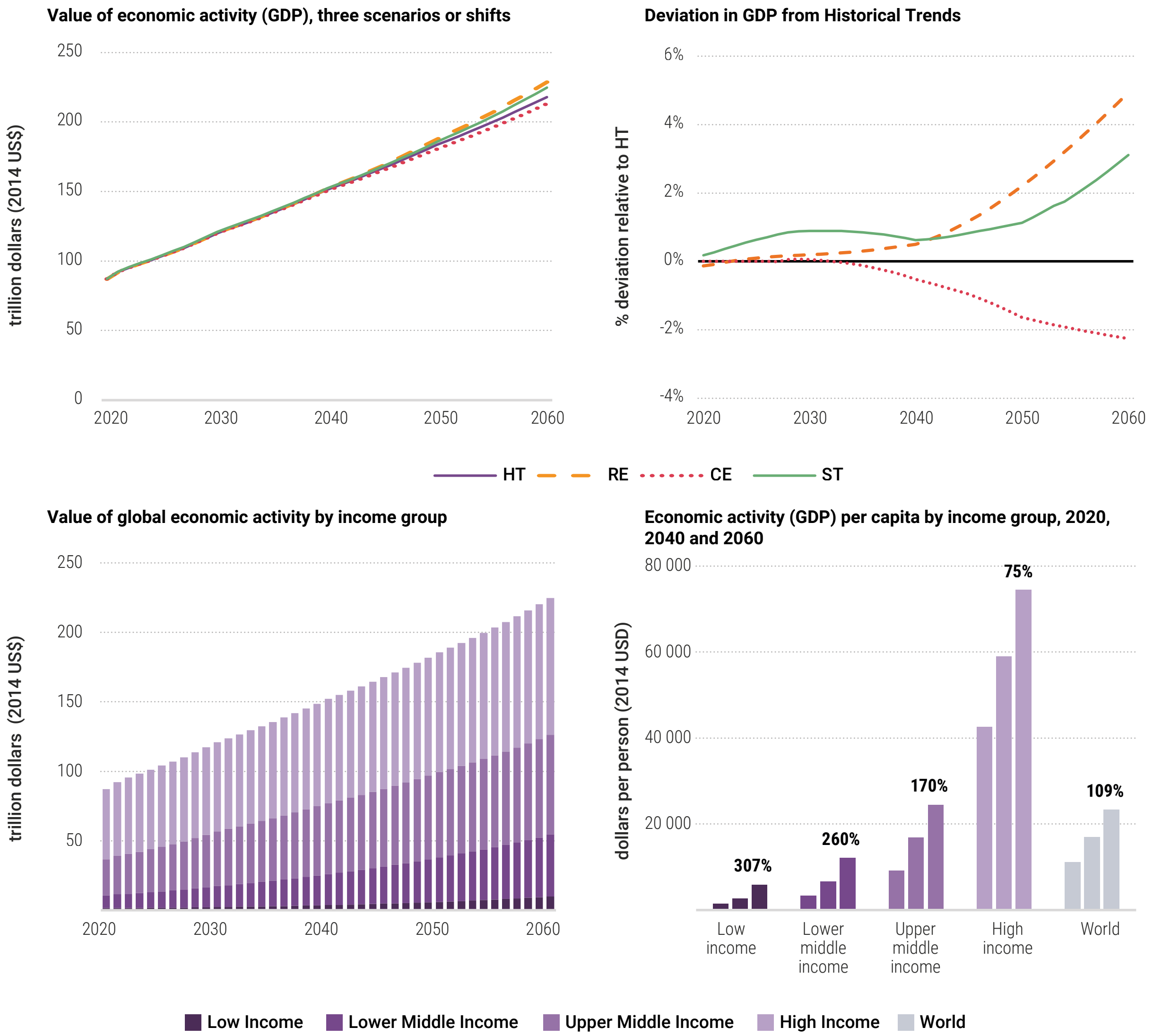
The Sustainability Transition scenario projects stronger trend economic growth than under Historical Trends, with global GDP 2.6% higher than Historical Trends in 2060. It is important to note, however, that different policy measures pull in different directions. In line with most other studies, the analysis finds that climate and energy policy measures reduce trend GDP growth. However, this dampening effect is more than outweighed by the economic benefits of resource efficiency, which in isolation would boost GDP by 4.9% in 2060. In interpreting these results, it is important to note that the modelling does not account for the benefits of avoided climate change or other environmental impacts and damage, and thus is likely to understate the economic benefits of policies included in the Sustainability Transition scenario.

Examining the results on a per capita basis, GDP per person more than doubles in the Sustainability Transition Scenario, increasing by 109% between 2020 and 2060, rather than 100% under Historical Trends.

Low and lower middle-income countries benefit more from this uplift in economic growth, helping to narrow existing economic inequalities. This builds on the partial convergence in GDP per capita under Historical Trends, driven by underlying income and productivity growth in low and lower middle-income countries that is much stronger than the global average (with GDP per capita increasing to between 3.6 and 3.8 times 2020 levels, relative to the global average of 2.0 times). Together, this indicates the ratio of GDP per capita across low- and high-income countries reduces by around a third between 2020 and 2060. However, the distribution of income and wealth remains vastly unequal.

As noted above, these strong growth and development outcomes are complemented by improved sufficiency. Per capita resource use in lower income countries increases to an average of 7 tonnes per capita or more, which is consistent with dignified living for all, while per capita resource use (DE) and material footprints (MF) fall in higher income countries with elevated resource consumption.

Figure 4.20: The outlook for economic growth and GDP per capita in the Sustainability Transition and other scenarios.



Note: Global GDP (or aggregate global Gross Domestic Product) is also referred to as Gross World Product. HT = Historical Transition, RE = Resource Efficiency shift, CE = climate and energy shift, ST = Sustainability Transition.

Source: GRO24 scenario modelling.

4.4. Conclusions

The scenario modelling combines the strengths of three established global models to explore and assess an integrated set of policies and societal shifts, representing more than 12 of the SDGs (see Figure 4.1).

For the first time, the analysis demonstrates the potential for integrated policy action to decouple pressures and impacts across multiple energy and resource use domains, while improving well-being outcomes and reducing economic and resource-use inequalities.

- It finds resource pressures moderate in the Sustainability Transition scenario. Global resource extractions peak in 2045 and then stabilize (falling slightly) to around 20% above 2020 levels by 2060. The mix of resource use shifts towards renewables, with food and fibre biomass extraction increasing 40% by 2060. Primary energy use falls by around 25% by 2040 and then stabilizes. The area of agricultural land shrinks by around 5%, while agricultural output increases.
- It also finds key impact indicators fall from current levels for climate, while biodiversity impacts are moderated. Greenhouse gas emissions fall by 81% by 2060. For life on land, the legacy effects of past actions drive ongoing biodiversity losses. However, sustainability measures result in 38% lower impact than projected for Historical Trends.
- These reductions in pressures and impacts are achieved while well-being and economic performance improve, with HDI up 24% globally by 2060 and GDP per capita up 109%, and both higher in the Sustainability Transition than projected for Historical Trends.

The modelling demonstrates that achieving these reductions in pressures and impacts can make it easier for developing countries to achieve their socioeconomic and environmental objectives under the 2030 Sustainable Development Agenda thanks to stronger economic growth and reduced economic inequalities.

The analysis also finds strong synergies between resource efficiency, greenhouse gas abatement and land use policies – with resource efficiency contributing to achieving climate mitigation while reducing the overall cost of combined policy ambitions.

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05

Call to action for sustainable resource use – Sustainable prosperity only possible with immediate transformative action

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Main policy findings

The science is clear: it is no longer a question of whether a transformation towards global sustainable resource use is necessary, but how to make it happen now. Such a transformation needs to be just, making it possible to reach dignified living standards for all within the limits of the planet.

Action for sustainable resource management should be integrated with other global sustainability and environmental agreements and be science based, guided by specific targets plus monitored and evaluated.

Implementing the shifts modelled in the Sustainability Transition scenario in Chapter 4 can significantly reduce environmental impacts and requires determined action in resource governance, finance, trade, consumption and production, as well as measures relating to specific provisioning systems.

Immediate action by policymakers at all levels (national, regional and international) is needed to: integrate natural resource use within global sustainability agendas; define sustainable resource use paths; direct finance and public subsidies towards sustainable resource use; make trade an engine of sustainable resource use through fair trade and local value retention policies; mainstream sustainable goods and services and regulate marketing practices leading to overconsumption; and boost circular economy solutions and businesses.

Moving to low-impact, high-performing provisioning systems is an important part of any transition towards sustainable resource use and dignified living standards for all. This requires specific resource-related actions by system, whose effectiveness is illustrated by the Sustainability Transition scenario and which align with global assessments recommendations. These include (*inter alia*):

- Food: Reducing the demand for the most impactful food commodities, reducing food loss and food waste and protecting and restoring productive land.
- Built environment: Assuring sustainability of the new building stock, retrofitting the existing building stock, more intensive use of buildings and decarbonization of material production.
- Mobility: Cities moving towards active mobility and public transportation, reducing carbon-intensive frequent traveling modalities and decreasing the emission intensity of transport modalities.
- Energy: Decarbonizing electricity supply through the scaling up of low-resource renewable energies and increased energy efficiency, as well as decarbonizing fuels.

5.1 Introduction: Crucial global commitment to a just transformation and sustainable resource use

In 2024, the world faces sustainability challenges of unprecedented proportions, posing increasing impacts and risks. This report demonstrates how the triple planetary crisis of climate change, biodiversity loss and pollution is strongly connected to the use and production of natural resources. At the same time, resources are critical for delivering human development across the globe.

The report also shows how inequitable, ineffective and inefficient current resource use patterns are: while there has been progress in delivering on some of the Sustainable Development Goals (SDGs), global action is not on track to meet goals on ending hunger, access to clean drinking water and sanitation or access to clean energy, among many others by 2030 (SDG tracker 2023). The systems providing us with food, mobility, energy and shelter are responsible for the majority of resource related global impacts including 70% of climate impacts, more than 75% of biodiversity loss and almost 80% of health burden impacts due to pollution. Furthermore, these impacts greatly exceed internationally agreed climate and biodiversity targets.

Moreover, this report shows the unequal distribution of the benefits and impacts from resource use along the value chain: on a per capita basis, high-income countries cause more than 10 times more climate impacts to obtain provisioning systems of food, energy, mobility and built environment than low- and lower middle-income regions. In 2022 alone, more than half of global land-related biodiversity loss occurred in Africa and Latin America due to the extraction of biomass for agriculture and forestry, a great share of which was consumed in higher income countries. However, less than 5% of global value added was generated in those regions. Conversely, almost half of the total global value added of resource use was generated in Europe and North America, while less than 10% of global water stress and biodiversity loss occurred in these regions. Addressing this reality, based on evolving concepts of a just transition, is an essential part of any credible and justifiable way forward (see Box 5.1).

While policy responses to mitigate environmental pressures have proven successful in some cases, the scenario modelling undertaken in this report shows that without fundamental changes it will not be possible to achieve multilateral global climate, biodiversity, pollution and land degradation goals and agreements. For instance, the Historical Trends scenario (which includes current policies agreed to by countries) shows that current Nationally Determined Contributions under the UN Framework Convention on Climate Change (UNFCCC) will still lead to an overshoot of 2 degrees Celsius warming. Loss of natural habitats is also expected to increase.

The science is clear. The key question is no longer whether a transformation towards global sustainable resource consumption and production is necessary, but how to make it happen now. Rapid and far-reaching actions of a type never before attempted must be put into practice (UN Secretary-General 2018). Responses need to address the forces perpetuating and locking us into unsustainable consumption and production patterns, overall and for each provisioning system. Crucially, a sustainable transition needs to address existing socioeconomic inequalities (Swilling and Annecke 2012).

Box 5.1. A just transition – considerations from climate justice literature

(Ekins, 2024, Stopping Climate Change: Policies for Real Zero, Routledge, London/New York.)

The energy transition is one of the main responses to climate mitigation. This includes phasing down the use of fossil fuels (UNFCCC, COP 27)[46] and deploying clean energy sources. These strategies are expected to have profound social and economic implications. In this context, the 2015 Paris Agreement articulated explicit social conditions and constraints on climate action, recognizing the fundamental priority of safeguarding food security. It stipulated that, when taking action to address climate change, Parties should consider their obligations on human rights, the right to health and the rights of indigenous peoples and local communities. These conditions are intrinsically related to justice in the way resources are used.

Carley and Konisky (2020) consider that a just energy transition needs to include, among other aspects, an equitable distribution of material resources and recognition and compensation for the historical context. There is agreement on the fact that more industrialized countries must compensate less developed countries due to their differential contribution to climate change. However, there is no clear agreement on disputes such as whether unexploited fossil fuel reserves in less developed countries should be exploited, considering the remaining carbon-emission budget to meet the global climate targets,[47] or whether these countries should be compensated to avoid this material extraction.[48] Another question relates to the need to compensate established fossil fuel producers to phase down their production, especially when referring to countries that are not poor (Ekins 2024).

The 2015 Paris Agreement also established that Parties, when deploying climate action, should take into account the "imperatives of a just transition of the workforce and the creation of decent work and quality jobs in accordance with nationally defined development priorities" (UNFCCC 2015a). While the need of countries to support domestic workers in carbon-intensive industries is broadly acknowledged, studies across the world illustrate the many challenges that policy interventions are facing (Ekins 2024). For instance, countries will need to support workers and communities displaced by changes to the fossil fuel industry, and address possible inequities based on gender or race, or access to the opportunities created by new energy technologies (Carley and Conisky 2020). There may also be indigenous communities affected by the location of clean energy infrastructure. The transition may also require capacity building and access to clean technologies in developing countries, and especially vulnerable and disadvantaged communities. Homberg and McQuistan (2019) state that the funding required should come from richer countries, to reflect their greater responsibility for climate change, as well as their greater ability to pay for mitigation. In a European context, Sovacool *et al.* (2019) identified no fewer than 120 "distinct energy injustices" in terms of the effects of low-carbon energy interventions.[49] This includes not only effects on employment but also other indirect socioeconomic impacts, such as changes in energy prices or tax regimes.

The energy transition will bring also extensive benefits and allow the rise and development of many sectors. Justice considerations should therefore be put at the core of a transition towards sustainable resource use.

46 https://unfccc.int/process-and-meetings/conferences/sharm-el-sheikh-climate-change-conference-november-2022/five-key-takeaways-from-cop27

47 The study by Williges *et al.* (2022) found that, applying justice criteria to allocate the climate budget to remain well below a 2°C temperature increase, North America, Europe, Australia and Japan had almost exhausted their carbon budgets by 2020. This means that, under their interpretation of climate justice, either the world will not stay well below 2°C or these countries will need to compensate for their emissions by paying countries with significantly larger remaining carbon budgets, which then will need to emit substantially below their allocation.

48 It might be regarded as unjust that richer countries that have already benefited greatly from fossil fuel production continue to do so, while poorer countries are denied these benefits. On the other hand, extraction in countries where it is economically less efficient could result in increased prices, which will have a negative impact of low-income countries that are importing fossil fuels (Ekins forthcoming).

49 Nuclear power in France, smart meters in the United Kingdom, electric vehicles in Norway and solar energy in Germany.

5.2 Some actions in the right direction

Despite the fact that faster and more comprehensive transformations in core systems of consumption and production are needed, steps are already being taken towards global sustainable resource use. These could then be consolidated in the interests of the transition.

At the global level, the United Nations continues its Sustainable Consumption and Production Programme,[50] enhancing its work on circular economy.[51] An intergovernmental negotiating committee has been set up to forge an international legally binding agreement by 2024 to deal with the root causes of plastic pollution (UNEP 2023b). [52] Resource management strategies were included in the global biodiversity targets agreed at the Kunming-Montreal Global Biodiversity Framework at the Convention on Biological Diversity (CBD) in 2022. This commits Parties to actions to reduce the negative impact of resource extraction on nature: for example, reforming harmful subsidies, operationalizing integrated land use planning and enabling sustainable consumption choices (UN CBD 2022a). As for climate, despite resource use being still underrepresented in national climate strategies, the IPCC's 2022 mitigation report highlights the importance of the use of materials, land and water for the first time, along with energy.[53] Despite the huge amount of further action necessary on climate mitigation, UNFCCC COP27 in 2022 established a historic Loss and Damage fund, mandating high-income countries to channel financial resources towards low-income countries that have faced damage from climate change to date (UNFCCC 2022).

Organizations of countries are also acting. For instance, at UNEA-5.2, member states adopted a resolution on sustainable management of metals and minerals (Resolution 5/12), paving the way for deeper international collaboration. The 2022 Berlin Roadmap on Resource Efficiency and Circular Economy (G7 2022) commits G7 countries to action on resource efficiency and circularity in climate and biodiversity action. The G7 has also committed to a Five-Point Plan on Critical Mineral Security, which prioritizes the role of good environmental and social governance for the extractive sector, as well as circular economy levers for reducing virgin critical mineral demand (G7 2023a). In 2023, the G7 also committed to six Circular Economy and Resource Efficiency Principles (CEREP), which aim to facilitate implementation of circular economy levers by the private sector (G7 2023b). The 2023 Indian G20 presidency has emphasized the role of consumption in its deliberations through its cross-cutting Lifestyles for the Environment (LiFE) Initiative. For continued policymaker discourse on resource efficiency and circular economy, the G7 is hosting a Resource Efficiency Alliance, while the G20 is to hold Resource Efficiency Dialogues.[54,55]

There are multiple examples of ongoing and emerging policies or initiatives towards sustainable consumption and production at country and subnational level: several are detailed under relevant recommendations in section 5.5. These are examples to build on.

However, multiple barriers and lock-ins need to be overcome (as detailed in Chapter 1), and changes are not taking place at the speed and scale needed.

5.3 Immediate and decisive action can transform resource use for the benefit of humanity

The Sustainability Transition scenario described in Chapter 4 explores a possible path involving the shifts needed for the sustainable use of resources. The scenario illustrates the contribution of a set of policy packages and societal shifts to decoupling human well-being from resource use and environmental impacts. Results from this scenario show that action now can achieve dignified living standards for all, moderated resource use and decreased environmental impacts by 2060 (as compared to the Historic Trends scenario.

The scenario's policy packages and societal shifts are based on improved resource efficiency and circularity, through strategies such as increased product life spans, reuse and recycling. The scenario also includes sustainable consumption and production shifts, as well as tailored actions on specific provisioning systems towards a just transition (see below and section 5.6). This is reflected in pathways for the decoupling of human well-being from resource use and environmental impacts, which differ by development context (see Figure 4.6 in Chapter 4): while absolute decoupling is needed in high-income contexts, there is space for increased resource use in lower income contexts. Environmental impact decoupling is central to all contexts.

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50 In 2022 the UN General Assembly renewed the mandate of the 10-year Framework of Programmes on Sustainable Consumption and Production.
51 At the fifth UN Environment Assembly (UNEA 5.2), a resolution on circular economy was agreed.
52 UNEA-5.2 also included a landmark resolution on ending plastic pollution through the establishment of a new legally binding international instrument. Work towards formation of this new Global Plastic Treaty has begun, with governments engaging in two negotiation sessions in 2022.
53 However, resource use is currently underrepresented in national climate and biodiversity strategies: analysis of Nationally Determined Contributions (NDCs) showed that inclusion of resource efficiency strategies was dwarfed by energy efficiency strategies. In terms of the built environment, for example, there were three times as many energy efficiency strategies as plans for resource efficiency. For mobility, the situation was slightly better, but there were still nearly twice as many strategies for energy efficiency compared to resource efficiency.
54 G7 Alliance on Resource Efficiency (https://www.g7are.com/).
55 G20 Resource Efficiency Dialogue (https://g20re.org/).

Shifts in key provisioning systems

The Sustainability Transition scenario in Chapter 4 identified and modelled major shifts needed across resource-intensive and impact-intensive provisioning systems assessed by this report. These are food and nutrition, built environment, mobility and energy. Implementing these shifts means rethinking how these provisioning systems meet human needs.

While transition dynamics are specific to provisioning (sub) systems and contexts, changes in governance, finance, trade and consumption and production at the system level will provide a generic context that enables sustainable pathways (see section 5.5). For example, using pricing mechanisms to meet environmental sustainability standards for resource use (internalizing environmental and social costs) will make inefficient resource use prohibitively expensive. This will act to reduce unnecessary consumption and waste in key provisioning systems: reducing food waste and driving resource efficiency in buildings and mobility. Such changes need to be implemented in a way that centralizes just outcomes. For example, increases in costs need to be carefully managed to avoid negatively impacting vulnerable populations. Overall shifts to institutionalize resource management in global governance, including through resource use paths, will also drive reductions in unnecessary resource use. See section 5.5.6 for policy recommendations for provisioning systems.

5.4 Critical actions towards sustainable resource use can achieve desired outcomes

The 2019 edition of this report called for policy solutions[56] such as the setting of indicators and targets on natural resources, the development of national plans for sustainable resource use, enabling access to finance, innovation for a circular economy and cross-country cooperation to accelerate the transition. This chapter builds on these proposals and goes a step further, giving more specific recommendations for immediate action to enable the shifts towards the sustainable use of resources that are needed at global level. This relies on the findings from Chapters 2 and 3, and on the policy packages and societal shifts explored by the Sustainability Transition scenario described in Chapter 4.

The recommendations (Figure 5.1) refer to five critical aspects of the transitions, including resource institutionalization, finance, trade, consumption and production (Table 5.1), and to critical aspects by provisioning system (Table 5.2). They go beyond optimization –incremental improvements that are proving to be insufficient (too slow and not at scale) – and rather consider the multiple barriers to systemic transformation, by referring to both demand- and production-side actions.

This chapter relies on the levers for action identified in previous chapters, especially on the policy packages and societal shifts explored by the Sustainability Transition scenario of Chapter 4. As such, while the recommendations have a strong focus on climate and biodiversity,[57] they are also expected to have a positive impact on pollution abatement. The recommendations build on the recommendations provided in the IRP body of literature, especially the work on sustainability transitions (IRP 2024a), minerals governance (IRP 2020a) and finance (IRP 2024). Most recommendations align with those from the global climate and biodiversity agendas (see Table 5.1 below), yet there are some novel proposals.

While the recommendations in this chapter rely on the action and interplay of many actors, ranging from public policymakers and institutions to business and the civil society, the focus is on global and national policymakers. For each recommendation, it is essential to recognize the critical role of women, youth, indigenous peoples and local communities alongside all constituents of civil society in sustainable and equitable natural resource management for meeting human global needs, by also prioritizing their inclusion and empowerment.

The recommendations are, by definition, not prescriptive (that is not the role of scientific assessments) but are clear on the direction of the transition and the science-based conditions under which it can occur. While specific instruments are mentioned (subsidies, taxes, nudges, infrastructure, planning and so forth), in line with long-standing recommendations from global/regional bodies and scientific communities, they should not be taken as conclusive or exclusive, since no systematic analysis of the effectiveness of precise policy options across different regional and country governance backdrops has been undertaken.

56 Within the so-called "8 elements for multi-beneficial policy making".
57 As stated in Chapter 4, the "underlying causal processes and structure of the multi-model framework allow more robust projections for greenhouse gas emissions and land use change".

While a number of policy recommendations have been tried and tested or described in the literature or good practice, the chapter also suggests innovative ways forward, even of the type never attempted. While further assessment of the effectiveness of interventions is needed, the urgency of the triple planetary crisis means action must proceed now based on the precautionary principle of evolving best available science.

To understand the potential effectiveness of proposals, the latter rely on the evidence from the results of the Sustainability Transition scenario and on the existence of similar policies in the real world. Considerations for the proposal's implementation across different development contexts are also provided. However, effectiveness assessments are often not available and could significantly vary across contexts. This chapter therefore also calls for improved monitoring and evaluation of policy interventions.

In a context of increasing global uncertainty, strategies and actions may not immediately yield desired results. However, relying on recommendations informed by scientific assessments can help steer the course.

Figure 5.1: Six critical aspects for the transitions towards sustainable resource use.

Table 5.1: Recommendations for action towards sustainable resource use

Critical aspects for transitions		Recommendations for action	Production-side	Consumption-side	Modelled in Sustainability Transition scenario	Similar recommendations from climate, biodiversity, land degradation and pollution agendas (UNFCCC, UNCBD, UNCCD, IPCC, IPBES, UNCCD-SPI) (non-exhaustive)
Critical aspects for transitions	Institutionalizing resource governance and defining resource use paths	1. Global and national institutionalization of resource use in sustainability agendas and environmental agreements	X	X	Not explicitly, yet some of the measures implemented require joint and decisive global collaboration	• Not explicitly recommended (resource specific) • **Land degradation:** UNCCD's Science Policy Interface-(UNCCD-SPI) (2022) recommends strengthening integrated land-use planning policy instruments, and using them to better coordinate different sectoral policies.
		2. Defining global and national resource use paths		X	Not explicitly, yet many measures would be facilitated by national pathways, and the scenario settings are themselves based on assumptions for e.g. resource efficiency	• Not explicitly recommended (resource specific) • **Climate:** Overarching target agreed by UNFCCC (2015): The Paris Agreement, limiting temperature rise to 1.5 degrees Celsius above pre-industrial levels. • **Biodiversity:** Overarching targets agreed by UNCBD: Global Biodiversity Framework, including protecting 30% land and sea by 2030. • **Land degradation:** UNCCD (2015) has established a Land Degradation Neutrality Target Setting Programme (LDN TSP), supporting countries to define LDN baselines and set voluntary LDN targets. • **Pollution:** The UN Global Plastic Treaty has begun work towards a legally binding instrument to tackle plastic pollution.
	Defining global and national resource use paths	3. Internalizing the environmental and social costs of resource extraction	X		Yes: carbon levy, resource extraction tax and enforcement of protected areas for land use	• **Climate:** IPCC (2022) Mitigation Report recommends high carbon pricing. • **Pollution:** UNEP's Global Chemicals Outlook II recommends creating fiscal incentives for sound chemicals management.
		4. Redirecting, repurposing and reforming public subsidies for sustainable resource use	X		Partly: fossil fuel subsidies and crop-based biofuels are phased out	• **Climate:** IPCC (2022) and IPCC (2023) recommend phasing out fossil fuel subsidies. • **Biodiversity:** UN CBD (2022b), Target 18: eliminate, phase out or reform subsidies harmful to nature. • **Biodiversity:** IPBES's (2019a) recommends eliminating harmful subsidies. • **Land degradation:** UNCCD recommends subsidies for sustainable land management, including payments for ecosystem services (UNCCD 2022 and UNCCD-SPI 2017) • **Land degradation:** UNCCD's Global Land Outlook 2 recommends that countries disproportionately responsible for climate, biodiversity and other environmental crises financially support developing countries as they restore land resources, and build healthy and resilient societies.
		5. Channelling private finance towards sustainable resource use	X	X	Not explicitly, but the scenario explores major increase in innovation to enable the scale up of resource efficiency	• **Climate:** IPCC (2023) recommends mobilizing private financial flows for sustainability • **Biodiversity:** UNCBD (2022b), Target 19: leverage private and blended finance for investment in biodiversity. • **Biodiversity:** IPBES (2019a) recommends channelling finance towards combatting nature loss. • **Land degradation:** UNCCD's Global Land Outlook 2 (2022) recommends innovative financing for land restoration. • **Pollution:** UNEP's Global Chemicals Outlook II recommends innovative financing, and private sector metrics and reporting for sound chemicals management.
		6. Incorporating resource-related risk into public and central bank mandates		X	No	• **Climate:** IPCC (2022) and IPCC (2023) highlight the role of central banks and financial system regulators in acting on climate risk. • The role of central banks in guiding finance towards climate and biodiversity-positive action has been discussed and recommended by several UN reports

Critical aspects for transitions		Recommendations for action	Production-side	Consumption-side	Modelled in Sustainability Transition scenario	Similar recommendations from climate, biodiversity, land degradation and pollution agendas (UNFCCC, UNCBD, UNCCD, IPCC, IPBES, UNCCD-SPI) (non-exhaustive)
Critical aspects for transitions	Making trade an engine of sustainable resource use	7. Trade governance for fair and sustainable resource use	X	X	Not explicitly, but the scenario explores the implementation of a resource tax with provisions to avoid increased inequality consequences	• **Climate:** IPCC (2022) notes that trade rules have the potential to stimulate international adoption of mitigation technologies. • **Biodiversity:** IPBES (2019a) highlights trade as a tool to combat nature deterioration.
		8. Enabling local resource value retention in producer countries	X		Partly: return of resource extraction tax as part of global dividend	• **Biodiversity:** UN CBD (2022b), Target 19 (d): stimulate innovative benefit-sharing schemes.
	Mainstreaming sustainable consumption options	9. Developing action plans to improve access to affordable and sustainable goods and services	X	X	Yes: many specific assumptions around improved performance of provisioning systems based on demand-side actions	• **Climate:** IPCC (2022), IPCC (2023) and IPBES (2019a) highlight the role of mainstreaming sustainable consumption. • **Biodiversity:** UN CBD (2022b), Target 16: encourage people to make sustainable consumption choices. • **Land degradation:** UNCCD-SPI (2022) recommends action from government, business and citizens to shift towards healthy and sustainable diets.
		10. Raising awareness and regulating marketing practices that lead to overconsumption		X	Not explicitly, but the scenario assumes moving to more less resource-intensive consumption choices	• **Climate:** IPCC (2023) recommends awareness-raising campaigns for dietary shifts.
	Creating circular, resource-efficient and low-impact solutions and business models	11. Setting up monitoring and evaluation systems to establish priorities and developing ambitious circular economy action plans	X		Yes: strong resource efficiency policies. Circular economy policies not explicitly represented due to the challenges in the modeling of some circular strategies	• **Climate and biodiversity:** IPCC (2022), IPCC (2023) and IPBES (2019a) highlight the need for rapid and far-reaching transition towards resource efficiency and circular economy.
		12. Developing and reinforcing regulations to boost circular economy business models	X		Yes: the resource efficiency policies are based, among other, on a resource levy, whose revenue is assumed to be used to support resource efficiency innovation	• **Climate and biodiversity:** IPCC (2022), IPCC (2023) and IPBES (2019a) highlight the need for rapid and far-reaching transition towards resource efficiency and circular economy. • **Pollution:** UNEP's Global Chemicals Outlook II (2019) recommends circular economy initiatives for chemicals management, enabled by policy.
		13. Building circular economy capacity and coalitions	X		Not explicitly, yet assumptions of the scenario require joint and decisive global collaboration	• **Climate and biodiversity:** IPCC (2022), IPCC (2023) and IPBES (2019a) highlight the need for rapid and far-reaching transition towards resource efficiency and circular economy. • **Pollution:** UNEP's Global Chemicals Outlook II (2019) recommends collaboration along supply chains to enable and monitor circular production process.

5.4.1 Institutionalizing resource governance and defining resource-use paths

The complex and systemic nature of resource management challenges requires new governance responses (IRP 2024a). Chapter 2 charts how consumption and production patterns have consistently driven up resource use across time. Chapter 3 maps the impacts of that use and highlights the need for a more equal use of natural resource. Meanwhile, Chapter 4 depicts the unsustainable trajectory of a Historic Trends scenario and illustrates how directing resource use using global mechanisms for a just and equitable transition and prioritizing policies aligned with the SDGs could ensure dignified life standards for all with significantly lower environmental impacts (such as an 80% fall in GHG). To operationalize these sustainability outcomes, it is vital to explicitly recognize and integrate the use and production of resources at the core of the global sustainability agendas of climate, biodiversity and pollution, while acknowledging the resource-use implications of existing multilateral climate and biodiversity goals. It is also essential to understand which resource-use paths could meet the goals of these interconnected sustainability agendas.

Recommendation 1: Global and national institutionalization of resource use in sustainability agendas and environmental agreements

There are several ways in which natural resource use can be integrated into global sustainability agendas. For example, Bringezu *et al.* (2016) highlighted the need for monitoring of global resource use and regular benchmarking of countries regarding their resource consumption and productivity. Through such monitoring and benchmarking, resource use could be integrated into existing monitoring and verification mechanisms of global conventions. Under international agreements, countries could make national pledges for decoupling and develop action plans for implementation. National pledges should be based on inclusive and active participation of stakeholders, including local communities, small-scale producers and the scientific community. Examples of national pledges include the leaders' pledge for nature,[58] a commitment to undertake urgent actions by 2030 "to put nature and biodiversity on a path to recovery by 2030". Another example is to incorporate the consumption perspective into Nationally Determined Contributions of the Paris Climate Agreement under the United Nations Framework Convention on Climate Change (UNFCCC). This will mean accounting not only for domestic greenhouse gas (GHG) emissions but also for GHG emissions of the production chain elsewhere, to meet a country's consumption demand.

A more far-reaching proposal is to establish an International Mineral and Metals Agency as previously proposed by IRP (2020a and 2024b), with a UNEA mandate. The mandate of such an agency could include improved monitoring, benchmarking and strengthening of national competences. This could provide oversight and information about the situation and outlook for the world's non-energy mineral resources or markets and could be the coordinating hub for a global sustainable resource management programme, with strong linkages to the other multilateral environmental agreements. This might lead to a stronger legal basis in the form of a global convention on resources as part of increased institutionalization.

The effectiveness of implementing such a recommendation will depend on the quality of governance institutions at country level[59] and of resource governance mechanisms in particular, for which the picture is very uneven across countries.[60]

Recommendation 2: Defining global and national resource use paths

Targets have been widely used for environmental management (see Box 5.2) and there are also many examples of resource-related targets around the world. The Roadmap on sustainable waste management and resource circulation in South Asia, 2019-2030 (IGES 2019) includes targets on waste reduction (10%). European Union (EU) countries have targets on resource productivity (European Environment Information and Observation Network (EIONET 2022)) and circularity rate.[61] As an example, the Austrian Circular Economy[62] has set targets on resource use.[63] In general though, there is a clear lack of coherent targets for the use and impact of resources. This hampers strong policy trajectories and effective follow-up and evaluation.

It is essential to define resource use paths and targets at the global, national and other governance levels in order to monitor progress towards sustainable resource use. Setting targets is an effective way to lead transitions, at least when the implementation instruments are coherent (Kern and Howlett 2009). Targets need to be sufficiently

58 See https://www.leaderspledgefornature.org/ and https://www.leaderspledgefornature.org/wp-content/uploads/2021/06/Leaders_Pledge_for_Nature_27.09.20-ENGLISH.pdf
59 For example, see results of the Worldwide Governance Indicators (http://info.worldbank.org/governance/wgi/).
60 For example, see Resource Governance Index (https://resourcegovernanceindex.org/).
61 https://www.eionet.europa.eu/etcs/etc-ce/products/draft-report-for-dg-env_final.pdf
62 https://www.bmk.gv.at/themen/klima_umwelt/abfall/Kreislaufwirtschaft/strategie.html
63 Domestic Material Consumption, Material Footprint, resource productivity, circularity rate and so on.

ambitious and be clearly and authentically linked to climate, biodiversity, land degradation and pollution impacts and goals. These targets could be translated into an internationally agreed pathway for resource use (materials, land and water), considering the differential impacts of different resource categories. Different pathways for various development contexts are needed to ensure an equitable transition (countries, or even groups with different incomes or consumption patterns within countries). The translation of global goals into national targets could, for example, be based on international principles of common but differentiated responsibilities, established according to metrics such as income level or material footprint per capita. This would be guided by the gradual operationalization of the concept of sufficiency as depicted by the Sustainability Transition scenario, which describes various resource paths for different income-level regions. It is also important to consider that, in each specific context, different aspects of development can be more or less relevant (as Tasaki *et al.* (2021) show for some Asian countries).

This recommendation can build on existing monitoring frameworks and research. Reporting of SDG indicators on sustainable consumption and production (12.2.1, 12.2.2 and 12.3.1)[64] already provides country-level data on material footprint and domestic material consumption in absolute values, per capita and per unit of GDP. The SDG framework provides indicators related to the performance of provisioning systems.[65] The IRP work on science-based targets (see Box 5.2) and decoupling (IRP 2018a)[66] or the work by the Doughnut Economics Action Lab (Fanning *et al.* 2022),[67] , among others, could be relevant inputs to define science-based resource use targets. Sustainability frameworks such as the planetary boundaries (Rockström *et al.* 2023) could also explicitly assess the contribution of resource use to Earth capacity's overshoot.

While the information on which to base targets needs to be strengthened, an international database on global resource use could be developed to overcome this challenge. Such a database could also reinforce national capacities to develop and leverage robust data on resource use, while also covering the environmental footprint of products. This kind of global database could build on pre-existing databases[68] and tools to drive policy development for the necessary transformation of current resource use models.[69] The database could be hosted by an international competence centre (similar to the Mineral and Metals Agency) that could provide data, as well as analysis and interpretation support, for governments seeking to improve sustainable resource management at multiple scales (Bringezu *et al.* 2016). The digital transformation can be a key enabler of improved information and transparency.

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64 12.2.1 (8.4.1) Material footprint, material footprint per capita, and material footprint per GDP, 12.2.2 (8.4.2) Domestic material consumption, domestic material consumption per capita, and domestic material consumption per GDP, 12.3.1 (a) Food loss index and (b) food waste index.
65 Food and nutrition, access to energy, sustainable cities and so forth.
66 The IRP's Weight of Cities report advocates approximately a 50% reduction in current Domestic Material Consumption.
67 Estimating social thresholds for nutrition and other basic human needs.
68 Such as the Global Material Flows database or input-output tables such as GLORIA, Exiobase, EORA, OECD-ICIO and so on.
69 Such as SCP-HAT or the ad hoc tool developed in Chapter 3.

Box 5.2. IRP work on science-based targets for sustainable resource use

(Based on IRP forthcoming)

In today's globalized world, commodity price signals determine how resources are managed and allocated. However, since the 20th century resource use has continued to grow, while the externalities associated with the exploitation of natural resources have not been properly priced and regulated.

Historically, air and water pollution control policies made use of science-based target concepts such as critical loads to determine the levels of pollution that ecosystems can withstand without significant harm, while also allowing for economic development and other human activities. Long-distance atmospheric transport of pollutants prompted the implementation of regional emission control systems. More recently, phenomena such as climate change and biodiversity degradation have come to be considered of systemic importance to the stability of human life support systems on a planetary scale.

The most researched and politically relevant science-based target (SBT) of today is the formulation of climate targets. The UNFCCC established an international cooperation framework for to address climate change, with the "ultimate objective and any related legal instruments that the Conference of the Parties may adopt is to achieve stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner". The targets were based on the principle of "common but differentiated responsibilities", recognizing that developed economies have a greater historical responsibility for climate change and a greater capacity to address it. Implicitly, the common vision of a sustainable climate target was 450ppm CO_2eq in the atmosphere, which is considered to be roughly in line with reaching a 2 degree warming target by 2100, but could also reach equilibrium warming of 4.5 degrees Celsius given climate uncertainties. In 2015, the Parties to the UNFCCC adopted the Paris Agreement, which set a global goal of keeping the increase in global average temperature to well below 2 degrees Celsius above pre-industrial levels and pursuing efforts to limit the increase to 1.5 degrees Celsius. The Paris Agreement, in 2015, also established a framework for countries to regularly submit and update their Nationally Determined Contributions (NDCs), which are their own targets for reducing greenhouse gas emissions and are formulated in pathways reaching net zero emissions mostly around 2050. To date, the sum of country-based emission pledges remains insufficient to achieve the goal set by the Paris Agreement and the principle of common but differentiated responsibilities has not yet been fully respected.

In most international agreements, setting long-term targets remain elusive and targets are regarded as tools for agenda setting rather than being used for implementation planning within a credible compliance system. However, there are successful examples in more straightforward international environmental agreements: the management of the stratospheric Ozone layer under the Montreal Protocol has been recognized as a model for future international problem-solving agreements. It has led, after a very thorough science-based target exercise, to a reduction of more than 90% in the consumption of ozone-depleting substances, and the ozone hole over Antarctica has slowly begun to recover.

Setting targets for sustainable resource use requires an integrated and holistic approach to decision-making. The SDGs and their 176 targets constitute a first attempt to establish a science-based target system for sustainable resource use. This could be contrasted with material flow indicators such as those assessed in Chapter 2 (Domestic Material Consumption/Material Footprint) and provides a proxy for countries' overall environmental pressure and estimates of environmental impacts (see Chapter 3). It is important to note that resource-use targets for might clash, as restricting one resource can lead to additional pressure on another.

Targets should be consistent with the latest scientific knowledge, technically feasible, measurable, time-bound, relevant, developed in collaboration with stakeholders, regularly reviewed, transparent, integrated across different sustainability domains and have a long-term vision. The IRP is currently working on developing and demonstrating a systems approach to target setting for resource management. It considers targets for different stages along the DPSIR framework and different stages along the policy cycle (operational, planning and so forth). The assessment in Chapter 3 (section 3.1.2) is an attempt to show how scientific knowledge can be used to benchmark resource used based on climate and biodiversity loss impacts.

5.4.2. Directing finance towards sustainable resource use

The Paris Agreement calls for all countries to align financial flows with low-carbon and climate-resilient development pathways (UNEP 2022a; UNFCCC 2015b). The Kunming-Montreal Global Biodiversity Framework (UN CBD 2022b) includes several targets on aligning financial flows with nature positivity and regulating the financial system to help bend the curve on biodiversity loss.[70] Despite these agreements, however, current financial and economic structures support the continuation of unsustainable patterns of consumption and production and an unequal exchange of materials between countries.

First, the environmental costs of virgin material extraction are at best only incompletely internalized into prices, which leads to market actors making unsustainable decisions. Under existing market prices, primary resource extraction is still the cheapest option in many cases, even when associated with negative environmental impact (Dasgupta *et al.* 2021).[71] Therefore, internalizing the environmental (and social) costs of resource extraction is a key part of the necessary transition.

Second, financial flows need to be redirected towards sustainable development (UNEP 2011; UNEP 2015): During the last few decades "much capital has been poured into property, fossil fuels" and relatively small amounts of capital have been allocated to sustainable resource use. This applies to public as well as private finance. Public subsidies for unsustainable practices are still the norm — subsidies for fossil fuel surged to a record USD 7 trillion in 2022 (IMF 2023a). Channelling financial flows towards the SDGs is a priority for the United Nations, as documented by the work of the Inter-Agency Task Force on Financing for Development (UN Inter-Agency Task Force on Financing for Development 2023).

As resource use drives climate change and biodiversity loss, changing the financing of resource extraction will be essential for meeting environmental commitments. This will also help reduce environmental impacts and the associated costs.[72] Indeed, The UN's Secretary-General has called for a re-allocation of capital for achieving the SDGs, and recent work by Songwe, Stern *et al.* highlights the necessary reallocation of capital towards climate finance, in particular to low-income countries (Songwe *et al.* 2022; UN 2023). Both public and private financial actors have roles to play in setting the direction and rules for reallocation of capital (driven by public actors, including central banks and multilateral development banks) and practically targeting investments (driven by private financial actors).

Recommendation 3: Internalizing the environmental and social costs of resource extraction

Regulation, such as a tax on impacts caused by virgin resource extraction, would help to incentivize the use of secondary materials and increased efficiency in production, as well as internalizing environmental and social costs. The Resource Efficiency policy package described in Chapter 4 models a gradually increasing tax on extraction of non-renewable resources that raises costs per tonne by around 30% by 2060. As well as encouraging resource efficiency, this also enables a modest shift of taxation away from income and consumption. Ideally, such a tax would take into account the impacts of resource extraction, rather than being purely based on tonnes extracted.

The revenue from such a tax could contribute to resource efficiency innovations. Implementation would require improved transparency, linking resource use and financial flows along entire value chains, building on impact methods similar to those used in Chapter 3. With appropriate monitoring and governance, the revenues of resource extraction taxation could be redistributed to finance the achievement of SDGs (as in the SDG uplift policy package under the Sustainability Transition scenario).

Trade-offs are possible: efforts would be needed to avoid negative distributional impacts of implementing a resource tax. A fair tax would have to be designed and implemented to ensure that the highest income consumers and high-income countries (including corporations based in high-income countries) bear the cost (see also trade recommendation 7 in section 5.5.3). In its 2023 Synthesis report, IPCC notes that revenue from carbon taxes could be used to support low-income households, addressing distributional issues (IPCC 2023). There are successful experiences in terms of using taxation to internalize environmental and social externalities that could be applied to resource extraction (such as traffic pollution charges, taxation of alcohol and tobacco).[73] The Works for Taxes Scheme of the Peruvian State[74] aims to improve well-being by channelling income tax paid by private companies towards investment in national and subnational projects to improve quality of life. Working Groups for this mechanism currently focus on education, health, water/sanitation and environment (Catacora-Vargas *et al.* 2022).

70 Targets 15 and 18.
71 Chapter 9.
72 Current environmental damages are estimated to amount to between USD 5 trillion and USD 7 trillion annually. Source: Dasgupta *et al.* (2021), Annex 8.1.
73 Environmentally targeted taxes can be effective: analysis of effectiveness of environmental taxes on reducing CO_2 emissions in European countries found a statistically significant reduction in emissions in countries applying environmentally friendly taxes. Source: Wolde-Rufael and Mulat-Weldemeskel (2021).
74 https://openknowledge.worldbank.org/entities/publication/68bc7be7-1363-5ab9-b1d7-229a588c0814

Taxes on resource extraction can also be used to enable local areas to retain larger shares of the value of resources extracted from them. In 2020, the Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development (IGF) and the African Tax Administration Forum (ATAF) launched a joint initiative to rethink how developing countries could benefit from their mineral resources. The initiative is running public consultations on the future of resource taxation and in 2023 report, The Future of Resource Taxation (IGF 2023), gives ideas for implementing resource taxation to benefit producer countries.

However, challenges remain: examples of implementing resource taxes remain scarce, and comprehensive feasibility assessments are currently lacking in the literature.

Recommendation 4: Redirecting, repurposing and reforming public subsidies for sustainable resource use

Aligning public spending with humanity's long-term interests means aligning subsidies with sustainable resource use. This means redirecting, repurposing, reforming or eliminating economic incentives that contribute to unsustainable resource use and drive the triple planetary crisis, as well as scaling up subsidies for sustainable resource use practices.

Aligning publicly subsidized economic incentives with low-resource, low-impact consumption will make sustainable choices more affordable for all. The 2023 IMF report Detox Development: Repurposing Environmentally Harmful Subsidies estimates the direct subsidies to agriculture, fishing and fossil fuels at USD 1.25 trillion per year and the costs caused by those subsidies (harm to the environment and health) at USD 6 trillion per year. The report is very clear that this subsidy lock-in needs to be phased out as soon as possible to have some chance of achieving the SDGs (IMF 2023b).

This call is obviously not new. Subsidy reform is — in principle — already a priority for global governance: Target 18 of the UN CBD Global Biodiversity Framework (GBF) aims to "Eliminate, phase out or reform incentives, including subsidies, which are harmful to biodiversity by 2030, starting with the most harmful incentives". It aims to reduce harmful subsidies by at least USD 500 billion per year by 2030 (CBD 2022b). In addition, the World Trade Organization (WTO) has agreed to curb harmful fishery subsidies; illegal and unreported fishing,[75] fishing of overfished stocks and fishing on the high seas outside the control of regional fisheries management organizations (WTO 2022).

Some financial institutions and individual countries are also taking action to align subsidies with combatting the triple planetary crisis: in 2019 the European Investment Bank decided to phase out the financing of unabated fossil fuel energy projects, making them the first international financial institution to focus support on projects that are fully aligned with the Paris Agreement (EIB 2023). To ensure that financial flows are genuinely nature-positive, OECD recommends transparent evaluation of the effectiveness of biodiversity finance and related policy instruments (OECD 2020a). This could be expanded to transparent evaluation of the effectiveness of flows towards sustainable resource use overall, building on data on the environmental impact of resource use (Chapter 3).

Phasing out harmful subsidies could have implications for the livelihoods of those who currently rely on such support. Therefore, governments and multilateral organizations could consider accompanying phasing out stages with investments in local sustainable livelihoods and capacity building.

The key message is that, after decades of talking about harmful subsidies, it is essential to actually phase them out effectively and do it fast.

Recommendation 5: Channelling private finance towards sustainable resource use

Besides scaling up public finance for sustainable resource use, public and private actors can channel private financial flows in the same direction. Frameworks can play an important role in scaling up sustainable finance (BIS 2021). Financial regulators, including central banks and Multilateral Development Banks (MDBs), could work towards developing interoperable and compatible frameworks (classification systems, such as taxonomies) for financing sustainable resource use – along the entire value chain.

Several sustainable finance taxonomies already exist, but weaknesses have been identified, including: lack of relevant and measurable performance indicators, lack of granularity and lack of verification of sustainability benefit achieved (BIS 2021). To overcome these weaknesses, an overarching taxonomy for sustainable resource use should aim to: correspond to specific sustainable resource use objectives, in alignment with other environmental goals (such as the Paris Agreement and Post-2020 Global Biodiversity Framework); monitor achievement against specific indicators; and shift from voluntary to mandatory transparency against specific resource-related targets.[76]

75 Subsidy recipients must prove they are not supporting illegal and unreported fishing.
76 In line with recommendations from BIS (2021).

There is progress to build on: several stakeholders including China, the EU, Russian Federation, South Africa, South Korea, Colombia, Malaysia, Mongolia and Sri Lanka have already adopted sustainable finance taxonomies, while more are being developed in other countries including Argentina, Australia, Chile, India and Mexico (WWF 2022). Some financial institutions are adopting frameworks for specific environmental impacts: the Development Bank of Latin America and the Caribbean (CAF) has introduced a Strategic Biodiversity Framework, aiming to "catalyze transformational change in CAF member countries by ensuring that biodiversity is valued, protected, restored, and used conscientiously to maintain a consistent flow of ecosystem services and an equitable distribution of benefits" (CAF 2022).

Although these are encouraging developments, there are concerns that key aspects of sustainability are missing from these taxonomies: for example, among 29 taxonomies adopted or under development at the end of 2022, only 12 considered nature-related aspects (WWF 2022). As resource use is driving all aspects of the triple planetary crisis, having an overarching taxonomy for sustainable resource use would alleviate the narrow focus on selected outcomes. Certain kinds of resource use are needed for meeting existing environmental commitments: for example, extraction of minerals for the energy transition (IEA 2021a). The IRP's upcoming work on Financing the Extractive Sector recommends that, if meeting good social and environmental governance standards, extraction of key energy transition materials should be classified as sustainable in sustainable finance taxonomies (IRP 2024b).

The shift towards mandatory disclosure of environmental risk has already begun: the Taskforce for Climate-related Financial Disclosures (TCFD) sets out a framework for asset managers and companies to report on their climate-related risks, so that their investors, lenders and insurance underwriters can assess the climate risk to which they are exposed.[77] The United Kingdom Government made it mandatory for the largest businesses to disclose their climate related risks and opportunities, in line with TCFD, in 2022 (UK Government 2021a). The Taskforce for Nature-related Financial Disclosures (TNFD) aims to do the same for nature-related risk.[78] Target 15 of UN CBD's Global Biodiversity Framework encourages countries to introduce legislation to ensure that large businesses and financial institutions disclose their nature-related risks, dependencies and impacts (UN CBD 2022b). For example, to aid investment in circular material use, Japan has published Guidance for Disclosure and Engagement for Promoting Sustainable Finance toward a Circular Economy (METI 2021).

Recommendation 6: Incorporating resource-related risks in public and central bank mandates

Redefining finance for sustainable resource management involves a consideration of financial system regulators, public financial regulatory bodies and central banks. Central banks should make reducing resource-related risk a priority in their mandates – as some pioneering central banks are doing for climate and biodiversity risk.

Many financial institutions, including central banks, MDBs and Sovereign Wealth Funds (SWFs),[79] have made commitments to align their activities with a transition to sustainable development. Central banks, which have the mandate to maintain economy stability and which have become primary drivers of the global economic recovery, are increasingly thinking about aligning their investments and regulatory action with long-term sustainability. In 2020, for instance, the Bank for International Settlements (BIS) – which is jointly owned by 63 central banks[80] – made it clear that central banks have a key role to play in avoiding future climate-related financial disasters (BIS 2020). Ambitious central banks are incorporating climate risk, and to a lesser extent biodiversity risk, into their mandates. The Bank of England (2023) and the European Central Bank (ECB 2021) have made commitments to support the transition to net zero; the Dutch Central Bank (De Nederlandsche Bank 2020) and Norwegian Sovereign Wealth Fund (Norges Bank 2021) are accounting for nature-related risk in their investments. The Network for Greening the Financial System (NGFS)[81] brings together over 90 central banks and financial supervisors to share best practice on development of climate risk management in the financial sector. Nearly all development finance institutions (organizations providing funds for development projects) have adopted commitments to align their investments with the SDGs, including divesting from fossil fuels.

The SWFs (invested pools of money owned by the State, and primarily used to cushion a country from economic shocks) accounted for almost 2% of all global financial assets in 2020, with the value of their assets nearly doubling since 2007. In 2020, the International Forum of Sovereign Wealth Funds (IFSWF) partnered with One Planet Sovereign Wealth Funds (OPSWF) to align SWFs with climate goals and the SDGs (IFSWF and OPSWF 2023). There is the potential to incorporate natural resource considerations into this work.

77 https://www.fsb-tcfd.org/about/
78 https://tnfd.global/about/
79 SWFs accounted for USD 8 trillion worth of assets by 2018, or 1.7% of the total value of all financial assets in 2020. Since 2007 their assets have nearly doubled from USD 3.9 trillion in 2008 to USD 7.67 trillion by August 2018.
80 https://www.bis.org/about/index.htm
81 https://www.ngfs.net/en

5.4.3. Making trade an engine of sustainable resource use

Chapter 2 shows that high-income countries in 2024 consume six times more materials than low-income countries. High-income consumption is underpinned by what is referred to as the unequal exchange, which means raw materials, final energy and labour consistently flow from lower to higher income countries at unfairly low prices. In addition, Chapter 3 shows that high-income countries displace environmental impacts to all other income country groups. In other words, they import resources and materials that cause environmental impacts in the exporting regions, without bringing much value added to the countries of origin.

Trade in raw materials has been also associated with capital flight,[82] especially from resource-rich countries in Africa (Ndikumana and Boyce 2022), which means these economic assets are not available for local development. Capital outflow from Africa in 2018[83] was estimated at more than three times the total debt owed by African countries in 2018, almost equal to all Overseas Development Assistance (ODA) between 1990 and 2015 (Hickel *et al.* 2022).

Additional challenges to sustainable resource trade relate to how the global financial system operates (IRP 2024a). Sustainable resource extraction requires a stable investment climate. On the contrary, there has been an increasing financialization of material commodity markets over the last two decades, which has led to the decoupling of price setting in commodity markets from the fundamentals of physical supply and demand (see Box 5.3). This has led to extreme price volatility in almost all commodity markets, creating instability and challenging the ability of poorer households to meet their basic needs.

The unequal exchange of resources, capital flight and unsustainable trading practices highlight the need to make importing countries and the trading system more accountable for the environmental and socioeconomic impacts linked to resource extraction.

Box 5.3. The financialization of commodity markets

(Based on IRP 2024a)

Sustainable resource extraction requires a stable investment climate. Over the last two decades, there has been an increasing financialization of material commodity markets, with a small number of commodity traders controlling a significant proportion of resource trade.[84] Revenues from this trade have been sometimes above Wall Street bank revenues (Baines and Hager 2021), with high revenues from transit trading (trade activities without typically importing or exporting products to or from the country where the transit trade resides). Moreover, commodity traders increasingly trade in derivatives (options and futures) of various kinds,[85] which profit from speculation about the direction of prices changes. This situation has led to extreme price volatility in almost all commodity markets, creating political and macroeconomic instability and challenging the ability of poorer households to fulfil basic consumption.

Normative commitments to sustainable resource use via decoupling will achieve very little in practice if the existing global commodity trading system continues to operate as it does.

82 Capital flight is the loss of financial capital from a region, country or continent, and is the subject of considerable literature, including Ndikumana and Ibi Ajayi (eds.) (2014), Ndikumana and Sarr (2019) and Ayamena Mpenya *et al.* (2016).

83 USD 2.4 trillion, including interest on capital offshored since 1970. Source: Ndikumana and Boyce (2022).

84 For example, the four largest agricultural commodity traders control between 75% and 90% of the international grain trade; three traders account for half of the Organization of the Petroleum Exporting Countries (OPEC) oil output, while just one commodity trader accounts for 55% of the global zinc market and 36% of the global copper market. Source: Baines and Hager (2021).

85 For example, data from the London Metal Exchange show that the ratio of the trade volume in copper derivatives to the physical production of copper increased from 40:1 in 1982 to 2000:1 in 2014. Source: Seddon (2020).

Recommendation 7: Trade governance for fair and sustainable resource use

To respond to the challenge of making importing countries and the trading system more accountable for their environmental and socioeconomic impacts, there is scope for multilateral trade governance to strengthen its actions on improving the sustainability of resource flows (for example through the World Trade Organization (WTO) and regional trade bodies). In addition, the overall quality of governance is often reflected in resource trade.

Changes to trade governance that recognize and reflect the (externalized) environmental and social costs of resource extraction could help extractors and producers to implement sustainable production practices. Incorporating these externalities would create a level playing field, preventing a race to the bottom on environmental standards along resource value chains.

Trade governance innovations could include:

- Provisions for sustainable resource use in trade agreements such as reaffirming commitments to existing global environmental agreements. Some trade agreements already include provisions to support global nature commitments: as of 2018, 105 regional trade agreements have included provisions that address endangered species, invasive species, protected areas and other biodiversity-relevant aspects (Morin *et al.* 2018), as well as the Paris Agreement (Karousakis and Yamaguchi 2020). If resource management was concretely incorporated into global environmental agendas' governance architecture (see section 5.4.1), trade agreements would probably be able to include specific resource-related requirements more easily.
- Strengthened regulation of financial commodity markets to minimize price volatility and protect access to basic commodities. The fact that commodity trading is concentrated in a small number of jurisdictions means that targeted regulation could make a significant difference (IRP 2024a).
- Implementation of impact-related border adjustment policy instruments that incorporate environmental impacts of resource extraction and processing into the cost paid for consumption. Revenues from accurate resource pricing could be used to reduce impacts at sites of extraction (for example, by implementing cleaner and more land-efficient mining practices), with adequate monitoring and evaluation (see also recommendation 1 in section 5.4.1). Border adjustment mechanisms should rely on robust, openly available and geographically specific resource flow and impact data (as in Chapters 2 and 3). Upcoming IRP work recommends that importer countries introduce a Raw Material Border Adjustment Mechanism (RMBAM) to stimulate high Environmental, Social and Governance (ESG) standards in raw material extraction (IRP 2024b). Environmentally motivated border adjustment mechanisms are already entering into force, such as The EU's Carbon Border Adjustment Mechanism (CBAM).[86] It has been put in place to internalize the cost of climate change impact as embodied in goods imported to the EU to encourage cleaner industrial production in both the EU and countries importing to the EU. To avoid unintended consequences for producer countries, border adjustment mechanisms should be flexible enough to recognize efforts to improve ESG performance from low levels, as well as existing high ESG standards (IRP 2024b).
- Strengthened mandatory due diligence to set sustainable resource management standards for imported commodities. Monitoring for strengthened due diligence should be based on the best available environmental impact data, along whole value chains (building on approaches used in Chapter 3). Ideally, such data would be fully transparent and openly available. Importer countries are already beginning to strengthen due diligence: for example, the United Kingdom's Environment Act enforces due diligence with a view to eliminating illegal deforestation in agricultural commodity supply chains (UK Government 2021b). Some stakeholders highlight possible unintended consequences of strengthened due diligence: without safeguards, applying strong due diligence could have implications for producer livelihoods, especially for smaller businesses. Capacity building and producer-consumer collaboration along the value chain can help to ensure equitable outcomes. For example, the Food and Agriculture Commodity Trade (FACT) Dialogues (hosted by UNFCCC COP26) brought producer and consumer countries and actors from along the value chain together to accelerate shared solutions for sustainable land management.[87]

86 Entered into force in May 2023 to implement a carbon tariff on some carbon-intensive products.
87 https://www.factdialogue.org/

Recommendation 8: Enabling local resource value retention in producer countries

Local communities and host governments in producer countries are looking for real shared value from resource extraction, as opposed to the current unequal exchange (IRP 2024a). They seek to use their non-renewable resources to achieve long-term and sustainable growth in living standards, while also safeguarding their natural environments through local value added (for instance by retaining monetary value in resource-extraction areas).

There are examples of projects and national regulations to add value locally. For example, resource-rich countries can retain a higher share of resource value by onshoring downstream value chain processes (IRP 2024b). By extracting and refining domestically, countries can retain a greater value share by exporting the higher-value refined product. Currently, there are limited examples of low-income producer countries planning to onshore downstream processing, especially for energy transition minerals (Goodenough *et al.* 2021), but this is beginning to change.[88]

Onshoring downstream processing can reduce the climate impacts associated with material production: evidence from Chile shows the climate benefits of refining copper domestically – shipping emissions would be significantly reduced by higher domestic refining (Sturla-Zerene 2020). Toledano *et al.* (2021) suggest that the mining sector in Africa could benefit from the carbon pricing policies in developed countries, since multinational companies could be incentivized to move intermediate stages of production closer to the source of mineral extraction to avoid excess emissions and waste.

Countries are also acting to ban or increase the price of lower-value raw material exports: Zimbabwe has banned the export of raw chromite (chrome ore), while South Africa has put an export tax on ferrochrome. Both these measures are meant to boost local ferrochrome producers, as well as the production of stainless steel (Dzirutwe 2021). Guinea has some of the world's largest bauxite deposits and has threatened to withdraw mining licences if companies do not invest in in-country processing (Reuters 2022).

Local content policies are another example: mandating mining companies to do more local processing and use a minimum share of local inputs and suppliers (Östensson 2017). These policies also apply to infrastructure projects, setting minimum proportions of equipment and services to be sourced locally (Ettmayr and Lloyd 2017) and contribute to increased domestic security of supply.[89] However, mixed results appear in real world implementation (see Box 5.4). Literature has converged on four main factors that can determine the effectiveness of local content policies in promoting local industrial development: (1) market size and stability (some existing domestic market exists; this market is relatively predictable and stable in the long-term); (2) policy certainty (the local content policy is transparent and aligned with other industrial policies); (3) limited restrictiveness (not requiring an overambitious proportion of local content); and (4) an industrial base (skills exist in the local supply chain) (Hansen *et al.* 2020; Ettmayr and Lloyd 2017). In some contexts, local content policies have successfully stimulated sustainable industries: in India, Brazil and China, local content policies have contributed to the development of domestic solar photovoltaic production (Hansen *et al.* 2020; Swilling *et al.* 2022).

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88 Countries are developing refining capacity locally: for example, in the Democratic Republic of Congo (DRC) the Manono Project will produce and export refined primary lithium sulphate. (AVZ Minerals Limited (2020), AVZ Delivers Highly Positive Definitive Feasibility Study for Manono Lithium and Tin Project).

89 Critical mineral refining is very geographically concentrated, making it vulnerable to local shocks. Source IEA (2021). Therefore, diversifying refining geographically would likely make supply more secure.

Box 5.4. Local content policies in Africa

(Julius Gatune)

There is a growing trend for enacting local content national laws, which force mining companies to carry out more local processing (value addition) and aim to ensure greater use of local inputs and suppliers (Östensson 2017). A review (IRP 2024b) shows that at least 17 countries across Africa have put in place local content laws.

However, the actual transformative benefits of such policies are under discussion (Dietsche and Steve 2018; Östensson 2017; African Center for Economic Transformation [ACET] 2017) and remain highly controversial (Weiss 2016). Implementing local content successfully requires having capacities and institutions. Many countries are lacking these elements, which means that a phased implementation is needed as capacity is built. Nigeria is a good case study of this phased implementation, which has led to successful results. The Nigerian Oil and Gas Industry Content Development Act set progressive targets on local content, starting at 45% in 2007, 70% in 2010 and above 80% in 2020 (Adedeji *et al.* 2016). Nigeria has also established a specialized body[90] to oversee implementation. This policy has successfully raised local procurement of goods and services from 5% to 70% between 2004 and 2015, with 24 indigenous oil-producing companies owning and managing oil and gas production assets, and collectively producing 10% of total output (ACET 2017).

Implementing local content policies may cause unintended effects, which should be prevented. This is the case of the Ghanaian local content policy (Gatune and Baseda 2020), where requirements to use local suppliers mean mining companies can appoint locally connected people as intermediaries to import supplies. This can be less efficient than mining companies importing directly and can create new patrimonial networks: the root of corruption.

Gender issues also should be integrated, and the extent to which this has been the case varies among countries. For example, while Ghana's local content laws include provisions for local employment (as described above), there is no provision made for gender. In contrast, South Africa's local content policy underscores the importance of including women and youth in mining procurement. The policy requires that at least five per cent of the overall 70 per cent minimum local content requirement be produced by companies controlled by women or youth.[91]

Local content policies, in particular high-income countries boosting of more local processing capacity, has become more relevant in the last years, with noted changes in world geopolitics, as a strategy from some high-income countries to reduce their dependence on materials, especially critical raw materials, coming from Asia. For instance, the United States recently signed a memorandum of understanding with the Democratic Republic of Congo and Zambia to explore ways to support the plan to develop an electric-vehicle value chain together.[92]

90 The Nigerian Content Development and Management Board (NCDMB).
91 Government of South Africa 2018. Broad-Based Socio-Economic Empowerment Charter for the Mining and Minerals Industry. Source: International Labour Organization [ILO] 2021.
92 https://news.bloomberglaw.com/environment-and-energy/us-agrees-to-support-ev-battery-plan-by-congo-zambia

5.4.4. Mainstreaming sustainable consumption options

Chapter 3 shows that the provisioning of food, built environment, mobility and energy contributes approximately 70% to total global climate impacts (2022), and a considerable amount of biodiversity loss. High-income countries, through their consumption, are responsible for most of the environmental impacts mapped in Chapter 3. Indeed, income is the main driver of consumption, and the wealthiest part of the global population contributes to more GHG emissions than the world's poorest 50% (see Box 5.5). This points to the need to primarily target the high-income fraction of the global population (Otto *et al.* 2019). Moreover, resource-intensive lifestyles set the consumption aspirations in the rest of the world (UNEP 2022b). An extreme example is the patterns of hyperconsumption by the wealthiest whereby a relatively small group of people place disproportionate pressures on the global environment due to their affluent consumption patterns (for example private jets or exorbitant homes).

Organizations such as UNEP (2022b) call for a fair consumption space that reduces consumption in higher income contexts, while also acknowledging the need to increase consumption for those who have yet to reach basic life standards.

Box 5.5. Drivers of consumption and how to improve consumption without rebound effects

(Stefanie Hellweg, Andreas Froemelt, Livia Cabernard, Jonas Mehr and Rhythima Shinde, based on SDG Action 2022)

In multiple studies, income is identified as the most relevant driver of consumption impacts (Hertwich and Peters 2009; Baiocchi *et al.* 2010; Ivanova *et al.* 2016). The consumption-related GHG emissions of the 0.54% wealthiest part of the global population are estimated to amount to 3.9 Gt CO_2eq emissions per year, with air travel being the main contributor (Otto *et al.* 2019). This amount is higher than the GHG emissions of the world's poorest 50%, which illustrates that consumption-related measures for lowering environmental impacts should primarily target the high-income proportion of the global population (Otto *et al.* 2019).

Apart from income, lifestyle varies greatly by factors including age group and household size, and determines the environmental footprint of consumption. For example, a Swiss study (Froemelt *et al.* 2018) showed that the household group having the lowest per capita environmental footprint were young parents with small children, as they tended to have low-mobility impacts, low apartment area per person and a balanced diet at home. Those who had a high footprint included relatively well-off couples close to retirement age that lived in over-dimensioned houses and spent much of their free time travelling, as well as young unmarried couples with high income who tended to travel and eat out a lot. There are also low-impact households with comparably high incomes (Girod and De Haan (2009): They tend to be less mobile, live in houses with green heating systems (like heat pumps) and generally consume high-quality goods.

While addressing environmental consumption hotspots is essential, it is also critical to avoid rebound effects which may offset some of the environmental gains. For example, Chitnis *et al.* (2014) showed that money saved by avoiding food waste is often spent on other consumption with comparable or even higher impacts. On average, for food waste reduction in the United Kingdom, approximately 80% of the initial GHG reduction saving was lost due to the impact of such alternative consumption. It is therefore vital to pay attention to what is done with the saved money or time, and to be aware of the risks of problem-shifting.

Sustainable consumer choices should avoid overconsumption and replace high-impact consumption with low-impact consumption. This includes avoiding flights and car travel and instead using more public transport and switching to electric mobility and, for shorter distances, bikes. Living in a well-insulated apartment close to the workplace reduces mobility and heating demands. Eating high-quality seasonal food with only a few animal products can improve both environmental impact and health (see Box 3.2). Such actions depend on the availability of sustainable consumption options, which needs to be ensured by policy. Systemic societal changes in the whole economy are needed to improve access to sustainable and affordable goods and services, which include among others transitioning to a renewable energy system and creating a circular economy.

Results of the Sustainability Transition scenario illustrate how implementing demand-side measures (to address consumption across provisioning systems) can significantly reduce environmental impacts. This is in line with IPCC (2022), which reports that demand-side measures such as diets with less animal protein, compact cities, more public transport and so on can reduce GHG emissions by between 40% and 70% by 2050.

Providing citizens with robust information on the environmental performance of companies and products is critical. However, focusing on individual-led solutions has led to not addressing pressing problems in a systemic way (Chater and Loewenstein 2022). For instance, it is unrealistic to assume that citizens' consumption can be directed towards sustainable choices mainly through information and education while market signals and advertising push citizens strongly in unsustainable directions, with infrastructure to deliver sustainable mobility, housing, energy supply and so on still lacking. Therefore, moving to sustainable consumption requires an intentional shift in consumption patterns by disincentivizing highly resource-intensive options and scaling up goods and services that use fewer resources to satisfy human needs.

This section provides recommendations on how to mainstream sustainable goods and services and improve the environmental performance of provisioning systems from a consumption perspective. For recommendations specific to each provisioning system, with a stronger focus on the need to rethink the ultimate needs for resources, see section 5.4.6.

Recommendation 9: Developing action plans to improve access to affordable and sustainable goods and services

Action plans to ensure that sustainable goods and services are available and affordable should include measures to make sustainable options accessible, economically competitive and socially acceptable (Lenton *et al.* 2022; UNEP 2022b).[93] This would require regulation, a shift towards resource pricing to reflect the environmental cost of resource extraction and use ,as well as removing harmful subsidies and channelling of subsidies towards low-resource intensive, low-impact options (see section 5.4.2). Reducing prices could be particularly challenging for some products and services. In such cases, pricing approaches would need to be accompanied by effective approaches focusing on consumer preferences (Blocker *et al.* 2023).

Action plans, such as those at the national or regional level, should seek to identify and address the context-specific barriers that prevent sustainable consumption, as well as consumption hotspots and their drivers. It is vital to strengthen the capacity of statistical offices and research organizations to develop and analyse the relevant data to inform the development of action plans. As per best practices, consultation and stakeholder engagement should form a key part of action plan development. Action plans could be deployed to enable citizens to make sustainable choices. Demonstrative actions could be deployed and lessons learned then taken on board around their effectiveness. The most effective actions could be scaled up, depending on the specific barriers and progress made. In Asia, for example, the work by Hirao *et al.* (2021) points to critical entry points for the development of sustainable consumption and production policies.

Disincentivizing and regulating resource-intensive options (such as low-energy efficiency products and non-essential single use plastics) out of the market is another way of scaling up sustainable consumption. Such regulation could be based on choice editing, which refers to the practice of influencing choice by "organizing the context in which people make decisions" (UNEP 2022b). Choice editing can include pricing or goods bans, among other approaches. It has been primarily used for major concerns related to public safety, health and security (seatbelts in cars, smoking ban in public places and banning low-efficiency products such as incandescent light bulbs or some electronic equipment). The current sustainability emergency can justify determined action based on this approach. There are many product initiatives where action could be taken. For instance, the CE marking in the EU illustrates how a product regulation could be introduced — in this case with a focus on safety, being required for some specific products such as electronic equipment, when placed in the market, to make ensure products' conformity with European health, safety and environmental protection standards.[94] The report Enabling sustainable lifestyles in a climate emergency (UNEP 2022b) provides examples of policies on choice editing across the globe.

93 It includes also lifestyles in general, which goes beyond consumption, and refers to how people satisfy their needs, including non-economic activities such as making art, caring for others volunteering, leisure and so forth.

94 https://europa.eu/youreurope/business/product-requirements/labels-markings/ce-marking/index_en.htm. Accessed 19 April 2023.

Regulations to adapt the taxation of consumer goods might be based on their environmental footprint, which could send positive signals to citizens making consumption choices. The taxation of goods with proven negative health impacts such as alcoholic drinks or tobacco is an example of how governments have been increasingly using this approach to raise government revenues while also changing consumer behaviour (OECD 2020b). As an example for the food system, Springmann *et al.* (2017; 2018) assess how taxes on specific food products could reduce climate and health impacts, especially in high-meat consumption regions. Having robust estimates of environmental footprint and recognizing the limitations of this approach would be essential for a sound implementation (Plevin *et al.* 2014).

For effective implementation, attention should be also paid to potential backlash from companies and citizens, as well as possible rebound effects. For the latter see Box 5.5, which explains that the ways in which consumers spend time and money need to be considered holistically, making sure not to shift their footprint from one consumption area to another. In addition, a socially and politically sensitive issue is how to approach hyperconsumption by the wealthiest on this planet (see also Box 5.5), where these social groups are currently in no way stimulated to change behaviour, let alone banned from some of the most impactful consumption patterns.

Recommendation 10: Raising awareness and regulating marketing practices that lead to overconsumption

For sustainable alternative goods and services to thrive, they also need to be desirable and socially accepted (Lenton *et al.* 2021). Currently, enormous amounts of money are invested in advertising resource-intensive products (UNEP 2022b).[95] It is therefore crucial to guide marketing practices towards sustainable options, including business-to-consumer and business-to-business marketing, and covering both physical and e-commerce.

Removal of information barriers to sustainable consumption is needed for that. For instance, compulsory display of information on environmental footprints for the products and services with the highest impacts (flying, Sports Utility Vehicles (SUVs) or fossil-driven cars, beef and so on) can support sustainable consumption decisions. Similar strategies have already been applied for tobacco products, which need to display the negative health effects in many countries. Clearer nutritional labelling is also used in some countries to influence consumer behaviour (Julia *et al.* 2018; De Temmerman *et al.* 2021).[96] Car manufacturers are forced to provide consumers with a label showing a car's fuel efficiency and CO_2 emissions, according to the EU car labelling directive.[97]

Accurate estimates of products' environmental footprints are needed, and they should go beyond what many eco labels currently display. A proper implementation will require not only the use of eco labels but also certification schemes with appropriate underlying due diligence. Widely accepted environmental labels already exist for many products,[98] yet their use and the existence of certification schemes is very uneven across the globe. The Consumer Information programme of the One Planet Network[99] provides guidance and training on how to improve consumer information covering ecolabels, life-span extension, packaging, food, product information in e-commerce and so forth.

This action could be complemented by regulations banning the advertisement of high-impact products. Examples of similar actions include the ban on marketing of unhealthy products for children under 14 years of age in Chile,[100] or the ban on the advertising of carbon-intensive transportation in subway stations[101] in Amsterdam, the Netherlands.

To create a level playing field and prevent consumer choice being misled, these actions could be complemented by the banning of publicity with green claims lacking evidence, so-called green-washing. Along these lines, there is an upcoming regulation on substantiating green claims in the EU.[102]

95 Global advertising market reaches new heights and exceeds pre-COVID levels: 22% increase in advertising spending in 2021, to reach an all-time high USD 710 billion. Digital advertising sales represent 62% of total advertising sales worldwide.
96 Assessments of the Nutri-Score, https://www.santepubliquefrance.fr/en/nutri-score, used in France and many other countries.
97 Directive 1999/94/EC, https://eur-lex.europa.eu/eli/dir/1999/94/2008-12-11
98 https://www.ecolabelindex.com/ and OECD (2021).
99 https://www.oneplanetnetwork.org/programmes/consumer-information-scp
100 https://www.oneplanetnetwork.org/knowledge-centre/resources/62-ways-enabling-sustainable-consumption-collection-examples-research
101 Amsterdam is banning advertising for fossil fuel products from the subway stations, https://verbiedfossielereclame.nl/first-step-amsterdam-is-banning-advertising-for-fossil-fuel-products-from-the-subway-stations/
102 Initiative on substantiating green claims, https://ec.europa.eu/environment/eussd/smgp/initiative_on_green_claims.htm

To support the development of actions tailored to different world contexts, the UNEP work on sustainable lifestyles[103] could be reinforced. This workstream provides information on consumption and environmental impact hotspots and issues guidance on how to develop initiatives and campaigns for sustainable consumption. Based on that, a global campaign could be developed, based on the factors with a stronger impact on environmental behaviour (e.g. White *et al.* 2019) and to make communication more meaningful and effective (UNEP 2017).[104] The Lifestyle for Environment (LiFE) campaign of the Government of India puts an individual and collective duty on everyone to live a life that is in tune with Earth and does not harm it.[105] Some cultures and religions already advocate for harmony with nature and reject any type of overconsumption (IPBES 2019a).

5.4.5. Creating circular, resource-efficient and low-impact solutions and business models

Chapter 3 highlights the need to accelerate resource efficiency. Such acceleration is outlined in the Sustainability Transition scenario, which illustrates how increased resource efficiency that relies on increased investment and innovation can reduce the amount of virgin resources required by more than 20%, as well as decreasing the associated environmental impacts.

Further resource efficiency could be achieved by circular economy strategies, which include eco-design, repair, reuse, remanufacturing, refurbishment and recycling. Such strategies maintain the value of products and materials for longer, thereby reducing the need for virgin material extraction and the disposal of waste. These strategies refer to how products are made and how services are delivered (production side) but also to a reduction in the final demand for resources (demand side).

It is essential to further accelerate the uptake of the circular economy, even for players considered frontrunners (see Box 5.6). This should take account of the different development stages and needs across world regions and build on the opportunities of current local circular business models. It also needs to consider the different potential for impact mitigation of different circular economy strategies (IRP 2020b) and across sectors (Cantzler *et al.* 2020). Moving to a more circular bioeconomy is also critical, since the use of biomass is one of the main impact hotspots and since sustainably managed biomass is a scarce resource. This section includes recommendations to accelerate the uptake of circular economy strategies and the development of related business models. Recommendations for specific provisioning system are provided in section 5.4.6.

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103 Sustainable lifestyles UNEP, https://www.unep.org/explore-topics/resource-efficiency/what-we-do/sustainable-lifestyles
104 For instance by using culturally relevant practices to clearly show the impacts of the action, create competitions to reach the goals and so on.
105 https://www.mygov.in/life/

Box 5.6: Moving towards a circular economy in the Netherlands

The Netherlands Government intends to achieve a fully circular economy by 2050 and to halve the use of primary abiotic raw materials by 2030. It sees monitoring as an important way of tracking progress of the desired transition. Therefore, every two years, PBL Netherlands Environmental Assessment Agency, in cooperation other national knowledge institutions, publishes the Integral Circular Economy Report (ICER) (Hanemaaijer *et al.* 2021; Hanemaaijer *et al.* 2023).

In many ways the Netherlands is a front runner in the transition to a circular economy. It was one of the first countries with a national circular economy plan (IenM and EZ 2016; IenW *et al.* 2023). According to 2020 data, it outperforms other European countries in terms of avoiding waste landfilling, waste recycling and resource efficiency (CBS 2023a; Eurostat 2022).

At the same time, ICER2023 concludes there has been no noticeable acceleration in the transition to a circular economy yet. Current recycling is predominantly low value recycling and there has been no structural decrease in the amount of material use and no visible structural reduction in environmental footprints. Circular companies still make up no more than about 6% of the total number of companies (Royal HaskoningDHV 2022), and financial support for circular activities has been constant for years, with about 10% of total support from the schemes surveyed (RVO 2022). Many circular initiatives are still in an early phase, without many scale-up or breakthrough activities. As yet, substantial market demand for and supply of circular products and services (such as bioplastics or car sharing) is lacking.

Current policies, such as Extended Producer Responsibility (EPR), do not yet provide sufficient incentives to use fewer natural resources in the design, production and use of products, nor do they serve to promote longer product life cycles. Although the national government recognizes the relevance of the circular economy for climate (IenW *et al.* 2023), possible effective circular economy measures for climate mitigation – such as increased life span and reduction of the carbon footprint from emissions outside the country – are currently not eligible for funding from the climate fund (Hanemaaijer *et al.* 2023).

ICER2023 thus concludes that realizing the Dutch CE-ambitions requires policy intensification and an expansion of the current policy mix with more coercive measures in the Netherlands and Europe. Standardization and pricing are important policy instruments in this respect. A broad set of policy instruments from all ministries is needed to change the rules for consumption and production. The responsible handling of material resources should be a priority for the entire Netherlands government. The challenge for the next few years is to move from government-wide ambition to government-wide commitment.

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Recommendation 11: Setting up monitoring and evaluation systems to establish priorities and developing ambitious action plans for a circular economy

There is often little quantitative evidence for the effectiveness of circular economy strategies to mitigate impact. Moreover, assessments often refer to potential savings rather than real effectiveness. In addition, circular economy measures assessed by the literature often focus on incremental rather than systemic changes (Cantzler *et al.* 2020).

Therefore, one important priority is to develop monitoring systems to establish priorities for action and to serve as a basis for developing action plans. Post analysis (policy performance evaluation) of the action plans (is also critical to refine strategies. While the picture is very heterogenous across world regions and countries, Cantzler *et al.* (2020),[106] with a focus on climate impacts, point to industry, energy and transport as the sectors where circular economy action could lead to higher emissions mitigation. Mid-range savings could be expected for the waste and building sector, and the lowest mitigation would be in agriculture. As for specific circular economy strategies, the meta-analysis by Koide *et al.* (2022) points to upgrading, repair, refurbishing and pooling (such as carpooling) as showing moderate to high potential for climate mitigation but also lower risks of rebound effects. Other strategies, such as sharing or reuse, were found to be associated with higher risks. A better understanding is also needed of how to boost circularity of biomass (circular bioeconomy) to maximize well-being creation while also minimizing environmental impacts.

The IRP material flows database provides indicators that can be used to monitor the final outcomes of circular economy action plans: resource extraction, material consumption and material footprint and the derived indicators on resource efficiency. The EU Circular Economy Monitoring Framework, which was set up to monitor the progress of the EU Circular Economy action plan (2015 and 2020), includes similar metrics, as well as ones on waste generation and management, secondary materials and socioeconomic aspects. These EU action plans have been the basis for the deployment of more ambitious policies to improve the environmental performance of products over their whole life cycle, including improved management of waste streams.[107].However, this action plan has not been successful in reducing consumption and waste generation, and the related environmental impacts (EEA forthcoming). The EU proposal for a new Ecodesign for Sustainable Products Regulation intends to address these and other challenges.[108]

Additional metrics are also needed to better understand the internal metabolism of resources and identify hotspots and levers for action. While data to monitor critical circular economy aspects are still limited or lacking, OECD (2020c) gives an overview of many circular economy monitoring indicators. The EEA Circularity Metrics Lab[109] presents additional circularity metrics, informing about changes in the behaviour and performance of business, consumers and so on.

Recommendation 12: Developing and reinforcing regulations to boost circular economy business models

To increase energy and material efficiency, reduce waste generation and ensure that the products brought to market are safe and more circular, the regulatory framework needs to favour circular economy business models. It should also promote the development of innovative approaches and demonstrative examples, which could then be scaled up. This also refers to biomass, in a context of increasing competing demand for this type of resources. Biomass use for maximum value and well-being creation, with minimal environmental impacts, should be prioritized, while the sourcing of biomass from waste should also be promoted.

The regulatory framework should include setting eco-design standards for products that are brought to market or imported to determine aspects such as resource-efficiency, durability, repairability, recyclability and content of hazardous chemicals – which can be barriers to circularity. Eco-design standards, initially focusing on reducing energy use, have proven effective in improving the energy performance of products (European Parliament 2028). Lessons to improve regulation can be learnt from the EU regulation on eco-design,[110] whose impact has been reduced due to "delays in the regulatory process and non-compliance by manufacturers and retailers" (European Court of Auditors 2020). Applying these principles is also crucial in the building and transport sectors, where embodied impacts along the whole life cycle of the product should be factored into the design phase.

106 With a focus on climate mitigation.
107 https://ec.europa.eu/eurostat/web/circular-economy/monitoring-framework
108 https://ec.europa.eu/info/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/sustainable-products/ecodesign-sustainable-products_en
109 https://www.eea.europa.eu/en/circularity/
110 Rules and requirements for energy labelling and ecodesign, https://commission.europa.eu/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/energy-label-and-ecodesign/rules-and-requirements_en

Resource-efficiency standards could also be set for extractive, processing and manufacturing industrial sectors at the national level. Best Available Techniques (BAT) policies[111] have proven effective to reduce emissions from the world's most polluting industries with an integrated pollution control approach (simultaneously considering pressures on water, air, soils and resource use) (OECD 2019). It is critical to ensure that the techniques identified as BAT reflect the most adequate means of achieving emissions targets. Also, the targeted emission levels must consider resource use level and be adequate to meet the environmental objectives.[112] As an example, BAT documents are available and mainstreamed for several industries.[113] Industrial symbiosis strategies (Chertow and Park 2016), when relevant, can facilitate the use of waste as feedstocks or material inputs.

Improved regulation could also prevent valuable materials from becoming waste at their end of life. For instance, collection, reuse and recycling targets could be established, and the landfilling of certain waste streams could be taxed or banned. In a European context, countries with the highest recycling rates for bio-waste use well-designed landfill taxes and convenient collection systems (EEA 2023). Extended Producer Responsibility (EPR) approaches, which extend the liability for the end-of-life of a product to the producer, have been a way to prevent waste generation, with mixed results in terms of effectiveness. The work of the OECD[114] is a reference in the field, which could be used to better understand the limitations and potential of such approaches.

Incentives (through regulation and financial incentivization) could facilitate the development of pilot projects and boost the uptake of innovative, more circular business models. Product-as-a-service[115] is among the business models that could be promoted. This approach means producers will provide a service (lighting, mobility) instead of the product (light bulb, car), which could incentivize producers to design, produce and use products with longer life-spans and using fewer resources. Examples of emerging product-as-a-service business can be found in different areas.[116] The development of such approaches should learn from cases where this approach has not proven to generate net environmental benefits (Cooper and Gutowski 2017).

Recommendation 13: Building circular economy capacity and coalitions

It is essential to build capacity and adapt skills to develop and scale up new practices, technologies and business models. Deploying resource efficiency and circular economy strategies is expected to increase jobs in the relevant sectors (OECD 2020d). New skills will be needed for bridging the technology, labour and information requirements of new forms of processing materials and products. Less industrialized countries could benefit from building on existing circular business models including those that have emerged in the informal sector (IRP 2018b). For instance, Mr. Green Africa is a circular economy platform in Kenya that also incorporates informal waste pickers. It participates in the plastic waste challenge and advance a circular economy for plastics in Africa.[117]

To support capacity building, research and innovation should be encouraged across public and private sectors. It is also crucial to prioritize the development and/or reinforcement of platforms for sharing resource efficiency and circular economy ideas and making use of existing ones. There is an increasing number of platforms connecting stakeholders and mainstreaming best practices across the world, such as the Global Alliance on Circular Economy and Resource Efficiency (GACERE), the African Circular Economy Alliance, Latin American Circular Economy Alliance or the Platform for Accelerating the Circular Economy (PACE). Coordination at the regional level could help to build coalitions and share resources and best practices between countries. These coalitions could also help provide resources and assistance for the development of processing capacities and demonstrative facilities.

111 The most effective techniques (both technologies and the way in which the installation is designed, built, maintained, operated and decommissioned) in achieving a high level of protection of the environment, which are considered available (namely, developed on a scale which allows implementation in the relevant industrial sector under economically and technically viable conditions). Definition from the EU Council Directive 96/61/EC of 24 September 1996 concerning integrated pollution prevention and control.

112 While progress in reducing some key environmental pressures has been made (such as some air emissions), policies had not delivered as expected in protecting ecosystems, human health and well-being.

113 For instance, in the context of the European Union: https://eippcb.jrc.ec.europa.eu/reference/

114 https://www.oecd.org/environment/extended-producer-responsibility.htm

115 UNEP. The role of product systems in a sustainable society, https://wedocs.unep.org/bitstream/handle/20.500.11822/8072/-The%20Role%20of%20Product%20Service%20Systems%20In%20a%20Sustainable%20Society-20021172.pdf?sequence=2&%3BisAllowed= (Accessed 12 April 2023)

116 Ibid.

117 See https://www.mrgreenafrica.com/post/advancing-a-circular-economy-for-plastics-in-africa

5.4.6. Achieving more effective resource-intensive provisioning systems

Taking a provisioning systems perspective can help with rethinking and designing solutions that transform the way human needs are fulfilled, while also meeting sustainability goals (Schaffartzik *et al.* 2021). This means developing socially and environmentally superior food supply chains, built environment and energy and mobility services.

As described in Chapter 1, to assess resource use by provisioning system, this report has mapped economic sectors into each of the relevant provisioning systems. This means, for instance, that fuels for energy used by the food industry will be assigned to the latter (and not to the energy system).

To improve provisioning system performance, transitions in resource governance, finance and trade measures are required (see recommendations in sections 5.4.1, 5.4.2 and 5.4.3). Overall consumption and production measures also need to be put in place (see sections 5.4.4 and 5.4.5,). These measures would combine to make provisioning systems more circular and to reduce their ultimate demand for resources. Specific actions by provisioning system are also needed, and would focus on the need to rethink how well-being is delivered by the system, and cover consumption and production measures. Recommendations build on the shifts modelled by the Sustainability Transition scenario, and on resource-related recommendations from global assessments that point to the most critical entry points for transformative action across provisioning systems.

Table 5.2: Recommendations to achieve better performing resource-intensive provisioning systems.

Provisioning system	Recommendation	Production-side	Consumption-side	Modelled in Sustainability Transition scenario
Food	Reducing the demand of the most impactful food commodities	X	X	Diet shift away from red meat to other protein
	Reducing food loss and food waste	X	X	Fast reduction of loss and waste: 50% reduction of food waste from 2020 levels by 2050
	Protecting and restoring productive land while meeting demand for nutrition	X	X	Land use protections on biodiverse areas fully enforced by 2030 High investment in R&D resulting in high yield growth Improved water application efficiency
Built environment	Assuring sustainability of the new building stock	X	X	Building materials include recycled content and timber Lightweighting/lean design for new buildings Lifetime extension for new buildings
	Retrofitting the existing building stock	X	X	Improved energy efficiency of existing buildings
	More intensive use of buildings		X	Lower floor space per capita Higher household occupancy
	Decarbonizing material production	X		Yes
Mobility	Cities moving towards active mobility and public transportation		X	Modal shift towards active and public transport
	Reducing carbon-intensive frequent travelling modalities		X	Reduced overall demand for travel (through increased teleworking and service accessibility)
	Decreasing emissions intensity of transport modalities	X		More intensive use of vehicles Vehicle lifespan extension Vehicle lightweighting
Energy	Decarbonizing electricity supply through the scaling up of low-resource renewable energies and increased energy efficiency	X	X	Accelerated uptake of renewable electricity Doubling of the rate of energy efficiency by 2030
	Decarbonizing fuels	X		Yes

Note: The policy packages and societal shifts modelled by the Sustainability Transition scenario are restricted to measures for which there is robust evidence that can be quantitatively modelled. Note that this scenario considers increased consumption of resources for food, built environment and mobility in regions that would otherwise remain below minimum standards.

Food

More than 50% of impacts on biodiversity, 60% of impacts on water and 21% of climate impacts are linked to the provision of food. Chapter 3 points to the need for demand-side measures to move away from animal protein and reduce food waste (to reduce final demand for food). On the production-side, actions are needed to protect ecosystems, improve land management, avoid food loss and decarbonize the food supply chain. Noticeably, agriculture and food production are concentrated in few corporations globally, and this needs to be considered when implementing action (EEA 2017). All these measures are implemented in the Sustainability Transition scenario (see Table 5.2), which illustrates a slight reduction (1%) of the demand for resources but a higher reduction of the related environmental impacts. The moderate reduction in resource demand is linked to the fact that the scenario also models an increase in food security.

To move away from animal protein, synergies could be established with the human health agenda, since some of the most impactful commodities have also negative impacts on health (such as red meat, processed food and so on). National dietary guidelines could be updated based on joint health and resource use considerations, referring also to the negative impacts of food overconsumption on health. It is critical to deploy instruments that are suited to the context, and build on local cultural and social preferences, since diets would vary considerably by local context, with different prevailing diets and food production systems (IGES 2019).

To improve the sustainability of the food system, FAO, UNDP and UNEP recommend removing subsidies and other incentives for consumption and production of animal-based products (UNEP 2022b). The suggestions from IPCC (2022) are to move agricultural subsidies away from the production of the commodities with the most harmful impacts, such as beef. There is extensive room for action since, as Springmann and Freund (2022) highlight, about two-thirds of all agricultural transfer payments worldwide come without any strings attached. The authors also point to great differences in terms of the type of agricultural businesses targeted by subsidies across countries, which should factor into policy design. Such subsidies could be redirected to payments for positive impacts to protect and restore productive land, as Payment for Ecosystem Services schemes can do (IPBES 2019b). Promoting sustainable peri-urban and urban agriculture can generate livelihoods and reduce inequalities (IRP 2021). Regenerative agricultural practices also seem a promising way to restore soils, sequestrate carbon and enhance biodiversity (Dixson-Decléve *et al.* 2022). Better matching land use with land potential (see Box 3.4 in Chapter 3) could simultaneously increase production, and maintain and improve soil health. Examples across the world illustrate how land restoration could deliver social and environmental benefits: the Community Forest Management of the Maya Biosphere Reserve in Guatemala (Catacora-Vargas *et al.* 2022) has halted deforestation and illegal forestry, while also contributing to the advancement of multiple SDG targets. The Manguinhos Community Garden in Rio de Janeiro, Brazil, the most extensive horticultural garden in Latin America, distributes 2 tons of organic food per month to 800 households at no cost (IRP 2021).

Regulating and creating incentives for nudge mechanisms and innovations could be used to promote more sustainable food choices. Pechey *et al.* (2018), based on a United Kingdom example, found that when more healthy options and vegetarian meals were available in cafeterias, calorie intake and meat consumption were both reduced, despite meat and less healthy options still being available. Hollands *et al.* (2018) found that, when cafeteria portion sizes were reduced, calorie intake decreased significantly, but overall satisfaction with the meal remained.

Developing effective action against food waste (at final consumption) and food loss (link to the food production chain) relies on a good understanding of where the hotspots stand (IPCC 2022; FAO 2019). The monitoring of these two concerns[118] is improving and can therefore support better-informed policymaking. An example of this is the UNEP work (UNEP 2021e), as well as the work on improved national estimates.[119] As an example of policy actions, China has planned to enact a law to reduce food waste in restaurants;[120] and France has banned the disposal of excess/unsold (soon-to-expire) food especially by large retailers.[121]

118 SDG target 12.3 calls for the halving of food waste at the retail and consumer level and the reduction of food loss across supply chains by 2030, which is monitored by indicator 12.3.1 (a) Food loss index and (b) food waste index.
119 For instance in the EU: https://ec.europa.eu/eurostat/web/products-eurostat-news/-/ddn-20220925-2
120 https://www.theguardian.com/world/2020/dec/23/china-to-bring-in-law-against-food-waste-with-fines-for-promoting-overeating
121 https://www.theguardian.com/world/2016/feb/04/french-law-forbids-food-waste-by-supermarkets

Built environment

The built environment accounts for 18% of total global climate and pollution impacts. The impact of the system is less relevant for impacts on biodiversity and water (around 9% and 6%, respectively). Climate impacts from the sector more than doubled between 1995 and 2022, mainly as a result of infrastructure build-up in Asia, which is likely to occur also in other developing regions where such infrastructure is necessary. Nevertheless, high-income countries are responsible for most resource use and have much higher impacts per capita than low- and lower middle-income regions. Chapter 3 states that impacts can be lowered by replacing carbon-intensive materials (such as cement and steel) with sustainably sourced wood in construction, material efficient design and increased circularity.

The Sustainability Transition scenario illustrates that determined action can lead to a 30% reduction in material demand by the built environment. This includes improved design for lower material and energy requirements, increased recycled content and use of timber as construction material, increased lifespan of new buildings and more intensive use of buildings. These actions are identified as critical by key global assessments: UNEP (2022a) and IRP (2020c) call for the reduction of floor area per capita; UNEP (2022b) points to the need to support building retrofitting and adopting energy-saving habits (UNEP 2022a); and other research points to the need of increased efficiency in the use of structural materials (Orr *et al.* 2019) and to reduce the footprint of material production. Governments can wield considerable influence in shaping the built environment system, since they have competences in land use planning, building codes, public financing of the sector and so forth. Action in this field needs to account for the variety of materials and needs in various contexts worldwide (different locally available materials, climate variations and so on)

Reducing the demand for virgin materials through increased reuse and recycling of existing buildings and building materials could reduce demolition waste and virgin material consumption, as well as reducing related environmental impacts. To reduce the demand for virgin materials and replace them more often with secondary materials, taxes on virgin construction materials could be raised and landfill taxes introduced (Arup 2019). The reduced used of virgin materials and related impact savings could be reflected in building labelling, based on standards that could be defined in building codes. This could help the uptake of the standards by the professionals in the market, where resource efficiency will become an economic asset. Timber could replace more resource-intensive options, yet restricted to cases whenever sustainable forest management is achieved.[122]

Improved regulation on buildings could also improve the design, lifespan and energy efficiency of new buildings. This could be also determined in building codes that establish standards for the use of low-carbon materials (substitutes for energy-intensive materials such as steel and concrete) (IRP 2020b; Dunant *et al.* 2021), the reduction of material intensity (UNEP 2022b), the sustainable sourcing of materials, increased energy efficiency of the building and increased use of renewable energy for heating/cooling. The action could be partly financed by the funds raised to support the transitions towards sustainable resource use (see section 5.4.2). Energy labels for buildings are common, for instance in locations with high average heating expenses. In their comparative analysis of the effectiveness of energy efficiency labelling strategies, applied to commercial buildings in Los Angeles between 2005 and 2012, Asensio and Delmas (2017) found that energy savings ranged between 18% and 30%. They also point to some effectiveness limitations: strategies did not "substantially reduce emissions in small and medium sized buildings, which represent about two-thirds of commercial sector building emissions".

The recommendations above are more relevant to countries that are developing their building stock, where providing quality housing for large number of citizens, particularly in low-income countries, remains central to delivering on the SDGs – especially in Africa and parts of Asia. In these cases, resource consumption will contribute to the stock of such houses and dwellings. It is important that this happens with the principles of sustainable resource use at the core. For countries with older building stocks, regulation and incentives could be set up to accelerate the retrofitting rate of the existing stock of buildings, which is currently very low.[123]

Urban planning could be adapted to promote a more intensive use of space, which will reduce floorspace per capita. This could involve a slower growth rate in the space occupied by cities due to increased density in the urban planning (IPCC 2022). This may also avoid impacts on productive land and nature. The potential for reducing resource use and related impacts is higher for regions where most urbanization will happen over the next decades. For areas with a more developed building stock, promoting the multifunctional use of space could help reducing additional land uptake (EEA 2022b).[124]

122 Indeed, Chapter 3 shows that the biodiversity footprint of wood in construction has more than doubled since 1995, as wood is increasingly sourced from regions with high ecosystem value in South-East Asia, Latin America and Africa.
123 IEA 2021b in UNEP 2022a. It states that retrofitting rate should be between 2.5% and 3.5% every year, whereas the current figure is below 1%.
124 For instance, using work canteens as restaurants in the evening or using schools for other social purposes during weekends.

Material production also needs to be more efficient, which is particularly important for steelmaking and cement production (UNEP 2022a): industries that face multiple challenges (such as infrastructure and process lock-ins). A level playing field in international trade would be essential to prevent products with higher carbon-intensity appearing as competitive in the global market. Raw Material Border Adjustment Mechanisms could be applied for that (see recommendation 7 in section 5.4.3). Technology transfer and international collaboration would be needed for the research and the global scaling up of low-carbon materials. The EU Green Deal Industrial Plan[125] intends to provide a more supportive environment for the transition towards a net-zero industry through simplified regulation, access to finance, improved skills and resilience of the supply chain. The Mission Possible Partnership is bringing together industry stakeholders to develop net-zero pathways for carbon-intensive sectors including steel and concrete production.[126]

Mobility

The mobility system is responsible for 7% of global impacts on climate, 6% of pollution impacts and between 2% and 5% of impacts on biodiversity. Indeed, most energy consumption is currently met by oil, with road transport being the main consumer of oil (EIA 2021). Private car transport is infrastructure-dependent, where roads, servicing and parking facilities take vast amounts of public space at the expense of social and environmental uses.

The Sustainability Transition scenario illustrates that the following shifts, combined with other resource efficiency measures, can halve resource use from the mobility system: moving towards active[127] and public transport, reducing the overall demand for travel and decreasing emissions intensity of transport modalities (more intense use plus vehicle lifespan extension and lightweighting).

Switching from motorized vehicles to active mobility and public transport could be facilitated through regulations that grant near access to services, for instance through land use planning (IRP 2018a), limiting the expansion of private car infrastructure, restricting private car access to city centres and increasing safety for pedestrians and cyclists. The municipality of New York has car-free hours, days and locations.[128] Stockholm has deployed a variety of rules for entering the city centres.[129] The Mobility bill in India prioritizes public transport systems and multimodal travel chains.[130]

Price incentives should also signal the least resource-intensive mobility option and intermodal transportation networks could help in urban contexts. Additional options could include revising taxation on ownership and/or use of private vehicles, as well as the promotion of flexible working schedules and teleworking (Hook *et al.* 2020). Financial incentives to employees (travel allowances) could favour active commuting, use of public transport and car or ride sharing.[131] Turning away from private car use can be perceived as limiting, yet it can also boost market demand for new business models and sustainable options (alternative transport modes and new ways to power them), fostering new consumer choices.

There are many of real-life examples of different initiatives being implemented: The 15 min city[132], which claims that urban citizens should have access to essential services within a 15-minute walk or bike ride, is being applied to cities such as Paris,[133] Barcelona,[134] and Portland.[135] For the latter, effectiveness was limited due to the lack of action to reduce car use. London[136] and Stockholm[137] have set fees to enter the city centre, and the proposed Karnataka Active Mobility bill in India[138] prioritizes public transport and multimodal travel chain in response to the exponential increase of private vehicles. In 2011, Beijing imposed a citywide restriction on the ownership of automobiles,[139] which has been effective with some caveats: further coordination among municipalities is needed to prevent citizens from purchasing automobiles in other locations, and the restriction needs to be combined with improved infrastructure for public transportation (Zhang *et al.* 2019). The Netherlands provides incentives to employees for commuting through active mobility.[140]

125 https://ec.europa.eu/commission/presscorner/detail/en/ip_23_510
126 Mission Possible Partnership (https://missionpossiblepartnership.org/sector-transition-strategies/)
127 Walking and cycling for transport purposes.
128 https://www.nyc.gov/html/dot/html/pedestrians/earthday.shtml
129 https://urbanaccessregulations.eu/countries-mainmenu-147/sweden-mainmenu-248/stockholm-charging-scheme
130 https://www.deccanherald.com/opinion/second-edit/mobility-bill-a-welcome-move-1066316.html
131 While improving public transportation could be more effective in very populated areas, strategies for car/ride sharing could be more effective in other contexts. Source: IRP 2020c.
132 https://www.15minutecity.com/
133 https://www.wri.org/insights/paris-15-minute-city
134 https://www.barcelona.de/en/barcelona-superblocks.html
135 https://digital.lib.washington.edu/researchworks/handle/1773/49275
136 https://tfl.gov.uk/modes/driving/congestion-charge
137 https://urbanaccessregulations.eu/countries-mainmenu-147/sweden-mainmenu-248/stockholm-charging-scheme
138 https://www.deccanherald.com/opinion/second-edit/mobility-bill-a-welcome-move-1066316.html
139 https://news.mit.edu/2021/car-ownership-china-0608
140 https://ops.fhwa.dot.gov/publications/fhwahop18071/ch4.htm

These recommendations apply mostly to upper middle-income and high-income countries (the biggest contributors to impacts from mobility) and to emerging economies (which could avoid being locked in inefficient land use planning modes and transportation infrastructure). In 2021, 57% of the world population lived in cities, and trends point to further increases in the share of urban population in all world income regions (United Nations Conference on Trade and Development [UNCTAD] 2022). Acting on cities could therefore deliver significant environmental footprint reductions. As the COVID-19 pandemic has accelerated the transition towards more flexible teleworking arrangements and the associated digitalization, these recommendations could build on the opportunity provided.

Reducing resource-intensive frequent travelling modalities could be achieved by removing such options from the market. For instance, France has banned domestic flights for routes that can be covered by train in 2.5 hours or less,[141] and the United Kingdom climate body is recommending the abolishment of air miles schemes[142] as they can encourage more flying. It will also be necessary to apply some of the strategies described in sections 5.4.2: divesting funds from private car infrastructure to public low-carbon transport systems, and further internalization of environmental costs and removal of harmful subsidies relating to freight transport and aviation.

From the production side, investments in innovation and deployment of less carbon-intensive transport could achieve increased material efficiency in the material cycle of passenger cars: downsizing vehicles, replacing carbon-intensive materials and using materials that add properties that reduce energy demand during the use phase (which is the life cycle stage that generates the most emissions) (IRP 2020c). This could also enable the shift to electric vehicles (powered by renewable energy) and hydrogen-fuelled vehicles. Priority should be given to options with lower resource demand and footprint over the whole life cycle. According to IRP (2020c), material efficiency strategies for cars could reduce emissions by between 30% and 40% in G7 countries and by between 20% and 35% in India and China, thereby also saving on life-cycle emissions in the use phase. Such a shift in the vehicle fleet could also have an indirect effect in lower-income countries, where used vehicles are being often exported by higher income countries (UNEP 2020).

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141 https://www.euronews.com/green/2022/12/02/is-france-banning-private-jets-everything-we-know-from-a-week-of-green-transport-proposals
142 https://www.theguardian.com/environment/2019/oct/14/air-miles-should-be-taxed-to-deter-frequent-fliers-advises-report

Energy

Chapter 3 highlights the urgent need to decarbonize the energy system[143] and material production, which would have further co-benefits (including a reduction in pollution-related health impacts). Chapter 3 also shows that fossil fuel power plants are the main drivers of health impacts, with hotspots in Asian countries, Europe and the United States of America. Unequal access to energy is one of the barriers for achieving the SDGs. Decoupling increasing impacts from improved access to energy for all is therefore a critical aspect of the transition.

The Sustainability Transition scenario illustrates that accelerating the uptake of renewable energy, increasing energy efficiency and decarbonizing fuels can drive a sharp decrease in energy demand, with reductions of climate impacts by more than 80%.

A transition to renewable energy needs to account for the massive increase of demand of some materials (see Box 1.3 in Chapter 1) and the possible bottlenecks in material supply that as a result (Carrrara *et al.* 2023).[144] Accelerating the uptake of renewable energy could be based on technologies already mature enough to deliver at scale such as wind, solar and hydropower (IPPC 2022). For this to happen, energy that is less intensive in terms of resource demand and related environmental footprint, such as wind and some typologies of solar energy, could be given priority. Investment is also needed in research and innovation of novel renewable energy sources, electricity distribution systems and long-term power storage. Action in each country should concentrate on targeting the main energy footprint hotspots. This will often also need cross-border coordination.

The uptake of electricity from renewable sources could be facilitated with demand-side measures such as incentives to make renewable electricity the default option for final users. In their study of several thousand German households, Ebeling and Lotz (2015) found that making green energy the default energy source for households significantly increased the proportion of households with a green energy supplier.

Avoiding future carbon lock-ins is critical (UNEP 2022a). This means that, in parallel to boosting renewable solutions, it is essential to stop subsidies for fossil fuel production and investments in related infrastructure and energy-intensive industries (see recommendations in section 5.4.2).

In addition, scaling up the use of low-carbon fuels could help with transitioning in sectors where electrification is not yet possible.[145] This will require decisive investment in R&D and innovation, and could focus on green hydrogen (UNEP 2022a; UNFCC 2021 in UNEP 2022b), energy sources useful for these applications yet of much lower efficiency and bio-based solutions (IPCC 2023). The green hydrogen industry is booming in some countries of Latin America, a region that relies on the relevant renewable energy and materials needed, and where pilot-scale projects are being developed for bus, long-haul trucking and marine transportation (United Nations, Economic Commission for Latin America and the Caribbean [ECLAC] 2022). Progress has also been made in China, with the application of hydrogen in fuel cells in heavy-duty trucks and the steel sector.[146]

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143 Including the production, conversion and supply of energy for end-consumers, including also industrial activities.
144 For instance, in the EU, the renewable energy sector requires the biggest share of raw materials within the set of materials considered “strategic”.
145 Even if demand is reduced to a minimum through designing other provisioning systems, some fuels will be still needed (for aviation, shipping and so on). In addition, some energy-intensive industrial processes are very hard to decarbonize.
146 https://www.iea.org/reports/hydrogen (accessed August 2023).

5.5 Conclusions

First, given the current and expected trajectory of global increased use of resources and their impacts, a shift towards modes of sustainable resource use and management is essential. The current models of resource use are driving the triple planetary crisis, hinder the delivery of the SDGs and involve a highly unequal distribution of costs and benefits.

Second, Chapters 3 and 4 of this report point out that the pathway towards delivering the SDGs must include a fundamental shift in the way resources are used. The Sustainability Transition scenario illustrates that this is possible, but the path is increasingly steep and narrow because of the failure to deliver on decades of global environmental and sustainable development objectives.

Third, the Sustainability Transition scenario is based on a number of assumptions that would involve significant changes in current provisioning systems. This implicates the functioning of the global economy and how it is reflected in specific places and sectors. Such changes are only possible through strong and deliberate choices in both the public and the private sectors and will have to happen at an unprecedented scale and speed.

Fourth, recommendations in this chapter illustrate the type of policies needed to trigger and enable the transition. While these are not prescriptive, strictly speaking, weak, partial, fragmented or slow policies will simply not work. Strong institutional embedding of resource dimensions in the existing environment, climate and health agendas, in addition to prioritizing aspects of equity and justice, will require courage to be included on the political and policy agenda and even more bravery when it comes to their implementation.

These points are similar to and strongly aligned with the conclusions of recent IPCC, IPBES, GEO and WHO reports based on the efforts of global research communities in multiple fields and subfields. In the specific case of this GRO2024, the recommendations build on the previous version plus more than 15 years of work by the International Resource Panel, including scientific work, reports and assessments by the Panel members, discussions with the Steering Committee members representing the countries and multiple interactions with a vast network of stakeholders. While the messages in this report are precise, clear and probably politically and economically uncomfortable, they should not come as a surprise. Ever since the 1972 Conference on the Human Environment, the fundamental link between society's impact on the environment, the unsustainable use of resources, blatant inequality in conditions for human development and the essential striving for a life of dignity has been repeated and assessed (1992 UNCED, Agenda 21 and SDGs). This report yet another call, one more package of evidence and knowledge, adding to the growing body of scientific assessments (IPCC, IPBES, IRP, GEO, WHO, World Bank and so on) in support of global sustainability agendas and the delivery of Multilateral Environmental Agreements. These assessments are to a very large degree aligned when it comes to conclusions and the necessary changes to current economic and social development models to achieve a trajectory towards sustainable development. Scientists bring the best knowledge and illustrate potential pathways in increasingly bold manner. But the authors of the report are not naive. Realistically, it must be bold political and boardroom decisions that can change the direction of travel.

To use the words of American poet Robert Frost:

> ***humanity has come to a "fork in the road". It is clear that we now have to choose the "road less travelled", because that will "make all the difference".***

Andriy Solovyov
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References

Adamkiewicz, G., Zota, A.R., Fabian, M.P., Chahine, T., Julien, R., Spengler, J.D. and Levy, J.I. (2011). Moving Environmental Justice Indoors: Understanding Structural Influences on Residential Exposure Patterns in Low-Income Communities. ***American Journal of Public Health*** 101(S1), S238–S245. doi: 10.2105/AJPH.2011.300119.

Adedeji, A.N., Sidique, S.F., Rahman, A.A. and Law, S.H. (2016). The role of local content policy in local value creation in Nigeria´s oil industry: A structural equation modeling (SEM) approach. ***Resources Policy*** 49, 61-73.

Adrianto, L.R., Pfister, S. and Hellweg, S. (2022). Regionalized Life Cycle Inventories of Global Sulfidic Copper Tailings. ***Environmental Science & Technology*** 56(7), 4553–4564. doi: 10.1021/acs.est.1c01786.

African Center for Economic Transformation (2017). Comparative Study on Local Content in Mineral, Oil and Gas Sectors: Policies, Legal and Institutional Frameworks-Trends and Responses in Selected African Countries, https://acetforafrica.org/research-and-analysis/reports-studies/multi-country-studies/comparative-study-on-local-content-and-value-addition-in-mineral-oil-and-gas-sectors-policies-legal-and-institutional-frameworks-trends-and-responses-in-selected-african-countries/

Agybay, Zh., Tolen, Zh. and Orynbassarov, D.. (2020). Protecting the rights of indigenous peoples in international law. 90(2):57-64. doi: 10.26577/IRILJ.2020.V90.I2.08

Arup (2019). Circular Business Models for the Built Environment. https://www.arup.com/perspectives/publications/research/section/circular-business-models-for-the-built-environment

Asensio, O. and Delmas, M. (2017). The effectiveness of US energy efficiency building labels. ***Nat Energy*** 2, 17033. https://doi.org/10.1038/nenergy.2017.33

Aurisano, N., Weber, R. and Fantke, P. (2021). Enabling a circular economy for chemicals in plastics. ***Current Opinion in Green and Sustainable Chemistry*** 31, 100513. doi: 10.1016/j.cogsc.2021.100513.

Ayamena Mpenya, H.T., Metseyem, C. andNgah Epo, B. (2016). Natural Resources and Capital Flight in Cameroon. ***African Development Review*** 28, S1 (https://doi.org/10.1111/1467-8268.12183)

Azevedo, L.B., van Zelm, R., Elshout, P. M. F, Jan Hendriks, A., Leuven, R.S.E.W., Struijs, J., de Zwart, D. and Huijbregts, M.A.J. (2013). Species richness-phosphorus relationships for lakes and streams worldwide. ***Global Ecology and Biogeography*** 22(12), pp. 1304–1314. doi: 10.1111/geb.12080.

Baines, J. and Hager, S.B. (2021). Commodity Traders in a Storm: Financialization, Corporate Power and Ecological Crisis. ***Review of International Political Economy*** DOI: 10.1080/09692290.2021.1872039.

Baiocchi, G., Minx, J. and Hubacek, K. (2010). The Impact of Social Factors and Consumer Behavior on Carbon Dioxide Emissions in the United Kingdom. ***Journal of Industrial Ecology*** 14(1), pp. 50–72. doi: 10.1111/j.1530-9290.2009.00216.x.

Bank of England (2023). Our Response to Climate Change (https://www.bankofengland.co.uk/climate-change#:~:text=In%202021%20the%20Bank%20committed,the%20transition%20to%20net%20zero.)

Baroni, L., Cenci, L., Tettamanti, M. and Berati, M. (2007). Evaluating the environmental impact of various dietary patterns combined with different food production systems. ***European Journal of Clinical Nutrition*** 61(2), 279–286. doi: 10.1038/sj.ejcn.1602522.

Bendik, I., Friedel, A., Roos, F.F., Weber, P. and Eggersdorfer, M. (2014). Vitamin D: a critical and essential micronutrient for human health. ***Frontiers in Physiology*** 5. doi: 10.3389/fphys.2014.00248.

BirdLife International 2017 World Database of Key Biodiversity Areas. developed by the KBA Partnership. Retrieved from www.keybiodiversityareas.org

Bank for International Settlements (2020). The green swan: central banking and financial stability in the age of climate change, https://www.bis.org/publ/othp31.pdf

Bank for International Settlements (2021). A taxonomy of sustainable finance taxonomies: Principles for effective taxonomies and proposed policy actions, https://www.bis.org/publ/bppdf/bispap118.pdf

Blocker, C.P., Manning, K.C. and Trujillo, C.A. (2023). Beyond radical affordability in the base of the pyramid: The role of consumer self-confidence in product acceptance. *Journal of Consumer Affairs* 57(1), 619– 647. https://doi.org/10.1111/joca.12514

Bobba, S., Carrara, S., Huisman, J. (co-lead), Mathieux, F. and Pavel, C. (2020). Critical materials for strategic technologies and sectors in the EU - a foresight study. European Commission, Report, 100 p. European Commission, Directorate General Joint Research Centre. doi: 10.2873/865242 ET-04-20-034-EN-C. https://ec.europa.eu/docsroom/documents/42881

Boulay, A.-M., Bare, J., Benini, L., Berger, M., Lathuillière, M. J., Manzardo, A., … Pfister, S. (2018). The WULCA consensus characterization model for water scarcity footprints: assessing impacts of water consumption based on available water remaining (AWARE). *The International Journal of Life Cycle Assessment* 23(2), 368–378. https://doi.org/10.1007/s11367-017-1333-8.

Bouma, J. (2014). Soil science contributions towards Sustainable Development Goals and their implementation: linking soil functions with ecosystem services. *Journal of Plant Nutrition and Soil Science* 177(2), 111–120. doi: 10.1002/jpln.201300646.

Bringezu, S. Toward Science-Based and Knowledge-Based Targets for Global Sustainable Resource Use. *Resources* 2019, 8, 140. https://doi.org/10.3390/resources8030140

Bringezu, S. , Potočnik, J., Schandl, H., Lu, L, Ramaswami, A, Swilling, M. and Suh, S. (2016). Multi-scale Governance of Sustainable Natural Resource Use—Challenges and Opportunities for Monitoring and Institutional Development at the National and Global Level. *Sustainability* 8(8), 778; https://doi.org/10.3390/su8080778

Bringezu, S. Possible Target Corridor for Sustainable Use of Global Material Resources. *Resources* 2015, 4, 25-54. https://doi.org/10.3390/resources4010025

Brosché, S., Strakova, J., Bell, L. and Karlsson, T. (2021). Widespread chemical contamination of recycled plastic pellets globally. International Pollutants Elimination Network (IPEN), December 2021.

Bustos, B., Mauro, S. E., García-López, G., Milanez, F. and Ojeda, D. (2023). Routledge Handbook of Latin America and the Environment. Taylor and Francis.

Cabernard, L. and Pfister, S. (2021). A highly resolved MRIO database for analyzing environmental footprints and Green Economy Progress. *Science of The Total Environment* 755, 142587. doi: 10.1016/j.scitotenv.2020.142587.

Cabernard, L., and Pfister, S. (2022). Hotspots of Mining-Related Biodiversity Loss in Global Supply Chains and the Potential for Reduction through Renewable Electricity. *Environmental Science & Technology* 56(22), 16357–16368. doi: 10.1021/acs.est.2c04003.

Cabernard, L., Pfister, S. and Hellweg, S. (2019). A new method for analyzing sustainability performance of global supply chains and its application to material resources. *Science of The Total Environment* 684, 164–177. doi: 10.1016/j.scitotenv.2019.04.434.

Cabernard, L., Pfister, S. and Hellweg, S. (2022). Improved sustainability assessment of the G20's supply chains of materials, fuels, and food. *Environmental Research Letters* 17(3), p. 034027. doi: 10.1088/1748-9326/ac52c7.

Cabernard, L., Pfister, S., Oberschelp, C and Hellweg, S. (2021). Growing environmental footprint of plastics driven by coal combustion. *Nature Sustainability* 5(2), pp. 139–148. doi: 10.1038/s41893-021-00807-2.

CAF (2022). Strategic Biodiversity Initiative (https://scioteca.caf.com/bitstream/handle/123456789/1909/Biocaf%202022-2026_English.pdf?sequence=4&isAllowed=y#:~:text=In%20this%20context%2C%20the%20core,an%20equitable%20distribution%20of%20benefits)

Cantzler, J., Creutzig, F., Ayargarnchanakul, E., Javaid, A., Wong, L. and Haas, W., (2020). Saving resources and the climate? A systematic review of the circular economy and its mitigation potential. *Environmental Research Letters* 15(12).

Carrara, S., Bobba, S., Blagoeva, D., Alves Dias, P., Cavalli, A., Georgitzikis, K. *et al.* (2023). Supply chain analysis and material demand forecast in strategic technologies and sectors in the EU – A foresight study, Publications Office of the European Union, Luxembourg, doi:10.2760/386650, JRC132889.

Catacora-Vargas, G., Tambutti, M., Alvarado, V. and Rankovic, A. (2022). Governance approaches and practices in Latin America and the Caribbean for transformative change for biodiversity, Project Documents (LC/TS.2022/203), Santiago, United Nations, Economic Commission for Latin America and the Caribbean (ECLAC).

CBS (2023). Indicatoren op basis van de Materiaal Monitor ten behoeve van de ICER 2023 [Indicators based on the Material Monitor for the ICER 2023]. Statistics Netherlands, The Hague.

Celis-Morales, C., Livingstone, K.M., Marsaux, C.F., Macready, A.L., Fallaize, R., O'Donovan, *et al.* Food4Me Study (2016). Effect of personalized nutrition on health-related behaviour change: evidence from the Food4me European randomized controlled trial. ***International Journal of Epidemiology*** dyw186. doi: 10.1093/ije/dyw186.

Chater, N. and Loewenstein, G. (2022). The i-frame and the s-frame: How focusing on individual-level solutions has led behavioral public policy astray. ***Behav Brain Sci*** Sep 5:1-60. doi: 10.1017/S0140525X22002023. Epub ahead of print. PMID: 36059098.

Chaudhary, A., Gustafson, D. and Mathys, A. (2018). Multi-indicator sustainability assessment of global food systems. ***Nature Communications*** 9(1), 848. doi: 10.1038/s41467-018-03308-7.

Chertow, M., and Park, J. (2016). Scholarship and Practice in Industrial Symbiosis: 1989–2014. In R. Clift and A. Druckman (Eds.), Taking Stock of Industrial Ecology (pp. 87-116): Springer International Publishing.

Chertow, M.R. (2000). The IPAT Equation and Its Variants. ***Journal of Industrial Ecology***. 4(4), pp. 13–29. doi: 10.1162/10881980052541927.

Cherubini, F., Peters, G.P., Berntsen, T., StroØmmann, A.H. and Hertwich, E. (2011). CO2 emissions from biomass combustion for bioenergy: atmospheric decay and contribution to global warming. ***GCB Bioenergy*** 3(5), 413–426. doi: 10.1111/j.1757-1707.2011.01102.x.

Chini, L., Hurtt, G., Sahajpal, R., Frolking, S., Klein Goldewijk, K., Sitch, S. *et al.* (2021). Land-use harmonization datasets for annual global carbon budgets. ***Earth System Science Data*** 13(8), 4175–4189. doi: 10.5194/essd-13-4175-2021.

Chitnis, M., Sorrell, S., Druckman, A., Firth, S.K. and Jackson, T. (2014). Who rebounds most? Estimating direct and indirect rebound effects for different UK socioeconomic groups. ***Ecological Economics*** 106, 12–32. doi: 10.1016/j.ecolecon.2014.07.003.

Christmann P., Ayuk E., Kumar V., Pedro A. (2022). Future mineral demand: the necessary transition towards sustainability. Chapter 5 of the Routledge Handbook of Extractive Industries and Sustainable Development (Yakovleva N. and Nickless E., Eds.). Taylor and Francis. ISBN (e-book) 9781003001317

Convention on Biological Diversity (2022a). Kuming-Montreal Global Biodiversity Framework. https://www.cbd.int/gbf/

Convention on Biological Diversity (2022b), Kunming-Montreal Global Biodiversity Framework (https://www.cbd.int/doc/c/e6d3/cd1d/daf663719a03902a9b116c34/cop-15-l-25-en.pdf)

Cooper, D. R., and Gutowski, T. G. (2017). The Environmental Impacts of Reuse: A Review. ***Journal of Industrial Ecology*** 21(1), 38-56. doi:10.1111/jiec.12388

Dasgupta, P. (2021). The Economics of Biodiversity: The Dasgupta Review (https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/962785/The_Economics_of_Biodiversity_The_Dasgupta_Review_Full_Report.pdf)

Day, M., Cooney, J.D. and MacKinnon, M. (1995). Degradation of contaminated plastics: a kinetic study. ***Polymer Degradation and Stability*** 48(3), 341–349. doi: 10.1016/0141-3910(95)00088-4.

De Nederlandsche Bank (2020). Indebted to nature: Exploring biodiversity risks for the Dutch financial sector (https://www.dnb.nl/media/4c3fqawd/indebted-to-nature.pdf)

De Temmerman, J., Heeremans, E., Slabbinck, H. and Vermeir, I. (2021). The impact of the Nutri-Score nutrition label on perceived healthiness and purchase intentions. ***Appetite*** Feb 1;157:104995. doi: 10.1016/j.appet.2020.104995. Epub 2020 Oct 15. PMID: 33068665.

Dellink, R., Chateau, J., Lanzi, E. and Magné, B. (2017). Long-term economic growth projections in the Shared Socioeconomic Pathways. ***Global Environmental Change***. 42, 200-214, ISSN 0959-3780,https://doi.org/10.1016/j.gloenvcha.2015.06.004.

Dietsche, E. and Esteves, A.M. (2018). What are the prospects for Mozambique to diversify its economy on the back of 'local content'? WIDER Working Paper 2018/113, September 2018. United Nations University World Institute for Development Economics Research.

Dittrich, M. and Bringezu, S. (2010). The physical dimension of international trade Part 1: Direct global flows between 1962 and 2005. ***Ecological Economics*** 69, 1838-1847.

Dittrich, M., Bringezu, S. and Schutz, H. (2012). The physical dimension of international trade, part 2: Indirect global resource flows between 1962 and 2005. ***Ecological Economics***. 79, 32-43.

Dixson-Decléve, S., Gaffney, O., Ghosh, J., Randers, J., Rockström, J. and Stoknes, P.S. (2022). Earth4All- a survival guide for humanity, New Society Publishers. https://www.clubofrome.org/publication/earth4all-book/

Dunant, C.F., Drewniok, M.P., Orr, J. and Allwood, J.M. (2021). Good early stage design decisions can halve embodied CO2 and lower structural frames' cost. ***Structures***. 33, 343-354, ISSN 2352-0124, https://doi.org/10.1016/j.istruc.2021.04.033.

Dzirutwe, M. (2021). Zimbabwe bans chrome ore exports to boost ferrochrome industry. Reuters. August 3 https://www.reuters.com/article/zimbabwe-chrome-idAFL8N2PA65U

Ebeling, F, and Lotz, S. (2015). Domestic uptake of green energy promoted by opt-out tariffs. ***Nature Clim Change*** 5, 868–871. https://doi.org/10.1038/nclimate2681

Edwards, P. (2014). Global cement emissions standards. ***Global Cement Magazine***. https://www.globalcement.com/magazine/articles/845-global-cement-emissions-standard

Ehrlich, P.R. and Holdren, J.P. (1971). Impact of Population Growth: Complacency concerning this component of man's predicament is unjustified and counterproductive. ***Science*** 171(3977)

Ekins, P. (2024). Stopping Climate Change: Policies for Real Zero, Routledge, London/New York.

Elshkaki, A. and Shen, L. (2019). Energy-material nexus: The impacts of national and international energy scenarios on critical metals use in China up to 2050 and their global implications. ***Energy*** [online] 180, 903–917. doi:10.1016/j.energy.2019.05.156

Ettmayr, C. and Lloyd, H. (2017). Local content requirements and the impact on the South African renewable energy sector: a survey-based analysis. ***South African Journal of Economic and Management Sciences*** 20:1–11 (10.1016/j.enpol.2019.110910)

European Central Bank (2021) (Press Release). ECB's Governing Council approves its new monetary policy strategy, https://www.ecb.europa.eu/press/pr/date/2021/html/ecb.pr210708~dc78cc4b0d.en.html

European Court of Auditors (2020). Special Report EU action on Ecodesign and Energy Labelling: important contribution to greater energy efficiency reduced by significant delays and non-compliance, https://www.eca.europa.eu/Lists/ECADocuments/SR20_01/SR_Ecodesign_and_energy_labels_EN.pd

European Environment Agency (2017). Food in a green light - A systems approach to sustainable food, EEA Report | No 16/2017, https://www.eea.europa.eu/publications/food-in-a-green-light

European Environment Agency (2022a). Enabling consumer choices for a circular economy, https://www.eea.europa.eu/publications/influencing-consumer-choices-towards-circularity

European Environment Agency (2022b). Building renovation: where circular economy and climate meet, https://www.eea.europa.eu/publications/building-renovation-where-circular-economy.

European Environment Agency (2023). Briefing on Economic instruments and separate collection systems — key strategies to increase recycling, https://www.eea.europa.eu/publications/economic-instruments-and-separate-collection

European Environment Agency (forthcoming), State and Outlook of the Circular Economy.

European Environment Information and Observation Network (2022). Country profiles on Circular Economy in Europe, https://www.eionet.europa.eu/etcs/etc-ce/products/etc-ce-reports-2022-5-circular-economy-country-profiles-a-set-of-30-country-profiles-that-summarise-policies-and-initiatives-in-the-area-of-circular-economy

European Investment Bank (2023). EIB Energy Lending Policy (https://www.eib.org/en/publications/20230164-eib-energy-lending-policy)

European Parliament (2018), Report on the implementation of the Ecodesign Directive (2009/125/EC), https://www.europarl.europa.eu/doceo/document/A-8-2018-0165_EN.html

Eurostat (2022). Generation of waste by waste category, hazardousness and NACE Rev. 2 activitly, env_wasgen (24 October 2022).

Fanning, A.L., O'Neill, D.W. and Büchs, M. (2020). Provisioning systems for a good life within planetary boundaries. ***Global Environmental Change*** 64, 102135, ISSN 0959-3780, https://doi.org/10.1016/j.gloenvcha.2020.102135.

Fanning, A.L., O'Neill, D.W., Hickel, J. and Roux, N. (2022). The social shortfall and ecological overshoot of nations. ***Nature Sustainability*** 5 (1). 26-36. https://doi.org/10.1038/s41893-021-00799-z

FAOSTAT, Food and Agriculture Organization of the United Nations. Available at: https://www.fao.org/faostat/en/#data [Accessed: 2 February 2023].

Finnish Geological survey. Download link: https://tupa.gtk.fi/raportti/arkisto/42_2021.pdf Fischer-Kowalski, M., Krausmann, F., Giljum, S., Lutter, S., Mayer, A., Bringezu, S., Moriguchi, Y., Schutz, H., Schandl, H. and Weisz, H. (2011). Methodology and Indicators of Economy-wide Material Flow Accounting. ***Journal of Industrial Ecology***,15, 855-876.

Florke, M., Schneider, C. and Mcdonald, R. I. (2018). Water competition between cities and agriculture driven by climate change and urban growth. ***Nature Sustainability*** 1, 51-58.

Food and Agriculture Organization of the United Nations (2019). The State of Food and Agriculture 2019: Moving forward on food loss and waste reduction. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy, 182 pp.Franco, A., and Diaz, A. R. (2009). The future challenges for "clean coal technologies": Joining efficiency increase and pollutant emission control. ***Energy*** 34, 348–354. https://doi.org/10.1016/j.energy.2008.09.012

Frank, S., Havlík, P., Tabeau, A., Witzke, P., Boere, E., Bogonos, M., Deppermann, A., van Dijk, M., Höglund-Isaksson, L. and Janssens, C. (2021). How much multilateralism do we need? Effectiveness of unilateral agricultural mitigation efforts in the global context. ***Environ. Res. Lett***. 16 104038 https://iopscience.iop.org/article/10.1088/1748-9326/ac2967

Franks, D.M., Stringer, M., Torres-Cruz, L.A., Baker, E., Valenta, R., Thygesen, K., Matthews, A., Howchin, J. and Barrie, S. (2021). Tailings facility disclosures reveal stability risks. ***Scientific Reports*** 11(1), 5353. doi: 10.1038/s41598-021-84897-0.

Friedlingstein, P., O'Sullivan, M., Jones, M. W., Andrew, R. M., Gregor, L., Hauck, J. *et al.* (2022). Global Carbon Budget 2022. ***Earth System Science Data*** 14(11), 4811–4900. doi: 10.5194/essd-14-4811-2022.

Frischknecht, R. and Jolliet O. (2017). Global Guidance on Environmental Life Cycle Impact Assessment Indicators (Volume 1). Paris, France.

Frischknecht, R. and Jolliet, O. (2019). Global Guidance for Life Cycle Impact Assessment Indicators (Volume 2). Paris, France.

Froemelt, A., Dürrenmatt, D.J. and Hellweg, S. (2018). Using Data Mining To Assess Environmental Impacts of Household Consumption Behaviors. ***Environmental Science & Technology*** doi: 10.1021/acs.est.8b01452.

Fuller, R., Landrigan, P.J., Balakrishnan, K., Bathan, G., Bose-O'Reilly, S., Brauer, M. *et al.*(2022). Pollution and health: a progress update. ***Lancet Planet Health*** 6(6):e535-e547. doi: 10.1016/S2542-5196(22)00090-0. Epub 2022 May 18. Erratum in: Lancet Planet Health. 2022 Jun 14;: PMID: 35594895.

G7 (2022). Berlin Roadmap on Resource Efficiency and Circular Economy (https://www.g7germany.de/resource/blob/974430/2044354/c43d64ba810dd65984fddcd18fd6323b/2022-05-27-3-g7-berlin-road-map-data.pdf?download=1#:~:text=With%20the%20Berlin%20Roadmap%2C%20the%20G7%20Alliance%20on,of%20chemicals%2C%20throughout%20the%20entire%20life-cycle%20of%20products.)

G7 (2023a). Five-Point Plan for Critical Minerals Security (https://www.meti.go.jp/information/g7hirosima/energy/pdf/Annex005.pdf) (Responsible supply chains and circular economy measures are prominent in this plan, however, systemic critical mineral demand reduction through measures such as those modelled in Chapter 4 are missing)

G7 (2023b). Circular Economy and Resource Efficiency Principles (CEREP) (https://www.meti.go.jp/information/g7hirosima/energy/pdf/Annex002.pdf)

Gasper, D., Shah, A. and Tankha, S. (2019). The Framing of Sustainable Consumption and Production in SDG 12. ***Global Policy*** 10, 83-95.

Gasser, T. , Kechiar, M., Ciais, P., Burke, E., Kleinen, T., Zhu, D., Huang, Y., Ekici, A. and Obersteiner, M. (2018). Path-dependent reductions in CO2 emission budgets caused by permafrost carbon release. ***Nature Geoscience*** 11(11), 830–835. doi: 10.1038/s41561-018-0227-0.

Gatune, J. and Baseda, H. (2020). Leveraging Mineral Value Chains for Broad-Based and Sustainable Development – Policy Options for Ghana. Working Paper - WP-2021/6 November 8, 2020. UNU-INRA 2020.

GBD 2016 Risk Factors Collaborators, Thomas, M., & Moraga, P. (2017). Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990–2016: a systematic analysis for the Global Burden of Disease Study 2016. Lancet, 390(10100), 1345-1422. https://doi.org/10.1016/S0140-6736(17)32366-8

GBD 2019 Risk Factors Collaborators, & Hird, T. (2020). Global burden of 87 risk factors in 204 countries and territories, 1990-2019: a systematic analysis for the Global Burden of Disease Study 2019. The Lancet, 396(10258), 1223-1249. https://doi.org/10.1016/S0140-6736(20)30752-2Georgitzikis, K., Grohol, M., Itul, A., Kuzov, T., Latunussa, C., Lyons *et al.*(2023) Supply chain analysis and material demand forecast in strategic technologies and sectors in the EU – A foresight study, EUR 31437 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-68-00339-8, doi:10.2760/386650.

Gibbs, H.K., Ruesch, A.S., Achard, F., Clayton, M.K., Holmgren, P., Ramankutty, N. and Foley, J.A. (2010). Tropical forests were the primary sources of new agricultural land in the 1980s and 1990s. ***Proceedings of the National Academy of Sciences of the United States of America*** 107, 16732-16737.

Gielen, D. (2021). Critical materials for the Energy Transition. Report, 43 p., Technical Paper 5/21. n, International Renewable Energy Agency, Abu Dhabi. https://irena.org/-/media/Files/IRENA/Agency/Technical-Papers/IRENA_Critical_Materials_2021.pdf

Giljum, S., Wieland, H., Lutter, S., Eisenmenger, N., Schandl, H. and Owen, A.. The impacts of data deviations between MRIO models on material footprints. ***Journal of Industrial Ecology***. 2019; 23: 946–958. https://doi.org/10.1111/jiec.12833

Girod, B. and De Haan, P. (2009). GHG reduction potential of changes in consumption patterns and higher quality levels: Evidence from Swiss household consumption survey. ***Energy Policy*** 37(12), 5650–5661. doi: 10.1016/j.enpol.2009.08.026.

Gonzalez-Garay, A., Heuberger-Austin, C., Fu, X., Klokkenburg, M., Zhang, D., van der Made, A. and Shah, N. (2022). Unravelling the potential of sustainable aviation fuels to decarbonise the aviation sector. ***Energy & Environmental Science*** 15(8), 3291–3309. doi: 10.1039/D1EE03437E.

Goodenough, K., Deady, E. and Shaw, R. (2021), Lithium resources, and their potential to support battery supply chains, in Africa. British Geological Survey. (http://nora.nerc.ac.uk/id/eprint/530698/1/Lithium_in_Africa_Report.pdf)

Grandell, L., Lehtilä, A., Kivinen, M., Koljonen, T., Kihlman, S. and Lauri, L.S, (2016). Role of critical metals in the future markets of clean energy technologies. ***Renew. Energy*** https://doi.org/10.1016/j.renene.2016.03.102

Guneralp, B., Lwasa, S., Masundire, H., Parnell, S. and Seto, K.C. (2018). Urbanization in Africa: challenges and opportunities for conservation. ***Environmental Research Letters*** 13.

Haas, W., Krausmann, F., Wiedenhofer, D. and Heinz, M. (2015). How Circular is the Global Economy?: An Assessment of Material Flows, Waste Production, and Recycling in the European Union and the World in 2005. ***Journal of Industrial Ecology*** 19, 765-777.

Habib, K., Hansdóttir, S. T., and Habib, H. (2020). Critical metals for electromobility: Global demand scenarios for passenger vehicles, 2015–2050. ***Resources, Conservation and Recycling*** 154, 104603. https://doi.org/10.1016/j.resconrec.2019.104603

Haddeland, I., Heinke, J., Biemans, H., Eisner, S., Florke, M., Hanasaki, N., Konzmann, M., Ludwig, F., Masaki, Y., Schewe, J., Stacke, T., Tessler, Z. D., Wada, Y. and Wisser, D. (2014). Global water resources affected by human interventions and climate change. ***Proceedings of the National Academy of Sciences of the United States of America*** 111, 3251-3256.

Hanemaaijer, A., Kishna, M., Brink, H., Koch, J., Prins, A. G., and Rood, T. (2021). Integral Circular Economy Report 2021: Assessment for the Netherlands. Retrieved from The Hague: PBL Netherlands Environmental Assessment Agency, The Hague.

Hanemaaijer, A., Kishna, M., Koch, J., Lucas, P., Rood, T., Schotten, K., and van Sluisveld, M. (2023). Integral Circular Economy Report 2023: Assessment for the Netherlands. PBL Netherlands Environmental Assessment Agency, The Hague.

Hansen, J. E., Sato, M., Simons, L., Nazarenko, L. S., Sangha, I., Kharecha, P., Zachos, J. C., Von Schuckmann, K., Loeb, N. G., Osman, M. B., Jin, Q., Tselioudis, G., Jeong, E., Lacis, A., Ruedy, R., Russell, G., Cao, J., & Li, J. (2023). Global warming in the pipeline. Oxford Open Climate Change, 3(1). https://doi.org/10.1093/oxfclm/kgad008 Hansen, U.E., Nygaard, I., Morris, M. and Robbins, G. (2020), The effects of local content requirements in auction schemes for renewable energy in developing countries: A literature review. ***Renewable and Sustainable Energy Reviews*** 127 (February):109843. DOI: 10.1016/j.rser.2020.109843.

Hansis, E., Davis, S.J. and Pongratz, J. (2015). Relevance of methodological choices for accounting of land use change carbon fluxes. ***Global Biogeochemical Cycles*** 29(8), 1230–1246. doi: 10.1002/2014GB004997.

Harris, P.G., (2023). COP27: From preventing dangerous climate change to salving loss and damage. PLOS Clim 2(1): e0000150. https://doi.org/10.1371/journal.pclm.0000150

Hatfield-Dodds, S., Schandl, H., Newth, D., Obersteiner, M., Cai, Y., Baynes. T., West, J. and Havlik, P. (2017). Assessing global resource use and greenhouse emissions to 2050, with ambitious resource efficiency and climate mitigation policies. *Journal of Cleaner Production* doi: 10.1016/j.jclepro.2016.12.170.

Heijlen, W., Franceschi, G., Duhayon, C. and Van Nijen, K. (2021). Assessing the adequacy of the global land-based mine development pipeline in the light of future high-demand scenarios: The case of the battery-metals nickel (Ni) and cobalt (Co). *Resources Policy* [online] 73, 102202. Available at: https://www.sciencedirect.com/science/article/pii/S0301420721002166#appsec1

Hellweg, S. and Canals, L.M.I. (2014). Emerging approaches, challenges and opportunities in life cycle assessment. *Science* 344, 1109-1113.

Helmes, R.J.K., Huijbregts, M.A.J., Henderson, A.D. and Jolliet, O. (2012). Spatially explicit fate factors of phosphorous emissions to freshwater at the global scale. *The International Journal of Life Cycle Assessment* 17(5), 646–654. doi: 10.1007/s11367-012-0382-2.

Herrero, M., Havlik, P., McIntire, J., Palazzo, A. and Valin, H. (2014). African Livestock Futures: Realizing the potential of livestock for food security, poverty reduction and the environment in Sub-Saharan Africa. Geneva, Switzerland: Office of the Special Representative of the UN Secretary General for Food Security and Nutrition and the United Nations System Influenza Coordination. https://hdl.handle.net/10568/41908

Hertwich, E.G. and Peters, G.P. (2009). Carbon Footprint of Nations: A Global, Trade-Linked Analysis. *Environmental Science & Technology* 43(16), 6414–6420. doi: 10.1021/es803496a.

Hickel, J., Dorninger, C., Wieland, H. and Suwandi, I. (2022). Imperialist appropriation in the world economy: Drain from the global South through unequal exchange, 1990–2015. *Global Environmental Change* 73:102467. DOI: 10.1016/j.gloenvcha.2022.102467

Hirao, M., Tasaki, T., Hotta, Y. and Kanie, N. (2021). Policy Development for Reconfiguring Consumption and Production Patterns in the Asian region. *Global Environmental Research* 25.

Hoekstra, A.Y. and Chapagain, A. K. (2007). Water footprints of nations: Water use by people as a function of their consumption pattern. Conference on Integrated Assessment of Water Resources and Global Change, Feb 2005 Bonn, GERMANY. 35-+.

Hoekstra, A.Y. and Mekonnen, M.M. (2012). The water footprint of humanity. *Proceedings of the National Academy of Sciences of the United States of America* 109, 3232-3237.

Hoekstra, A.Y. (2016). A critique on the water-scarcity weighted water footprint in LCA. *Ecological Indicators* 66, 564-573.

Hoekstra, A. Y., Mekonnen, M.M., Chapagain, A.K., Mathews, R.E. and Richter, B.D. (2012). Global Monthly Water Scarcity: Blue Water Footprints versus Blue Water Availability. Plos One, 7.

Hollands, G.J., Cartwright, E., Pilling, M., Pechey, R., Vasiljevic, M., Jebb, S.A.and Marteau, T.M. (2018). Impact of reducing portion sizes in worksite cafeterias: a stepped wedge randomised controlled pilot trial. *Int J Behav Nutr Phys Act* 15, 78. https://doi.org/10.1186/s12966-018-0705-1

Hook, A., Court, V., Sovacool, B. K., and Sorrell, S. (2020). A systematic review of the energy and climate impacts of teleworking. *Environmental Research Letters* 15(9). https://doi.org/10.1088/1748-9326/ab8a84

Hu, W., Fang, L., Zhang, H., Ni, R., and Pan, G. (2023). Changing trends in the air pollution – related disease burden from 1990 to 2019 and its predicted level in 25 years. *Environmental Science and Pollution Research*. 1761–1773. https://doi.org/10.1007/s11356-022-22318-z

Hund K., La Porta D., Fabregas T. P. , Laing T. and Drexhage J. (2020). Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition - Report, 112 p. - The World Bank Group - http://pubdocs.worldbank.org/en/961711588875536384/Minerals-for-Climate-Action-The-Mineral-Intensity-of-the-Clean-Energy-Transition.pdf

Huo, J., Wang, Z., Oberschelp, C., Guillén-gosálbez, G. and Hellweg, S. (2022). Net-zero transition of the global chemical industry with CO2-feedstock by 2050: feasible yet challenging. doi: 10.1039/d2gc03047k.

Hurtt, G. C., Chini, L., Sahajpal, R., Frolking, S., Bodirsky, B. L., Calvin *et al.*(2020). Harmonization of global land use change and management for the period 850–2100 (LUH2) for CMIP6. *Geoscientific Model Development* 13(11), 5425–5464. doi: 10.5194/gmd-13-5425-2020.

IenM and EZ (2016). Government-wide programme for a Circular Dutch Economy: 'a circular economy in the Netherlands by 2050'. Ministry of Infrastructure and the Environment and Ministry of Economic Affairs, The Hague.

IenW, BZK, EZK and LNV (2023). Nationaal Programma Circulaire Economie 2023-2030 [National Circular Economy Programme 2023-2030]. Ministry of Infrastructure and Water Management, Ministry of the Interior and Kingdom Relations, Ministry of Economic Affairs and Climate Policy, Ministry of Agriculture, Nature and Food Quality, The Hague.

Institute for Global Environmental Strategies (2019). Roadmap for Sustainable Waste Management and Resource Circulation in South Asia, 2019-2030, https://www.iges.or.jp/en/pub/roadmap-south-asia/enInstitute for Global Environmental Strategies, Aalto University and D-mat ltd. (2019). 1.5-Degree Lifestyles: Targets and Options for Reducing Lifestyle Carbon Footprints. Technical Report. Hayama, Japan, https://www.iges.or.jp/en/publication_documents/pub/technicalreport/en/6719/15_Degree_Lifestyles_MainReport.pdf

Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development) (2023),. The Future of Resource Taxation (https://www.igfmining.org/tax-base-erosion-and-profit-shifting/the-future-of-resource-taxation/)

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (2019a), Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. E. S. Brondizio, J. Settele, S. Díaz, and H. T. Ngo (editors). IPBES secretariat, Bonn, Germany. 1148 pages. https://doi.org/10.5281/zenodo.3831673

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (2019b). Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. S. Díaz, J. Settele, E. S. Brondízio, H. T. Ngo, M. Guèze, J. Agard, A. Arneth, P. Balvanera, K. A. Brauman, S. H. M. Butchart, K. M. A. Chan, L. A. Garibaldi, K. Ichii, J. Liu, S. M. Subramanian, G. F. Midgley, P. Miloslavich, Z. Molnár, D. Obura, A. Pfaff, S. Polasky, A. Purvis, J. Razzaque, B. Reyers, R. Roy Chowdhury, Y. J. Shin, I. J. Visseren-Hamakers, K. J. Willis, and C. N. Zayas (eds.). IPBES secretariat, Bonn, Germany. 56 pages, https://doi.org/10.5281/zenodo.3553579

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services -and Intergovernmental Panel on Climate Change (2021). Co-sponsored workshop biodiversity and climate change workshop report. https://www.ipbes.net/sites/default/files/2021-06/20210609_workshop_report_embargo_3pm_CEST_10_june_0.pdf?trk=public_post_comment-text

International Energy Agency (2023). Fossil Fuels Consumption Subsidies 2022, International Energy Agency, Paris https://www.iea.org/reports/fossil-fuels-consumption-subsidies-2022, License: CC BY 4.0

International Energy Agency (2022a). Global Supply Chains of EV Batteries. Report, 68 p. International Energy Agency, Paris. https://iea.blob.core.windows.net/assets/4eb8c252-76b1-4710-8f5e-867e751c8dda/GlobalSupplyChainsofEVBatteries.pdf

International Energy Agency (2022b). Special Report on Solar PV Global Supply Chains. Report, 126 p. International Energy Agency, Paris. https://iea.blob.core.windows.net/assets/4eedd256-b3db-4bc6-b5aa-2711ddfc1f90/SpecialReportonSolarPVGlobalSupplyChains.pdf

International Energy Agency (2022c). Securing Clean Energy Technology Supply Chains. Report, 45 pp. International Energy Agency, Paris

International Energy Agency (2022d), Global Energy and Climate Model, IEA, Paris https://www.iea.org/reports/global-energy-and-climate-model

International Energy Agency (2021a). The Role of The Role of Critical Minerals in Clean Energy Transitionshttps://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions/executive-summary

International Energy Agency (2021b). Oil 2021 - Analysis and forecast to 2021. Paris, France. https://www.iea.org/reports/oil-2021

International Energy Agency (2017), World Energy Outlook 2017, IEA, Paris

International Forum of Sovereign Wealth Funds and One Planet Sovereign Wealth Funds (2023). Newton's Second Law: Sovereign Wealth Funds' Progress on Climate Change, https://www.ifswf.org/sites/default/files/IFSWF_Newtons_Second_Law.pdf

International Labour Organization (2022). Just transition: An essential pathway to achieving gender equality and social justice.

International Labour Organization (2021). Women in mining: Towards gender equality. https://www.ilo.org/wcmsp5/groups/public/---ed_dialogue/---sector/documents/publication/wcms_821061.pdf

International Labour Organization (2018). The employment impact of climate change adaptation Input Document for the G20 Climate Sustainability Working Group, https://www.ilo.org/wcmsp5/groups/public/---ed_emp/documents/publication/wcms_645572.pdf

International Labour Organization (2015). Guidelines for a just transition towards environmentally sustainable economies and societies for all. https://www.ilo.org/global/topics/green-jobs/publications/WCMS_432859/lang--en/index.htm

International Monetary Fund (2023a). Fossil Fuel Subsidies Surged to Record $7 Trillion (https://www.imf.org/en/Blogs/Articles/2023/08/24/fossil-fuel-subsidies-surged-to-record-7-trillion)

International Monetary Fund (2023b), International Monetary Fund. Detox Development: Repurposing Environmentally Harmful Subsidies, https://www.worldbank.org/detoxdev

Intergovernmental Panel on Climate Change (2018a), Annex I: Glossary [Matthews, J.B.R. (ed.)]. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA,

Intergovernmental Panel on Climate Change (2018b), Summary for Policymakers. In: ***Global Warming of 1.5°C. An IPCC Special Report*****.** Cambridge University Press, Cambridge, UK and New York, NY, USA, doi:10.1017/9781009157940.001**.** pp. 541-562. https://doi.org/10.1017/9781009157940.008

Intergovernmental Panel on Climate Change (2021). Climate change 2021: the physical science basis: summary for policymakers : working group I contribution to the sixth Assessment report of the Intergovernmental Panel on Climate Change.

Intergovernmental Panel on Climate Change (2022), Climate Change 2022: Mitigation of Climate Change. Working Group III Contribution to the IPCC Sixth Assessment Report (https://www.ipcc.ch/report/ar6/wg3/about/how-to-cite-this-report)

Intergovernmental Panel on Climate Change (2023), Climate Change 2023: AR6 Synthesis Report (SYR) (https://www.ipcc.ch/report/sixth-assessment-report-cycle/)

International Organization for Standardization (n.d), ISO standard 14001 on Environmental Management.

International Organization for Standardization (2006), ISO standard 14044 on Environmental management – Life Cycle Assessment.

International Resource Panel (2016). Unlocking the Sustainable Potential of Land Resources: Evaluation Systems, Strategies and Tools. Herrick, J. E. *et al.* eds. Nairobi, Kenya: Working Group on Land and Soils of the International Resource Panel.

International Resource Panel (2017). Assessing global resource use: A systems approach to resource efficiency and pollution reduction. Bringezu, S., Ramaswami, A., Schandl, H., O'Brien, M., Pelton, R., Acquatella, J., Ayuk, E., Chiu, A., Flanegin, R., Fry, J., Giljum, S., Hashimoto, S., Hellweg, S., Hosking, K., Hu, Y., Lenzen, M., Lieber, M., Lutter, S., Miatto, A., Singh Nagpure, A., Obersteiner, M., van Oers, L., Pfister, S., Pichler, P., Russell, A., Spini, L., Tanikawa, H., van der Voet, E., Weisz, H., West, J., Wiijkman, A., Zhu, B., Zivy, R. A Report of the International Resource Panel. United Nations Environment Programme. Nairobi, Kenya

International Resource Panel (2018a). The Weight of Cities: Resource Requirements of Future Urbanization, https://www.resourcepanel.org/reports/weight-cities

International Resource Panel (2018b). Re-defining Value – The Manufacturing Revolution. Remanufacturing, Refurbishment, Repair and Direct Reuse in the Circular Economy. Nabil Nasr, Jennifer Russell, Stefan Bringezu, Stefanie Hellweg, Brian Hilton, Cory Kreiss, and Nadia von Gries. A Report of the International Resource Panel. United Nations Environment Programme, Nairobi, Kenya

International Resource Panel (2019a). Global Resources Outlook 2019: Natural Resources for the Future We Want. 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. A Report of the International Resource Panel. United Nations Environment Programme. Nairobi, Kenya. doi: 10.18356/689a1a17-en.

International Resource Panel (2019b). Global Resources Outlook 2019: Natural Resources for the Future We Want. Summary for policy makers.

International Resource Panel (2020a). Mineral Resource Governance in the 21st Century. Gearing extractive industries towards sustainable development.

International Resource Panel (2020b). Resource Efficiency and Climate Change: Material Efficiency Strategies for a Low-Carbon Future. Hertwich, E., Lifset, R., Pauliuk, S., Heeren, N. A report of the International Resource Panel. United Nations Environment Programme, Nairobi, Kenya. https://www.resourcepanel.org/reports/resource-efficiency-and-climate-change

International Resource Panel (2020c). Resource efficiency and climate change, Material Efficiency Strategies for a Low-Carbon Future, Implications for Business Leaders in Housing and Mobility. The report estimates that a 20 per cent reduction of floor space would result in around 30 per cent less emission over life cycle of a home.

International Resource Panel (2021). Urban Agriculture's Potential to Advance Multiple Sustainability Goals: An International Resource Panel Think Piece. Ayuk, E.T., Ramaswami, A., Teixeira, I., Akpalu, W., Eckart, E., Ferreira, J.,Kirti, D., and de Souza Leao, V. A think piece of the International Resource Panel. Nairobi: United Nations Environment Programme.

International Resource Panel (2022). Making Climate Targets Achievable: Improving Wellbeing through Reduced Absolute Resource Use. Potočnik, J., Teixeira, I. A think piece of the International Resource Panel Co-Chairs.

International Resource Panel (2024a forthcoming). Governing and understanding the financing of sustainability transitions in a resource dependent world.

International Resource Panel (2024b forthcoming). Financing the extractives sector to contribute to the achievement of the Sustainable Development Goals.

International Resource Panel (*forthcoming*). Report for the development of and IRP Science-based target strategy. A rapid study and assessment. Obersteiner, M., Pfister, S., Napiontek, J., Hatfield-Dodds, S., Weisz, H.

International Work Group for Indigenous Affairs (2023). The Indigenous World 2023. https://www.iwgia.org/en/resources/indigenous-world.html

Ivanova, D., Stadler, K., Steen-Olsen, K., Wood, R., Vita, G., Tukker, A. and Hertwich, E.G. (2016). Environmental Impact Assessment of Household Consumption. *Journal of Industrial Ecology* 20(3), 526–536. doi: 10.1111/jiec.12371.

Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R. and Law, K.L. (2015). Plastic waste inputs from land into the ocean. *Science* 347(6223), 768–771. doi: 10.1126/science.1260352.

Japan, Ministry of Economy, Trade and Industry and Ministry of the Environment (2021). Guidance for Disclosure and Engagement for Promoting Sustainable Finance toward a Circular Economy (https://www.meti.go.jp/english/press/2021/pdf/0119_004b.pdf)

Jiang, L.W. and O'Neill, B.C. (2017). Global urbanization projections for the Shared Socioeconomic Pathways. *Global Environmental Change-Human and Policy Dimensions* 42, 193-199.

Julia, C., Etilé, F., and Hercberg, S. (2018) Front-of-pack Nutri-Score labelling in France: an evidence-based policy, Lancet Public Health, 3, 4:E164, https://www.thelancet.com/journals/lanpub/article/PIIS2468-2667(18)30009-4/fulltext#articleInformation

Karousakis, K. and Yamaguchi, S. (2020), Trade Policy and The Post-2020 Global Biodiversity Framework', Trade for Development, (https://trade4devnews.enhancedif.org/en/news/tradepolicy-and-post-2020-global-biodiversity-framework).

K.C., S. and Lutz, W. (2017) The human core of the shared socioeconomic pathways: Population scenarios by age, sex and level of education for all countries to 2100, Global Environmental Change, Volume 42, 181-192, (2017), https://www.sciencedirect.com/science/article/pii/S0959378014001095

Katowice Committee on Impacts – United Nations Framework Convention on Climate Change (2022). Implementation of just transition and economic diversification strategies. A compilation of best practices from different countries.

Kern, F., and Howlett, M. (2009). Implementing transition management as policy reforms: a case study of the Dutch energy sector. *Policy Sciences* 42, 391-408.

Kinnunen, P., Karhu, M., Yli-Rantala, E., Kivikytö-Reponen, P. and Mäkinen, J. (2022). A review of circular economy strategies for mine tailings. ***Cleaner Engineering and Technology*** 8, 100499. doi: 10.1016/j.clet.2022.100499.

Klenert, D., Mattauch, L., Combet, E., Edenhofer, O., Hepburn, C., Rafaty, R., and Stern, N. (2018). Making carbon pricing work for citizens. ***Nature Climate Change*** 8(8), 669–677. https://doi.org/10.1038/s41558-018-0201-2

Klinglmair, M., Sala, S. and Brandao, M. (2014). Assessing resource depletion in LCA: a review of methods and methodological issues. ***International Journal of Life Cycle Assessment*** 19, 580-592.

Klotz, M., Haupt, M. and Hellweg, S. (2022). Limited utilization options for secondary plastics may restrict their circularity. ***Waste Management*** 141(February), 251–270. doi: 10.1016/j.wasman.2022.01.002.

Klotz, M., Hellweg, S. and Haupt, M. (2023). Potentials and limits of mechanical plastic recycling. ***Journal of Industrial Ecology*** (under review).

Koide, R., Murakami, S., and Nansai, K. (2022). Prioritising low-risk and high-potential circular economy strategies for decarbonisation: A meta-analysis on consumer-oriented product-service systems. ***Renewable and Sustainable Energy Reviews*** 155. doi:10.1016/j.rser.2021.111858

Krausmann, F., Fischer-Kowalski, M., Schandl, H. and Eisenmenger, N. 2008. The Global Sociometabolic Transition. ***Journal of Industrial Ecology*** 12, 637-656.

Krausmann, F., Gingrich, S., Eisenmenger, N., Erb, K. H., Haberl, H. and Fischer-Kowalski, M. 2009. Growth in global materials use, GDP and population during the 20th century. ***Ecological Economics*** 68, 2696-2705.

Krausmann, F., Lauk, C., Haas, W. and Wiedenhofer, D. 2018. From resource extraction to outflows of wastes and emissions: The socioeconomic metabolism of the global economy, 1900-2015. ***Global Environmental Change-Human and Policy Dimensions*** 52**,** 131-140.

Krausmann, F., Wiedenhofer, D., Lauk, C., Haas, W., Tanikawa, H., Fishman, T., Miatto, A., Schandl, H. and Haberl, H. (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 of the United States of America*** 114, 1880-1885.

Kulkarni, M.M. and Patil, R.S. 1999. Monitoring of Daily Integrated Exposure of Outdoor Workers to Respirable Particulate Matter in an Urban Region of India. ***Environmental Monitoring and Assessment*** 56(2), 129–146. doi: 10.1023/A:1005947301971.

M. Kusenberg, M. Roosen, A. Zayoud, M.R. Djokic, H. Dao Thi, S. De Meester, K. Ragaert, U. Kresovic, K.M. Van Geem (2022) Assessing the feasibility of chemical recycling via steam cracking of untreated plastic waste pyrolysis oils: Feedstock impurities, product yields and coke formation. ***Wate Management*** 1 Waste Manag., 141, 104-114. doi: 10.1016/j.wasman.2022.01.033

Lambin, E. F. and Meyfroidt, P. 2011. Global land use change, economic globalization, and the looming land scarcity. ***Proceedings of the National Academy of Sciences of the United States of America*** 108, 3465-3472.

Lamboll, R.D., Nicholls, Z.R.J., Smith, C.J. Kikstra, J.S., Byers, E. and Rogelj, J. (2023). Assessing the size and uncertainty of remaining carbon budgets. ***Nat. Clim. Chang*** https://doi.org/10.1038/s41558-023-01848-5

Laurent, A., Bakas, I., Clavreul, J., Bernstad, A., Niero, M., Gentil, E., Hauschild, M.Z. and Christensen, T. H. (2014). Review of LCA studies of solid waste management systems--part I: lessons learned and perspectives.. ***Waste Management*** 34(3), 573–588. doi: 10.1016/j.wasman.2013.10.045.

Leclère, D., Obersteiner, M., Alkemade, R., Almond, R., Barrett, M., Bunting *et al.* (2018). Towards pathways bending the curve of terrestrial biodiversity trends within the 21st century. International Institute for Applied Systems Analysis (IIASA).

Leclère, D., Obersteiner, M., Barrett, M., Butchart, S. H. M., Chaudhary, A., De Palma, A. *et al.* (2020) Bending the curve of terrestrial biodiversity needs an integrated strategy. Nature, 585, 551-556. https://doi.org/10.1038/s41586-020-2705-y Lenton, T. M., Benson, S., Smith, T., Ewer, T., Lanel, V., Petykowski, E., Powell, T. W. R., Abrams, J. F., Blomsma, F., and Sharpe, S. (2022). Operationalising positive tipping points towards global sustainability. ***Global Sustainability*** 5, E1. doi:10.1017/sus.2021.30

Lenzen, M., Geschke, A., West, J., Fry, J., Malik, A., Giljum, S. *et al.* (2022). Implementing the material footprint to measure progress towards Sustainable Development Goals 8 and 12. ***Nature Sustainability*** 5, 157-+.

Lenzen, M., Moran, D., Kanemoto, K. and Geschke, A. (2013). Building Eora: A Global Multi-Region Input–Output Database at High Country and Sector Resolution. *Economic Systems Research* 25(1), 20–49. doi: 10.1080/09535314.2013.769938.

Loorbach, D., Frantzeskaki, N. and Avelino, F. (2017). Sustainability Transitions Research: Transforming Science and Practice for Societal Change. *Annual Review of Environment and Resources 2017* 42:1, 599-626.

Lozano, R., Fullman, N., Everett Mumford, J., Knight, M., Barthelemy, C., Abbafati, C., Abbastabar, H., Abd-Allah, F., Abdollahi, M. and Abedi, A.. 2020. Measuring universal health coverage based on an index of effective coverage of health services in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. *The Lancet* 396(10258), pp. 1250–1284. doi: 10.1016/S0140-6736(20)30750-9.

Manisalidis, I., Stavropoulou, E., and Stavropoulos, A. (2020). Environmental and Health Impacts of Air Pollution : A Review. *Frontiers in Public Health* 8(February), 1–13. https://doi.org/10.3389/fpubh.2020.00014

Marcos-Martinez, R., Bryan, B. A., Schwabe, K. A., Connor, J. D. and Law, E. A. (2018). Forest transition in developed agricultural regions needs efficient regulatory policy. *Forest Policy and Economics* 86, 67-75.

Marscheider-Weidemann, F., Langkau, S., Baur, S.-J., Billaud, M., Deubzer, O., Eberling, E. *et al.* (2021). Raw materials for emerging technologies 2021. Report, 350 p. DERA Rohstoffinformationen 50: Editor: Deutsche Rohstoffagentur (DERA, German Raw Materials Agency) Berlin (Germany). https://www.deutsche-rohstoffagentur.de/DE/Gemeinsames/Produkte/Downloads/DERA_Rohstoffinformationen/rohstoffinformationen-50-en.pdf?__blob=publicationFile&v=2

May, R., Jackson, C.R., Middel, H., Stokke, B.G. and Verones, F. (2021). Life-cycle impacts of wind energy development on bird diversity in Norway. *Environmental Impact Assessment Review* 90, 106635. doi: 10.1016/j.eiar.2021.106635.

Mbow, C., Rosenzweig, C., Barioni, L., Benton, T., Herrero, M., Krishnapillai, M., Liwenga, E., Pradhan, P., Rivera-Ferre, M., Sapkota, T. *et al.* (2019). Food Security. In P. R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner (Eds.), Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems (pp. 437-550). Intergovernmental Panel on Climate Change (IPCC). https://www.IPCC.ch/site/assets/uploads/sites/4/2019/11/08_Chapter-5.pdf

McDuffie, E., Martin, R., Yin, H., and Brauer, M. (2021). Global Burden of Disease from Major Air Pollution Sources (GBD MAPS): A Global Approach (Vol. 5505, Issue 210).

McEvoy, C.T., Temple, N. and Woodside, J.V. (2012). Vegetarian diets, low-meat diets and health: a review. *Public Health Nutrition* 15(12), 2287–2294. doi: 10.1017/S1368980012000936.

Meys, R., Bachmann, M., Winter, B., Zibunas, C. and Suh, S. (2021). Plastics By a Circular Carbon Economy. *Science* 76(October), 71–76.

Michaux, S.P. (2021): Assessment of the Extra Capacity Required of Alternative Energy Electrical Power Systems to Completely Replace Fossil Fuels, GTK Open Work File internal report, Serial number 42/2021, ISBN 978-952-217-414-7, https://tupa.gtk.fi/raportti/arkisto/42_2021.pdf

Mills, S. (2021). Potential markets for high efficiency, low emissions coal-fired power plants. International Centre for Sustainable Carbon. https://www.sustainable-carbon.org/report/potential-markets-for-high-efficiency-low-emissions-coal-fired-power-plants/

Millward-Hopkins, J., Steinberger, J.K., Rao, N.D. and Oswald, Y. (2020). Providing decent living with minimum energy: A global scenario. *Global Environmental Change* 65, 102168. doi: 10.1016/j.gloenvcha.2020.102168.

Minerals UK. World mineral statistics data.

India, Ministry of Environment, Forest and Climate Change. (2021). A review report on new SO2 norms Notified by MOEF&CC for Thermal Power Plant.

Moreau, V., Dos Reis, P. and Vuille, F. (2019). Enough Metals? Resource Constraints to Supply a Fully Renewable Energy System. *Resources* [online] 8(1), 29. Available at: https://www.mdpi.com/2079-9276/8/1/29/htm [Accessed 16 Jul. 2021]

Morin, F., Dür, A. and Lechner, L.(2018), Mapping the Trade and Environment Nexus: Insights from a New Data Set. *Global Environmental Politics*18 (1): 122–139.

Moss, R. L., Tzimas, E., Kara, H., Willis, P., and Kooroshy, J. (2013). The potential risks from metals bottlenecks to the deployment of Strategic Energy Technologies. ***Energy Policy*** 55, 556–564. doi: 10.1016/j.enpol.2012.12.053

Mudd, G.M. and Jowitt, S.M. (2018). Growing Global Copper Resources, Reserves and Production: Discovery Is Not the Only Control on Supply. ***Economic Geology*** 113(6), 1235–1267. doi: 10.5382/econgeo.2018.4590.

Müller-Wenk, R. and Brandão, M. 2010. Climatic impact of land use in LCA—carbon transfers between vegetation/soil and air. ***The International Journal of Life Cycle Assessment*** 15(2), 172–182. doi: 10.1007/s11367-009-0144-y.

Muradian, R. and Martinez-Alier, J. 2001. Trade and the environment: from a 'Southern' perspective. ***Ecological Economics*** 36, 281-297.

Nansai, K., Tohno, S., Chatani, S., Kanemoto, K., Kagawa, S., Kondo, Y., Takayanagi, W., and Lenzen, M. (2021). Consumption in the G20 nations causes particulate air pollution resulting in two million premature deaths annually. ***Nature Communications*** 12(1), 1–6, https://www.nature.com/articles/s41467-021-26348-y.

Nathani, C., Frischknecht, R., Hellmüller, P., Alig, M., Stolz, P. and Tschümperlin, L. (2019). Environmental hotspots in the supply chain of Swiss companies Final report Federal Office for the Environment (FOEN).

Ndikumana, L. and Ibi Ajayi, S. (eds). OUP Oxford (2014). Capital Flight from Africa: Causes, Effects, and Policy Issues.

Ndikumana, L., Sarr, M. (2019). Capital flight, foreign direct investment and natural resources in Africa. ***Resources Policy*** 63,101427

Ndikumana, L. and Boyce, J.K. (2022), On the Trail of Capital Flight from Africa. Oxford University Press. DOI: 10.1093/oso/9780198852728.001.0001

Ng, K.S., Farooq, D. and Yang, A. (2021). Global biorenewable development strategies for sustainable aviation fuel production. ***Renewable and Sustainable Energy Reviews*** 150, 111502. doi: 10.1016/j.rser.2021.111502.

Norges Bank (2021). Expectations to Companies: Biodiversity and Ecosystems (https://www.nbim.no/en/the-fund/responsible-investment/principles/expectations-to-companies/biodiversity-and-ecosystems/)

O'Neill, D.W., Fanning, A.L., Lamb, W.F. and Steinberger, J.K. (2018). A good life for all within planetary boundaries. ***Nature sustainability***. 1(2), pp.88-95. https://doi.org/10.1038/s41893-018-0021-4

Oberle, B., Brereton, D. and Mihaylova, A. (2020). Towards Zero Harm: A Compendium of Papers Prepared for the Global Tailings Review. St. Gallen. Switzerland: Global Tailings Review. https://globaltailingsreview.org/.

Oberschelp, C., Pfister, S. and Hellweg, S. (2023). Global site-specific health impacts of fossil energy, steel mills, oil refineries and cement plants. ***Scientific Reports*** (13)13708. doi: 10.1038/s41598-023-38075-z.

Oberschelp, C., Pfister, S. and Hellweg, S. (2020). Globally Regionalized Monthly Life Cycle Impact Assessment of Particulate Matter. ***Environmental Science & Technology*** 54(24), 16028–16038. doi: 10.1021/acs.est.0c05691.

Obersteiner, M., Bednar, J., Wagner, F., Gasser, T., Ciais, P., Forsell, N., Havlik, P., Valin, H., Janssens, I.A., Penuelas, J., Schmidt-Traub, G. (2018). How to spend a dwindling greenhouse gas budget. ***Nature Climate Change*** 8(1), 7–10. https://doi.org/10.1038/s41558-017-0045-1

Organisation for Economic Co-operation and Development (2021) Labelling and Information Schemes for the Circular Economy. https://doi.org/10.1787/19970900

Organisation for Economic Co-operation and Development (2020a), A Comprehensive Overview of Global Biodiversity Finance. (https://www.oecd.org/environment/resources/biodiversity/report-a-comprehensive-overview-of-global-biodiversity-finance.pdf).

Organisation for Economic Co-operation and Development (2020b). Consumption Tax Trends 2020: VAT/GST and Excise Rates, Trends and Policy Issues, https://doi.org/10.1787/152def2d-en

Organisation for Economic Co-operation and Development (2020c). The OECD Inventory of Circular Economy indicators, https://www.oecd.org/cfe/cities/InventoryCircularEconomyIndicators.pdf

Organisation for Economic Co-operation and Development (2020d), The jobs potential of a transition towards a resource efficient and circular economy, https://www.oecd-ilibrary.org/environment/the-jobs-potential-of-a-transition-towards-a-resource-efficient-and-circular-economy_28e768df-en

Organisation for Economic Co-operation and Development (2019). Best Available Techniques (BAT) for Preventing and Controlling Industrial Pollution, Activity 3: Measuring the Effectiveness of BAT Policies, Environment, Health and Safety, Environment Directorate.

Orr, J., Drewniok, M.P., Walker, I., Ibell, T., Copping, A., Emmitt, S. 2019. Minimising energy in construction: Practitioners' views on material efficiency. ***Resources, Conservation and Recycling***. 140, 125-136, ISSN 0921-3449, https://doi.org/10.1016/j.resconrec.2018.09.015

Östensson, O. (2017). ***Local Content, Supply Chains, and Shared Infrastructure***. WIDER Working Paper 2017/96. Helsinki: UNU-WIDER.

Otten, J., Hellwig, J.P. and Linda, D. (2006). Dietary DRI Reference Intakes.

Otto, I.M., Kim, K.M., Dubrovsky, N. and Lucht, W. (2019). Shift the focus from the super-poor to the super-rich. ***Nature Climate Change*** 9(2), 82–84. doi: 10.1038/s41558-019-0402-3.

Ozturk, B. and Grubb, J.F. (2012). Corrosion of stainless steels and titanium in bromide-containing solutions. NACE - ***International Corrosion Conference Series.*** 3, 1841–1852.

Pastor, A.V., Palazzo, A., Havlik, P., Biemans, H., Wada, Y., Obersteiner, M., Kabat, P. and Ludwig, F. The global nexus of food–trade–water sustaining environmental flows by 2050. ***Nat Sustain***. 2, 499–507 (2019). https://doi.org/10.1038/s41893-019-0287-1

Pechey, R., Cartwright, E., Pilling, M., Hollands, G.J., Vasiljevic, M., Jebb, S.A., Marteau, T.M. (2018) Impact of increasing the proportion of healthier foods available on energy purchased in worksite cafeterias: A stepped wedge randomized controlled pilot trial, Appetite, 133:286-296 (https://www.sciencedirect.com/science/article/pii/S0195666318313746)

Pedersen, O. G. and De Haan, M. 2006. The system of environmental and economic accounts-2003 and the economic relevance of physical flow accounting. ***Journal of Industrial Ecology*** 10**,** 19-42.

Pivnenko, K., Granby, K., Eriksson, E. and Astrup, T.F. (2017). Recycling of plastic waste: Screening for brominated flame retardants (BFRs). ***Waste Management*** 69, 101–109. doi: 10.1016/j.wasman.2017.08.038.

Pivnenko, K., Laner, D. and Astrup, T.F. (2016). Material cycles and chemicals: Dynamic material flow analysis of contaminants in paper recycling. ***Environmental Science and Technology*** 50(22), 12302–12311. doi: 10.1021/acs.est.6b01791.

Plevin, R. J., Delucchi, M. A., and Creutzig, F. (2014). Using Attributional Life Cycle Assessment to Estimate Climate-Change Mitigation Benefits Misleads Policy Makers. ***Journal of Industrial Ecology*** 18(1), 73-83. doi:10.1111/jiec.12074

Potocnik, J. and Teixeira, T. (2022). Making Climate Targets Achievable: Improving wellbeing through reduced absolute resource use. An opinion piece of the International Resource Panel Co-Chairs.https://www.systemiq.earth/wp-content/uploads/2022/09/Resource-Efficiency_Co-Chair-Opinion-Piece-ext-s.pdf

Reuters (2022). Guinea asks bauxite miners to present local refinery plans by May. Reuters April 9, 2022

Riahi, K., Van Vuuren, D. P., Kriegler, E., Edmonds, J., O'Neill, B. C., Fujimori, S. *et al.*(2017). The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. ***Global Environmental Change-Human and Policy Dimensions*** 42, 153-168. doi:10.1016/j.gloenvcha.2016.05.009

Roberts, J. T., Steinberger, J. K., Dietz, T., Lamb, W. F., York, R., Jorgenson, A. K., Givens, J. E., Baer, P. and Schor, J. B. (2020). Four agendas for research and policy on emissions mitigation and well-being. ***Global Sustainability*** 3.

Rockström, J., Gupta, J., Qin, D., Lade, S.J., Abrams, J.F., Andersen, L.S. *et al.* (2023) Safe and just Earth system boundaries. ***Nature.*** DOI: 10.1038/s41586-023-06083-8

Rockström, J., W. Steffen, K. Noone, Å. Persson, F. S. Chapin, III, E. Lambin, T. M. *et al.* 2009. Planetary boundaries: exploring the safe operating space for humanity. ***Ecology and Society***. 14(2): 32. [online] URL: http://www.ecologyandsociety.org/vol14/iss2/art32/

Rosa, F., Di Fulvio, F., Lauri, P., Felton, A., Forsell, N., Pfister, S. and Hellweg, S. (2023). Can Forest Management Practices Counteract Species Loss Arising from Increasing European Demand for Forest Biomass under Climate Mitigation Scenarios? ***Environmental Science & Technology*** doi: 10.1021/acs.est.2c07867.

Rosenbaum, R.K., Bachmann, T.M., Gold, L.S., Huijbregts, M.A., Jolliet, O., Juraske, R. *et al.* (2008). USEtox—the UNEP-SETAC toxicity model: recommended characterisation factors for human toxicity and freshwater ecotoxicity in life cycle impact assessment. *The International Journal of Life Cycle Assessment* 13(7), 532–546. doi: 10.1007/s11367-008-0038-4.

Royal HaskoningDHV (2022). Meting circulaire bedrijvigheid 2022 [measuring circular companies]. Royal HaskoningDHV.

Rudel, T. K., Schneider, L., Uriarte, M., Turner, B. L., Defries, R., Lawrence, D., Geoghegan, J., Hecht, S., Ickowitz, A., Lambin, E. F., Birkenholtz, T., Baptista, S. and Grau, R. 2009. Agricultural intensification and changes in cultivated areas, 1970-2005. ***Proceedings of the National Academy of Sciences of the United States of America*** 106, 20675-20680.

RVO (2022). Monitoring transitie naar een circulaire economie op basis van overheidsondersteuning 2015-2020 [Monitoring transition to a circular economy based on government supprt 2015-2020]. Rijksdienst voor Ondernemend Nederland, Utrecht.

Schaffartzik, A., Pichler, M., Pineault, E. Wiedenhofer, D., Gross, R. and Haberl, H. (2021). The transformation of provisioning systems from an integrated perspective of social metabolism and political economy: a conceptual framework. ***Sustain Sci*** 16, 1405–1421. https://doi.org/10.1007/s11625-021-00952-9

Schandl, H., Hatfield-Dodds, S., Wiedmann, T., Geschke, A., Cai, Y. Y., West, J., Newth, D., Baynes, T., Lenzen, M. and Owen, A. (2016). Decoupling global environmental pressure and economic growth: scenarios for energy use, materials use and carbon emissions. ***Journal of Cleaner Production***. 132, 45-56.

Schandl, H. and Miatto, A. (2018). On the importance of linking inputs and outputs in material flow accounts. The Weight of Nations report revisited. ***Journal of Cleaner Production*** 204**,** 334-343.

Scherer, L. and Pfister, S. (2015). Modelling spatially explicit impacts from phosphorus emissions in agriculture. ***International Journal of Life Cycle Assessment***. 20(6) 785–795. doi: 10.1007/s11367-015-0880-0.

Schiller, G. and Roscher, J. 2023. Impact of urbanization on construction material consumption: A global analysis. ***Journal of Industrial Ecology*** 27, 1021-1036.

Schwarz, A.E., Ligthart, T.N., Godoi Bizarro, D., De Wild, P., Vreugdenhil, B. and van Harmelen, T. (2021). Plastic recycling in a circular economy; determining environmental performance through an LCA matrix model approach. ***Waste Management*** 121, 331–342. doi: 10.1016/j.wasman.2020.12.020.

SDG Action (2022). Rethinking consumption - We cannot hope to tackle the climate crisis without a fundamental shift in how, what, and why we consume, https://sdg-action.org/rethinking-consumption%ef%bf%bc/

SDG tracker (2023), Measuring progress towards the Sustainable Development Goals - SDG Tracker (sdg-tracker.org), accessed 07 March 2023.

Seddon, J. (2020). Merchants against the bankers: the financialization of a commodity market. ***Review of International Political Economy*** 27(3), 525–555. https://doi.org/10.1080/09692290.2019.1650795

Shen, J., Zhang, Q., Xu, L., Tian, S., and Wang, P. (2021). Future CO2 emission trends and radical decarbonization path of iron and steel industry in China. ***Journal of Cleaner Production*** 326 (September), 129354. https://doi.org/10.1016/j.jclepro.2021.129354

Sonderegger, T. and Pfister, S. (2021). Global Assessment of Agricultural Productivity Losses from Soil Compaction and Water Erosion. ***Environmental Science & Technology*** 55(18), 12162–12171. doi: 10.1021/acs.est.1c03774.

Songwe, V., Stern, N., and Bhattacharya, A. (2022) Finance for climate action: Scaling up investment for climate and development. (https://www.lse.ac.uk/granthaminstitute/wp-content/uploads/2022/11/IHLEG-Finance-for-Climate-Action-1.pdf).

Spangenberg, J.H., Lorek, S. (2019). Sufficiency and consumer behaviour: From theory to policy. ***Energy Policy*** 129, 1070-1079, ISSN 0301-4215, https://doi.org/10.1016/j.enpol.2019.03.013.

Spangenberg, J.H., Lorek, S. (2002). Environmentally sustainable household consumption: from aggregate environmental pressures to priority fields of action, ***Ecological Economics*** 43, 2–3, 127-140, ISSN 0921-8009, https://doi.org/10.1016/S0921-8009(02)00212-4.

Sprecher, B., Daigo, I., Murakami, S., Kleijn, R., Vos, M. and Kramer, G.J. (2015). Framework for Resilience in Material Supply Chains, With a Case Study from the 2010 Rare Earth Crisis. ***Environmental Science & Technology*** 49, 6740-6750.

Springmann, M. and Freund, F. (2022). Options for reforming agricultural subsidies from health, climate, and economic perspectives, Nature communications, https://doi.org/10.1038/s41467-021-27645-2.

Springmann, M., Mason-D'Croz, D., Robinson, S., Wiebe, K., Godfray, C., Rayner, M., and Scarborough, P. ((2018), Health-motivated taxes on red and processed meat: A modelling study on optimal tax levels and associated health impacts. PLoS ONE 13(11): e0204139. https://doi.org/10.1371/journal.pone.0204139

Springmann, M., Godfray, H.C.J., Rayner, M. and Scarborough, P. (2016). Analysis and valuation of the health and climate change cobenefits of dietary change. *Proceedings of the National Academy of Sciences* 113(15), 4146–4151. Doi: 10.1073/pnas.1523119113.

Springmann, M., Mason-D'Croz, D., Robinson, S., Wiebe, K., Godfray, C., Rayner, M., Scarborough, P.D. (2017), Mitigation potential and global health impacts from emissions pricing of food commodities. ***Nature Climate Change*** 7, 69–74 (2017). https://doi.org/10.1038/nclimate3155

Springmann, M., Wiebe, K., Mason-D'Croz, D., Sulser, T.B., Rayner, M. and Scarborough, P. (2018). Health and nutritional aspects of sustainable diet strategies and their association with environmental impacts: a global modelling analysis with country-level detail. *The Lancet Planetary Health*. 2(10), e451–e461. doi: 10.1016/S2542-5196(18)30206-7.

Stadler, K., Wood, R., Bulavskaya, T., Södersten, C.-J., Simas, M., Schmidt, S., *et al.* (2021). EXIOBASE 3 (3.8.2) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.5589597.

Stadler, K., Wood, R., Bulavskaya, T., Södersten, C.-J., Simas, M., Schmidt, S. *et al.*(2018). EXIOBASE 3: Developing a Time Series of Detailed Environmentally Extended Multi-Regional Input-Output Tables. *Journal of Industrial Ecology*. 22(3), 502–515. doi: 10.1111/jiec.12715.

Steffen, W., Rockström, J., Richardson, K., Lenton, T., Folke, C., Liverman, D., Summerhayes, C., Barnosky, A., Cornell, S., Crucifix, M., Donges, J., Fetzer, I., Lade, S., Scheffer, M., Winkelmann, R., Schellnhuber, H. 2018 Trajectories of the Earth System in the Anthropocene. *Proc Natl Acad Sci U S A* 2018 Aug 14;115(33):8252-8259. doi: 10.1073/pnas.1810141115.

Steffen, W., Richardson, K., Rockström, J., Cornell, S.E., Fetzer, I., Bennett, E.M. , Biggs, R., Carpenter, S.R., Vries, W. de, Wit, C.A. de, Folke, C., Gerten, D. , Heinke, J., Mace, G.M., Persson, L.M., Ramanathan, V., Reyers, B. and Sörlin, S. (2015). Planetary boundaries: Guiding human development on a changing planet. *Science* 347(6223).

Strangl, M., Schlummer, M., Maeurer, A. and Buettner, A. (2018). Comparison of the odorant composition of post-consumer high-density polyethylene waste with corresponding recycled and virgin pellets by combined instrumental and sensory analysis. *Journal of Cleaner Production* 181, 599–607. doi: 10.1016/j.jclepro.2018.01.137.

Sturla-Zerene, G., Figueroa B. E. and Sturla, M. (2020), Reducing GHG global emissions from copper refining and sea shipping of Chile's mining exports: A world win-win policy. ***Resources Policy*** 65, 101565 (https://doi.org/10.1016/j.resourpol.2019.101565)

Sukhdev, P. (2009). Costing the Earth. ***Nature***. 462, 277, https://www.nature.com/articles/462277a

Swilling, M. and Annecke, E. (2012). Just Transitions Explorations of sustainability in an unfair world. United Nations University Press.

Swilling, M., Nygaard, I., Kruger, W., Wlokas, H., Jhetam, T., Davies, M., Jacob, M., Morris, M., Robbins, G., Funder, M., Hansen, U., Olsen, K., Davy, El., Kitzing, L., Siddique, M. B. and Cronin, T. (2022), Linking the energy transition and economic development: A framework for analysis of energy transitions in the global South. ***Energy Research and Social Science*** 90. https://doi.org/10.1016/j.erss.2022.102567

Takiguchi, H. and Takemoto, K. 2008. Japanese 3R Policies Based on Material Flow Analysis. *Journal of Industrial Ecology* 12, 792-798.

Tanikawa, H., Fishman, T., Hashimoto, S., Daigo, I., Oguchi, M., Miatto, A., Takagi, S., Yamashita, N. and Schandl, H. (2021). A framework of indicators for associating material stocks and flows to service provisioning: Application for Japan 1990-2015. *Journal of Cleaner Production*. 285.

Tasaki, T., Tajima, R., Kameyama, Y. (2021). "Measurement of the Importance of 11 Sustainable Development Criteria: How Do the Important Criteria Differ among Four Asian Countries and Shift as the Economy Develops?" ***Sustainability*** 13, no. 17: 9719.

Taubenbock, H., Wegmann, M., Roth, A., Mehl, H. & Dech, S. 2009. Urbanization in India - Spatiotemporal analysis using remote sensing data. *Computers Environment and Urban Systems* 33, 179-188.

Tessum, C. W., Apte, J. S., Goodkind, A. L., Muller, N. Z., Mullins, K. A., Paolella, D. A., Polasky, S., Springer, N. P., Thakrar, S. K., Marshall, J. D., and Hill, J. D. (2019). Inequity in consumption of goods and services adds to racial – ethnic disparities in air pollution exposure. PNAS, 116(13), 6001–6006. https://doi.org/10.1073/pnas.1818859116

The Netherlands, PBL 2023, Integral Circular Economy Report 2023 Assessment for the Netherlands https://www.pbl.nl/en/publications/integral-circular-economy-report-2023-assessment-for-the-netherlands.

Toledano, P., Brauch, M. D., Bhuwalka, K. and Busia, J. The case for a climate-smart update of the African mining vision. https://iap.unido.org/articles/case-climate-smart-update-african-mining-vision (Accessed March 2023).

Tukker, A. (2016). Final Report Summary - DESIRE (Development of a System of Indicators for a Resource efficient Europe).

Turner, A. (2018). Black plastics: Linear and circular economies, hazardous additives and marine pollution. *Environment International* 117(April), 308–318. doi: 10.1016/j.envint.2018.04.036.

United Kingdom Government (2021a), UK to enshrine mandatory climate disclosures for largest companies in law (https://www.gov.uk/government/news/uk-to-enshrine-mandatory-climate-disclosures-for-largest-companies-in-law)

United Kingdom Government (2021b), Environment Act 2021 (https://www.legislation.gov.uk/ukpga/2021/30/contents/enacted)

United Nations (2019), Independent Group of Scientists appointed by the Secretary-General, Global Sustainable Development Report 2019: The Future is Now – Science for Achieving Sustainable Development, (United Nations, New York, 2019). Cover design and graphics by Camilo J. Salomon Copyright © 2019 United Global sustainable development report The Future Is Now Science For Achieving Sustainable Development

United Nations (2022). World Population Prospects 2022. Summary of Results. New York: United Nations.

United Nations (2023), United Nations Secretary-General's SDG Stimulus to Deliver Agenda 2030 (https://www.un.org/sustainabledevelopment/wp-content/uploads/2023/02/SDG-Stimulus-to-Deliver-Agenda-2030.pdf)

United Nations Conference on Trade and Development (2022). Total and urban population – UNCTAD Handbook of Statistics 2022 https://hbs.unctad.org/total-and-urban-population/

United Nations Conference on Trade and Development (2020). https://unctad.org/system/files/official-document/dtlstictinf2020d3_en.pdf

United Nations Convention to Combat Desertification) (2022), The Global Land Outlook, second edition. https://www.unccd.int/sites/default/files/2022-04/UNCCD_GLO2_low-res_2.pdf

United Nations Convention to Combat Desertification (2015), Voluntary LDN targets, https://www.unccd.int/our-work/country-profiles/voluntary-ldn-targets#:~:text=National%20voluntary%20LDN%20targets%20(original%20language),-%E2%96%AA&text=Increase%20soil%20fertility%20and%20Carbon,of%20cropland%20area%20by%202030.&text=Reduce%20land%20use%2F%20cover%20conversion,of%20forest%20area%20by%202030.&text=Reduce%20waterlogging%20in%20600%20km2%20area%20by%202030.

United Nations Convention to Combat Desertification Science-Policy Interface (SPI)) (2022), The Contribution of Integrated Land Use Planning and Integrated Landscape Management to Implementing Land Degradation Neutrality: Entry Points and Support Tools. A Report of the Science-Policy Interface. https://www.unccd.int/sites/default/files/2023-09/UNCCD%20Integrated%20Land%20Use%20Planning-rev.pdf

United Nations Convention to Combat Desertification Science-Policy Interface (SPI)) (2017), Sustainable land management contribution to successful land-based climate change adaptation and mitigation, https://www.unccd.int/resources/reports/sustainable-land-management-contribution-successful-land-based-climate-change

United Nations Inter-Agency Task Force on Financing for Development (2023). Financing for Sustainable Development Report 2023 (https://www.un.org/sustainabledevelopment/financing-for-development/)

United Nations Secretary-General (2018). https://news.un.org/en/story/2018/10/1023112#:~:text=%E2%80%9C%20Limiting%20temperature%20rise%20to%201.5%20degrees%20will,ministerial%20meeting%20on%20climate%20finance%2C%20in%20Bali%2C%20Indonesia

United Nations Department of Economic and Social Affairs (2023). National Accounts Main Aggregates Database. In: AFFAIRS, U. N. D. O. E. A. S. (ed.).

United Nations Development Programme (2022). Human Development Report 2021-22: Uncertain Times, Unsettled Lives: Shaping our Future in a Transforming World. New York.

United Nations, Economic Commission for Latin America and the Caribbean (2022). Hacia la transformación del modelo de desarrollo en América Latina y el Caribe: producción, inclusión y sostenibilidad, https://www.cepal.org/es/publicaciones/48308-la-transformacion-modelo-desarrollo-america-latina-caribe-produccion-inclusion

United Nations, Economic Commission for Latin America and the Caribbean (2023). Lithium extraction and industrialization: opportunities and challenges for Latin America and the Caribbean.

United Nations Environment Programme (2009). Global green new deal policy brief (https://wedocs.unep.org/bitstream/handle/20.500.11822/7903/A_Global_Green_New_Deal_Policy_Brief.pdf)

United Nations Environment Programme (2011). Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication - A Synthesis for Policy Makers (www.unep.org/greeneconomy)

United Nations Environment Programme (2015). The Financial System We Need: Aligning the Financial System with Sustainable Development, https://wedocs.unep.org/bitstream/handle/20.500.11822/9862/-The_Financial_System_We_Need_Aligning_the_Financial_System_with_Sustainable_Development-2015The_Financial_System_We_Need_EN.pdf.pdf

United Nations Environment Programme (2017), Fostering and Communicating Sustainable Lifestyles: Principles and Emerging Practices, https://wedocs.unep.org/bitstream/handle/20.500.11822/17016/fostering_Communicating_Sust_Lifestyles.pdf?sequence=1&isAllowed=y

United Nations Environment Programme (2019), Global Chemicals Outlook II: From Legacies to Innovative Solutions: Implementing the 2030 Agenda for Sustainable Development – Synthesis Report https://www.unep.org/resources/report/global-chemicals-outlook-ii-legacies-innovative-solutions

United Nations Environment Programme (2020), Global Trade in Used Vehicles Report.

United Nations Environment Programme (2021a). Catalysing Science-based Policy action on Sustainable Consumption and Production – The value-chain approach & its application to food, construction and textiles. Nairobi.

United Nations Environment Programme (2021b). Making Peace with Nature: A scientific blueprint to tackle the climate, biodiversity and pollution emergencies. Nairobi. https://www.unep.org/resources/making-peace-nature

United Nations Environment Programme (2021c). The use of natural resources in the economy: A Global Manual on Economy Wide Material Flow Accounting. Nairobi: United Nations Environment Programme.

United Nations Environment Programme (2021d). Emissions Gap Report 2021: The Heat Is On - A World of Climate Promises Not Yet Delivered. Nairobi

United Nations Environment Programme (2021e). Food Waste Index Report 2021. Nairobi.

United Nations Environment Programme (2022a). Emissions Gap Report 2022, https://www.unep.org/resources/emissions-gap-report-2022

United Nations Environment Programme (2022b), Enabling sustainable lifestyles in a climate emergency https://wedocs.unep.org/bitstream/handle/20.500.11822/39972/Lifestyles_climate.pdf?sequence=6&isAllowed=y

United Nations Environment Programme (2023a). Global Material Flows Database. https://www.resourcepanel.org/global-material-flows-database

United Nations Environment Programme (2023b), Intergovernmental negotiating committee (INC) on plastic pollution (https://www.unep.org/about-un-environment/inc-plastic-pollution)

United Nations Environment Programme (2023c). Turning off the Tap: How the world can end plastic pollution and create a circular economy. https://www.unep.org/resources/turning-off-tap-end-plastic-pollution-create-circular-economy

United Nations Environment Programme (2023d). Chemicals in plastics: a technical report. United Nations Environment Programme and Secretariat of the Basel, Rotterdam and Stockholm Conventions. https://www.unep.org/ resources/report/chemicals-plastics-technical-report.

United Nations Environment Programme and the Secretariat of the Basel, Rotterdam and Stockholm Conventions (2023). Chemicals in plastics: a technical report. Geneva. https://www.unep.org/resources/report/chemicals-plastics-technical-report

United Nations Environment Programme and the Society of Environmental Toxicology and Chemistry. (2016). Global guidance for life cycle impact assessment indicators - Volume 1. doi: 10.1146/annurev.nutr.22.120501.134539.

United Nations Framework Convention on Climate Change (2015a) Paris Agreement, https://unfccc.int/files/meetings/paris_nov_2015/application/pdf/paris_agreement_english_.pdf

United Nations Framework Convention on Climate Change (2015b). Paris Agreement, Article 2.1(c) (https://unfccc.int/sites/default/files/english_paris_agreement.pdf)

United Nations Framework Convention on Climate Change (2022). Decisions taken at the Sharm El-Sheikh Climate Change Conference.

United States Geological Survey (2022) Mineral commodity summaries 2022: US Geological Survey, 202 p., https://doi.org/10.3133/mcs2022.

Vélex-Henao, J.A. and Paulick, S. (2023) Material requirements of Decent Living Standards. ***Environ. Sci. Technol*** 2023 https://doi.org/10.1021/acs.est.3c03957

Villén-Pérez, S., Anaya-Valenzuela, L., Da Cruz, D. C., and Fearnside, P. M. (2022). Mining threatens isolated indigenous peoples in the Brazilian Amazon. ***Global Environmental Change-human and Policy Dimensions*** 72, 102398. https://doi.org/10.1016/j.gloenvcha.2021.102398

Vogt, C. (2013). International Assessment of Marine and Riverine Disposal of Mine Tailings. London, United Kingdom.

Walker, C., Gibney, E.R. and Hellweg, S. (2018). Comparison of Environmental Impact and Nutritional Quality among a European Sample Population - findings from the Food4Me study. Scientific reports 8(1), p. 2330. doi: 10.1038/s41598-018-20391-4.

Walker, C., Gibney, E.R., Mathers, J.C. and Hellweg, S. (2019). Comparing environmental and personal health impacts of individual food choices. ***Science of The Total Environment*** 685, 609–620. doi: 10.1016/j.scitotenv.2019.05.404.

Walker, C., Pfister, S. and Hellweg, S. (2021). Methodology and optimization tool for a personalized low environmental impact and healthful diet specific to country and season. ***Journal of Industrial Ecology*** 25(5), 1147–1160. doi: 10.1111/jiec.13131.

Wang, H. C., Lu, F., Gao, J. M. and Zheng, X. Y. (2016). Urbanization in China and Changes to the Environment.

Wang, Z. and Praetorius, A. (2022). Integrating a Chemicals Perspective into the Global Plastic Treaty. ***Environmental Science and Technology Letters*** doi: 10.1021/acs.estlett.2c00763.

Watari, T; Nansai, K; Giurco, D; Nakajima, K; Mclellan, B; Helbig, C (2020) Global Metal Use Targets in Line with Climate Goals, ***Environmental Science & Technology*** 54 (19), 12476-12483, DOI: 10.1021/acs.est.0c02471

Watari, T., Nansai, K. and Nakajima, K. (2020). Review of critical metal dynamics to 2050 for 48 elements. ***Resources, Conservation and Recycling*** [online] 155, 104669. Available at: https://www.sciencedirect.com/science/article/pii/S0921344919305750

Watari, T., McLellan, B., Ogata, S. and Tezuka, T. (2018). Analysis of Potential for Critical Metal Resource Constraints in the International Energy Agency's Long-Term Low-Carbon Energy Scenarios. ***Minerals*** [online] 8(4), 156. Available at: https://www.mdpi.com/2075-163X/8/4/156

Watson, J. E. M., Shanahan, D. F., Di Marco, M., Allan, J., Laurance, W. F., Sanderson, E. W., Mackey, B., and Venter, O. (2016). Catastrophic Declines in Wilderness Areas Undermine Global Environment Targets. ***Curr. Biol.*** 26, 2929–2934.

Weiss, M. (2016). The role of local content policies in manufacturing and mining in low- and middle-income countries. Department Of Policy, Research and Statistics Working Paper 19/2016. United Nations Industrial Development Organization (UNIDO), Vienna, 2016

Westhoek, H., Lesschen, J. P., Rood, T., Wagner, S., de Marco, A., Murphy, D., Leip, A., van Grinsven, H., Sutton, M. A., and Oenema, O. (2014). Food choices, health and environment: Effects of cutting Europe's meat and dairy intake. ***Global Environmental Change*** 26, 196–205. doi: 10.1016/j.gloenvcha.2014.02.004.

Westhoek, H., Ingram, J.S.I., Berkum, S. van, Özay, L., Hajer, M.A. and United Nations Environment Programme. International Resource Panel. Working Group on Food Systems and Natural Resources. (2016). Food systems and natural resources. UNEP.

White, K., Habib, R., and Hardisty, D. J. (2019). How to SHIFT consumer behaviors to be more sustainable: A literature review and guiding framework. ***Journal of Marketing*** 83(3), 22-49.

WMO (World Meteorological Organization) (2022). Climate update 2022–2026. UK Met Office/WMO, https://public.wmo.int/en/media/press-release/wmo-update-5050-chance-of-global-temperaturetemporarily-reaching-15%C2%B0c-threshold.

Wiedmann, T. O., Schandl, H., Lenzen, M., Moran, D., Suh, S., West, J. and Kanemoto, K. (2015). The material footprint of nations. ***Proceedings of the National Academy of Sciences of the United States of America*** 112, 6271-6276.

Wiesinger, H., Wang, Z. and Hellweg, S. (2021). Deep Dive into Plastic Monomers, Additives, and Processing aids. ***Environmental Science & Technology*** doi: 10.1021/acs.est.1c00976.

Willett, W., Rockström, J. and Loken, B. 2019. Healthy diets and sustainable food systems. ***The Lancet*** 394(10194), 215–216. doi: 10.1016/S0140-6736(19)31101-8.

Williges, K., Meyer, L. H., Steininger, K. W., and Kirchengast, G. (2022). Fairness critically conditions the carbon budget allocation across countries. ***Global Environmental Change*** 74, 102481. https://doi.org/10.1016/j.gloenvcha.2022.102481

Winkler, K., Fuchs, R., Rounsevell, M. and Herold, M. (2021). Global land use changes are four times greater than previously estimated. ***Nature Communications*** 12.

Wolde-Rufael, Y. and Mulat-weldemeskel, E. (2021). Effectiveness of environmental taxes and environmental stringent policies on CO2 emissions: the European experience. ***Environ Dev Sustain*** 25, 5211–5239. https://doi.org/10.1007/s10668-022-02262-1)

World Bank (2022), New World Bank country classifications by income level: 2022-2023, https://blogs.worldbank.org/opendata/new-world-bank-country-classifications-income-level-2022-2023

World Health Organization (WHO). 2019. Global Burden of Disease Study. USA.

WTO (World Trade Organization) (2022), Agreement on Fisheries Subsidies (https://docs.wto.org/dol2fe/Pages/SS/directdoc.aspx?filename=q:/WT/MIN22/W22.pdf&Open=True)

WWF (World Wildlife Fund for Nature) (2022), When Finance Talks Nature (https://wwfeu.awsassets.panda.org/downloads/when_finance_talks_nature.pdf)

Yu, B.B. (2021). Ecological effects of new-type urbanization in China. ***Renewable & Sustainable Energy Reviews*** 135.

Zennegg, M., Schluep, M., Streicher-Porte, M., Lienemann, P., Haag, R. and Gerecke, A.C. (2014). Formation of PBDD/F from PBDE in electronic waste in recycling processes and under simulated extruding conditions. ***Chemosphere*** 116, 34–39. doi: 10.1016/j.chemosphere.2013.12.101.

Zhang, C.-Y., Han, R., Yu, B., and Wei, Y. (2018). Accounting process-related CO2 emissions from global cement production under Shared Socioeconomic Pathways. ***Journal of Cleaner Production*** 184, 451–465. https://doi.org/10.1016/j.jclepro.2018.02.284

Zhang, L., Long, R., Chen, H. 2019. Do car restriction policies effectively promote the development of public transport?, ***World Development*** 119, 100-110, ISSN 0305-750X, https://doi.org/10.1016/j.worlddev.2019.03.007.

Zhang, L., Butler, T.L. and Yang, B. (2020). Recent Trends, Opportunities and Challenges of Sustainable Aviation Fuel. In: Green Energy to Sustainability. Wiley, pp. 85–110. doi: 10.1002/9781119152057.ch5.

Methodological Annexes

The full methodological annexes of Global Resources Outlook 2024 could be accessed at this link:
resourcepanel.org/sites/default/files/documents/document/media/gro24_annexes_final.pdf

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