Global Resources Outlook 2019: Natural Resources for the Future We Want (A Report of the International Resource Panel)

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GLOBAL RESOURCES OUTLOOK 2019

NATURAL RESOURCES FOR THE FUTURE WE WANT

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About the International Resource Panel

The International Resource Panel was established to provide independent, coherent and authoritative scientific assessments on the use of natural resources and their environmental impacts over the full life cycle. The Panel aims to contribute to a better understanding of how to decouple economic growth from environmental degradation while enhancing well-being.

Benefiting from the broad support of governments and scientific communities, the Panel is constituted of eminent scientists and experts from all parts of the world, bringing their multidisciplinary expertise to address resource management issues. The information contained in the International Resource Panel's reports is intended to be evidence based and policy relevant, informing policy framing and development and supporting evaluation and monitoring of policy effectiveness.

The Secretariat is hosted by the United Nations Environment Programme (UN Environment). Since the International Resource Panel's launch in 2007, twenty-six assessments have been published. The assessments of the Panel to date demonstrate the numerous opportunities for governments, businesses and wider society to work together to create and implement policies that ultimately lead to sustainable resource management, including through better planning, technological innovation and strategic incentives and investments.

Following its establishment, the Panel first devoted much of its research to issues related to the use, stocks and scarcities of individual resources, as well as to the development and application of the perspective of 'decoupling' economic growth from natural resource use and environmental degradation. These reports include resource-specific studies on biofuels, water and the use and recycling of metal stocks in society.

Building upon this knowledge base, the Panel moved into examining systematic approaches to resource use. These include looking into the direct and indirect impacts of trade on natural resource use; issues of sustainable land and food system management; priority economic sectors and materials for sustainable resource management; benefits, risks and trade-offs of Low-Carbon Technologies for electricity production; city-level decoupling; and the untapped potential for decoupling resource use and related environmental impacts from economic growth.

Upcoming work by the International Resource Panel will focus on governance of the extractive sectors, the impacts of land-based activities on marine and coastal resources, land restoration, scenario modelling of natural resource use and resource efficiency links to climate change.

More information about the Panel and its research can be found at: http://www.resourcepanel.org/.

GLOBAL RESOURCES OUTLOOK 2019

Natural Resources for the Future We Want

Foreword

Global gross domestic product has doubled since 1970, enabling immense progress, and lifting of billions of people out of poverty. At the same time, this economic growth has been fueled by a relentless demand for natural resources. At no point in time nor at any level of income, has our demand for natural resources wavered.

Our consume and throwaway models of consumption have had devastating impacts on our planet. This report finds that 90 per cent of biodiversity loss and water stress are caused by resource extraction and processing. These same activities contribute to about half of global greenhouse gas emissions.

Moreover, the benefits of this type of resource use remain limited to but a few. Inequalities in the material footprint of countries, i.e. in the quantity of materials that must be mobilized globally to meet the consumption of an individual country, are stark. High-income countries maintain levels of per capita material footprint consumption that are 60 per cent higher than upper-middle income countries and more than thirteen times the level of the low-income countries.

Economic growth which comes at the expense of our planet is simply not sustainable. Our challenge is to meet the needs of all people within the means of our planet. Realizing this ambitious but critical vision calls on governments, business, civil society and people to reshape what we understand by progress and innovate to change people's choices, lifestyles and behaviours.

Through a combination of resource efficiency, climate mitigation, carbon removal, and biodiversity protection policies, this report finds that it is feasible and possible to grow our economies, increase our wellbeing and remain within our planetary boundaries. But action must begin now. While the report highlights some progress, it is clear that much more needs to be done.

Scientific findings such as those by the International Resource Panel and other global assessments, presented at the 2019 United Nations Environment Assembly, provide us an opportunity to take a close look at the global use of natural resources and importantly, identify action that can have the maximum impact on our planet and ensure we sustainability manage natural resources for generations to come.

Joyce Msuya,
Acting Executive Director
UN Environment

Preface

For over 10 years, the International Resource Panel has provided scientific assessments of the trends in, patterns in and impacts of the way societies and economies extract, use and dispose of natural resources. This research has shown that the way in which we use natural resources has profound implications for the health and wellbeing of people and the planet, now and for future generations. Not only is the sustainable management of natural resources critical to achieving the Sustainable Development Goals, but also, the International Resource Panel findings point to its essential ties to international aspirations on climate, biodiversity and land degradation neutrality.

The Global Resources Outlook 2019 builds on this body of evidence to present the story of natural resources as they move through our economies and societies. It is a story of relentless demand and of unsustainable patterns of industrialization and development. Over the last 50 years, material extraction has tripled, with the rate of extraction accelerating since the year 2000. Newly industrializing economies are increasingly responsible for a growing share of material extraction, a situation largely due to the building of new infrastructure. Virtually none of the massive growth in materials consumption in the new millennium has taken place in the wealthiest countries; however, not much of it has taken place in the poorest countries either, which make up the group in the most urgent need of higher material living standards.

This is the story of the unequal distribution of the benefits of resource use and its increasingly global and severe impacts on human well-being and ecosystem health. While extraction and consumption are growing in upper-middle income countries, high-income countries continue to outsource resource-intensive production. An average person living in a high-income country consumes 60 per cent more than someone in an upper-middle income country and over 13 times what is consumed by someone in a low-income country. Overall, the extraction and processing of natural resources account for more than 90 per cent of global biodiversity loss and water stress impacts and for approximately half of global greenhouse gas emissions.

Finally, it is a story that can, and must, be changed. Modelling undertaken by the International Resource Panel shows that by 2060, with the right resource efficiency and sustainable consumption and production policies in place, growth in global resource use can slow by 25 per cent, global gross domestic product could grow by 8 per cent - especially for low- and middle-income nations - and greenhouse gas emissions could be cut by 90 per cent as compared with projections for continuing along historical trends. Such projections are based on the understanding that growth rates in emerging and other developing economies must be balanced by absolute reductions in resource use in developed countries.

There exist economically attractive and technologically feasible innovations and policy actions that can transform our production and consumption systems in such a way as to achieve our global sustainability aspirations. However, action must start now. The International Resource Panel welcomes this opportunity to provide to the international community science-based and policy-relevant recommendations for sustainable management of natural resources that enables economic prosperity and human wellbeing while also remaining within planetary boundaries. We will continue to produce the Global Resources Outlook publication every four years to support essential global deliberations that include natural resources as part of the solutions towards sustainability, climate, biodiversity and land aspirations. As Co-Chairs, we wish to thank the scientists and steering committee members of the Panel for their dedicated efforts towards this aim.

Janez Potočnik
Co-Chair,
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Executive Summary

The international community has set ambitious goals for global prosperity and protecting the planet, including the achievement of the Sustainable Development Goals and environmental conventions such as the United Nations Framework Convention on Climate Change (UNFCCC), the Convention on Biological Diversity (CBD) and the United Nations Convention to Combat Desertification (UNCCD). Progress towards these ambitions is in our grasp – but a fundamental change in how natural resources are used around the world is necessary if these objectives are to be achieved. Natural resources are used to build infrastructure and drive economic progress, but they also have consequences in terms of negative impacts for the environment and human well-being.

Fundamental change is embodied in the principles of sustainable consumption and production, which address the entire life cycle of economic activities from the extraction of natural resources, through the production and use phase of products and goods, and finally to the disposal of resources. Harnessing this change will promote a sustainable transition to a world where economic development is pursued while negative impacts to the environment and humans are reduced in absolute terms (in other words, decoupling).

Decoupling occurs when resource use or a pressure on the environment or human well-being grows at a slower rate than the activity causing it (relative decoupling) or declines while the economic activity continues to grow (absolute decoupling) (IRP, 2011). Absolute decoupling in high-income countries can lower average resource consumption, distribute prosperity equally and maintain a high quality of life. Relative decoupling in developing and economies in transition can raise average income levels and eliminate poverty, while still increasing levels of natural resource consumption until a socially acceptable quality of life is achieved. While past IRP reports have focused largely on decoupling resource use and impacts from economic growth, this report also considers another dimension of decoupling: well-being decoupling. Well-being decoupling means increasing the service provided or satisfaction of human need per unit of resource use.

The Drivers-Pressures-State-Impact-Response (DPSIR) framework is one type of systems approach that can be used to analyse how society is using natural resources and the various implications of this use. This report is structured along the DPSIR framework, with Chapter 2 describing the drivers and trends of materials, land, and water resources use and explaining how these create pressures on the environment. Chapter 3 continues the analysis through the lens of life cycle assessments. It takes the results from Chapter 2 and calculates the environmental impacts generated from the extraction and processing of these natural resources. Chapter 4 then provides two different outlooks – one based on Historical Trends and the other modelling the effects of concerted policy and societal actions to drive a transition Towards Sustainability. Finally, Chapter 5 reflects on the messages of chapters 2, 3 and 4, and then offers recommendations to policymakers, the private sector, and civil society that can support innovations for environmental challenges and sustainable consumption and production.

1.1 Drivers, Pressures, and Natural Resource Use Trends

Since the 1970s, global population has doubled and global Gross Domestic Product (GDP) has grown fourfold. These trends have required large amounts of natural resources to fuel economic development and attendant increase in human well-being. Indeed, there has not been a prolonged period of stabilization or decline in global material demand in the last 50 years. Rather, global resource extraction has grown rapidly in that time. Extraction reached 92 billion tons in 2017, compared with 27 billion tons in 1970.

Global material extraction has also become slightly more concentrated over the last five decades, with 10 economies responsible for over 68 per cent of global extraction in 2017. Upper-middle income economies dominate extraction of resources, even on a per capita basis (accounting for 56 per cent of the global total). Two key dynamics are at play here: an increasing demand to build up new infrastructure, especially in developing and emerging economies, and the outsourcing of the more materials and energy intensive stages of production chains by higher income countries to lower income but transitioning countries.

However, the global share of domestic material consumption by low-income countries has remained unchanged at below 3 per cent, despite this group posting the highest population growth rate among the different income categories. Further, looking at the material footprint per capita, the high-income countries maintain the highest material footprint consumption of approximately 27 tons, which is 60 per cent higher than the upper-middle income group and more more than 13 times the level of the low-income group.

For water, a slight relative decoupling of water use from population growth began in the 1990s, but global water use is increasing and 30 per cent of global river basin area has been under severe and mid water stress since 2010.

1.2 Environmental Impacts of Natural Resource Use

Natural resource extraction and processing[1] make up approximately 50 per cent of the total greenhouse gas (GHG) emissions. Resource-related impacts on water stress and biodiversity loss due to land use are even more significant at over 90 per cent. If the rising trend in resource-related impacts persists, the goals of the Paris agreement will become difficult to meet and the achievement of the Sustainable Development Goals, including SDG 15.5 to halt biodiversity loss, will be put at risk.

Moreover, an estimated 11 per cent of existing species will become globally and irreversibly extinct due to global land use activities. The consumption of water contributes to water stress, threatening the sustainable supply of freshwater to humans and ecosystems (UNEP SETAC, 2016). Agriculture is the main water consumer in the global economy, and accounts for approximately 85 per cent of global water stress. Other impacts of resource use include eutrophication and eco-toxic effects caused by the overuse of fertilizers in certain areas – and which can ultimately lead to biodiversity loss.

The good news is that, between 2000 and 2015, there was a relative decoupling of resource-related environmental impacts from GDP and a moderate relative decoupling of impacts from the extracted mass of resources. However, impacts still increased on an absolute scale, including global average per capita climate change and health impacts. Climate change impacts increased by a factor of 1.4 between 2000 and 2011, following a similar trend to that of total extracted mass of resources, which increased by a factor of 1.6. During the same time frame, water and land use-related impacts also increased, but by a lesser degree (indicatively, by a factor 1.2 for water stress) due to increased productivity in food production. Action is needed to reach absolute decoupling and remain within planetary boundaries.

Resource-related value added has doubled, although impacts and value creation are not equally distributed around the globe. Per capita impacts of high-income regions are between three and six times larger than those of low-income regions. This pattern is a result of globalization, with high-income countries specializing in high value-added product development and management activities while resource-intensive added manufacturing is located in low-cost countries.

Capital investments for the build-up of infrastructure were the main driver of resource use in emerging economies, while in industrial economies consumer goods dominate final demand. While general trends exist, such as increased impacts with increased income, there are also cases of low-emission households within high-income segments (showing that decoupling is possible).

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[1] Chapter 3 describes the impacts of natural resource extraction and processing, and in selected cases, extends this coverage to the economy-wide impacts.

1.3 Two Outlooks for Resource Use

The analysis and modelling results presented in this report represent a first attempt to develop coherent scenario projections for resource efficiency and sustainable production and consumption that decouple economic growth from environmental degradation, as called for by SDG 8.4 and SDG 12.2. This decoupling seeks to meet essential human needs for food, water, energy and shelter (represented by SDGs 2, 6, 7, and 9) while protecting natural and social capital (represented by SDGs 13, 14, 15, and 17) that underpins all life and earth system functions.

Well-chosen and coordinated sustainability actions – particularly resource efficiency and sustainable consumption and production policies – can achieve significant decoupling, while achieving increased economic growth and a more equitable distribution of income and access to resources. Ambitious actions modelled in the Towards Sustainability scenario see incomes and resource-based services increase significantly across all groups of countries, while environmental pressures and impacts fall dramatically. This is in sharp contrast to the outlook under Historical Trends, which has similar projected increases in income, but with higher resource extractions and escalating and clearly unsustainable environmental pressures – including increases in greenhouse gas emissions and pressure on water sensitive ecosystems, and reductions in the quality and extent of forests and other native habitats. Notably, under Historical Trends, global resource extraction grows to 190 billion tons by 2060, compared to 143 billion tons under Towards Sustainability – which is 25 per cent lower than historical trends. Decision makers and policymakers today can work to achieve this ambitious outcome.

The absolute impact decoupling and relative resource decoupling outlined in this model is not at the expense of economic growth. The policy packages implemented in this scenario lead to global net economic benefits from 2030 onwards. Global GDP reaches 8 per cent above Historical Trends by 2060, and economic growth increases relatively more quickly in low- and middle-income countries at 11 per cent on average compared to high-income nations at 4 per cent on average, denoting a more equitable distribution of GDP per capita while all country groups still benefit from economic gains.

1.4 A Societal Response to Determine Our Shared Future

Obstacles, such as environmental challenges and fundamental changes in consumption and production systems, come with opportunities. In particular, transformations in how natural resources are extracted, processed, used and disposed of around the world can be harnessed through the collective action of governments, the private sector and civil society organizations.

To translate the assumptions made in the Towards Sustainability scenario into policymaking and decision-making contexts, real world examples of policy implementation aligned with the model are presented in the report. Moreover, eight approaches for multi-beneficial policymaking are outlined. A separate Summary for Policymakers is available on the International Resource Panel website[2] that explains in detail the most relevant findings for policymakers.

The eight strategies include the use of indicators and targets at all levels of governance to inform national plans for a sustainable use of natural resources and enable governments to identify priorities and proceed in a coordinated way. Transitions to sustainability will require complementary measures that combine to achieve domestic objectives. The scope and context of each set of instruments will depend on the national situation. In all cases, the policy mixes developed to improve the use and management of natural resources should be closely coordinated with policies for climate mitigation, adaptation and biodiversity protection. Actions towards a circular economy promote value-retention and environmental impact reduction while simultaneously reducing costs and creating economic opportunities, thus contributing to resource efficiency and sustainable consumption and production.

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[2] www.resourcepanel.org/reports/global-resources-outlook.

Furthermore, engaging in dialogue to connect with citizens, civil society and the private sector builds consensus. International exchanges and cross-country cooperation can accelerate the transition to sustainability and support national decisions, thereby helping to: create a level playing field for businesses and goods, navigate obstacles, promote shared experiences and find ways to leapfrog. While it is clear that resource and impact decoupling and improving resource efficiency should be an internationally pursued effort with the involvement of all countries, due consideration will have to be given to the different responsibilities and capabilities of countries. These different aspects call for a global discussion.

The final message of this report should be one of hope and optimism. While additional research is needed, there is nonetheless already an extensive knowledge base about natural resources use, pressures and impacts. Existing or feasible technologies can be applied in the short term across all sectors and countries to improve natural resource use and management. Emerging business models and best practices that embrace the circular economy and leapfrogging technologies generate enormous resource and economic savings, while still driving development. Policymakers and decision makers have tools at their disposal to advance transformative change. Importantly, this involves national actors working together across borders to achieve this change. Using the results from this report, multi-stakeholder collaboration and innovative solutions, we can resource the future we want.

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AMV	Africa Mining Vision
ASGM	artisanal and small-scale gold mining
BAT	best available technology
BECCS	Bio-energy with carbon capture and storage
BCURE	Building Capacity to Use Research Evidence
BSP	Bio-Solar Purification
CBD	Convention on Biological Diversity
CCS	carbon capture and storage
CH4	methane
CO_2	carbon dioxide
CTIP	Circular Transformation of Industrial Parks
DAC	Direct Air Capture
DALYs	Disability Adjusted Life Years
DE	domestic extraction
DMC	domestic material consumption
DPSIR	Drivers-Pressures-State-Impact-Response
DRI	direct reduction of solid iron
EAF	electric-arc furnaces
EIPM	Evidence Informed Policy-Making
EECCA	Eastern Europe, Caucasus, and Central Asia region
FAO	Food and Agriculture Organization
G7	Group of Seven
G20	Group of Twenty
GDP	gross domestic product
GFC	global financial crisis
GHG	greenhouse gases
GMO	genetically modified organism
Gt	gigaton
GWP	Global Warming Potentials
HDI	human development index
IAEG	Inter Agency Expert Group
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IRP	International Resource Panel

LCA — life cycle analysis
MF — material footprint
MFA — material flows analysis
MI — material intensity
MJ — megajoule
Mt — million tons
N2O — nitrous oxide
NOx — nitrogen oxide
OECD — Organisation for Economic Co-operation and Development
PAYG SHS — Pay-as-you-go Solar home system
PM — particulate matter
PTB — physical trade balance
R&D — research and development
RECP — Resource Efficiency and Cleaner Production
RUSLE — Revised Universal Soil Loss Equation
RTB — raw material trade balance
SBTi — Science Based Targets initiative
SCP — sustainable consumption and production
SDG — Sustainable Development Goals
SO2 — sulfur dioxide
SSP — Shared Socio-economic Pathways
TLFF: — Tropical Landscapes Finance Facility
TWh — TeraWatt hours
UN — United Nations
UNCCD — United Nations Convention to Combat Desertification
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
USGS — United States Geological Service
WBCSD — World Business Council for Sustainable Development
WHO — World Health Organization

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Glossary

Based on IRP, 2017a, online IRP glossary, and technical online annex.

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 assessment, this is reported as part of the final demand per sector and region.

Circular economy: The circular economy is one in which the value of products, materials and resources is maintained in the economy for as long as possible, 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, i.e. 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-based perspective: The consumption-based perspective 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-gate: Denotes the system boundaries of a life cycle assessment study that only covers the first stages of the life cycle, which in this report refers to the resource extraction and processing stage (including the full supply chain of all inputs and disposal phase of all outputs arising in these stages).

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 (human toxicity and particulate matter health impacts). It quantifies the amount of life years lost or lived with health impairment (based on WHO).

Decoupling: Decoupling is when resource use or some environmental pressure either grows at a slower rate than the economic activity that is causing it (relative decoupling) or declines while the economic activity continues to grow (absolute decoupling). The concept of decoupling is represented in figure 1.2, which shows increasing trajectories for economic activity and human well-being. The figure also shows that resource use can increase at a much slower rate than economic activity (relative resource decoupling) and environmental impacts may actually decline (absolute impact decoupling). This conceptual figure therefore indicates the ideal goal of resource efficiency, through the notion of decoupling – that economic output and human well-being will increase at the same time as rates of resource use and environmental degradation slow down and eventually decline to levels compatible with planetary boundaries (thereby enabling resource use and the delivery of ecosystem goods and services to be sustained for future generations).

DPSIR (Drivers-pressures-state-impacts-response) framework: The DPSIR framework (see, inter alia, EEA, 1999) aims to provide a step-wise description of the causal chain linking economic activity (the drivers), the pressures (such as emissions of pollutants), changes in the state of the environment (including land cover change) and impacts (diminished human health and others). This then leads to a societal response aimed at adapting those driving forces to reduce impacts. It must 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 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 (chapter 3).

Environmental Impacts: Harmful effects of human activities on ecosystems. In the present report, the following methods and impact categories are used to assess environmental impacts:

1. **Climate change impacts:** Greenhouse gas emissions 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. 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 (for example, inhalation of air with pollutants) or indirect exposure (for example, crop uptake of pollutants from soil and ingestion of crop as food). Toxic effects may occur after exposure.

3. Land-use related biodiversity loss: Land use reduces natural habitat size and degrades ecosystems, thereby leading to species extinctions.

4. Water stress: Water stress addresses the impacts of water consumption on the water resource as a flow resource.[1] Additionally, absolute water scarcity (availability per area) is considered to combine natural and human-induced water stress in a single indicator (Boulay et al., 2018).

Footprints: Within this report, the term footprints is used to represent the whole system of environmental pressures exerted by a human activity, including direct pressures occurring within the geographical boundary where the activity occurs and indirect/or supply chain pressures outside (transboundary ones). Footprints can measure different types of pressures including resource use (such as materials and water), pollution emissions (including emission in air) and environmental impacts (climate change, water scarcity, biodiversity losses and so forth). The material footprint in this report encompasses all material resources used (biomass, fossil fuels, metals and non-metallic minerals extracted/harvested for use; unused extraction is not yet accounted for). To compare footprints across cities or nations, some type of normalization is necessary (although this has been the subject of much debate).

Health impacts: Harmful effects of human activities on the health of a population. In the present report, the following impact categories were used to assess health impacts:

1. Human toxicity: Emissions of toxic substances are transported, degraded and transferred between various environmental compartments (air, water and soil), where they may lead to direct exposure (for example, inhalation of air with pollutants) or indirect exposure (for example, crop uptake of pollutants from soil and ingestion of crop as food). Toxic effects may occur after human exposure. The full impact pathway is modelled for each substance in the impact assessment, as documented in Rosenbaum et al. 2008.

2. Particulate Matter (PM) health impacts: 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, ammonia).

Impact Assessment: Here 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 ISO 14040). It links environmental impacts to emissions and primary resource use.

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 (DPAD, 2018). These categories are used in all explanations in this report, except for the analysis concerning the scenarios in chapter 4. Chapter 4 uses three income categories (high-income, middle-income and low-income), as it assumes that some convergence of income will occur by 2060, and there is a certain level of uncertainty around country mobility within income groups.

Life Cycle Assessment: Compilation and evaluation of the inputs (resource use), outputs (emissions) and the potential environmental impacts of a system throughout its life cycle (according to ISO 14040).

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,

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[1] Flow resources are non-exhaustible and have a limited availability at a certain time (Udo de Haes et al., 2002), which means that they have to be used as, when and where they occur.

transportation/delivery, use, end of life treatment and final disposal (ISO, n.d.). Also termed "cradle-to-grave".

Production-based perspective: The production-based perspective 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).

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: Resource productivity describes the economic gains achieved through resource efficiency. It depicts the value obtained from a certain amount of natural resources. It may be presented together with indicators of labour or capital productivity.

Resources: Resources — including land, water, air and materials — are seen as parts of the natural world that can be used in economic activities to produce goods and services. Material resources are biomass (like crops for food, energy and bio- based materials, as well as wood for energy and industrial uses), fossil fuels (in particular coal, gas and oil for energy), metals (such as iron, aluminium and copper used in construction and electronics manufacturing) and non-metallic minerals (used for construction, notably sand, gravel and limestone).

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. SSPs are not scenarios themselves, but their building blocks (Riahi et al., 2016).

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 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 (i.e. preventing disruptions like in the case of 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 neither resource extraction and use nor the deposition of waste and emissions will surpass the thresholds of a safe operating space.

Systems approach: This approach is derived from systems thinking, which is used to identify and understand systems, as well as predicting their behaviours and devising modifications to produce desired effects (Arnold & 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.

Work risks: Work risks represent an aggregated indicator for social risks related to employment.

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Key Messages

1. The use of natural resources has more than tripled from 1970 and continues to grow.

Global population has doubled and global gross domestic product has grown fourfold since the 1970s. This has been fuelled by an ever-increasing supply and extraction of materials, thereby intensifying pressure on land and water. From 1970 to 2017, the annual global extraction of materials grew from 27 billion tons to 92 billion tons, while the annual average material demand grew from 7 tons to over 12 tons per capita.[2]

2. Historical and current patterns of natural resource use are resulting in increasingly negative impacts on the environment and human health.

The extraction and processing[3] of materials, fuels and food make up about half of total global greenhouse gas emissions (not including climate impacts related to land use) and more than 90 per cent of biodiversity loss and water stress. Agriculture is the main driver of biodiversity loss and water stress, while all types of resources carry a significant share of the climate change and health impacts from particulate matter. In emerging economies, the build-up of infrastructure plays an important role in resource-related climate change impacts.

3. The use of natural resources and the related benefits and environmental impacts are unevenly distributed across countries and regions.

The material footprint[4] of high-income regions is greater than their domestic material consumption, indicating that consumption in these countries relies on materials from other countries through international supply chains. Material footprints in high-income countries are around 27 tons per person; 60 per cent higher than the upper-middle income group in 2017; and more than 13 times the level of the low-income group. Per capita impacts of consumption in high-income countries are, depending on the impact category, between three and six times larger than those of low-income countries.

---

[2] Materials include biomass, fossil fuels, metals and non-metallic minerals, while natural resources encompass all materials plus water and land.

[3] The focus is on resource extraction and processing up to "ready-to-use" materials and fuels (including waste disposal processes in the extraction and processing phase). This is also termed 'cradle-to-gate'.

[4] Material use can be measured by domestic material consumption or through the material footprint. Domestic material consumption is a direct measure of the materials that are consumed in a national economy, while the material footprint attributes all of the material resources mobilized globally to the final domestic demand of a country.

4. In the absence of urgent and concerted action, rapid growth and inefficient use of natural resources will continue to create unsustainable pressures on the environment.

A scenario developed by the International Resource Panel on Historical Trends of material use shows that, unless a fundamental change drives natural resource use away from the status quo, this use will continue to grow to 190 billion tons and over 18 tons per capita by 2060. Moreover, under Historical Trends greenhouse gas emissions increase by 43 per cent from 2015 to 2060, industrial water withdrawal increases by up to 100 per cent from 2010 levels, and the area of agricultural land increases by more than 20 per cent in that time, reducing forests by over 10 per cent and other habitat (such as grasslands and savannahs) by around 20 per cent.

5. The decoupling of natural resource use and environmental impacts from economic activity and human well-being is an essential element in the transition to a sustainable future.

Decoupling occurs when resource use or a pressure on the environment or human well-being grows at a slower rate than the activity causing it (relative decoupling) or declines while the economic activity continues to grow (absolute decoupling). A relative decoupling of resource-related environmental impacts from GDP and a relative decoupling of impacts from extracted mass of resources has occurred since the year 2000. However, impacts still increased on an absolute scale. Absolute decoupling in high-income countries can lower average resource consumption, distribute prosperity equally and maintain a high quality of life. Relative decoupling in developing economies and economies in transition can raise average income levels and eliminate poverty, while still increasing levels of natural resource consumption until a socially acceptable quality of life is achieved.

6. Achieving decoupling is possible and can deliver substantial social and environmental benefits, including repair of past environmental damage, while also supporting economic growth and human well-being.

The Towards Sustainability scenario developed for this report shows that global resource use can slow down, while continuing to grow in emerging and other developing countries to meet their sustainable development needs. Well-being indicators grow faster than resource extraction, with improved resource productivity and a relative decoupling of well-being from resource use. Moreover, environmental pressures fall, achieving an absolute decoupling of environmental impacts from economic growth and resource use. This is feasible through absolute reductions in high-income countries. The Towards Sustainability scenario assumes implementation of a combination of resource efficiency policies across different time frames, based on scientific research and development, climate mitigation and carbon removal policies, as well as widespread biodiversity protection measures. These policy packages are complemented by societal change, marked by healthier diets and reduced food waste.

7. Policymakers and decision makers have tools at their disposal to advance worthwhile change, including transformational change at local, national and global scales.

Decoupling will not happen spontaneously, but will require well-designed and concerted policy packages. Well-chosen and coordinated sustainability actions – particularly resource efficiency, sustainable consumption and production and circular economy[5] policies – can achieve decoupling. The context and scope of the set of instruments required will depend on the national situation. These include setting targets and indicators, developing national plans for a sustainable use of natural resources, using existing or feasible technologies to improve natural resource use and management, as well as embracing emerging business models and leapfrogging technologies. In all cases, multiple benefits can be achieved by coordinating national plans for decoupling the use of natural resources with plans for climate change mitigation and adaptation, as well as with national plans for the protection, conservation and sustainable use of biodiversity.

8. International exchanges and cooperation can make important contributions to achieving systemic change.

Decoupling environmental impacts and resource use from economic activity and human well-being is required to achieve the Sustainable Development Goals while remaining inside the planetary boundaries. This further contributes to the achievement of the UNFCCC Paris Agreement, the Aichi Targets of the UNCBD and the Land Degradation Neutrality Objectives of the UNCCD. International exchanges and cross-country cooperation can accelerate transitions towards sustainable natural resource use, support national decision-making and create a level playing field for goods and services from different countries. While it is clear that decoupling should be an internationally pursued effort with the involvement of all countries, due consideration will have to be given to the different responsibilities and capabilities of individual countries. Agreed international guidelines may support the process of finding solutions to these global challenges. These different aspects call for a global discussion.

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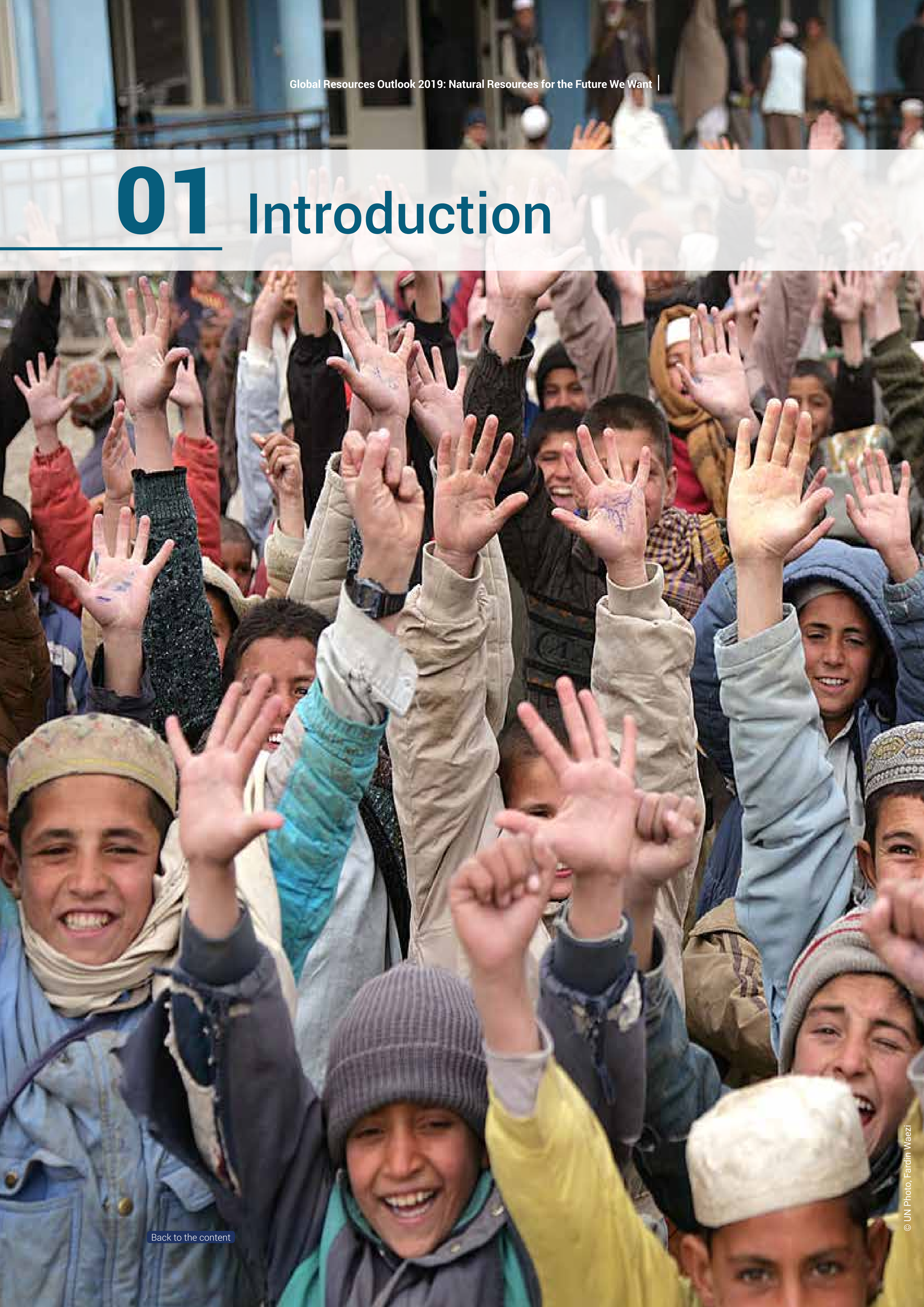
[5] The circular economy promotes value-retention and environmental impact reduction while simultaneously reducing costs and creating economic opportunities.

01 Introduction



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Authors

Bruno Oberle and Jessica Clement

Main findings

- Natural resources are inextricably linked to combatting climate change, biodiversity loss, and desertification, as well as the achievement of the Sustainable Development Goals. The achievement of these aims requires the use of natural resources. This use has consequences, and the uptake in natural resource use has contributed to the situation where four out of nine planetary boundaries are surpassing their recommended limits.
- Decoupling – when resource use or a pressure on the environment or human well-being grows at a slower rate than the activity causing it (relative decoupling) or declines while the economic activity continues to grow (absolute decoupling) – is necessary because the way in which society uses natural resources today will determine the course of environmental impacts, human well-being and the prosperity of national and global economies – as well as our success in achieving international commitments.
- Innovative solutions for environmental challenges and sustainable consumption and production can be key drivers for decoupling.
- Using a systems approach helps to identify solutions for improving natural resource use. The Drivers-Pressures-State-Impact-Response (DPSIR) framework (which is one such systems approach) creates linkages and feedback loops between the different components, making it an appropriate tool for locating the flows of natural resources in global society's interaction with the environment.

1.1 The Role of Natural Resources Across International Agreements

The international community has widely committed to combat climate change through the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement; biodiversity loss through the Convention on Biological Diversity (CBD); and land degradation through the United Nations Convention to Combat Desertification (UNCCD). These conventions are further incorporated in the Sustainable Development Goals (SDGs), which emphasizes the key role they play in achieving international sustainability ambitions.

Until now, the importance of natural resources has not been in the implementation domain of those internationally agreed-upon conventions. **Natural resources** – biomass (wood, crops, including food, fuel, feed and plant-based materials), fossil fuels (coal, gas and oil), metals (such as iron, aluminium and cooper), non-metallic minerals (including sand, gravel and limestone), water and land – provide the foundation for the goods, services, and infrastructure that make up our socioeconomic systems (IRP, 2017a). How society uses natural resources today will determine the course of environmental impacts, human well-being and the prosperity of national and global economies, as well as our success in achieving international commitments.

Natural resources are closely linked to the Sustainable Development Goals (SDGs). The SDGs aim, among other ambitions, to eradicate poverty, reduce inequalities, ensure prosperity and enhance the efforts to fight climate change (UN, 2015). Natural resources can directly or indirectly impact all 17 of the SDGs. Figure 1.1 shows the direct (blue outline) and indirect (yellow outline) relationships between

FIGURE 1.1 **Direct (blue outline) and indirect (yellow outline) relationship of natural resources to the three dimensions of sustainability (social, economic, and environmental) in relation to the SDGs.**

Source: this figure is re-drawn from IRP, 2017a; SRC, 2017) the SDGs and natural resources and how the SDGs are connected to the three dimensions of sustainability.

Many SDGs require a build-up of infrastructure, which requires the use of natural resources, to achieve social and economic progress. At the same time, certain Goals are dependent on protecting and improving the use of natural resources. Pursuing the former while delaying action on the latter will not work. This demands a fundamental transformation in how policymakers and decision makers prioritize the use of natural resources (UNEP, 2015).

However, the use of natural resources has consequences. The uptake in natural resource use has contributed to the situation where four out of nine[6] of the planetary boundaries are surpassing their recommended limits (IRP, 2017a; Rockström et al., 2009; Steffen et al., 2015). The planetary boundaries framework, which is based on the understanding of the long-term behaviour of the Earth system, underscores why it is necessary to change how natural resources are currently being used and managed. A global society living outside of the planetary boundaries may lead to an altered Earth system that is less hospitable than the current one (Steffen et al., 2015). Two of the planetary boundaries, climate change and biosphere integrity (including biodiversity loss), are regarded as core boundaries because the coevolution of life on Earth and the physical climate are defining aspects of the Earth system. Due to the interactions and feedbacks between life and climate, changes to either boundary have the potential to cause changes in the entire Earth system (Steffen et al., 2015).

Fundamental change is embodied in the principles of **sustainable consumption and production** (SCP). SCP considers the entire life cycle of economic activities, from the extraction of resources, processing these resources into materials and products, the use of these products, and finally their disposal as wastes or emissions. Systemic changes that drive sustainability throughout the life cycle promote SCP and help mitigate environmental challenges related to the planetary boundaries (UNEP, 2018a), as well as those associated with negative human well-being impacts. Changes in consumption and production patterns promote decoupling and can trigger transformations toward sustainability as envisaged in international obligations. Through a combination of extended product life cycles, intelligent product design and standardization, reuse, recycling and remanufacturing, the concept of the circular economy operationalizes SCP ambitions and promotes value-retention and environmental impact reduction, while simultaneously reducing costs and creating economic opportunities (IRP, 2018b). New environmentally sound technologies provide innovative solutions that advance circularity and also support sustainable consumption and production. Particularly relevant SDGs for this process include Targets 8.4 and 12.2. Target 8.4 aims to progressively improve global **resource efficiency** in consumption and production while decoupling economic growth from environmental degradation by 2030. Target 12.2 proposes to achieve the sustainable management and efficient use of natural resources by 2030.

1.2 Decoupling Natural Resource Use and Negative Environmental Impacts from Economic Growth

Decoupling occurs when resource use or a pressure on the environment or human well-being grows at a slower rate than the activity causing it (relative decoupling) or declines while the economic activity continues to grow (absolute decoupling)[7] (IRP, 2011). The decoupling aim is important because, as we aspire to improve human well-being and drive economic development around the world, we will continue to rely on natural resources for the goods and services we need. Extracting, processing and using these resources has serious environmental and human health impacts. Achieving decoupling can reduce the rate at which resources are consumed and, most importantly, diminish environmental degradation and the negative effects on human health caused by this use.

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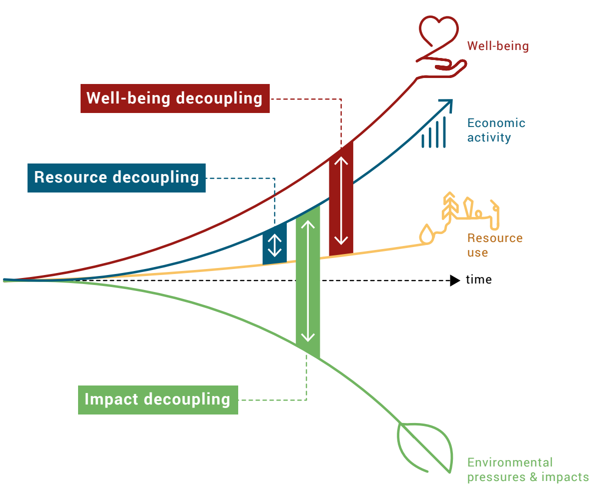
[6] The nine planetary boundaries are: climate change, ocean acidification, stratospheric ozone, global phosphorus and nitrogen cycles, atmospheric aerosol loading, freshwater use, land use change, biodiversity loss and chemical pollution (Rockström, et al., 2009).

[7] A full catalogue of definitions, including an expanded definition of decoupling, can be found on the IRP website: http://www.resourcepanel.org/glossary.

Figure 1.2 demonstrates the decoupling concept. Human well-being and economic activity are following increasing trajectories, while resource use is increasing, but at a much slower rate. This indicates **relative well-being decoupling** and **relative resource decoupling**, respectively. Moreover, economic activity is increasing while the environmental impacts are declining (**absolute impact decoupling**). This situation shows how decoupling will promote advances in human well-being, economic development and the well-managed deployment of natural resources, all while reducing the negative environmental (and health) impacts arising from natural resource use. Ultimately, the long term aim is for the absolute decoupling also of resource use from economic activity and human well-being.

Decoupling can be achieved at the national level by outsourcing production activities and their impacts. This situation can lead to a 'delusion' in terms of decoupling results (Jiborn et al., 2018). As a result, the International Resource Panel advocates the use of a consumption-based perspective, which means one that allocates the use of natural resources or their related impacts to the region where these resources are finally consumed.

FIGURE 1.2 **Decoupling Concept**



Source: This figure is re-drawn from IRP, 2017a by Zoi Environment Networks

A true decoupling of the impacts related to natural resource use requires a systemic transformation of how natural resources are used and managed in our economic and social systems (IRP, 2017a). All countries are urged to consider innovative solutions to address the environmental challenges associated with natural resource use and more sustainable methods of consumption and production. These innovative solutions can be thought of as "business unusual" approaches, as opposed to the traditional business-as-usual policies.

1.3 A Systems Approach: The DPSIR Framework

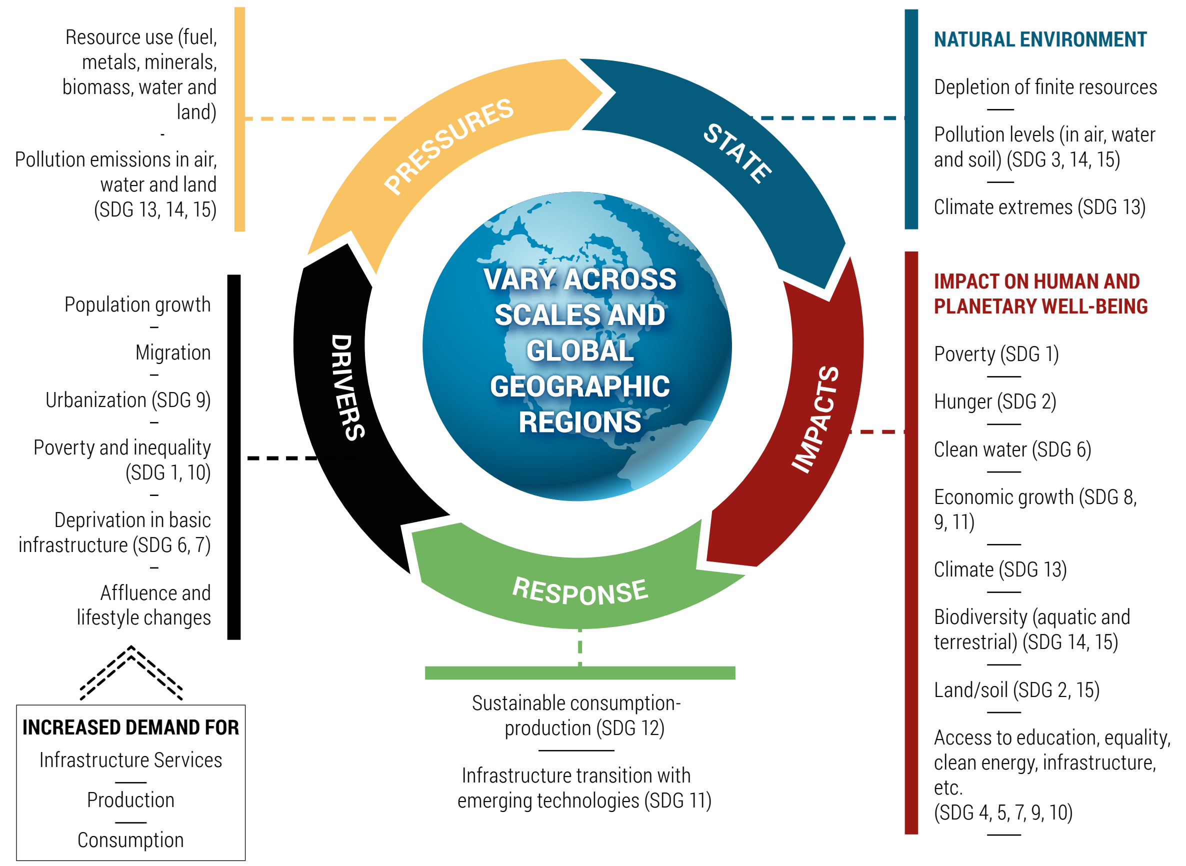
Focusing on resources, economic sectors, or different environmental or human impacts as individual silos will not encourage progress towards improved resource use or, more broadly, the achievement of international agreements and the SDGs. Addressing one area without consideration of the others may even have negative consequences.

A **systems approach** is crucial to maximize benefits across sectors and mitigate trade-offs from natural resource use. The authors of this report have chosen the **Drivers-Pressures-State-Impact-Response (DPSIR)** framework, one type of systems approach, to analyse natural resource use. The DPSIR framework is an appropriate tool for locating the flows of natural resources in global society's interaction with the environment, as the framework creates linkages and feedback loops between the different components. The DPSIR framework also shows how societal, political and economic actions can affect the system (Müller et al., 2017).

Socioeconomic **drivers** from human activities are the first factors in the chain of causal links. These drivers cause **pressures** on the environment, which in turn affect the **state** of the environment. The changing state of the environment can be seen through environmental and human **impacts**. A **response** is needed that can influence the key drivers and enable positive changes throughout the entire system through a continuous process.

This approach enables an integrated view of how society is using natural resources and the various implications of this use. **Natural resource management** benefits from a systems approach, as it provides insight and enables policymakers to steer development towards the SDGs (IRP, 2017a).

FIGURE 1.3 **DPSIR Framework and the SDGs**



Source: This figure is re-drawn from IRP, 2017a by Zoi Environment Networks

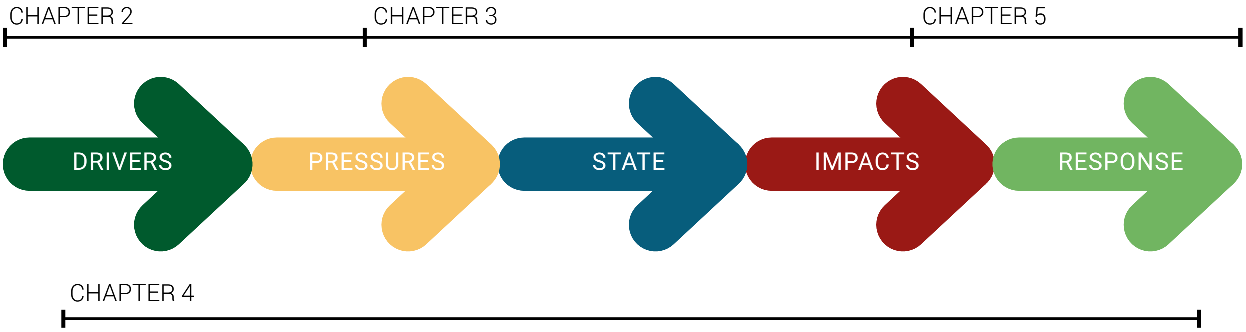
1.4 The DPSIR Framework and the Structure of this Report

This report is structured according to the DPSIR framework (see figure 1.4). The analysis in this report is divided into to seven regional groups to provide an encompassing view of the global situation: Africa; Asia and the Pacific; Eastern Europe, Caucasus and Central Asia (EECCA); Europe; Latin America and the Caribbean; North America; and West Asia (see UNEP, 2012). Natural resource use is also examined according to income groups. The income groups used in this report are high-income economies, upper-middle income economies, lower-middle income economies and low income economies (see DPAD, 2018). With some exceptions, which are noted after their use, these aggregations are used throughout the report.

Chapter 2 describes the overall trends of natural resource use. It shows that the global extraction of natural resources increased from 27.1 billion tons to 92.1 billion tons between 1970 and 2017. In the same period, the average person consumed 65 per cent more natural resources in 2017 compared to 50 years ago, despite an increase in per capita GDP of only 50 per cent. Even with global slowdowns of GDP and population since 2000, the accelerated demand and use of natural resources continues. Such a historic overview of natural resource use helps to identify points of change that explain how drivers are creating pressures.

Chapter 3 continues the analysis by adopting a life cycle assessment approach. It takes the amounts of natural resources used (from the previous chapter) and calculates the environmental pressures and impacts generated from the extraction and processing of these natural resources. This approach provides information about the state of

FIGURE 1.4 **DPSIR Framework underlying the structure and findings of this Report**



the environment, and how this changing state generates impacts on human health/well-being and the environment.

Chapter 3 finds a relative decoupling of resource related impacts from GDP, as well as a moderate relative decoupling of impacts from the extraction of resources occurred between 2000 and 2015. However, it also reveals a serious cause for concern: the overall impacts from the extraction and processing of natural resources is increasing in absolute terms.

Resource extraction and processing of materials account for about half of total greenhouse gas (GHG) emissions. This impact has increased by a factor of 1.4 since the year 2000. Additionally, the extraction and processing of natural resources contribute to over 90 per cent of global biodiversity loss and water stress impacts.

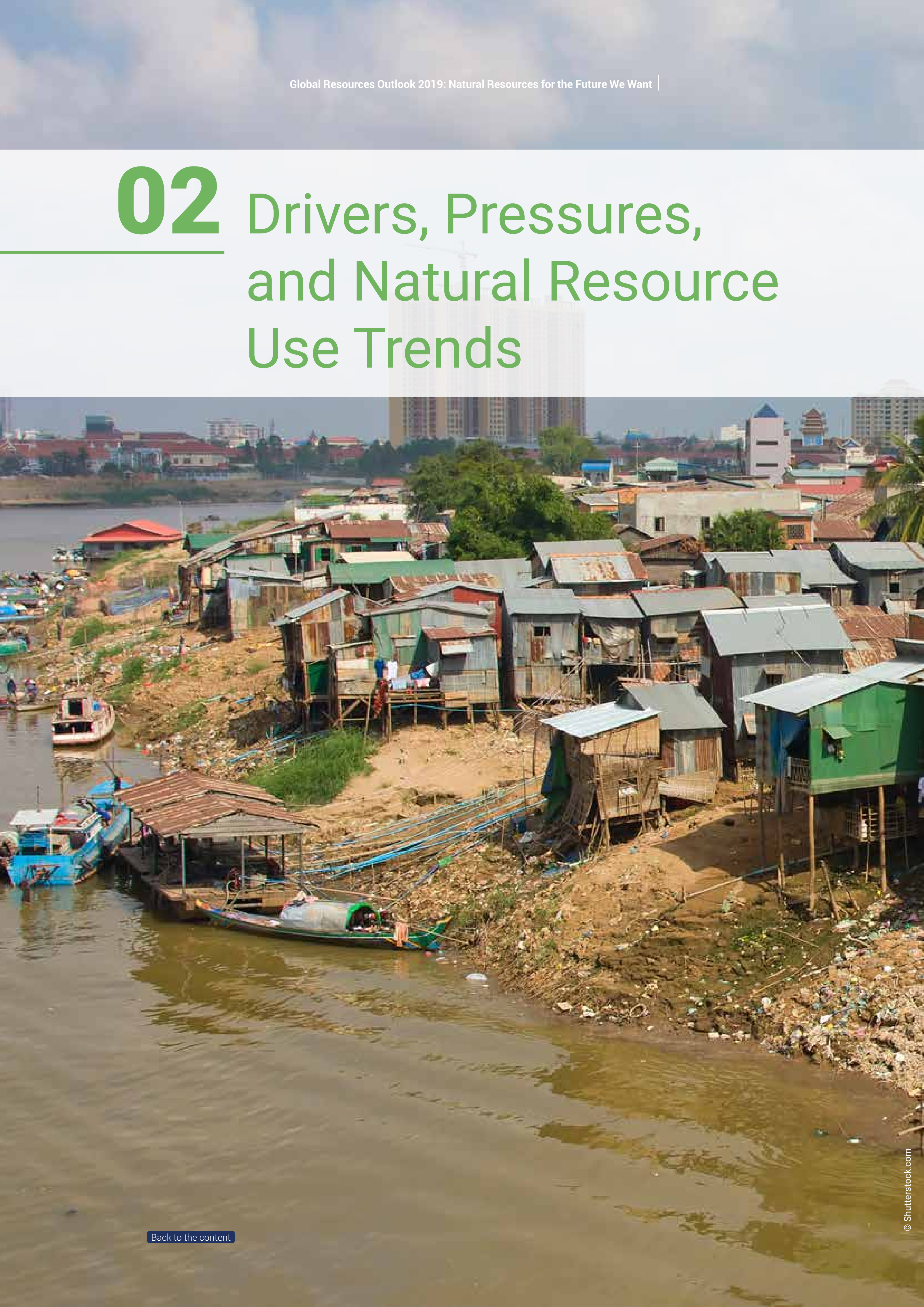
This report adopts a production and consumption perspective when analysing resource use and the associated environmental impacts. Chapter 2 adopts these perspectives to study natural resource use across countries and regions, while Chapter 3 adopts these perspectives to describe the impacts of resource extraction and processing. The **production-based perspective** allocates the use of natural resources or the impacts related to natural resource extraction and processing to the location where they physically occur. The **consumption-based perspective** allocates the use or impacts throughout the supply chain to the region where these resources, incorporated in various commodities, are finally consumed by industries, governments and households (Dao et al., 2018; Wood et al., 2018).

Chapter 4 posits that without fundamental changes, the use of natural resources will continue as in the past, making it difficult to achieve international agreements such as the Paris Agreement and the SDGs. In the same chapter, however, an alternative is provided in the form of a much more optimistic outlook. Adopting a combination of societal changes as well as resource efficiency policies based on scientific research and development, climate mitigation and carbon removal policies, and widespread biodiversity protection measures can lead to an absolute decoupling of negative environmental impacts from natural resource use and economic growth and a relative decoupling of natural resource use from GDP per capita. It is possible to achieve **dual decoupling** that can lead to well-being decoupling and impact decoupling (see figure 1.2).

Chapter 5 reflects on the messages of chapters 2 to 4, and then offers a response to the natural resource use and management evaluated in this report. This includes practical examples of polices that are used in the *Towards Sustainability* scenario and eight elements for multi-beneficial policymaking. The response is largely relevant for policymakers in the public sector or at international levels, and is also important for the private sector and civil society.

02

Drivers, Pressures, and Natural Resource Use Trends



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Main findings

- Global population has doubled and global economic activity (GDP) has grown fourfold since the 1970s, raising living standards and human well-being in many parts of the world. The growing population and expanding global economy were fuelled by a fast-growing material supply and extraction of primary materials, increasing pressure on land and water. During the period 1970 to 2017, annual global extraction of materials grew from 27.1 billion tons to 92.1 billion tons (average annual growth of 2.6 per cent). The global average of material demand per capita grew from 7.4 tons in 1970 to 12.2 tons per capita in 2017.
- Domestic material consumption patterns have changed rapidly in the last 50 years. In 1970, Asia and the Pacific, Europe, and North America each required equal shares of primary materials of about a quarter of the global total. In 2017, Asia and the Pacific accounted for almost 60 per cent of the global total.
- Global inequalities in material use have continued. The material footprint - a final demand-based measure of material use - attributes global material extraction to the point of final use. High-income countries consume 27 tons of materials on average, which is 60 per cent higher than the upper-middle countries and more than thirteen times the level of the low-income group (at two tons per capita).
- Global material productivity (the efficiency of material use) has grown substantially slower than labour and energy productivity. Global material productivity started to decline around the year 2000, and has stagnated in recent years. Even though material productivity improved rapidly in both the old and new industrialized countries, the simultaneous shift in shares of global production away from economies that have a higher material productivity, to economies that have a lower material productivity explains how difficult it is to bring about a rapid improvement in global material efficiency.
- Although slight relative decoupling of water use from population growth began in the 1990s, global water use is increasing and 30 per cent of global river basin area - excluding hyper-arid[1] zones and Antarctica - have been under severe and mid water stress since 2010. Between 2000 and 2010, total global cropland area increased by 1.34 per cent from 15.2 million to 15.4 million km$^{2.}$
- The integration of economic and environmental policies needs to continue to facilitate improvements in resource productivity, and to promote production and consumption systems that provide essential services such as housing, transport, food and energy, with much lower material and energy throughputs and lower levels of emissions. This probably requires a fundamental rebalancing of the trade-off between increasing resource and labour productivity, in favour of resource productivity and ultimately allowing for an absolute decoupling of human well-being and resource use.

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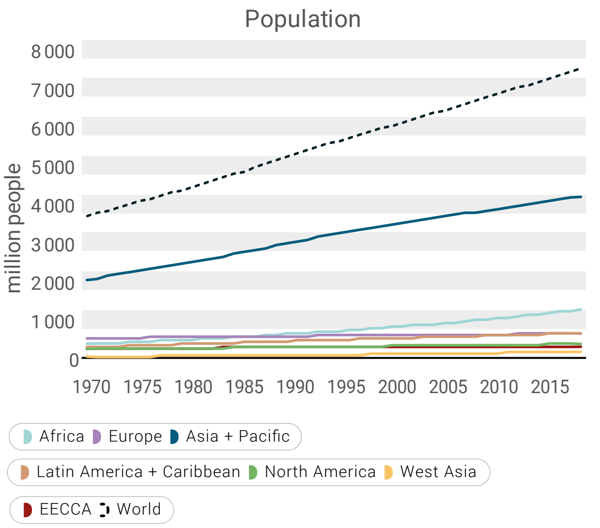
[1] Aridity index ≤ 0.05.

2.1 What Drives Our Resource Use Trends?

Population growth and economic activity (measured by growth in gross domestic product (GDP) are commonly seen as the two most important drivers of natural resource use (UNEP, 2016b). Overall, global population has doubled and global GDP has grown fourfold since the 1970s, thereby requiring large amounts of natural resources to fuel economic development and human well-being.

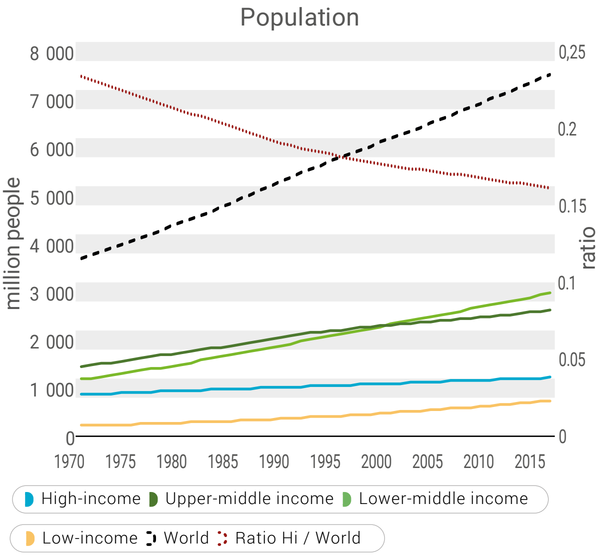
GDP expanded much faster than global population, at a yearly rate of 3 per cent from 18.9 trillion US$ in 1970 to 76.5 trillion US$ in 2016 (measured in constant 2010 prices) (UN, 2017a). Asia and the Pacific experienced the highest rate of growth, averaging 4.5 per cent per year, and accounted for the largest single share by 2011 (increasing from 17 per cent of the global total in 1970 to 32 per cent in 2016). All other world regions experienced growth in GDP of over 2.2 per cent per year throughout the period. However, those with the lowest growth rates - EECCA[2] and Europe - saw their share of global GDP decrease markedly, from 4 per cent to 3 per cent and 39 per cent to 27 per cent respectively (see figure 2.3). The group of high-income countries produced 80 per cent of global GDP in 1970 and was still responsible for 65 per cent of global GDP in 2016, while experiencing the slowest growth at an average of 2.6 per cent per year. The fastest growth of GDP was experienced by the lower-middle income group of countries at 5.1 per cent per year (see figure 2.4).

FIGURE 2.1 **Distribution of population among seven world regions, 1970 – 2017, million people**



Source: UNDESA, 2017

FIGURE 2.2 **Distribution of global population among four national income bands, with ratio of high-income group to total, 1970 – 2017**



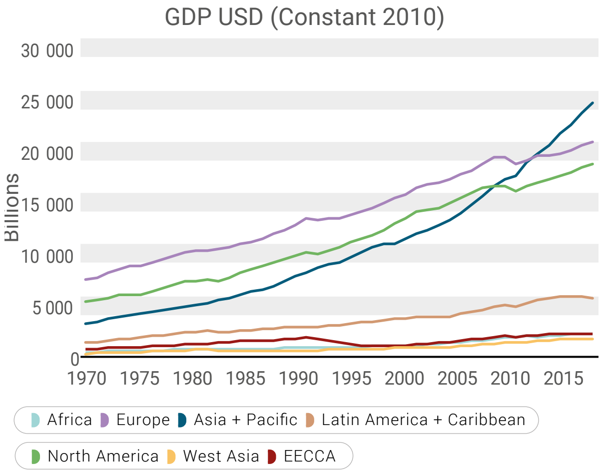
Source: UNDESA, 2017

Since the 1970s, global population has grown by a yearly average of over 1.5 per cent, increasing from under 3.7 billion people in 1970 to over 7.5 billion people in 2017 (UNDESA, 2017). Asia and the Pacific remained by far the most populous region across the entire period, but the rapid rate of increase in Africa's population is another salient feature with implications for future natural resource use distribution (see figure 2.1). The share of people living in the high-income group of countries has fallen from 23 per cent of the global total in 1970 to around 16 per cent in 2017. This indicates that lower population growth rates are linked to higher per capita wealth, a relationship that is validated by examining each band of the four individual income bands in figure 2.2, with the low-income band experiencing the fastest growth in population (at almost 2.7 per cent average per year).

---

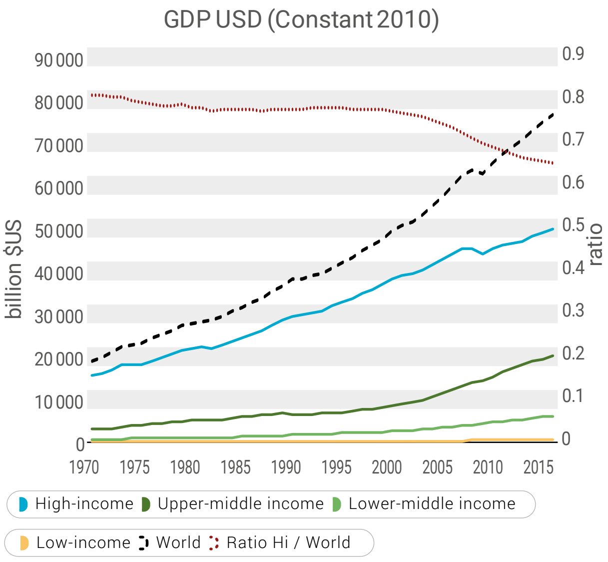
2 The Eastern Europe, Caucasus, and Central Asia (EECCA) region is composed exclusively of independent nations that formed following the dissolution of the USSR. Of those successor states, the Baltic States (Lithuania, Latvia and Estonia) are not included in the EECCA region.

FIGURE 2.3 **Distribution of global GDP among seven world regions, 1970 – 2016, billion US$ (Constant 2010 prices)**



Source: UN, 2017a

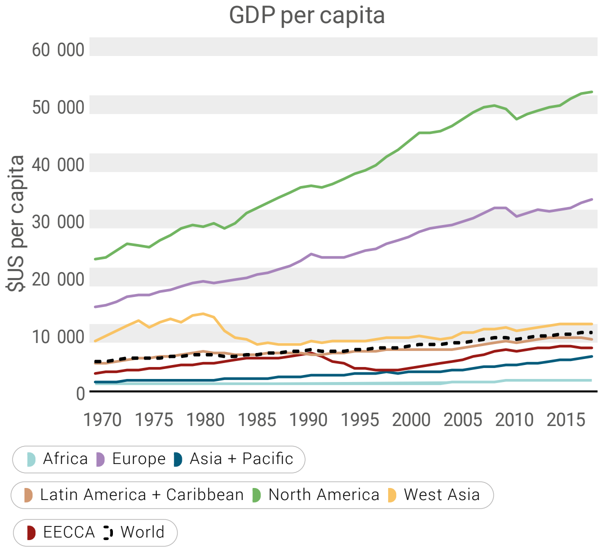
FIGURE 2.4 **Distribution of global GDP among four national income bands, with global total and ratio of high income group to total, 1970 – 2017, billion US$ (Constant 2010 prices)**



Source: UN, 2017a

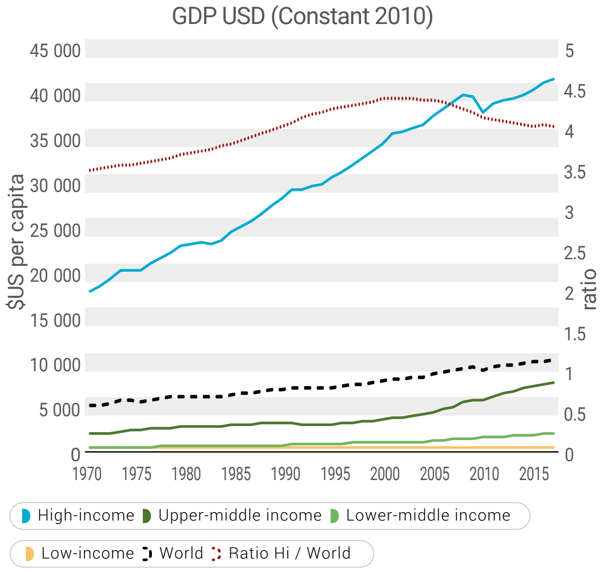
Per capita GDP is a better predictor of material living standards than total GDP. Global per capita GDP doubled between 1970 and 2016, and reached an average per capita of around 10,000 US$, with substantial ongoing inequalities among world regions. However, the decrease in per capita incomes following important historical events is mirrored in the per capita GDP trajectories of the seven world regions (see figure 2.5). In West Asia, for example, levels of GDP per capita have never recovered to levels seen during the second oil price shock of the late

FIGURE 2.5 **Per-capita GDP for seven world regions, plus global average, 1970 – 2016, US$ per capita (Constant 2010 prices)**



Source: UN, 2017a

FIGURE 2.6 **Per-capita GDP for four national income bands, plus global average, 1970 – 2016, US$ per capita (Constant 2010 prices), with ratio of high income group to world total**



Source: UN, 2017a

1970s-early1980s, as a result of the protracted reductions in real oil prices for many years, combined with the most rapid, sustained population increase of any region over the period (with average growth of over 3.3 per cent per year). There was also a noticeable decrease in wealth for people in the EECCA region in the decade following the dissolution of the former USSR, while the impact of the Global Financial Crisis (GFC) can be seen as a clear imprint on national incomes in Europe and North America.

Grouping countries by income groups provides a clearer illustration of the effect that rising population has on individual wealth (in the form of GDP per capita) (see figure 2.6). In contrast to the clear decrease in the share of global GDP of high-income nations seen in figure 2.4, the ratio of per capita income to the global average in high-income countries increased between 1970 and 2016. All of this relative increase happened prior to the new millennium, at which point rapid growth of GDP in the upper-middle income group (4.7 per cent per year from 2000 to 2016, driven by the industrialization of parts of Asia and the Pacific and Latin America), combined with a major moderation in population growth in the Asia and the Pacific region (1.1 per cent for 2000 to 2016 per year as compared to 1.8 per cent per year from 1970 to 2000) began to reduce this ratio. Importantly, the detailed data summarized in figure 2.6 indicates that the ratio of high-income countries' per capita GDP to low-income countries' GDP per capita doubled over the period as a whole, signalling rising income and wealth inequality among and within wealthy and poor economies (Alvaredo, et al. 2017).

In combination, the growing population and expanding global economy have required an ever-increasing supply of materials and extraction of primary materials, thereby intensifying pressures on land and water usage.

In the following sections we investigate the trends in environmental pressures caused by the drivers of global economic and population growth by assessing global demand trends in materials, water and land (as these are the essential natural resources that fuel economic processes and societal well-being).

2.2 Historical Analysis of Material Resource Use

Material resources are biomass, fossil fuels, metals and non-metallic minerals used in the economy (IRP, 2017a). What were the trends in natural material use over the last five decades and has there been a trend of decoupling of economic growth and human well-being from the demand for material resources?

2.2.1. Global Trends in Material Extraction

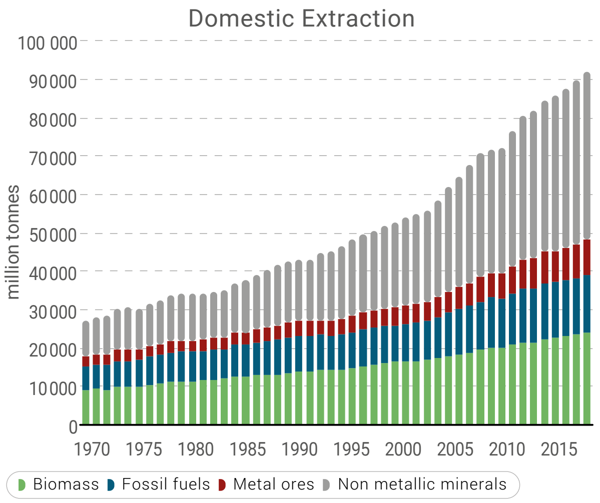
Economic activity, infrastructure and material standards depend on a permanent throughput of materials to fuel the economic process and underpin social well-being. Materials are extracted and traded, then transformed into goods or used to enable services. They are finally disposed of in the environment as waste or emissions. Environmental impacts occur at all stages of the supply chain, and have been intensifying in proportion with the growing global demand for materials.

The global data show that there has been no prolonged period of stabilization or decline in global material demand over the last five decades.

During the period 1970 to 2017, annual global extraction of materials grew from 27.1 billion tons to 92.1 billion tons (see figure 2.7), an annual average growth of 2.6 per cent. The new millennium ushered in a major increase in global material requirements, which grew at 2.3 per cent per year from 1970 to 2000, but accelerated to 3.2 per cent per year from 2000 to 2017 (UNEP, 2016; Schandl et al., 2017). The growth of global material demand was largely driven by major investments in infrastructure and increased material living standards in developing and transitioning countries, especially in Asia (Schandl & West, 2010). While there was a brief slowdown in the growth rate of demand for materials between 2008 and 2010 as a result of the global financial crisis, this has clearly had a very limited impact on the overall trajectory.

The global average of material demand per capita was 7.4 tons in 1970 and grew to 12.2 tons per capita in 2017. During the same time, per capita GDP grew from 5,198 US$ per capita to 10,606 US$ per capita. While per capita GDP more than doubled, material use grew by around two thirds between 1970 and 2017. It is important to note, however,

FIGURE 2.7 **Global material extraction, four main material categories, 1970 - 2017, million tons. Obtained by totalling domestic material extraction for all individual nations**



Source: UNEP & IRP, 2018

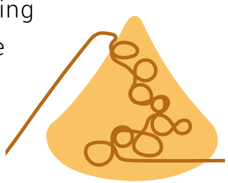
that the acceleration of global material extraction since the year 2000 has coincided with a slowdown in GDP and population growth. One driver of this phenomenon is likely to be the disproportionate concentration of GDP growth in economies that are moving through a stage of transition from an agrarian based to an urban-industrial economic mode that is particularly intensive in material and energy (Krausmann et al., 2008).

Biomass – crops, crop residues, grazed biomass, timber, and wild catch of fish – accounted for one third of all extracted materials in 1970, and by 2017, its share of total materials had been reduced to just over one quarter. This reflects the greater reliance of countries at early stages of economic development on biomass-based materials and energy systems. As an increasing proportion of the global population began to transition to higher levels of industrialization during the last five decades, the materials demand profile increasingly reflected the higher demand for minerals-based material and energy systems that characterize industrialized nations.

It is important to note that, while the share of biomass decreases in industrialized countries, the total amount used per capita often continues to grow. Thus, even as the share of biomass decreased, the total tonnage of biomass demand increased from 9.1 to 24.1 billion tons between 1970 and 2017. This is an average 2.1 per cent increase per year, considerably higher than the corresponding growth rate of global population of 1.6 per cent per year. Crop harvest has grown at an annual rate of 2.2 per cent over the last five decades and was the most important component of biomass extraction in 2017 (9.5 billion tons accounting for 40 per cent of the total). Grazed biomass for livestock animals has grown at a similar average rate, reflecting the growing importance of an animal and dairy based diet for the expanding middle class in many parts of the world (Myers and Kent, 2003). The rate of growth has been slowest in biomass sub-categories for which non-biomass alternatives are most easily substituted (such as wood - as fuel and building material) and where there are hard limits on yields that are not easily improved by advancing technology (such as for wild-caught fish).

Fossil fuels – coal, petroleum, natural gas, oil shale and tar sands – have grown in absolute terms from 6.2 billion tons to 15 billion tons, but their share in global extraction decreased from 23 per cent in 1970 to 16 per cent in 2017. They grew by a yearly average of 1.9 per cent between 1970 and 2017. Natural gas had a growth rate of 2.8 per cent average yearly growth and coal displayed 2.1 per cent yearly growth, which were higher than for petroleum with 1.3 per cent yearly growth. This is mainly a reflection of the expanded electricity generation capacity of coal/gas-fired power stations. More recently, coal use has nevertheless stagnated as lower gas prices, a surge in renewables and energy efficiency improvements have contributed to a slowdown in global coal consumption (IEA, 2017).

Metal ores – iron, aluminium, copper and other non-ferrous metals – accounted for 9.5 per cent of global material extraction (2.6 billion tons) in 1970, which grew slightly to around 10 per cent (9.1 billion tons) in 2017. This represented average growth of 2.7 per cent per year and reflects the importance of metals for the construction industry, energy and transport infrastructure, equipment, manufacturing and for many consumer goods. The extraction of ferrous ores grew much faster, at a yearly average of 3.5 per cent compared to non-ferrous ores, which grew at 2.3 per cent per year. The high average growth rates for ferrous metals and non-metallic minerals for construction reflect the major build-up of urban and transport infrastructure in transitioning countries.



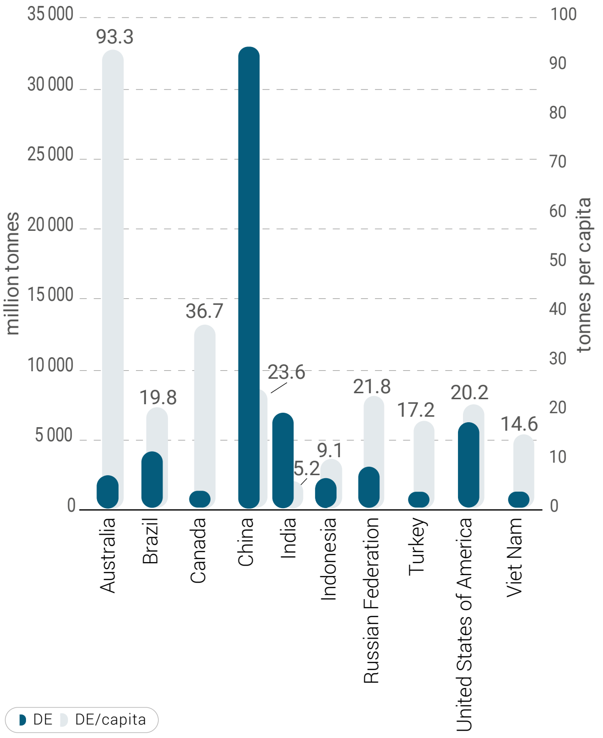
Non-metallic minerals – including sand, gravel and clay – are the largest component of material use and posted the largest growth in relative terms up from 34 per cent (9.2 billion tons) in 1970 to over 48 per cent (43.8 billion tons) in 2017. This reflects the major shift in global extraction from biomass to mineral-based natural resources. While all minerals can be thought of as non-renewable in human time scales, the bulk of non-metallic minerals are construction aggregates (essentially crushed rock with some sand). While there may be local shortages of these materials, there is no prospect of any major global supply constraints for centuries to come. This contrasts with some smaller but extremely important sub-categories, such as fertilizer minerals and minerals in the fossil fuel and metal ore categories.

The transition in the material composition of the global economy from biomass and renewables towards minerals and non-renewable based systems has changed the nature of major environmental pressures, and increasingly moved impacts from the local to the global scale.

Global material extraction has also become marginally more concentrated over the last five decades, with ten economies responsible for over 68 per cent of global extraction in 2017, compared to around 64 per cent in 1970. More than a third of all materials in 2017 were extracted in China, followed by 7.6 per cent in India and 7.1 per cent in the United States. Of the ten largest extractors in 2017, shown in figure 2.8, Australia had by far the highest material extraction per capita at 93.3 tons, which was over two and a half times the next highest (Canada with 36.7 tons per capita), and almost four times China's per capita rate. While India had the second highest total domestic extraction (DE) in 2017, it is significant that this is even with current per capita extraction levels at less than a quarter of the Chinese rate. If India follows broadly similar patterns of historical industrialization, the impact on global materials extraction will be similarly profound.

The pattern of global materials extraction in 2017 by world region (figure 2.9) clearly shows the dominant role of the Asia and Pacific region, as it accounts for over 57 per cent of total extraction. This level reflects the very large population, combined with a per capita domestic extraction rate slightly higher than Europe (12.6 tons per capita compared to 12.1 tons per capita). North America has the highest per capita domestic extraction, followed by West Asia and EECCA, which are characterized by a heavy reliance on the extraction and export of fossil fuels for export income.

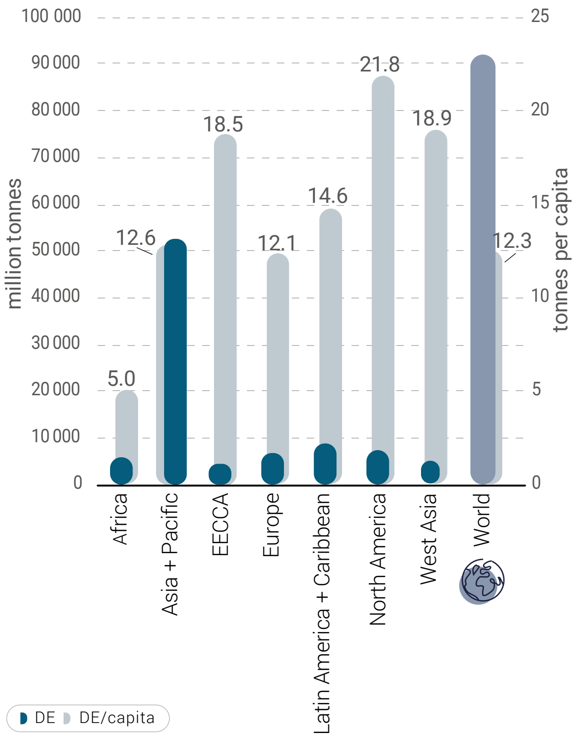
FIGURE 2.8 **Domestic extraction of materials – the ten largest extractors in 2017, million tons, with tons per-capita.**



Source: UNEP & IRP, 2018

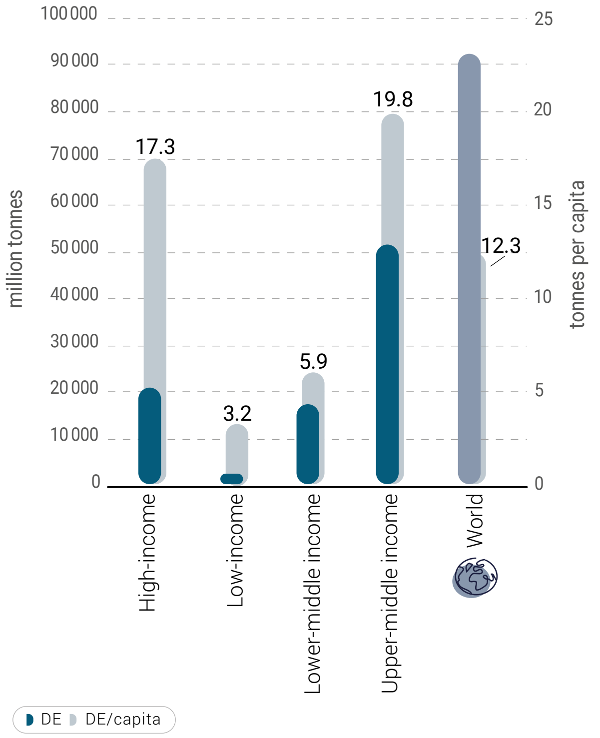
The pattern of global materials extraction for country groups by income (figure 2.10) shows that materials extraction is dominated, in absolute terms, by upper-middle income countries, which account for 56 per cent of the global total. Per capita levels of extraction are also highest for this group, at almost 15 per cent higher than for the high-income group. This reflects two major dynamics. The first is the demand for materials to build up the infrastructure required for newly industrializing countries. A second driver is likely to be the outsourcing of the more

FIGURE 2.9 **Domestic extraction of materials by seven world regions in 2017, million tons, with corresponding DE tons per-capita**



Source: UNEP & IRP, 2018

FIGURE 2.10 **Domestic extraction of materials by four national income bands in 2017, million tons, with corresponding DE tons per-capita**



Source: UNEP & IRP, 2018

material- and energy-intensive stages of production chains by higher income countries to lower-income transitioning countries. This relocation of material-intensive processes to middle-income countries is encouraged by lower environmental standards (especially in terms of local pollution) compared with those typically enforced in countries of the higher-income group.

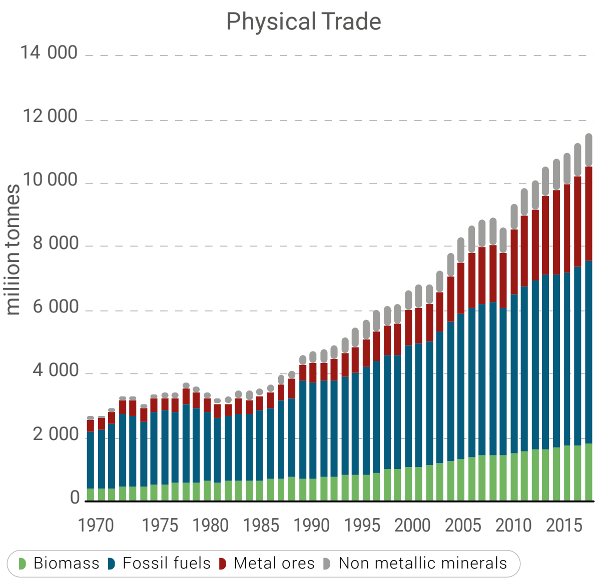
2.2.2. Global Trade of Materials

Global trade in primary materials mitigates regional imbalances in material resource availability, supporting global systems of production and consumption (Dittrich and Bringezu, 2010). While some materials (such as biomass or sand/gravel) are locally sourced in the main, others such as metal ores and fossil fuels are often disproportionately concentrated in some world regions or else impractical to exploit where present in other locations. Fossil fuels are the most traded primary material, accounting for half of the global total of 11.6 billion tons of direct physical exports in 2017. Metal ores accounted for a further quarter of the global total (figure 2.11).

Markets and supply chains for many materials that are strategically important for production systems and essential service provision have become globalized. As a result, the prices paid and received for these commodities locally are in large part determined by world events, and reflect global market prices and volatility (UNEP, 2016).

The physical trade balance (PTB) is an indicator of whether a country or region is a net importer or exporter of primary materials, and gives an idea of a country's position and role in global supply chains. PTB is calculated as physical imports minus physical exports. Regional PTB shown in figure 2.12 indicates that Europe was the world's major net importer region for most of the 1970 to 2017 period, but that its total balance remained relatively stable at around 1 billion tons (with moderate volatility of around +/- 300 million tons around the average over time). This volatility reflected events such as a move away from Middle Eastern sources of petroleum in the early 1980s, as the North Sea sources increased production in the wake of the Oil Price Shocks, and reduced demand for imports more generally during the GFC because of the economic slowdown.

FIGURE 2.11 **Global trade in materials, four main material categories, 1970 – 2017, million tons**

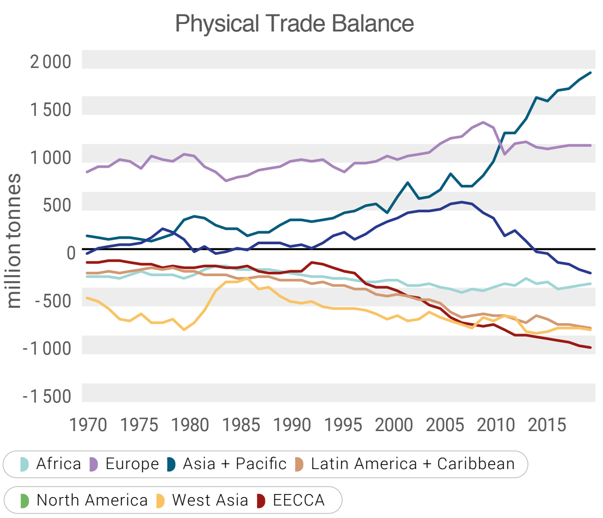


Source: UNEP & IRP, 2018

In contrast, the Asia and Pacific region saw ongoing growth in its requirement for net imports, with a rapid acceleration in the new millennium mainly resulting from this region's growth. Growth in the Asia and Pacific region's PTB was 5.9 per cent per year from 2000 to 2017, which led to it supplanting Europe as the world's major net importing region by 2009, and then continuing to be 70 per cent higher than Europe just eight years later. West Asia was the largest net exporting region from 1970 to 2006, at which point it was supplanted by EECCA. In both cases, fossil fuels dominate exports. The rapid global substitution of other sources of supply for Middle Eastern petroleum, in the wake of Oil Price Shocks, shows clearly in West Asia's physical trade balance in the early 1980s as a recognizable inverse of the trend described for Europe.

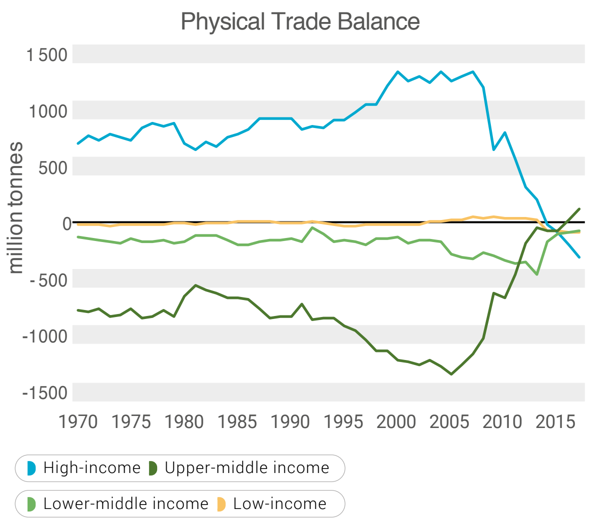
In figure 2.13, grouping physical trade balance by wealth bands reveals the upper-middle income and high-income countries to be almost mirror images of each other, with steadily growing net exports from the former balancing steadily growing net imports by the latter for the first three and a half decades, followed by a very rapid rebalancing of both towards zero PTB over the final decade, with a minor reversal of roles in the final two years. The cause for these trends again lies mainly in the rapid industrialization of some countries in the upper-middle income group and the shift of much global production to this group, especially in the wake of the global financial crisis[3], which disproportionately affected high-income countries. This resulted in the reallocation of much of the domestic extraction that from the upper-middle income group to local production and consumption, as well as ultimately drawing in primary materials exports from all other groups.

FIGURE 2.12 **Physical trade balance by seven world regions, 1970 – 2017, million tons**



Source: UNEP & IRP, 2018

FIGURE 2.13 **Physical trade balance by four national income bands, 1970 – 2017, million tons**



Source: UNEP & IRP, 2018

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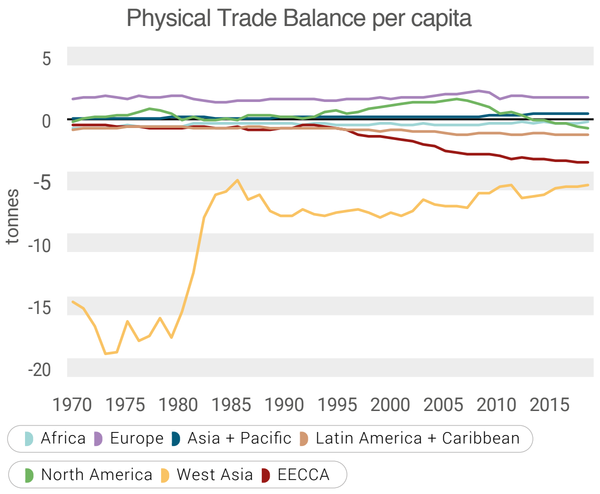
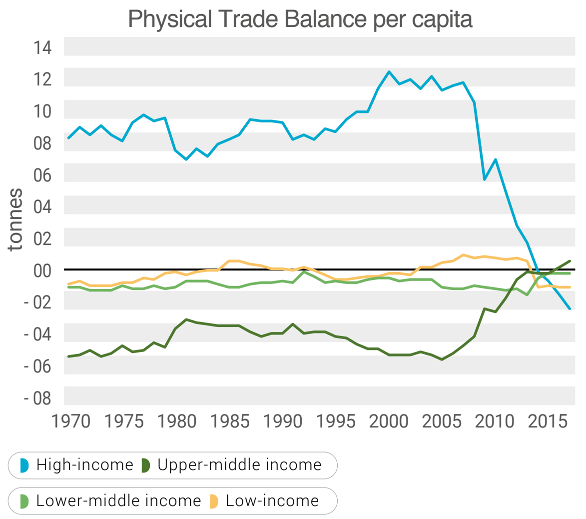
[3] A noteworthy detail is that the decline in net exports for the upper-middle income group began two years ahead of the global financial crisis, and so the industrialization process appears to have been an established dynamic behind rebalancing, which was then just accelerated by the GFC.

FIGURE 2.14 **Per-capita physical trade balance by seven world regions, 1970 – 2017, tons**



Source: UNEP & IRP, 2018

FIGURE 2.15 **Per-capita Physical trade balance by four national income bands, 1970 – 2017, tons**



Source: UNEP & IRP, 2018

In driving commodity prices higher, this made exporting 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, was over 730 million tons, which on its own could account for around half the decrease in PTB of the high-income group from its highest level of over 1.3 billion tons.

The apparent near balance of the physical trade balance of low-income countries across the entire 1970-2017 period largely reflects the fact that this group does not account for major volumes of international trade in terms of imports or exports.

Per capita levels of PTB are within a range of +/- 1.8 tons for five of the seven world regions (see figure 2.14). The two regions that have operated outside this relatively narrow band are again West Asia (for the entire period, and generally at over three times this level per capita) and EECCA post-2000. This reflects their importance as global suppliers of petroleum and natural gas. Despite the ongoing growth in West Asia's net exports since the major reduction of the early 1980s (see figure 2.14), population growth there has been sufficiently rapid that net per capita exports have been slowly declining since the 1990s (-1.4 per cent per year from 1990 to 2017).

In contrast, broadly comparable growth in net exports in EECCA has flowed through to a very strong increase in per capita net exports (5.8 per cent per year over the same period). Given the reliance of key countries in these regions on petroleum and gas for export income, this illustrates that West Asia is under pressure to continuously increase extraction just to maintain current living standards, while the EECCA region (with much lower population growth) does not face this challenge.

The per capita physical trade balance for four country income groups accentuates the trend identified for total PTB for income groups (figure 2.15).

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 aforementioned trend for physical trade balance in the upper-middle income group of countries, its net import levels of 1.4 tons per capita remain relatively low. This is less than a third that of Asia's second largest economy, Japan, and less than a fifth of South Korea's level.

The largest net exporter of materials in 2017 by far was Australia, followed by the Russian Federation, Brazil, Indonesia and Saudi Arabia. The detailed data available from the IRP website[4] show that Australia's extremely high levels of net exports are dominated by two categories

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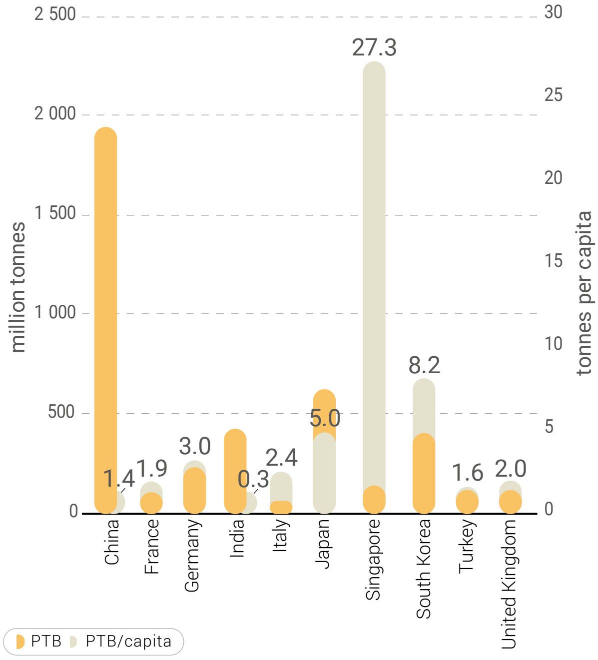
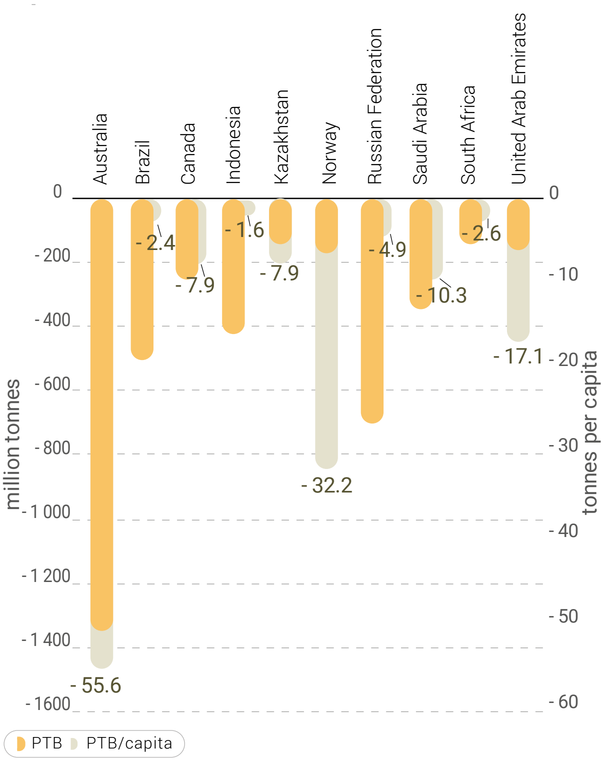
[4] See www.resourcepanel.org/global-material-flows-database.

FIGURE 2.16 **Top-ten net importers of materials measured by the Physical Trade Balance (PTB), 2017, million tons and tons per capita**



Source: UNEP & IRP, 2018

FIGURE 2.17 **Top-ten net exporters of materials measured by the Physical Trade Balance (PTB), 2017, million tons and tons per capita**



Source: UNEP & IRP, 2018

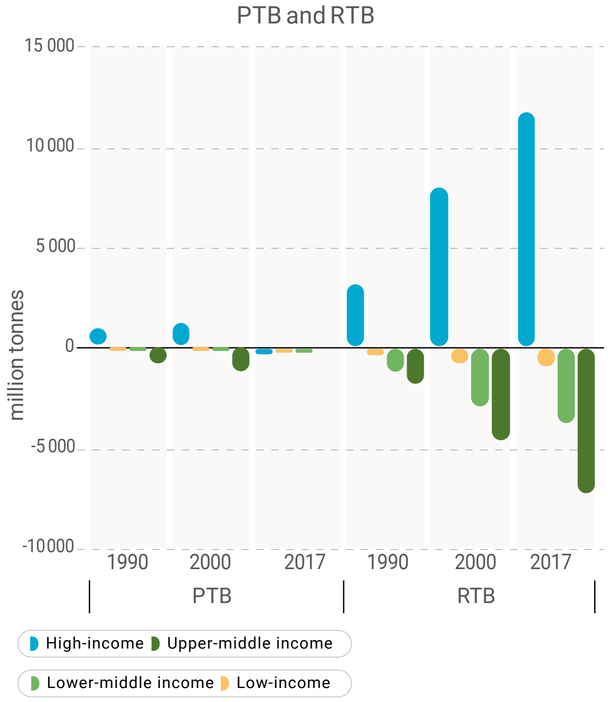
- ferrous ores and coal - the bulk of which is destined for other countries in the Asia and Pacific region. Brazil's exports are dominated by ferrous ores, while those of Russia, Saudi Arabia, Norway and the UAE are all largely the result of petroleum and/or natural gas exports. On a per capita basis, Australia is again almost twice the level of the next major exporter, Norway. The presence of the two large international traders in ferrous ores in this figure (Australia and Brazil), while dominant exporters of other metals (notably Chile with regard to copper) are absent, simply reflects the fact that most non-ferrous metals are traded in highly concentrated or refined forms.

Where PTB gives the balances of direct physical tonnages traded, the raw material trade balance (RTB) metric, included in figure 2.18 and figure 2.19, considers the embodiment of materials that did not physically cross borders with traded goods, but that were nevertheless required for their production. This links material extraction, wherever it may physically take place, through global production chains to end consumers in a way that cannot be achieved using the direct physical trade metrics like PTB. The method by which extracted materials are attributed to final consumption is rather complex, and both data and computationally intensive (Lenzen et al. 2017), but in general terms, monetary flows in the world's economy are used as proxies to attribute parallel material flows to final demand.

The total tonnages accounted for by the raw material trade balance are much larger than for the physical trade balance because of its much more inclusive scope. In many cases, materials are highly concentrated before they are first traded across borders. For non-ferrous ores, for example, the concentrate or crude metal that is traded internationally will usually be one or more times more concentrated than the ore originally extracted. While direct physical trade measures will usually exclude the vast bulk of this ore left behind in the country of extraction, as well as any other materials, for example fossil fuels, which had to be consumed to process it, the raw material trade balance seeks to include it. As shown in figure 2.18, whereas PTB for high-income countries in 2017 implies that this group of countries was in fact a minor net exporter of 302 million tons of materials, the RTB measure indicates that, after re-attributing all extraction according to final consumption, the trade of this group in fact was equivalent to a net virtual transfer equivalent to 11.8 billion tons of primary extraction from elsewhere in the world into this group. Similarly, for the upper-middle income group, net imports of just under 124 million tons on a PTB basis are dwarfed by the net export of the equivalent of 7.3 billion tons of primary extraction out of this group to the rest of the world. Comparing RTB among the groupings in figure 2.18 indicates that the economic activity in the high-income group of countries depends on very large and increasing levels of extraction of primary materials in other countries, which are effectively "imported" in virtual form and embodied in traded commodities.

Figure 2.19 shows the same virtual transfers of extracted primary materials, on a per capita basis. From this perspective the average person in the high-income group was reliant on the mobilization of 9.8 tons of primary materials elsewhere in the world in 2017. This reliance on external materials has been increasing at a rate of 1.6 per cent per year since the year 2000.

FIGURE 2.18 **Distribution of physical trade balance (PTB) and raw material trade balance (RTB) across four national income bands, for 1990, 2000 and 2017, million tons**



Source: UNEP & IRP, 2018

2.2.3. Domestic Material Consumption

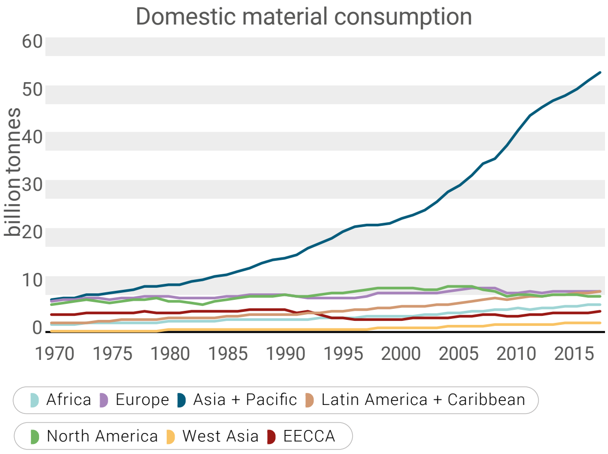
Domestic material consumption (DMC) is another direct measure of the materials that are consumed in a national economy. It is calculated as domestic extraction (DE) plus physical trade balance and, as such, it directly measures the physical quantity of materials that are extracted from or imported into a nation's territory (minus any physical exports). This is a direct indicator of the total materials that must be directly managed in a nation's territory. These materials may be consumed over the short term (such as most fossil fuels) and so turned into waste and emissions, or remain for prolonged periods of time in national stocks (for example metals and building materials in vehicles and consumer durables, buildings, transportation and other network infrastructure). Ultimately, however, the materials accounted for in DMC will need to be disposed of back into the environment as some form of waste or emission. This is why DMC can also be thought of as an indicator of the long-term waste potential of a national economy.

At the global level, domestic material consumption and domestic extraction are equivalent. In figure 2.20, the

FIGURE 2.19 **Comparison of per-capita physical trade balance (PTB) and raw material trade balance (RTB) across four national income bands, for 1990, 2000 and 2015, tons per capita**

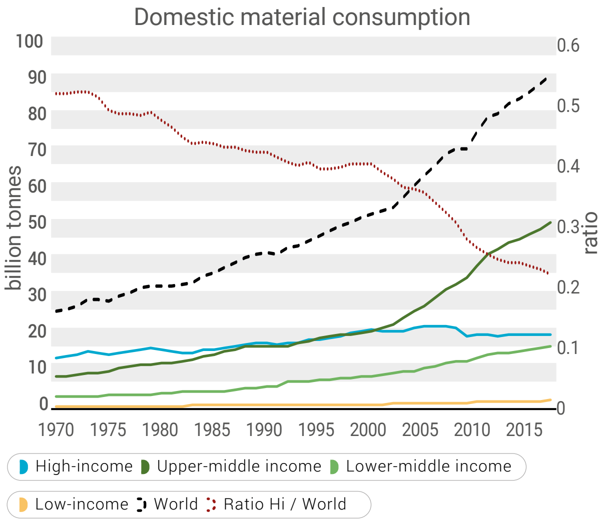
Source: UNEP & IRP, 2018

FIGURE 2.20 **Domestic material consumption by seven world regions, 1970 – 2017, billion tons**



Source: UNEP & IRP, 2018

FIGURE 2.21 **Domestic material consumption by four national income bands and World total, 1970 – 2017, billion tons, with ratio of High-Income group to world total**

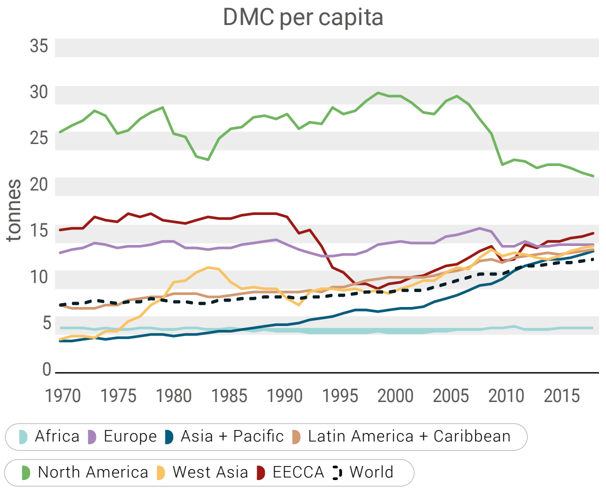


Source: UNEP & IRP, 2018

rapidly increasing dominance of the Asia and Pacific region in global DMC is clear. In 1970, this region accounted for 25 per cent of the global total of 27 billion tons, similar to Europe's 24 per cent and North America's 22 per cent shares. Between 1970 and 2017, however, while the DMC of Europe and North America grew at 0.6 per cent per year and 0.5 per cent per year respectively, in the Asia and Pacific region it grew at 4.5 per cent per year. By 2017, the Asia and Pacific region accounted for almost 60 per cent of the global total of 92.1 billion tons, while Europe's and North America's combined share decreased to less than 18 per cent.

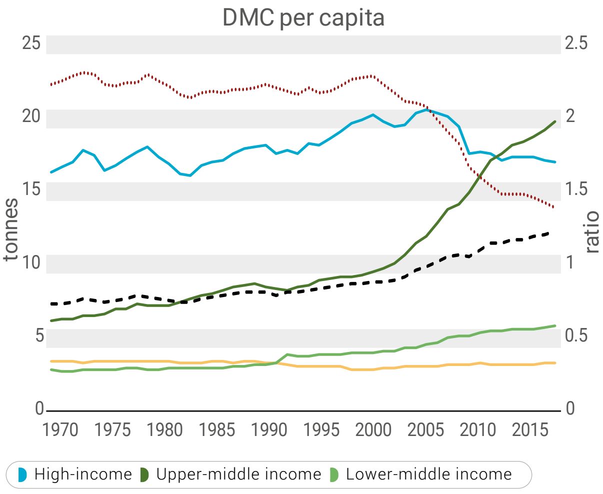
The share of global domestic material consumption accounted for by high-income nations is rapidly decreasing, as illustrated by the high-income countries/ world ratio in figure 2.21. This is due to the rapidly rising DMC of the upper-middle income group of nations, which increased its share of the global total from 33 per cent

FIGURE 2.22 **Per-capita domestic material consumption capita by seven world regions, with world average, 1970 – 2017**



Source: UNEP & IRP, 2018

FIGURE 2.23 **Per-capita domestic material consumption by four national income bands, with world average, 1970 – 2017, and ratio of high-Income group to world total**



Source: UNEP & IRP, 2018

in 1970 to 56 per cent in 2017, while the share of high-income countries dropped from 52 per cent to 22 per cent. The share of DMC accounted for by lower-middle income countries also grew from 12 per cent to 19 per cent, however the share of the low-income group remained unchanged at under 3 per cent, despite having by far the fastest growth in population. This shows that, while virtually none of the massive growth in materials consumption in the new millennium has gone to the wealthiest countries, neither has much of it gone to the poorest countries despite the latter being the group in most urgent need of improved material living standards.

In figure 2.22, the trajectory of domestic material consumption per capita for the seven world regions reflects, and in some cases magnifies, the aforementioned features and events. Rapidly increasing per capita consumption in the Asia and Pacific region is a major factor, as is the impact of the global financial crisis on North American consumption (although this impact is much less obvious in Europe's DMC per capita). The dramatic fall in DMC per capita in the EECCA region following the dissolution of the USSR is particularly marked in figure 2.22, as the fall in DMC there was driven by two dynamics operating in tandem. The first was the overall depression of economic activity, which suppressed domestic demand for domestic extraction and for imports. The second dynamic, which operates over the longer term, was the re-orientation of major EECCA economies to global rather than internal/eastern bloc markets. Much of the DE that had previously been used internally (thus contributing to the EECCA's DMC account) was made available for external sale and export (decreasing the DMC account). Figure 2.22 shows that the EECCA region has still not returned to the levels of DMC per capita seen at the end of the Soviet era, despite the region's GDP per capita levels having recovered and exceeded Soviet-era levels.

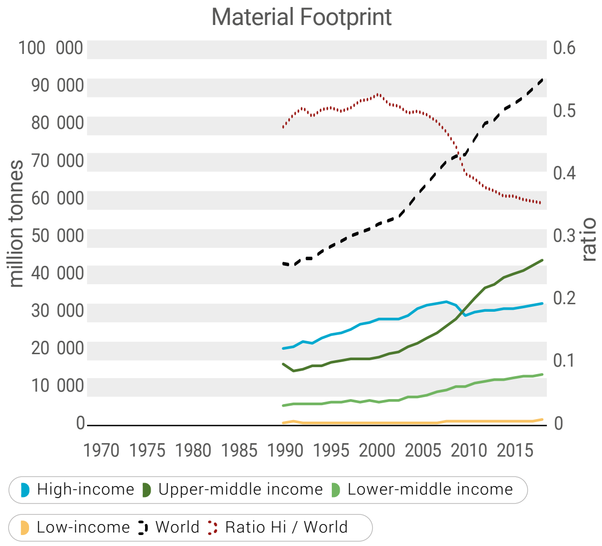
The decreasing significance of high-income countries in determining global DMC is further reflected in a DMC per capita basis, in terms of the high-income to world ratio. More significantly, per capita levels of DMC in the upper-middle income group surpassed those of the high-income group by 2012. While the time series since 2012 is too short to infer any robust trend, any evidence for a convergence and stabilization of DMC levels below 20 tons per capita is lacking. Given that we know there has been a large and ongoing transfer of global production shares from high-income countries to the upper-middle income countries, this observation calls into question how much the mooted stabilization of DMC at higher income levels (Steinberger et al., 2013) is real, and how much of it is actually just a result of the transfer of material- and energy-intensive production stages to transitioning countries. This is a question of great importance in determining likely future trends in material resource demand.

Domestic material consumption has been selected by the Inter Agency Expert Group (IEAG) as the basis for indicators to monitor 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 in this role by the 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 ton. Finally, it is critical that the DMC be used in combination with a consumption-based measure. DMC's strength 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 on the global level.

2.2.4. Material Footprint of Consumption

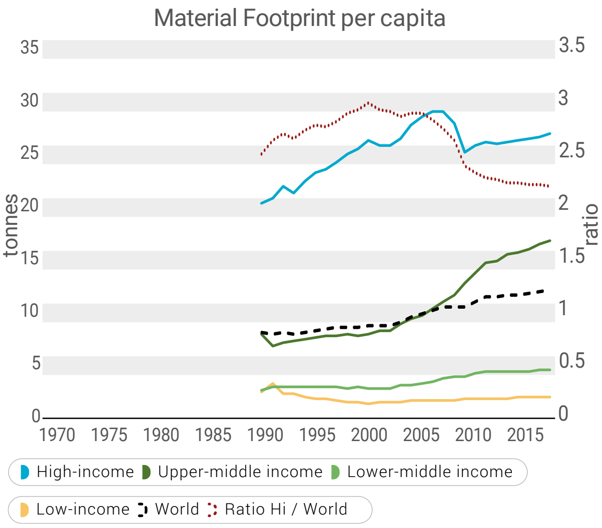
Material footprint (MF) is the other material flow indicator that has been selected to monitor progress in the context of the SDGs, and more specifically SDG 8.4 on resource efficiency. The material footprint is a demand-based - rather than a territorially based - indicator, bearing the same relationship to DMC as the previously discussed RTB and PTB. In short, it attributes all of 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 underpinning a country's consumption, but that largely take place in other countries' territories and

FIGURE 2.24 **Material footprint by four national income bands, with world average, 1970 – 2017, and ratio of high-income group to World total**



Source: UN, 2017a; UNEP & IRP, 2018

FIGURE 2.25 **Material footprint per capita by four national income bands, with World average, 1970 – 2017, and ratio of high-income group to world total**



Source: UNEP & IRP, 2018

impose their environmental costs there, are attributed to an end consumer's account.

The time series available for material footprints and MF per capita only run from 1990 to 2017 (see figures 2.24 and 2.25). As a general trend, the share of MF attributed to wealthier regions and country groups is much higher compared to domestic material consumption. Note that in global totals, DE = DMC = MF, so it is just the relative shares of responsibility for global domestic extraction that are being redistributed by the material footprinting calculations.

The material footprint of the upper-middle income group did not exceed that of the high-income group until the global financial crisis, and by 2017 the high-income group still accounted for over 35 per cent of global MF, compared to only 22 per cent seen previously for DMC. The combined share of the lower-middle and low-income groups dropped from 22 per cent of DMC to 18 per cent of MF.

There has not been a level of global wealth at which material demand has stabilized or declined.

On a per capita basis, the high-income group has not been overtaken but rather maintains levels of MF consumption of around 27 tons (which is 60 per cent higher than the upper-middle income group) through to the end of the time series. This is also more than 13 times the level of the low-income group (at 2 tons per capita). After a rapid reduction of MF in high-income countries during the GFC, MF per capita resumed a modest and ongoing upward growth trajectory. This contrasts with the stagnant to slow decrease seen for DMC per capita, and suggests that improvements for the high-income group on that metric do indeed come from outsourcing production rather than any decrease in underlying material consumption.

2.2.5. Material Productivity

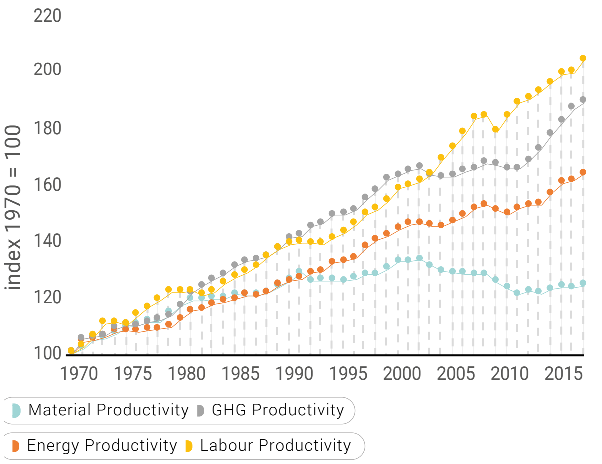
Material productivity, the efficiency of material use, is of economic importance and helps reduce environmental pressure and impacts. Material productivity, however, needs to be reviewed in the context of other key productivity measures. It is therefore illustrated in Figure 2.26 alongside three additional aspects of productivity (labour, energy and GHG emissions). Each of these additional measures is defined and discussed briefly, followed by a more detailed discussion of material productivity – the economic gains achieved through resource efficiency (stated as the value obtained from a certain amount of natural resources).

The global economic settings have focused on improvements in labour productivity at the cost of material and energy productivity. This was justifiable in a world where labour was the limiting factor of production. We are now in a world where natural resources and environmental sinks have become the limiting factor of production, and shifts are required to focus on **resource productivity.**

Labour productivity – US$ of GDP per hour of work – has improved substantially since the 1970s and has doubled over the last five decades. An important aspect of labour productivity is that, historically, one of the main ways of increasing it has been to substitute increased inputs of materials and (especially) energy for labour. It is also improved by increasing the knowledge and/or skills of workers.

Energy productivity – US$ of GDP per megajoule (MJ) of primary energy use – has increased more or less continually throughout the period from 1970 to 2016, but may be divided into two fairly distinct phases. It increased relatively strongly from 1970 through to the early 2000s, although at a lower rate than labour productivity. From then on, there was a distinct slowdown in the rate of improvement through to the current time, with short multi-year periods where productivity declined. Energy productivity has, however, not displayed the longer-term deterioration seen for material productivity. The main driver of this slowing rate of improvement is probably the same as that for the decline in material productivity, which is the increasing share of global production taking place in low energy productivity countries. There is also an element of the substitution of energy for labour, as the energy systems in transitioning countries have developed (with increasing electrification and more widespread use of fossil fuels for transportation).

FIGURE 2.26 **Global resource productivity (material, energy and CO_2 emissions) and labour productivity, index, 1970 – 2017**



Source: EDGAR World Emission Database; IEA World Energy Database; ILO Labour Statstics; UN, 2017a; UNEP & IRP Global Material Flows Database

GHG Emission Productivity – US$ of GDP per kg of CO_2 equivalent emissions – GHG emissions to a large degree mirror the trajectory of energy productivity, as most are produced from the burning of fossil fuels, although there are significant contributions from land use and agriculture. Where GHG productivity was increasing faster than energy intensity from 1970 to 2000, this likely reflected simple ongoing improvements in energy efficiency among major users of fossil fuels (better internal combustion engines and more efficient generators), and perhaps some shift from more carbon intensive fuels, particularly coal, to either less carbon intensive fossil fuels (notably natural gas), or non-fossil fuel energy sources such as hydroelectricity and nuclear. From around the year 2000, GHG productivity begins to parallel or even under-perform against energy productivity. This coincides with a rapid increase in China's share of the world economy, and in large part reflects the very high reliance of that country's energy systems on coal. Since 2010, GHG productivity has again started to grow at a faster rate than energy productivity. Factors that might explain this include the improved efficiency of much of the Chinese coal generator fleet, a major shift to natural gas rather than coal-fired electricity generation in the United States of America (due to the deployment of hydraulic fracking technology) and the increased use of lower carbon technologies, including renewable energy sources, more generally.

Material Productivity – US$ of GDP per kg of material use – posted the slowest growth of all four productivity factors and started to decline around the year 2000, stagnating in recent years. This means that the average environmental pressure and impact per dollar of products and services have been increasing in the global economy since the start of the new millennium. This is particularly discouraging from an environmental point of view, as increasing material productivity is one necessary (but not sufficient) condition to enable the continuation of economic growth while reducing environmental impacts.

The general lack of improvement in material productivity at a global level seems somewhat counterintuitive, given the ongoing improvement of technical process efficiencies in most industries. It seems even more counterintuitive given the fact that the majority of individual countries show ongoing improvements in resource productivity over the time period, including the top countries in terms of GDP and material flows. For example, material intensity for the People's Republic of China (the inverse of material productivity) improved rapidly over the entire 1970-2017 period, and continued improving at a rate over 2.4 per cent per year from 2000 to 2015. The reason why global material productivity has not improved, even given the above, is that there has been a simultaneous shift in the share of global production from economies with high material productivity to economies that have much lower material productivity. This is reflected in the relatively high materials use per capita for the upper-middle income group seen in figure 2.23, and is partly a result of the outsourcing of material and energy intensive processes by many of the wealthiest countries. Material productivity in transitioning countries is inherently lower, because the infrastructure and plants for industrialization need to be built, and because these economies lack much of the high value adding/low material requirement service sectors (for example finance, education and research) that have built up over time in the highest income countries.

Improving material productivity (and energy productivity) in the future requires a new economic paradigm. Economic and environmental policy needs to be more integrated to facilitate improvements in resource productivity, and to promote production and consumption systems that provide essential services such as housing, transport, food and energy with much lower material and energy throughputs. This will probably requires a fundamental rebalancing of the trade-off between increasing resource and labour productivity towards greater resource productivity.

2.2.6. Material Intensity of Production and Consumption

One important measure of the sustainability of current resource management practices is how efficiently natural resources are being used by the economy to generate each unit of goods and services, as reflected by GDP. A standard metric used is material intensity (MI), defined as domestic material consumption/gross domestic product (this is simply the inverse of material productivity, seen in section 2.2.5).

For a number of years, global material intensity has stagnated despite improvements in material efficiency in most individual countries, world regions and income groups. This is clearly shown in figure 2.27. The underlying explanation for this counter-intuitive phenomenon, as also reflected in material productivity, was discussed in detail in section 2.2.5.

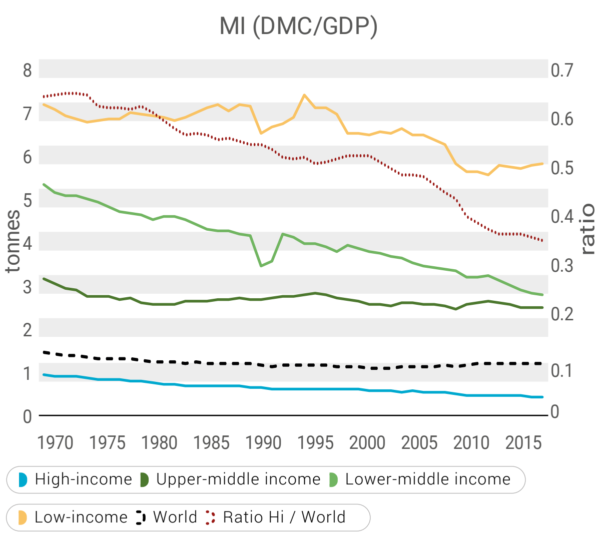
Global material efficiency has stalled because the shift in economic activity from highly resource-efficient countries to less resource-efficient countries has been faster than the improvements in resource efficiency in individual countries.

Resource efficiency has been improving (such that material intensity has been decreasing) for all income groups throughout the 1970-2016 period, and the ratio of high-income countries to the world indicates that the rate of improvement was highest for the high-income group, which decreased at a rate of -1.7 per cent per year. All individual income groups improved faster than the aggregated world rate of -0.4 per cent per year. In the more recent 1990 to 2016 period, while all individual income groups decreased their material intensity by rates (-0.3 to -1.6 per cent per year), global aggregated material intensity deteriorated (increased) at slightly more than 0.1 per cent per year. An important observation here is that the MI of the high-income group and the upper-middle income group in 2016 are 0.4 kg/US$ and 2.5 kg/US$. For every US$ in economic activity that shifts from the former to the latter, the amount of materials required to produce that dollar will increase by more than six-fold given current supply chain and production characteristics.

Using material flow indicators of domestic material consumption and material footprints (territorial and consumption-based) in addition to the standard territorial definition of material intensity (DMC/GDP) provided in figure 2.27, we provide a consumption-based version using MF/GDP in figure 2.28 and refer to it as Adjusted MI.

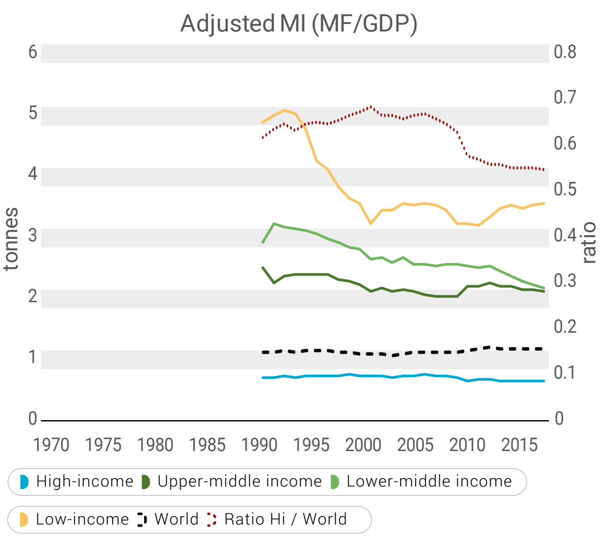
The changes in trajectories for different income groupings when Adjusted Material Intensity is used are given in figure 2.28. Interpreting these differences in detail is difficult, as much variation is probably due to fluctuations in the exchange rate over time, which affects both the aggregated measure of GDP used directly in the indicator, and the mechanism for redistributing DE used to generate the material footprint indicator. General features that should be robust, however, include Adjusted MI being notably lower than MI for low-income countries and higher for wealthier countries. Aggregated global adjusted MI and its trend over time are identical for both Adjusted MI and MI.

FIGURE 2.27 **Material intensity (DMC / GDP) by four national income bands, with world average, 1970 – 2017, and ratio of high-income group to World total**



Source: UN, 2017a; UNEP & IRP, 2018

FIGURE 2.28 **Material intensity of consumption (Material Footprint / GDP) intensity by four national income bands, with world average, 1990 – 2017, and ratio of high-income group to world total**



Source: UNEP & IRP, 2018

2.2.7. Drivers of Material Use

We use the notion that environmental pressure and impact can be expressed as a combination of population size, affluence and resource use or environmental impact intensity to discuss the extent to which population growth and consumption have determined resource demand in the past. This relationship was expressed by the well-known IPAT formula (Ehrlich & Holdren, 1971), which we modify and use as a framework for analysing the relative importance of three different, economy-wide scale drivers of materials demand. The original formulation is:

$$I = P * A * T$$

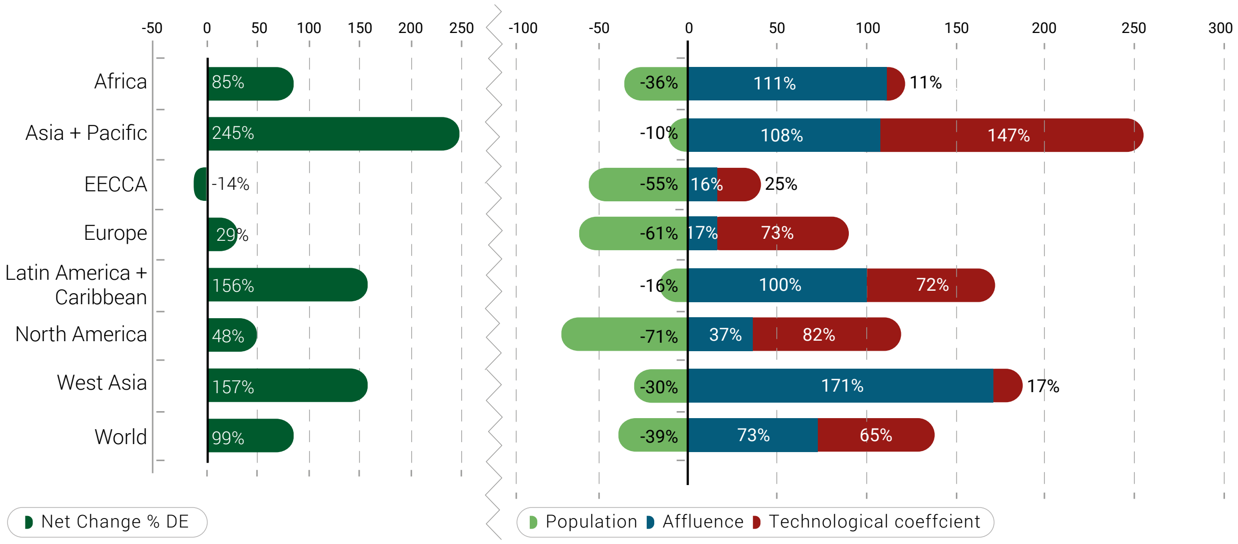
Where I is environmental impact, *P* is population, *A* is Affluence and *T* is a technological coefficient, which usually just translates as the intensity of *I* per unit of money used in the Affluence term. The original form of the equation also needs to be transformed to a logarithmic form to facilitate attribution of discrete shares of impact growth among the three drivers, in keeping with the formulation provided in Herendeen (1998).

For use here, the impact of concern substituted for *I* is domestic extraction, then material footprint. *A* is GDP/population in all analyses, while *T* is domestic extraction/GDP, then Adjusted Material Intensity.

A key agenda behind this analysis is to assess the degree to which societies would need to improve the efficiency of materials use to offset the largely monotonic growth in both population and GDP.

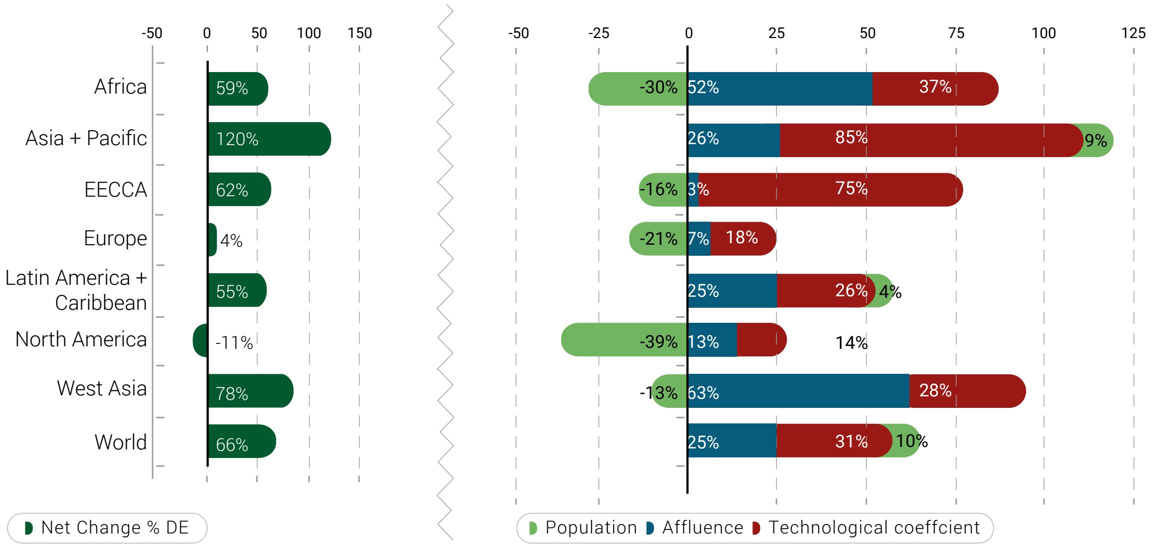
Therefore, taking the formula *domestic extraction = population * GDP/population * domestic extraction/GDP*, we find that from 1970 – 2000, the rate of improvement in technology (DE/GDP) was sufficient to offset the combined effects of the growth in population and affluence in only one of the seven world regions, which was the EECCA region. Despite a relatively rapid improvement in *T*, and the very low growth rates for both population and affluence that characterized the region over the period, the extractive burden for the EECCA region decreased by just 14 per cent. Elsewhere, improvements in *T* were often not sufficient to offset even one of the other drivers. This is most clearly the case in the Asia and Pacific region, where the increases in domestic extraction driven by population and affluence were an order of magnitude larger than the nominal 10 per cent decrease that would have been driven by improved efficiency alone. The highest offsetting efficiency technology improvements were achieved in North America, although this was not enough to cancel out the increases driven by affluence alone. Population growth was the strongest driver of increased domestic extraction in three of the seven regions, and for the world in aggregate.

FIGURE 2.29 **Drivers of domestic extraction, 1970 – 2000, percentage**



Source: UNEP & IRP, 2018

FIGURE 2.30 **Drivers of domestic extraction, 2000 - 2016, percentage**



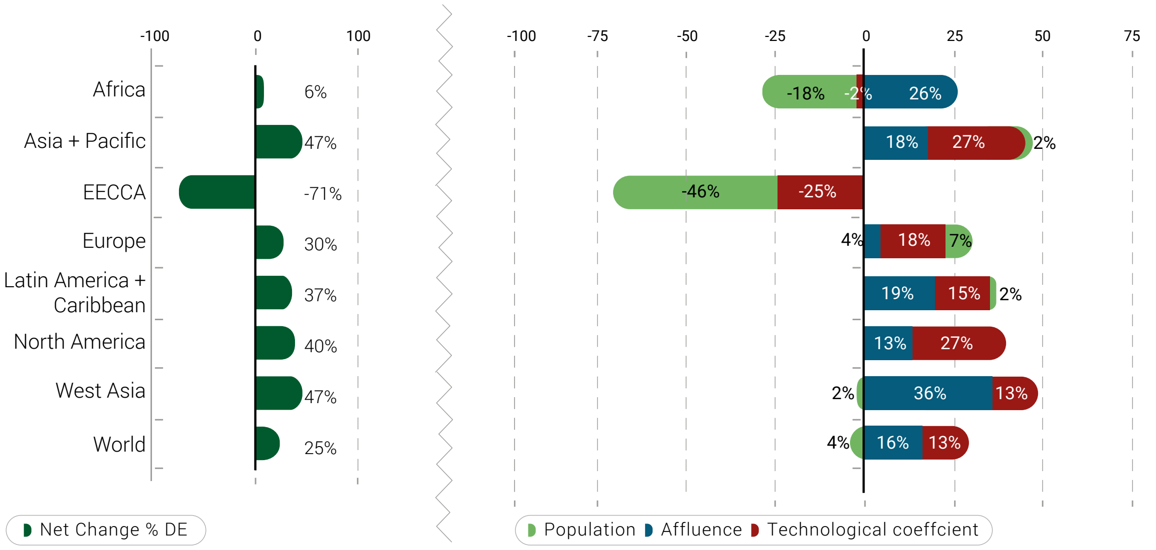
Source: UNEP & IRP, 2018

From 2000 onwards, increasing affluence replaced population as the largest driver of growth in material extraction globally, although at a regional level population was the most significant factor in both Africa and West Asia. The only region where technological improvement was sufficient to offset growth in population and affluence combined was North America. DE/GDP decreased by 39 per cent over the period. In the Asia and Pacific region, which is by far the most significant region in terms of domestic extraction, technological change did not offset growth in population and affluence, and it actually served to drive it higher. This deterioration in T is another manifestation of an intra-regional shift of production share from lower material intensity nations to higher intensity ones.

Although the general pattern of material footprint drivers in the earliest period differs considerably from that seen for domestic extraction, much of this is likely due to the different and shorter time used in the analysis for material footprints. The greatest departure is seen for the EECCA region, and this is largely explained by the 1990 to 2000 time period coinciding with the dissolution of the USSR and the long period of economic dislocation that followed for that region. This region provides a rare example of the fall in affluence being sufficient to drive a large and protracted decrease in material footprint at a regional scale. Increasing population was still the strongest driver of materials demand over the period globally, and for three of the seven individual regions. Change in the technological coefficient actually exacerbated rather than offset growth in MF in five of the regions and (marginally) for the world in aggregate.

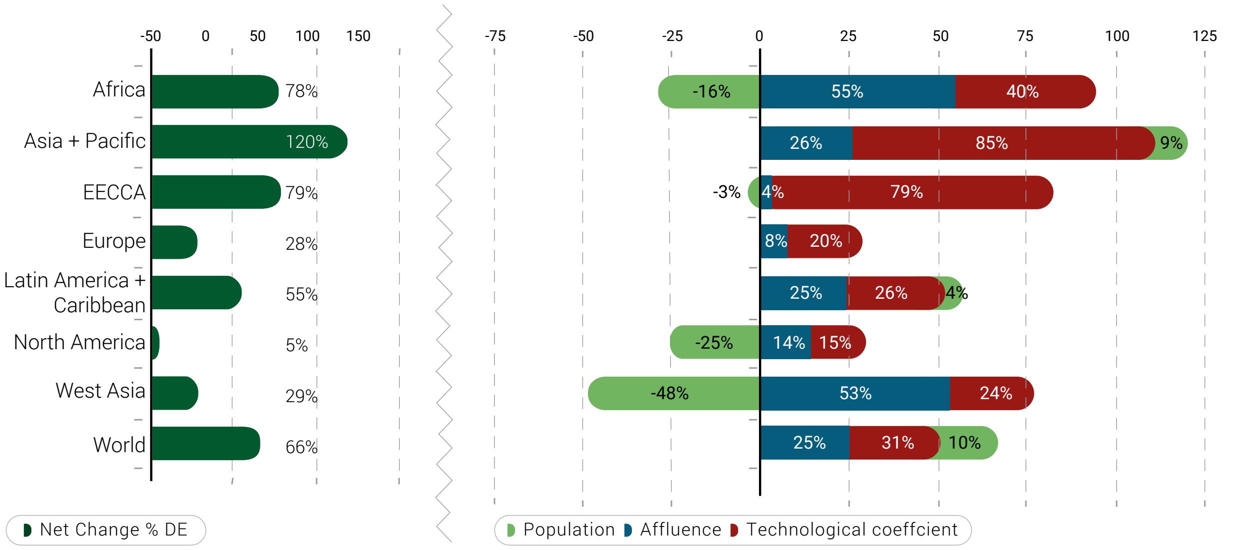
For the later period from 2000 to 2016, which matches the latter period used for domestic extraction, we see a much greater similarity between the result for domestic extraction and material footprint. At the global level, the contribution of drivers is identical for both, which is how it should be as, globally, MF = DE. The proportional relationship between population and affluence remains similar, but the absolute percentages generally change. The change in impact and the change in technological coefficient is a result of the changed reallocation of global DE by country that takes place in the footprinting process.

FIGURE 2.31 **Drivers of material footprint, 1990 - 2000, percentage**



Source: UNEP & IRP, 2018

FIGURE 2.32 **Drivers of material footprint, 2000 - 2016, percentage**



Source: UNEP & IRP, 2018

2.3 Historical Analysis of Water

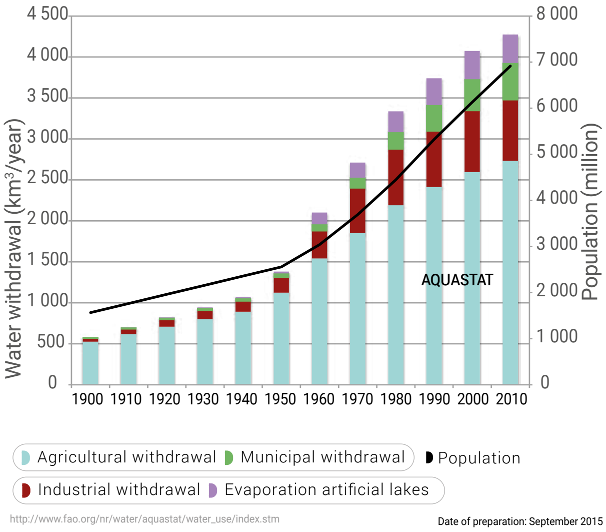
Continents are supplied with freshwater by precipitation of almost 110,000 km^3 per year (FAO, 2016). About 56 per cent of this amount is evapotranspired by forests and natural landscapes and 5 per cent by rainfed agriculture. The remaining 39 per cent or 43,000 km^3 per year is converted to surface runoff (feeding rivers and lakes) and groundwater recharge (feeding aquifers). Part of these renewable freshwater resources is being removed from these rivers or aquifers by water management infrastructure. This removal of water is called water withdrawal. Most of the withdrawn water is returned to the environment some time later, after it has been used. When it was evaporated, incorporated into products, or consumed by humans and livestock or transpired (for example by irrigated plants) this accounts for water consumption. Even after non-consumptive use, when the used water returned to the same river or aquifer, its quality is often changed (with regard to temperature or chemical composition).

2.3.1. Global Trends

Global water withdrawal for agriculture, industries, and municipalities increased sharply in the second half of the 20th century (Figure 2.33). During that period, water withdrawal grew at a faster rate than human population. From 1970 to 2010, the growth rate of withdrawal slowed, while, nevertheless, growing from 2,500 km^3 per year to 3,900 km^3 per year (FAO, 2016a). Since the 1990s, global water withdrawal by agriculture, industries, and municipalities has decoupled in relative terms (figure 2.33).

FIGURE 2.33 **Global water Withdrawal and losses from artificial lakes from 1900 to 2010**

Global population and water withdrawal over time



http://www.fao.org/nr/water/aquastat/water_use/index.stm

Date of preparation: September 2015

Source: FAO, 2016

In addition to the water withdrawal by those three sectors, water was lost by evaporation from artificial lakes or reservoirs with dams. This category can also be counted as anthropogenic water consumption.

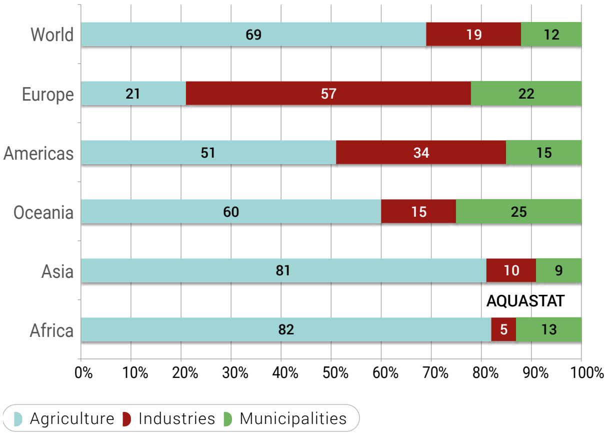
2.3.2. Sectors and World Regions

Based on country measurements between 2000 and 2012, the global sum of water withdrawals is dominated by agriculture at 70 per cent, mainly for irrigation (including livestock and aquaculture). Industry withdrawal accounts for 19 per cent, with municipalities responsible for 11 per cent (FAO, 2016a).

Depending on the geographical conditions and the state of infrastructure development, these proportions vary across continents (figure 2.34).

FIGURE 2.34 **Water withdrawal ratios by continent**

Water withdrawal ratios by continent



http://www.fao.org/nr/water/aquastat/water_use/index.stm

Date of preparation: September 2015

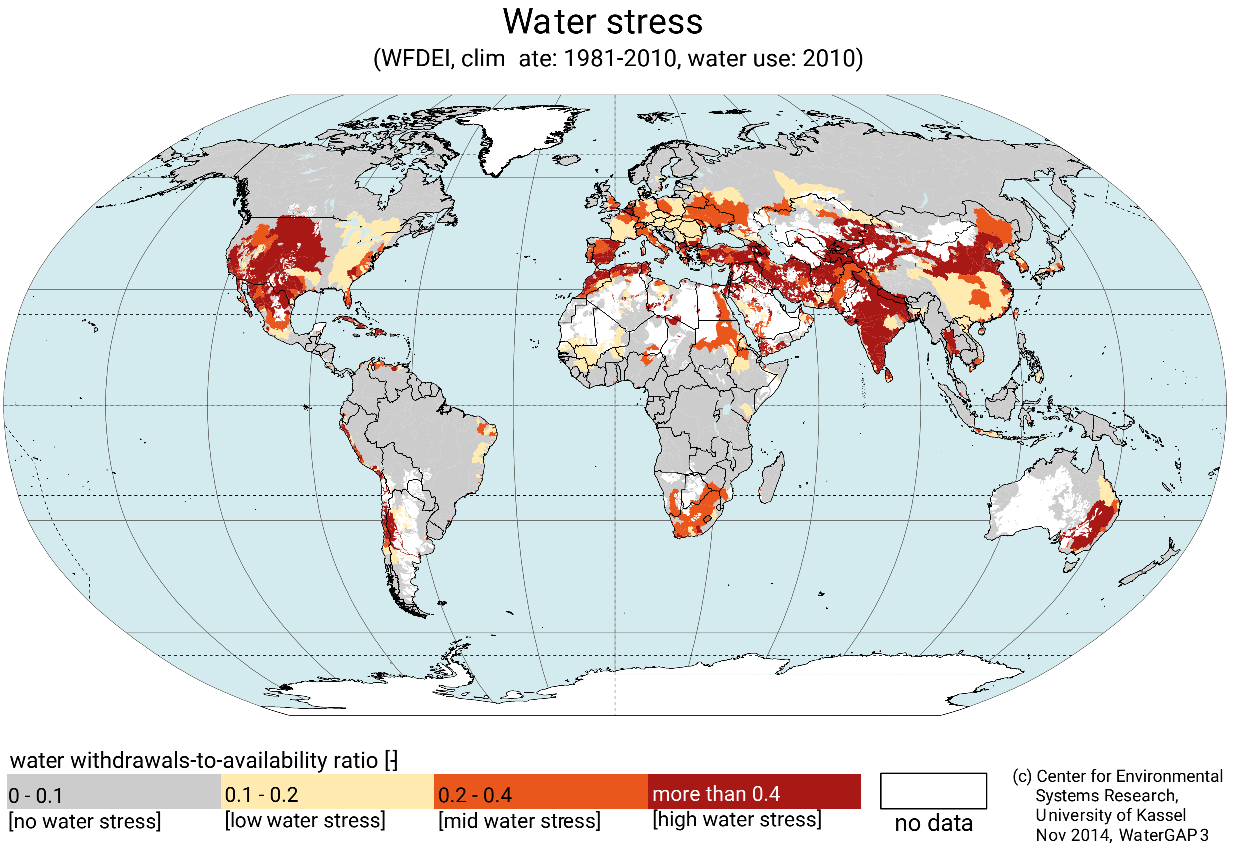
Source: FAO, 2016. Note: water is analysed through the six regions as defined by FAO

2.3.3. Water Scarcity: High Withdrawal in Relation to Availability

The larger the volume of water withdrawn, used and discharged back into a river, the more the river flow is depleted and/or degraded for users downstream (including the environment), , and thus the higher the water stress. The withdrawals-to-availability ratio is used to indicate water stress. This indicator has the advantage of being transparent and computable for all river basins and has been used in several studies (see, for example, Alcamo et al., 2007).

There are 844 million people who lack access to water (WHO & UNICEF, 2017). High water stress occurs when more than 40 per cent of the water input of a river basin is used. This can be observed in most of India, Northern China, Central Asia, the Middle East, the Mediterranean rim countries, Eastern Australia (the Murray Darling basin), Western Latin America, large parts of the Western United States and Northern Mexico (figure 2.35). Overall, river basins in these regions are at greater risk of seasonal or inter-annual variations in water flow.

FIGURE 2.35 **Water stress in river basins of the world 2010**



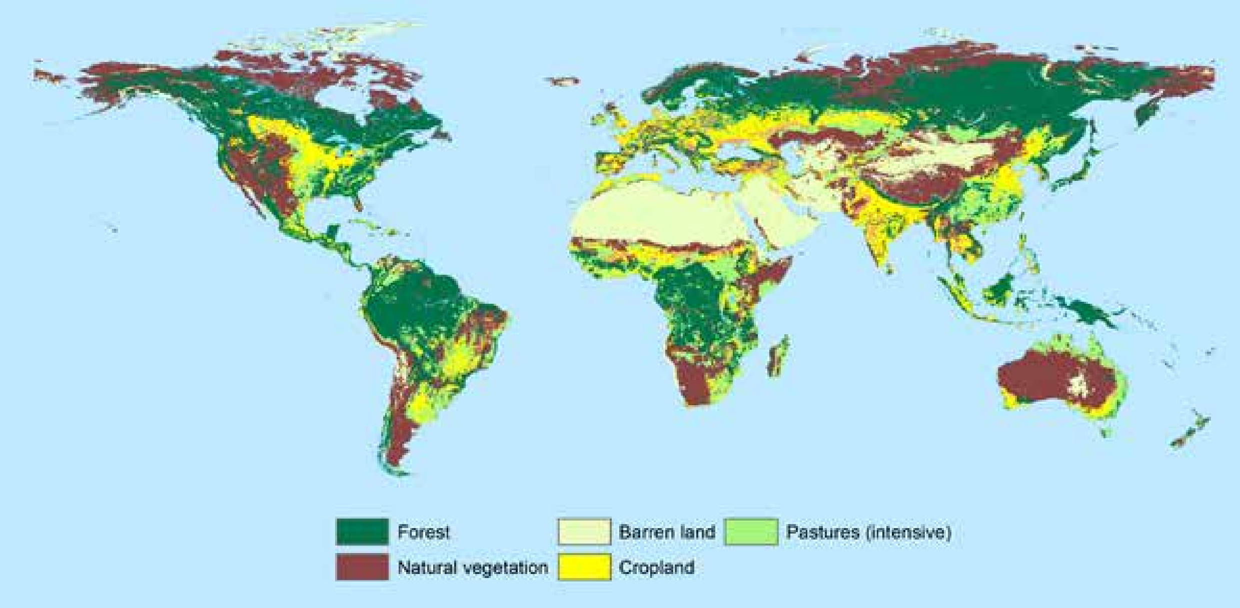
Source: UniKassel/CESR

2.4 Historical Analysis of Land Use

2.4.1. Land-Use Change Between 2000 and 2010

The continents cover 134 million km^2 (not including Antarctica and Greenland). In 2010, these were mainly covered by forest (31.7 per cent); grassland, shrubland and savannah (19.1 per cent); intensively managed pastures (12.2 per cent), cropland (11.4 per cent); and barren land (14 per cent) (figure 2.36). In the light of varying definitions and methods of measurement, it seems reasonable to assume that built-up areas covered by settlements and infrastructure account for 1 to 3 per cent of the total area (based on Potere et al., 2009; UNEP, 2014).

FIGURE 2.36 **Global land cover in 2010**



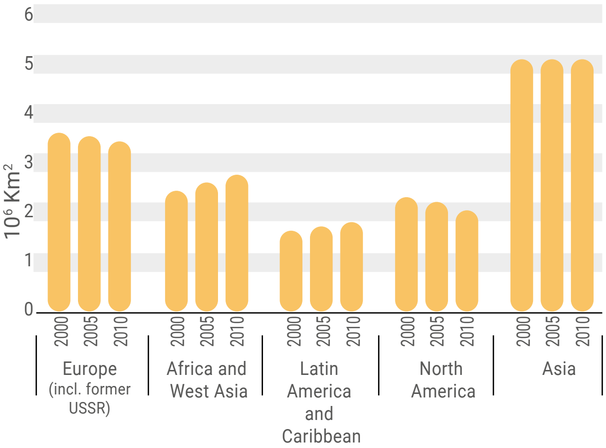
Source: UniKassel/CESR

2.4.2. Cropland and Pasture

Between 2000 and 2010, total global cropland area increased by 1.34 per cent from 15.2 million to 15.4 million km². While cropland area declined in Europe and North America, there were increases in Africa, Latin America and, more moderately, in Asia (figure 2.37).

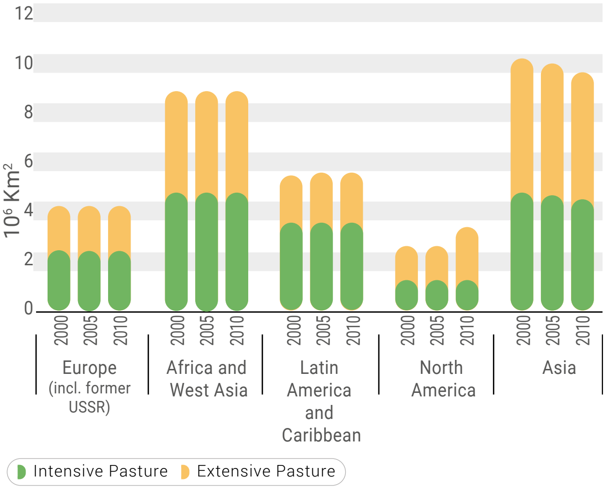
Global pasture area has decreased slightly from 31.3 million to 30.9 million km². While slight increases can be observed in North America, Latin America and Africa, there was a decrease in Europe and more significantly in Asia (figure 2.38). Globally in 2000, 53 per cent of this area was intensively managed pasture, 47 per cent were grassland, savannahs, shrubland and barren land that were extensively grazed. Up to 2010, these proportions hardly changed.

FIGURE 2.37 **Development of cropland area in world regions between 2000 and 2010**



Source: UniKassel/CESR

FIGURE 2.38 **Development of pasture area in world regions between 2000 and 2010. Pasture is subdivided according to intensive management practices and extensive management practices with only minor effects on natural ecosystems**



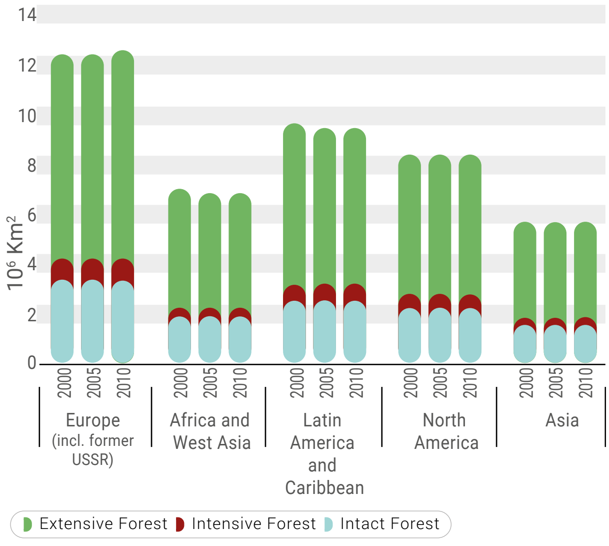
Source: UniKassel/CESR

2.4.3. Forest and Other Natural Ecosystems

Net forest losses can be observed in Africa (-1.3 per cent) and Latin America (-1.6 per cent) (figure 2.39). The other world regions show slight net increases in forest areas. The overall forest area in Asia appears fairly stable, while a more detailed spatial analysis shows that South Asia is a deforestation hotspot. Shrinking forests in that region are compensated by forest expansion in East Asia in terms of land cover, although impacts on biodiversity may be severe (see chapter 3). About two-thirds of world forests are extensively used, 6 per cent are intensively managed (for example, fast-growing plantations), while 28 per cent remain largely intact. These shares are more or less constant in the three time steps.

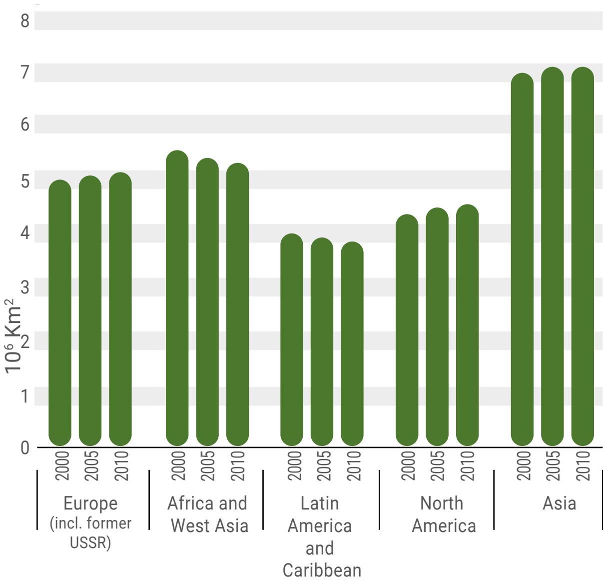
Figure 2.40 shows the development of grassland, shrubland and savannahs. In total, there has been almost no change. Decreases in Africa and Latin America are compensated by increases in the other parts of the world.

FIGURE 2.39 **Development of forest area in world regions between 2000 and 2010**



Source: UniKassel/CESR

FIGURE 2.40 **Development of grassland, shrubland and savannahs in world regions between 2000 and 2010. Some of these natural ecosystems are used as extensively managed pasture**



Source: UniKassel/CESR

2.5 Conclusions

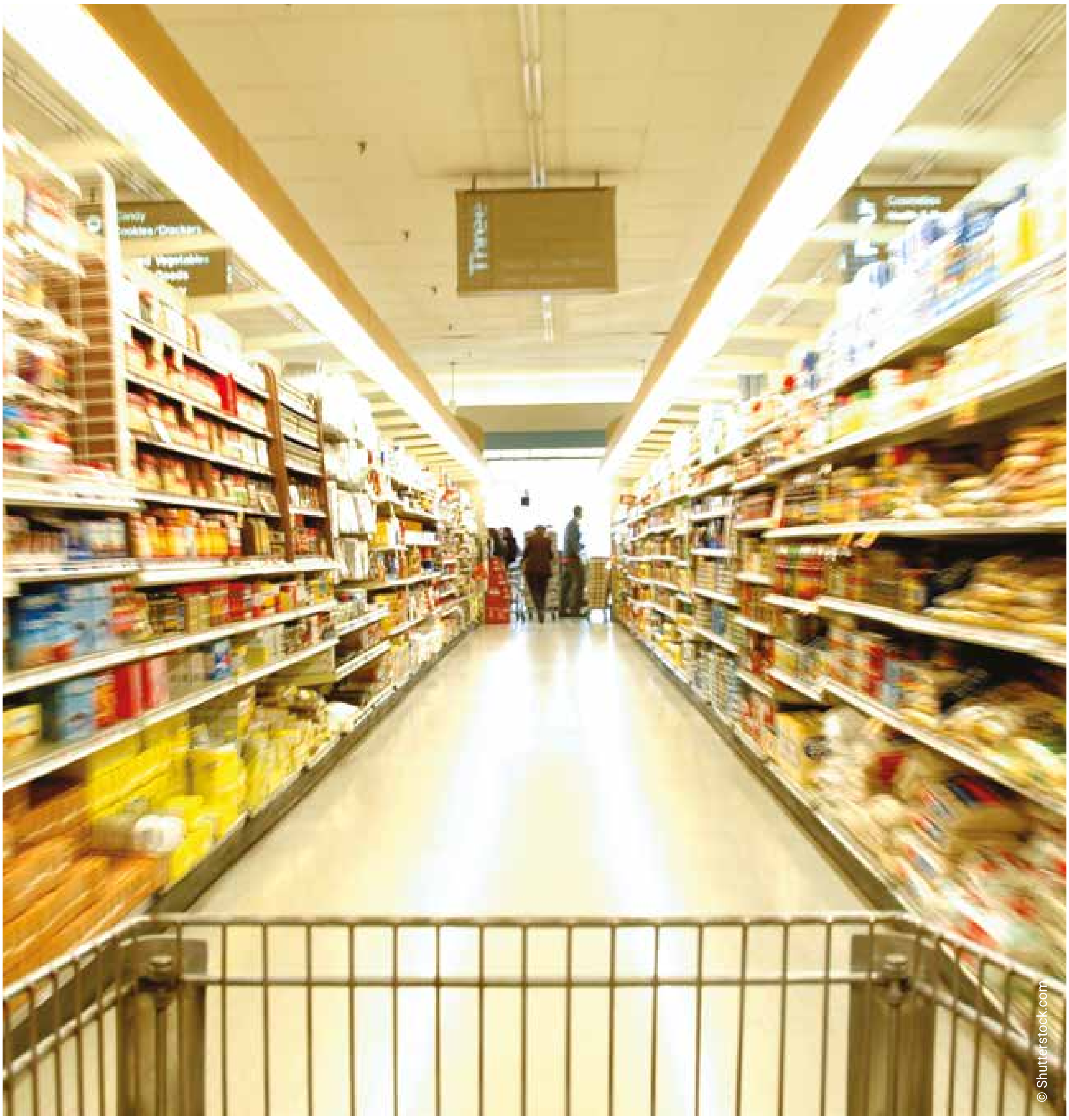
This chapter has shown that, since the 1970s, global population has doubled and global GDP has grown fourfold. These trends have required large amounts of natural resources to fuel economic development and human well-being. The data presented in this chapter demonstrate that there has never been a prolonged period of stabilization or decline in global material demand in the last 50 years.

Global material extraction has also become slightly more concentrated over the last five decades, with ten economies responsible for over 68 per cent of global extraction in 2017 (compared with around 64 per cent in 1970). Upper-middle income economies dominate extraction of resources, accounting for 56 per cent of the global total. Two dynamics are at play here: an increasing demand to build up new infrastructure and the outsourcing of the more material- and energy-intensive stages of production chains by higher income countries to lower income but transitioning countries.

The share of global domestic material consumption accounted for by high-income countries is decreasing, while the share of domestic material consumption of the upper-middle income countries is increasing. The global share of low-income countries remains unchanged at below 3 per cent, despite this group posting the highest population growth rate among the different income categories. In terms of material footprint per capita, high-income countries maintain the highest consumption of approximately 27 tons. This is 60 per cent higher than the upper-middle income group.

For water, a slight relative decoupling of water use from population growth began in the 1990s, but global water use is increasing and 30 per cent of the global river basin area has been under mid to severe water stress since 2010.

Overall, this chapter has presented the global trends of drivers (such as population and GDP) on pressures such as material extraction, trade of materials, domestic material consumption, material footprints and material productivity, along with a historical analysis of water and land use change. Based on the information on resource extraction provided in this chapter, chapter 3 addresses the impacts of these trends.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03

Environmental Impacts of Natural Resource Use

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Main findings

- Resource extraction and processing make up about half of the total global greenhouse gas emissions and more than 90 per cent of land- and water-related impacts (biodiversity loss and water stress). If the rising trend in resource-related impacts persists, it will be difficult to achieve the goals of the Paris Agreement and the Sustainable Development Goals (including SDG 15.5 to halt biodiversity loss).
- Impacts and value creation are not equally distributed around the globe. Per capita impacts of consumption in high-income regions are between three and six times larger than those of low-income regions. This is reinforced by trade: some high-income regions outsource environmental impacts to other regions, such that a part of the total environmental impacts of their consumption occurs abroad. At the same time, the value created through these traded materials in the countries of origin is relatively low.
- Between 2000 and 2015, there was a relative decoupling of resource-related environmental impacts from GDP and a moderate relative decoupling of impacts from extracted mass of resources. However, impacts still increased on an absolute scale. Agriculture is the main driver of global biodiversity loss and water stress, while build-up of infrastructure was the main driver for the increase of climate change impacts. Policy actions are required to maintain the impacts of resource use within planetary boundaries while allowing for development and build-up of infrastructure in developing and emerging economies.
- Potential measures for the simultaneous reduction of agricultural impacts include food waste reduction and shifts in diets towards less meat and animal products from intensive livestock systems. Focusing on long-term material use of sustainably grown wood in the construction sector can lead to co-benefits in terms of climate change and biodiversity. Similarly, conserving valuable forest ecosystems and avoiding deforestation contribute to reducing both climate change and biodiversity impacts.

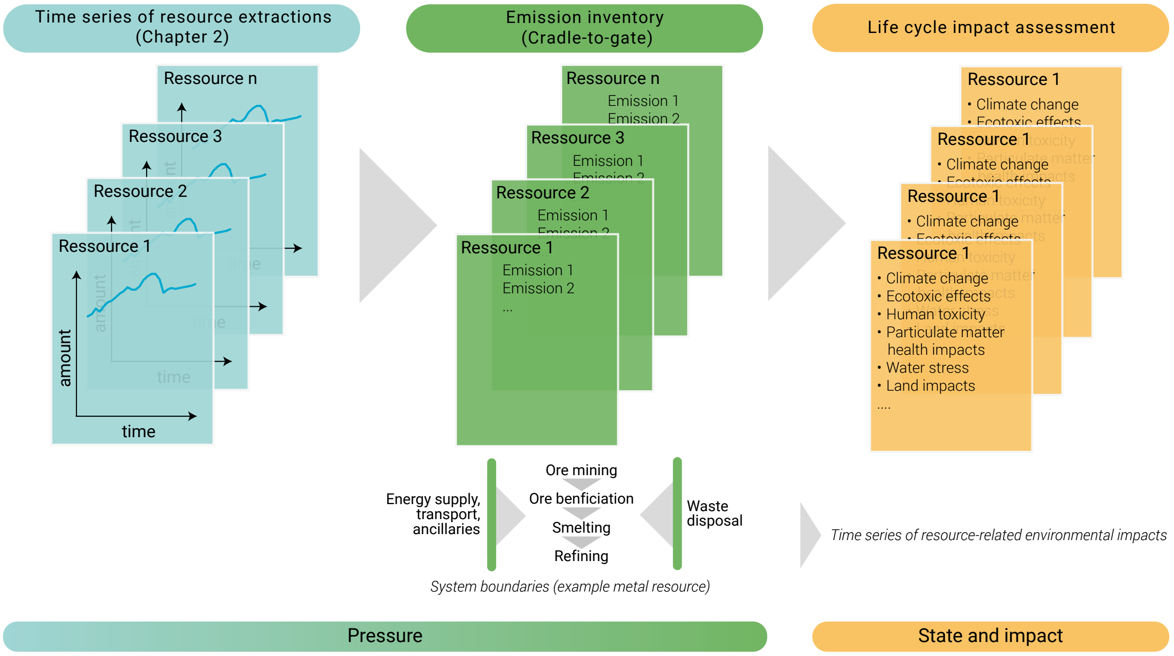
3.1 Introduction

Decoupling economic growth and environmental degradation requires sustainable sourcing and management of resources over the whole life cycle. While the mass-flow indicators of chapter 2 are very useful for understanding the environmental pressures from material consumption, information about the environmental impacts of resource use and resource management practices is also needed to support policymaking for the sustainable use of natural resources (Voet et al., 2005). This chapter focuses on the environmental consequences of resource extraction and processing. It illustrates the legitimate need for appropriate policy to manage natural resources, which is required if we are to remain within the safe operating space (Steffen et al., 2015) and achieve the SDGs.

Relevant environmental impacts are assessed on the basis of the information on resource extraction provided in chapter 2. The focus is on the resource extraction and processing phase of production, and stops at the "ready-to-use" materials and fuels phase (which includes the waste disposal processes in the extraction and processing phase, such as emissions and impacts of mine tailings). As all human activity involves the use of resources, assessing the use phase of all of them would involve assessing the entire global economy. Therefore, while resource extraction and processing are assessed for all resources (denoted as "resource related" and "**cradle-to-gate**"), the impacts including the use and disposal phase (denoted as "economy wide" and "**cradle-to-grave**") are discussed only in exemplary cases to highlight the importance of resource quality in the complete life cycle of materials. The cases where the use and disposal phases are considered are presented within a box.

This chapter addresses the "pressure" as well as the "state" and "impact" components of the DPSIR framework. The amounts of resources from the IRP Material Flow Accounting database (part of the "pressure" component) were used as a starting point (chapter 2). For waste and recycling, additional data on recycling amounts were added to complete resource coverage. For each resource, an inventory of emissions and indirect resource consumptions (including land and water resources) was set up, corresponding to the "pressure" component of DPSIR. The data were mainly derived from inventory and input-output databases: Exiobase 3.4 was used to assess the cumulated upstream impacts of all resource types of the whole economy (macroanalysis, Section 3.2) (Exiobase, n.d.; Stadler et al., 2018). Double counting was avoided using an adapted version of the approach by Dente et al. (Dente et al., 2018) (see methodological appendix), assigning the impacts of resources to the final material or fuel (such that the impacts of coal and coke going into steel production would be part of "metal processing" and not "fossil extraction" or "fossil processing"). In addition to the Exiobase "macroanalysis", data were used from ecoinvent 3.4 (Wernet et al., 2016) to study single resources and materials in depth (section 3.3). In these detailed studies, there was no need to aggregate the impacts of various resource types, and therefore no need to correct for double counting. Regional conditions, such as country-specific electricity mixes, were considered where relevant. Finally, the inventory was assessed in terms of environmental and health impacts.

FIGURE 3.1 **Overview of methodological procedure to assess the health and environmental impacts of resource extraction and processing. For some resources a complete life cycle perspective was additionally adopted (cradle to grave; these cases are marked by a box)**



In the **impact assessment** step, emissions and resource use (for example land and water use) were grouped according to the type of impact they produce and converted to common impact units to make them comparable (Hellweg & Mila i Canals, 2014). The best-practice guidelines of the UNEP-SETAC Life Cycle Initiative for use in **Life Cycle Assessment** were followed (UNEP SETAC, 2016). Recommended methods exist for impacts of climate change (IPCC, 2007), eco-toxicity (Rosenbaum et al., 2008), water stress (Boulay et al., 2018), biodiversity loss from land use (Chaudhary et al., 2016a), human toxicity (Rosenbaum et al., 2008) and human health impacts from **particulate matter** (PM) exposure (documented in UNEP SETAC, 2016). This impact assessment phase corresponds to the "state" and "impact" components of the DPSIR framework. For example, greenhouse gas emissions were weighted according to the concentration change they produce in the atmosphere (considering persistence and chemical transformations) 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 of the earth is accumulated over a defined time horizon (typically 100 years) and published by IPCC as "Global Warming Potentials, GWPs" (IPCC, 2013). The impacts herein are called *climate change impacts*, but are also known as the *carbon footprint.* Note that climate change impacts in this chapter do not include emissions from land use change. For toxicity impacts, the fate of the emissions in the environment is modelled (degradation and partition between environmental media such as water, air and soil) and combined with the substance-specific toxic effects on humans and ecosystems (Rosenbaum et al., 2008). Similarly, for health impacts from emissions of particulates and precursor gases transformed to particulate matter in the atmosphere (SOx, NOx, ammonia), the fate of emissions is modelled in the atmosphere, leading to atmospheric concentration increases of particulate matter. Inhalation exposure leads to elevated risk of cardiovascular and respiratory diseases (ranging in health outcomes from diseases like asthma to increased mortality) (WHO, 2013). Health impacts due to particulate matter exposure and human toxicity are both expressed in terms of **Disability Adjusted Life Years** (DALYs), meaning the amount of life years lost or lived with health impairment. Impacts relating to ecosystem damage from land use (causing habitat loss) are expressed in terms of global species loss, such as the fraction of globally existing species that are committed to extinction due to habitat loss (Chaudhary et al., 2015). While this unit does not cover all aspects of biodiversity loss (for example, genetic diversity) or ecosystem services, it remains a highly relevant indicator. Regionalized impact assessment methods were used whenever relevant and possible in order to decrease uncertainties. This was particularly true for the assessment of land and water use, because the magnitude of impacts is not only a function of land area or water amount consumed, but also depends on the location where land and water are used and how they are managed. For example, land use in tropical regions often leads to the extinction of more unique species than land use in less valuable ecosystems. However, a regionalized assessment was not possible for toxicity impacts and only partially for PM health impacts, due to a lack of appropriate regionalized methods (which leads to major uncertainties in terms of such impacts). Interactions between impact categories also exist. For example, the relation between health and biodiversity is extensively discussed in Romanelli et al., 2015.

The selection of impact categories fits well with the "core planetary boundaries" of climate change and biodiversity loss (Steffen et al., 2015), and additionally includes the most relevant pathways for human health impacts from outdoor air pollution (Lim et al., 2012). Furthermore, all these impacts are relevant for resource use, and some of them have been shown to correlate with (and therefore represent) other impacts too. In particular, climate change impacts have been demonstrated to correlate with ozone depletion, acidification and eutrophication for resource extraction and processing (Steinmann et al., 2018). Therefore, these impact categories are not shown separately, unless they diverge from the development of climate change impacts and are predominant with regard to resources (as with phosphorus use as fertilizer and its relation to eutrophication, which is extensively discussed in section 3.3.2).

In order to relate the environmental impacts to economic benefits and social impacts, we also accounted for the value added by the extraction and processing of resources as well as the number of full-time equivalent positions required for this purpose (denoted as "**employment**" below). Different types of value-added categories as well as the workforce numbers per skill-level are listed for each region and industrial sector in Exiobase 3.4 (Exiobase, n.d.; Stadler et al., 2018). In an additional analysis, "**work risks**" were quantified using region-sector specific weighting factors derived from the social hotspot database (Benoit-Norris et al., 2012) to account for social risks (Zimdars et al., 2018). The weighting factors consider human safety, human health, human rights and labour rights, with a view to quantifying the exposure to work risk factors of people working in the resource sectors.

One focus was the assessment of trade impacts. Opportunities include the fact that, ideally, trade and international cooperation could lead to goods being produced where they cause the least environmental impacts and create most social benefits. In many cases, however, profit concerns govern the flow of traded resources and materials, while social and environmental impacts tend to play a secondary role. There is therefore a risk of displacing environmental pressures through trade, with regions consuming resources that were originally extracted and processed in another region. This is considered by presenting results from both a production-based and a consumption-based perspective, as defined in chapter 1.4. We derived "net trade benefits and impacts" from the difference of the production-based and consumption-based perspectives of each respective region (Wood et al., 2018).

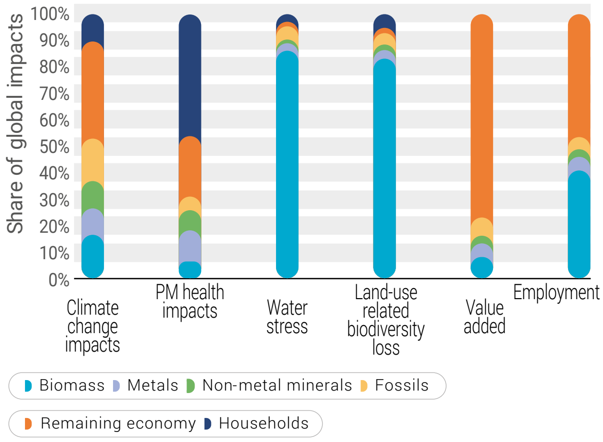
More details about the methodological procedure are provided in the method annex.[5]

3.2 Overview of Impacts of Resource Extraction and Processing

3.2.1 Decoupling Resource Impacts from Human Well-being and Economic Growth

Resource extraction and processing account for more than 90 per cent of global biodiversity and water stress impacts (figure 3.2), and approximately half of global climate change emissions (not including climate impacts related to land use). These results illustrate that resources need to be put at the centre of climate and biodiversity policies, so as to stay within the safe operating space (Steffen et al., 2015) and facilitate the achievement of commonly agreed international targets, such as the Paris Agreement, the Aichi targets of the Convention on Biological Diversity and the Sustainable Development Goals (including SDG 15.3 on land-degradation neutrality and SDG 15.5 on halting biodiversity loss).

FIGURE 3.2 **Split of the total global environmental impacts and socio-economic benefits between resource types (extraction and processing), the remaining economy (i.e. without the resource extraction and resource processing sectors) and households**



Data sources: Exiobase 3.4 (Exiobase, n.d.; Stadler et al., 2018), combined with land-use data from chapter 2 and impact assessment methods (Section 3.1). Reference year: 2011

In contrast to climate impacts, water-stress and land-related biodiversity impacts, resource extraction and processing make a limited contribution to the global health impacts of particulate matter exposure (figure 3.2) - although these may be relevant on a local scale. Health effects are dominated by combustion-related emissions in the use phase of biomass and fossil resources (figure 3.2). Note that health effects from particulate matter in figure 3.2 exclude indoor emissions, which would increase the share of impacts from "households" even more. In fact, indoor exposure to particulate matter from cooking with solid fuels, particularly biomass, represents one of the most important health risks globally.

Water stress and land use-related biodiversity impacts are mainly caused by biomass resources. This is in contrast to climate change and health impacts from particulate matter, for which all types of resources carry a significant share of the overall impacts (figure 3.2).

Environmental impacts of material provision showed a relative decoupling from economic growth, but per

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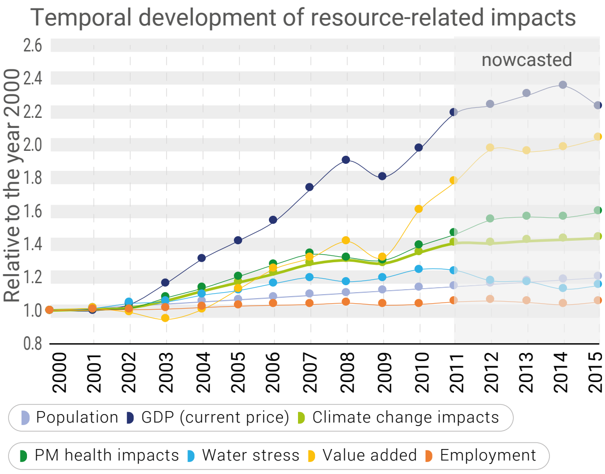
[5] Available at www.resourcepanel.org/reports/global-resources-outlook-2019.

FIGURE 3.3 **Temporal development of environmental impacts from resource extraction and processing (up to "ready-to-be-used" materials or fuels) and socio-economic indicators from 2000 to 2015**



Reported data was available between 2000 - 2011, while all Figures after 2011 were "nowcasted" (Tukker et al., 2018); PM: particulate matter; year 2000 = index 1
Data source: Exiobase 3.4 (Exiobase, n.d.; Stadler et al., 2018)

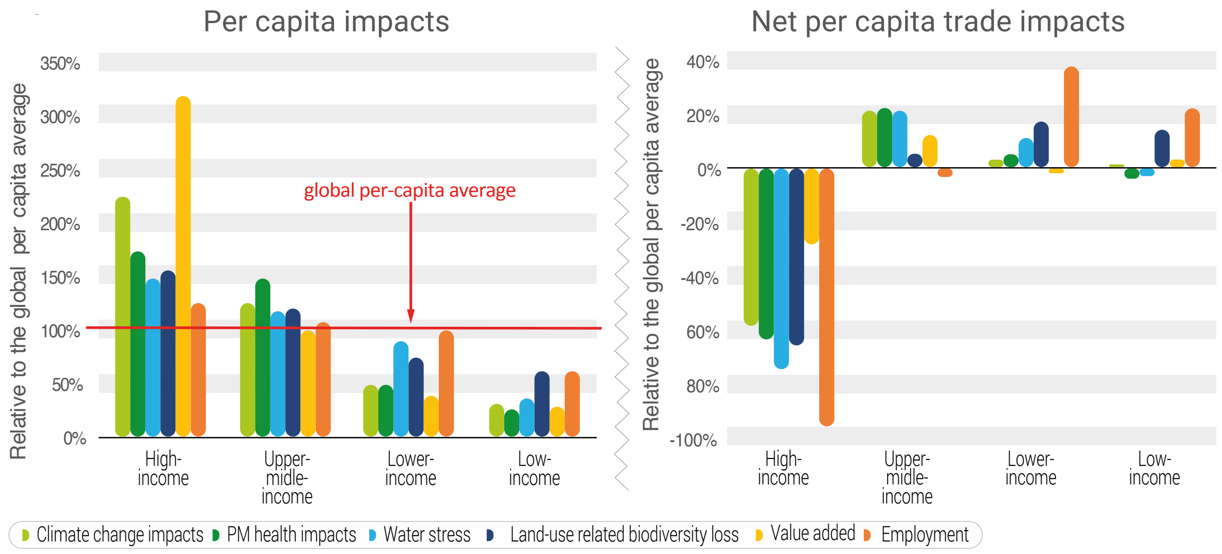
capita impacts increased between 2000 and 2015. In spite of the relative decoupling from economic growth, all impacts increased in absolute terms in comparison to the year 2000 (figure 3.3). The temporal trend of biodiversity impacts from land use has already been discussed in a previous IRP report (IRP, 2017a) and was found to increase on an absolute scale, while the geographical impacts and changes are discussed in section 3.3.6, based on new land use data (chapter 2). The new data did not make it possible to assess the temporal trend, as the land use maps only showed the predominant (not total) land use per grid cell (the uncertainty is larger than the changes in impact).

Resource-related value added per GDP showed an increasing trend between 2009 and 2011 (end of reported data), while all environmental impacts per GDP decreased in this time period (figure 3.3). This is a positive development, as sector specific value-added increased by a greater extent than GDP, and environmental impacts were decoupled (relatively). Nonetheless, resource extraction and processing generate a low share of economy-wide added value (<23 per cent), while providing work to approximately 50 per cent of the global workforce (mainly through agriculture) (figure 3.2). The number of workplaces remained rather constant over time (Figure 3.3), in spite of the increase in resource use, due to increasing labour productivity.

3.2.1 Impacts by Region and the Role of International Trade

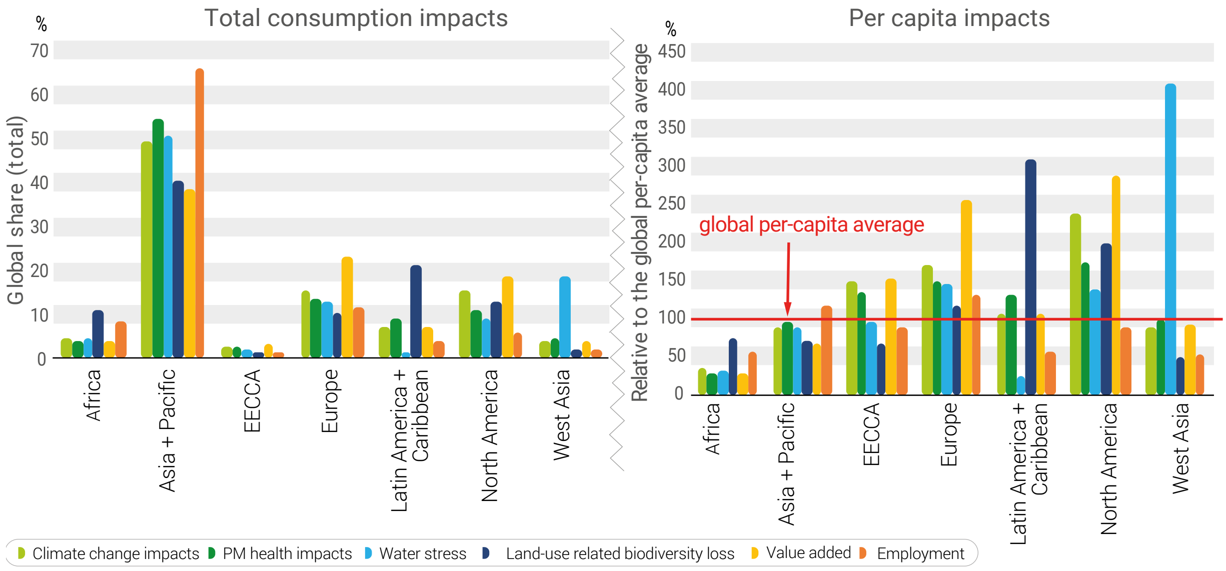
Per capita impacts caused by consumption of high-income countries are between three and six times larger than those of low-income countries (figure 3.4, left). This

FIGURE 3.4 **Left: Per capita impacts (climate change impacts, PM health impacts, water stress, land-use related biodiversity loss) and socio-economic 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.**



Notes: Left: The 100 per cent line marks the global per capita average impact. Right: Negative values refer to an outsourcing of environmental impacts or value/workplace creation to other regions, positive values refer to environmental impacts occurring in the region of the production of export materials. Reference year: 2011
Data source: Exiobase 3.4 (Exiobase, n.d.; Stadler et al., 2018).

FIGURE 3.5 **Impacts (climate change impacts, PM health impacts, water stress, land use-related biodiversity loss) and socio-economic footprints (value added, employment) attributed to the region of consumption**



Left: Total footprints as a share of total global impacts (values for all regions together add up to 100 per cent).
Right: Per capita footprint, where the 100 per cent line marks the global per capita average. Reference year: 2011
Data source: Exiobase 3.4 (Exiobase, n.d.; Stadler et al., 2018).

illustrates the unequal contribution that the consumption of richer and poorer regions make to global environmental impacts. Water and land impacts show a smaller variation between income groups than climate change and PM health impacts. This is because they are mainly related to food consumption, and food intake is less variable than fuel or material use between income groups. Furthermore, high-income regions import resources and materials and outsource environmental impacts from production to middle- and low-income regions (figure 3.4, right).

The total footprints of the world regions vary by more than one order of magnitude, mainly due to the different sizes of regions (figure 3.5 left).[6] Asia and the Pacific has the largest footprints (more than half of the global climate, PM health and water-stress impacts). Climate change and PM health impacts show a similar pattern in regional footprints, while water stress and land use related biodiversity loss diverge from this pattern (figure 3.5). This is mainly caused by the spatial variability of the water and land use impacts of biomass production, which depend on the climate and ecoregion conditions, in addition to production efficiency and consumption.

The per capita footprints show that some regions consistently cause above-average impacts through consumption (Europe and North America), while other regions only have minor per capita consumption-related environmental impacts (particularly Africa) (figure 3.5, right). However, impacts do not always show the same trend. For example, West Asia generally displays below-average consumption impacts, but shows above-average impacts in terms of water stress due to the large-scale domestic irrigation required by the climate and the intensive agricultural activities. A similar, above-average deviation in the impacts applies to land use-related biodiversity loss in Latin America, which is due to the impact of domestic agriculture on valuable ecosystems.

The climate change impacts of most world regions are mainly caused by private consumption (figure 3.6, and annex for PM health impacts), while capital formation plays a small role, either because the infrastructure has already been built up in the past (for example North America and Europe) or because infrastructure has not been fully built up yet (for example Africa). This is different in Asia and the Pacific, where build-up of infrastructure is the main driver of impact (figure 3.6). The latter is caused primarily by recent development in the People's Republic of China. China is the country with the highest resource-related climate change and PM health footprints in the world, although per capita

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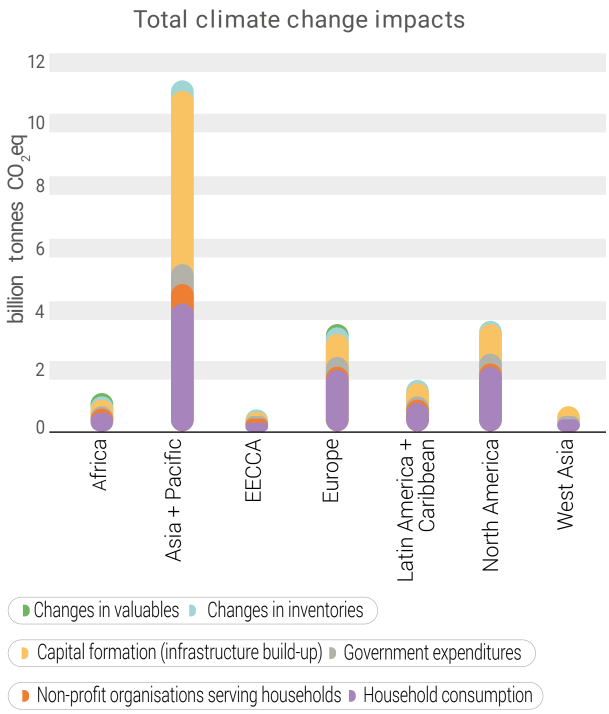
[6] In Chapter 3, Iran is included in West Asia and Mexico is included in North America.

FIGURE 3.6 **Climate change impacts split according to final demand categories.**



Note: Total impact by region (year 2011);
Data source: Exiobase 3.4 (Exiobase, n.d.; Stadler et al., 2018)

impacts are in line with or even below the global average. As of 2011, over 65 per cent of all impacts and 80 per cent of all infrastructure development impacts in the Asia and the Pacific region were contributed by China. The overall footprint for climate and PM health impacts has increased substantially in the past 15 years and can be explained by the buildup of infrastructure, especially as regards climate impacts. This infrastructure build-up represents a long-term investment, and many developing countries are likely to follow this pattern of increased infrastructure investment in the future. Therefore, policy actions are required to maintain the impacts of resource use within planetary boundaries while still allowing for development and build-up of infrastructure in developing and emerging economies.

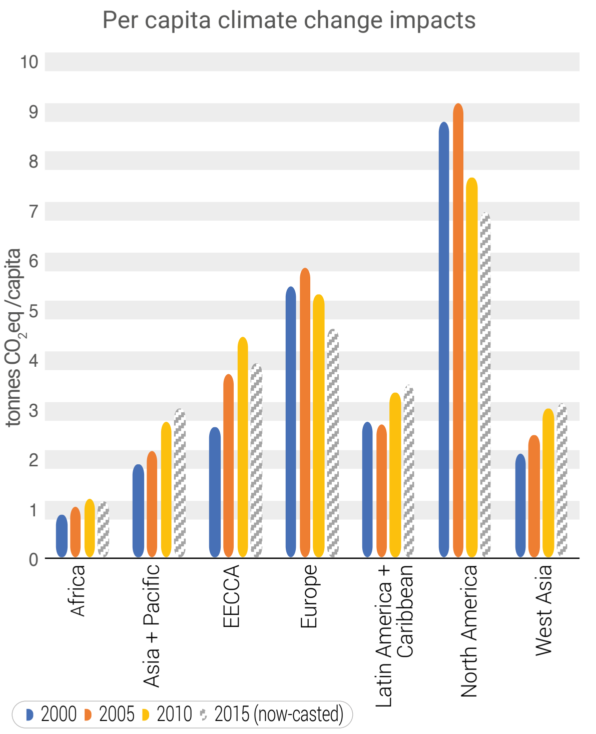
Water stress and land-related biodiversity loss are mainly caused by household food consumption in all regions (see annex), although capital formation can play a significant role in some sub-regions (for example due to wood used to build up infrastructure in the south-east of Asia).

Globally, resource-related climate change footprints associated with consumption converged, with per capita high-footprint regions lowering their impacts at the same time that low-footprint regions increased their impacts. Lower impacts in high-footprint countries suggest efficiency gains in production, but were also affected by the financial crisis and the associated reduced consumption (figure 3.7).

Figure 3.8 provides an overview of the regions that are net exporters or net importers of resource-related environmental pressures and socioeconomic benefits (following the method of Wood et al., 2018). Europe and North America show higher footprints for all impact categories than domestic impacts due to their comparatively higher consumption than production of biomass, metals and particularly fossils (figures 3.8 and 3.9). These regions therefore “outsource” impacts to other regions, while creating only minor economic benefit (in terms of value added) in the countries of origin (figure 3.10).

West Asia and Asia and the Pacific have the largest water-stress impacts, while Latin America and Asia and the Pacific have the largest land use-related impacts, due to their unique ecosystems. For all these regions,

FIGURE 3.7 **Time series of resource-related per capita climate change impacts by region (consumption perspective)**



BOX 3.1 Life Cycle impacts of household consumption (including the use phase of resources)

On an individual country level as well as on a global level, numerous studies have consistently identified three major consumption hotspots that are crucial from an environmental point of view: mobility/transport, food and housing/shelter (for example, see Hertwich & Peters, 2009; Tukker & Jansen, 2006). However, there is considerable variability in behaviours among households from different countries but also within each country. Consequently, the relative scale and absolute amounts of emissions in different consumption areas differ from country to country, as well as among socioeconomic groups. For instance, basic needs such as food or shelter have a relatively higher share of total impacts in lower income countries, while mobility is especially relevant in high-income economies (Hertwich & Peters, 2009). In cross-country comparisons, GDP is considered the most informative explanatory factor for national per capita carbon footprints (Hertwich & Peters, 2009) and material or land use footprints (Ivanova et al., 2016). Similarly, income distribution can explain much of the variability in household environmental footprints within countries (Baiocchi et al., 2010). Many studies show a macrotrend of a positive relationship between income and environmental impacts (Baiocchi et al., 2010; Jones & Kammen, 2014; and Weber & Matthews, 2008). This is also shown by Froemelt et al., 2018, for the case of Switzerland, but they additionally reveal that some household groups diverge from these general tendencies indicating a certain decoupling. Low-impact households in industrialized countries were found to opt for higher priced goods, less mobility and green heating (for example heat pumps or wood-based technologies) (Girod & De Haan, 2009). A relative decoupling effect was also found for the top income quintile in the European Union (Sommer & Kratena, 2017). However, this does not offset the much higher impacts caused by these high-income households.

Apart from income, household size and location (rural versus urban) are often analysed as factors influencing household behaviours and associated environmental impacts (Baiocchi et al., 2010; Hertwich, 2011; Tukker et al., 2010). The economy of scale originating from household size appears in many studies: the larger the household, the lower its per capita footprint. However, at a certain income level, this trend is less pronounced (Froemelt et al., 2018; Underwood & Zahran, 2015; Weber & Matthews, 2008). The influence of household size is especially significant in view of the decreasing number of persons per household in industrialized countries (Underwood & Zahran, 2015). In contrast to household size, the impact of location is less distinct. In general, households in dense urban areas tend to have lower impacts, especially in the domains of mobility (shorter distances) and housing (smaller apartments) (Baiocchi et al., 2010; Tukker et al., 2010; Wiedenhofer et al., 2018). This, however, is partially offset by smaller household sizes and higher incomes in cities (Jones & Kammen, 2014; Wiedenhofer et al., 2018), although the latter greatly depends on the national context (Baiocchi et al., 2010) . Furthermore, Jones & Kammen, 2014 reveal that high-density areas in the United States of America do indeed show lower environmental footprints for households. However, the suburbs around these central metropolitan areas can erode this effect and even lead to increased impacts in the area as a whole. Note that studies seeking to understand these drivers of household environmental footprints focus mostly on high-income countries and may therefore not be applicable to developing economies.

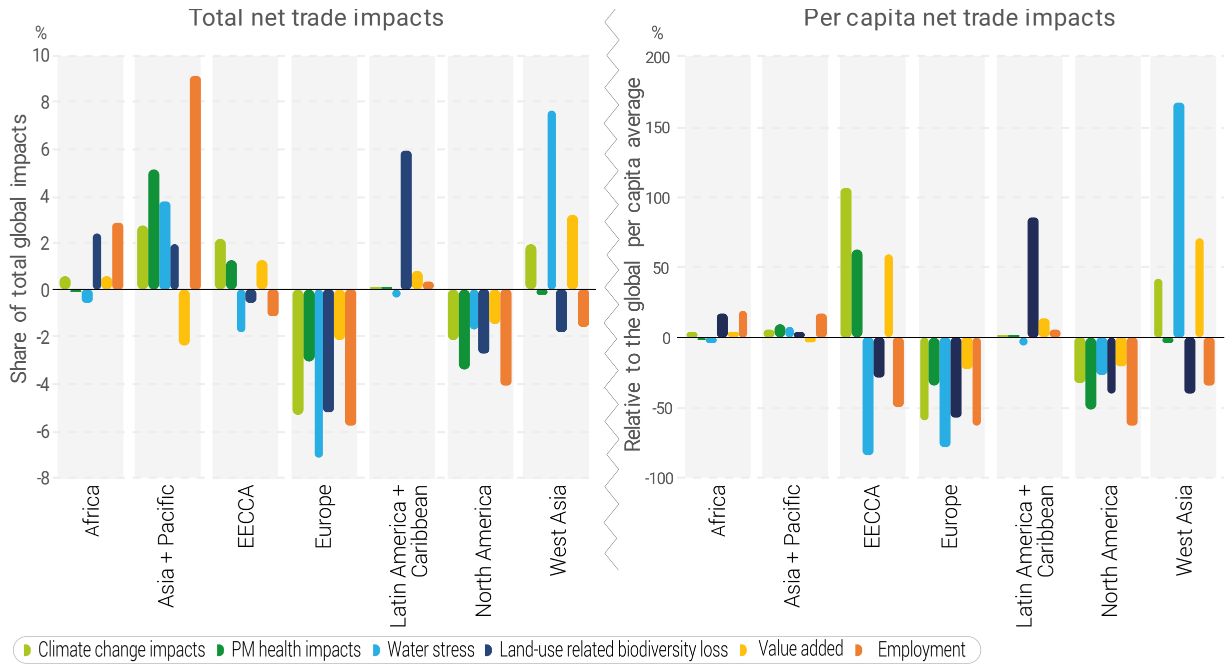
In conclusion, the environmental impacts of different lifestyles are affected by a multitude of factors and therefore show high variability in terms of total amounts and composition, not only among different countries (Hertwich & Peters, 2009; Ivanova et al., 2016) but also among different household types (Baiocchi et al., 2010; Jones & Kammen, 2014) and even within socioeconomic household segments (Froemelt et al., 2018; Saner et al., 2013; Weber & Matthews, 2008). Even though some general trends, such as increased impacts with increased income, or consumption hotspots (like food, mobility and housing) can be identified, this highly complex situation reveals that there is no one-size-fits-all solution to support a pathway towards low-impact consumption patterns (Froemelt et al., 2018; Jones & Kammen, 2014). For a successful change towards more sustainable lifestyles, measures, policies and programmes aiming at reducing the impacts of households should be tailored as much as possible to the target region or even to the target household groups (Froemelt et al., 2018).

the production-related impacts inside the region are higher than the consumption impacts (figure 3.8), due to the export of agricultural products. Europe is the largest beneficiary, as it imports agricultural products from water-scarce regions.

Total resource-related greenhouse gas emissions and PM health impacts are largest in Asia and the Pacific (figure 3.9). Asia and the Pacific, EECCA and West Asia have higher domestic climate impacts than consumption footprints due to their importance in the extraction and processing of fossils (figures 3.8 and 3.9). For PM health impacts, metal processing additionally contributes to this effect in the case of EECCA.

Making the electricity system more renewable (as outlined in SDG 7.2) will lower the climate impact of resource extraction and processing, since greenhouse gas intensity per kWh electricity decreases. However, such a decrease in climate impact will be limited as the

FIGURE 3.8 **Net trade impacts by region, calculated as the difference between production-based and consumption-based footprints**



Notes: Left: Total net trade impacts represented as a share of total global impacts; Right: Per capita net trade impacts relative to the global per capita average impact. Negative values refer to an outsourcing of environmental impacts and socio-economic benefits to other regions, positive values refer to environmental impacts and socio-economic benefits occurring in the region of the production of export materials. Reference year: 2011
Data source: Exiobase 3.4 (Exiobase, n.d.; Stadler et al., 2018)

contribution of electricity inputs to the impacts of resource extraction and processing is already just 10 per cent (data not shown; calculated from Exiobase 3.4). Furthermore, renewable electricity demands more metal and non-metal mineral resources, which will increase the climate impact of resources (IRP, 2017c). The combined impacts of an increased renewable future energy system are discussed in a separate IRP report (UNEP, 2017).

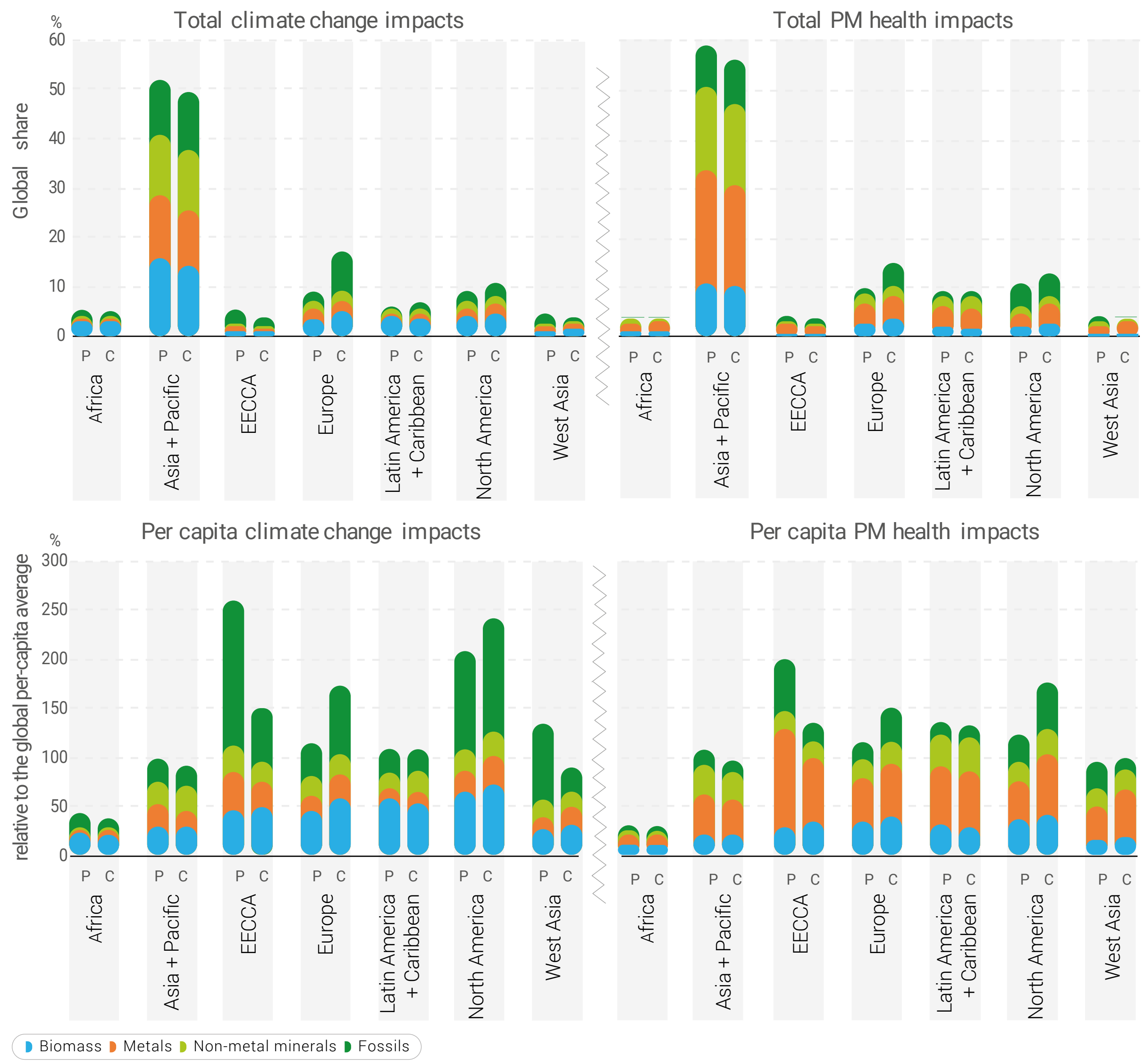
Per-capita added value is largest in Europe and North America (figure 3.10). Europe generates 20 per cent of the global resource-related value added, but only 5 to 10 per cent of the environmental impacts occur there. In contrast, as an example, 24 per cent of the global water stress impacts, 8 per cent of climate change impacts, 7 per cent of PM health impacts and 7 per cent of land use biodiversity impacts arise in India, but only 4 per cent of the resource-related value added is generated there. This inverse pattern of domestic resource-related value added and environmental impacts may be a sign of varying environmental standards, but may also indicate the unequal distribution of resource-related benefits and impacts. This is reinforced by international trade, as discussed above.

There is considerable variation in the dependence of world regions on the resource sector. Employment in the resource sector is especially high in Asia and the Pacific, where more than 40 per cent of all people work in resource extraction and production sectors - mainly in biomass production (figure 3.10). In North America, less than 10 per cent of the population works in this sector. The comparison between the consumption and production perspective shows that many people in Asia and the Pacific or Africa work for the production of resources (mainly biomass) that are consumed in regions such as Europe, North America and West Asia (figure 3.10).

Full, productive employment and decent work is a requirement under SDG 8.5. Figure 3.11 shows the distribution of workplaces, the value added, as well as the salaries (compensation of employment) in the material production sector. There is considerable variability among the world regions in terms of these indicators. While high levels of employment are indeed positive for achieving the SDGs, the work risks (adverse work conditions based on the social hotspot database; see section 3.1 and annex) also need to be considered. For regions with high relative shares of employment compared to value added (such as low- to middle-income regions), these risks are higher than in the regions with a high share of value added compared to occupation. Improved working conditions and increased salaries in the resource sectors of low- and middle-income countries are therefore important steps in achieving the aim of decent work enshrined in SDG 8.5.

Human well-being is often measured by the human development index (HDI), which includes aspects relating to GDP, health and education. Patterns of production-related water and land impacts on subnational administrative units were analysed for various classes of HDI (figure 3.12). Regions with very high human development indices (HDI >0.8) combine just 6 per cent of global population with 50 per cent of GDP, 11 per cent of biodiversity loss due to land use and 8 per cent of global water scarcity. The majority of the impacts occur in regions of HDI 0.6-0.8 (middle to high human development), with 27 per cent of global population, 42 per cent GDP but 63 per cent biodiversity loss and 65 per cent water scarcity (mainly due to biomass cultivation). Many areas with an HDI<0.4 are situated in central Africa, where irrigation is all but absent and biodiversity loss is relatively low. This reflects low economic development in this region.

FIGURE 3.9 **Regional distribution of climate change impacts (left) and particulate matter (PM) health impacts (right) from resource extraction and processing from the production (P) and consumption (C) perspective in 2011**



Notes: Left: Left: total impacts; Right: Per capita impact; P: production perspective, C: consumption perspective.
Data sources: Exiobase 3.4 (Exiobase, n.d.; Stadler et al., 2018)

FIGURE 3.10 **Regional distribution of socio-economic indicators from resource extraction and processing**

Notes: Left: Share of population working in the resource sector (full-time-equivalents per capita); Right: Value added (Euro) P: production perspective, C: consumption perspective. Reference year: 2011.
Data sources: Exiobase 3.4 (Exiobase, n.d.; Stadler et al., 2018)

FIGURE 3.11 **Global share of total value added, value added for compensation of employment (salaries), and number of employed people related to material production**

Notes: Left axis: Values for all regions together add up to 100 per cent; Right axis: Work risks, where a factor of 1 corresponds to the global average (details in annex). Reference year: 2011.

FIGURE 3.12 **Global share of GDP, population and impacts of water stress and land use-related biodiversity loss in the production perspective (Biodiversity Loss Land use)**

Classified by human development (HDI class, x-axis). The impacts were calculated on subnational administrative units based on data from (Kummu et al., 2018) with the same geographies for local HDI, GDP and population data.

3.3 Environmental and Health Impacts by Resource Group

This section opens with a discussion of the contribution of four material resource groups (metals, non-metallic minerals, fossils and biomass) to the environmental impacts of climate change, ecotoxicity, human toxicity and human health impacts from primary and secondary particulate matter emissions (sections 3.3.1 to 3.3.4). The extraction, processing and use of these resources leads to another indirect resource use, namely water consumption and land use. The resulting impacts of water stress and biodiversity loss from land use are extensively discussed at the end of the section (sections 3.3.5 and 3.3.6). Each section contains an in-depth discussion of those resources that contribute most to impacts and have the highest leverage in impact mitigation.

3.3.1 Impacts of Metal Resources

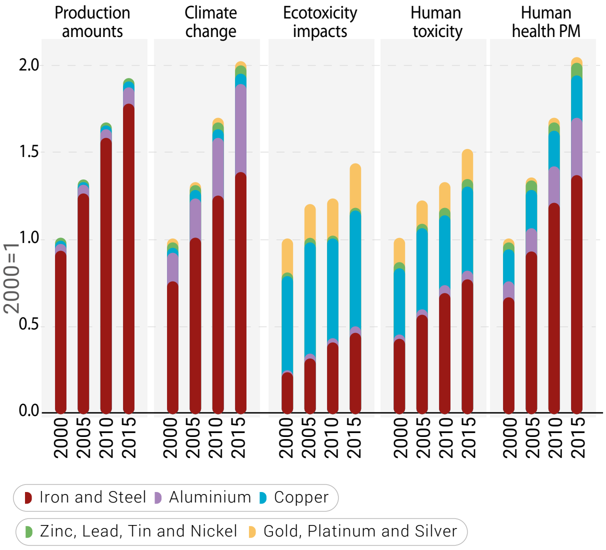
Metals are essential for the kind of technology that underpins modern society. From structures and industrial equipment to information technology, virtually all activities and products rely on metals, at least indirectly. However, the extraction and processing of metals from mined ores have an associated environmental cost. In 2011, metals were responsible for 18 per cent of resource-related climate change and 39 per cent of PM health impacts (figure 3.2). Considering the period 2000-2015, the climate change and PM health impacts of metals more or less doubled. Toxicity impacts also increased in the same time period, but at a slower pace (figure 3.13).

Steel is the most widely used metal, mainly as a construction and engineering material, because of its good mechanical properties and affordability. Among metals, the global iron-steel production chain causes the largest climate change impacts (figure 3.13). This is due to the large volumes of steel produced yearly and the energy-intensive processing of the ore into iron and steel, with the sector representing around one quarter of global industrial energy demand. Further significant contributions to the total climate change impacts of metals arise from aluminium production (figure 3.13), again due to considerable production amounts and high energy requirements for the smelting of aluminium via electrolysis.

The mining and processing of copper and precious metals cause high toxicity impacts compared to their production amounts (figure 3.13). Sulfidic mining tailings are the main source of toxicity impacts for both metals. Processed materials are stored in tailing impoundment dams, but can nevertheless involve continuous leaching of pollutants into the soil and groundwater and might additionally present risks of contamination from spills in case of failure (Beylot & Villeneuve, 2017). The predominant contribution of tailings to toxicity impacts can also be related to the large amounts of rock processed per mass of refined metal. Gold and precious metals are mined at much lower concentrations than bulk metals such as iron or aluminium. As physical separation methods typically require higher ore grades, sodium cyanide compounds have been used for more than a century in the industrial extraction of gold, with an estimated 18 per cent of world cyanide production dedicated to the formal gold mining sector (Hilson & Monhemius, 2006). Since cyanide degrades spontaneously in the environment, the risks associated to its use consist mainly in the sudden release of this pollutant, which can be averted with careful management of waste streams.

Recycling represents one possible pathway towards decreased environmental impacts deriving from metal use. Metals are ideal candidates for closing material

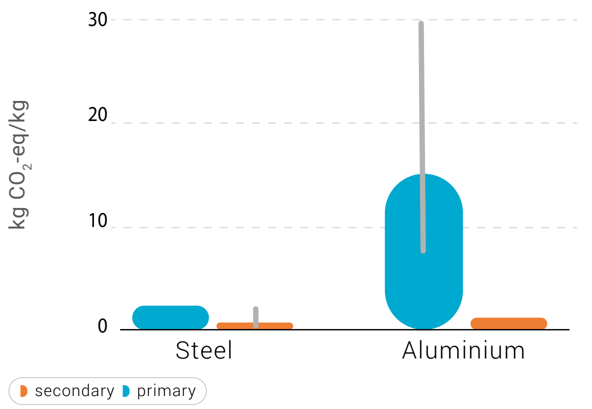
FIGURE 3.13 **Metal production amounts and environmental impacts of metal mining and processing from 2000 to 2015 (selection of 10 metals covering > 95 per cent of global domestic extraction of metal ores in 2015, MFA database).**



Data sources: BGS, USGS, ecoinvent 3.4, World Steel. Note that secondary aluminum was not included for the ecotoxicity score due to a mistake in ecoinvent 3.4.

loops in a circular economy approach, because they can be melted and reused indefinitely (as long as alloys are not contaminated by weakening or toxic elements). In general, secondary production considerably reduces the environmental impacts of metal use, because it avoids the impacts from the extraction and processing of ores. For example, the climate change impacts of steel recycling are between 10 and 38 per cent of that of primary production and for aluminium recycling between 3.5 and 20 per cent (figure 3.14). This variability is mainly explained by the difference in the electricity mixes among countries: the lowest impacts occur in countries with renewable electricity mixes - such as Norway, Iceland and Canada - while India and China display the largest per-kg impacts (see annex). However, metals such as steel are used in many products with long lifetimes (for example in the construction sector), so that the scrap amounts available today for recycling correspond to a share of the production amounts that entered the market many years ago. Taking steel as an example, this characteristic coupled with increasing demand means that the amounts of scrap steel available are unable to match the large global increase in steel demand (figure 3.15). As a result, increase in demand is covered mainly by primary steel, thereby decreasing the overall share of secondary steel. In 2000, electric-arc furnaces (EAF) suitable for secondary steel covered 34 per cent of global crude steel production, while in 2015 this share fell to 25 per cent (World Steel Association, 2017). This trend was most visible in China, which has become the world's top steel producer, and contributed more than half of the sector's greenhouse gas emissions in 2015. Its primary steel production increased more than six times between 2000 and 2015, while the share of EAF decreased from 16 per cent in 2000 to 6 per cent in 2015. This is in contrast to "old economies", such as Europe, where the bulk of the infrastructure was built up a long time ago and both demand and recycling rates are on a steadier trajectory. However, approximately 20 per cent of the Chinese climate change impacts from the iron-steel industry are due to exports to other regions (Exiobase, n.d.; Stadler et al., 2018). Globally, while steel recycling is a good way of lowering the impacts of steel production and recycling should be increased, its overall potential is limited by the availability of scrap. In the context of expanding demand over the medium term, this limitation will remain an important constraint in the coming decades (Van der Voet et al., 2018).

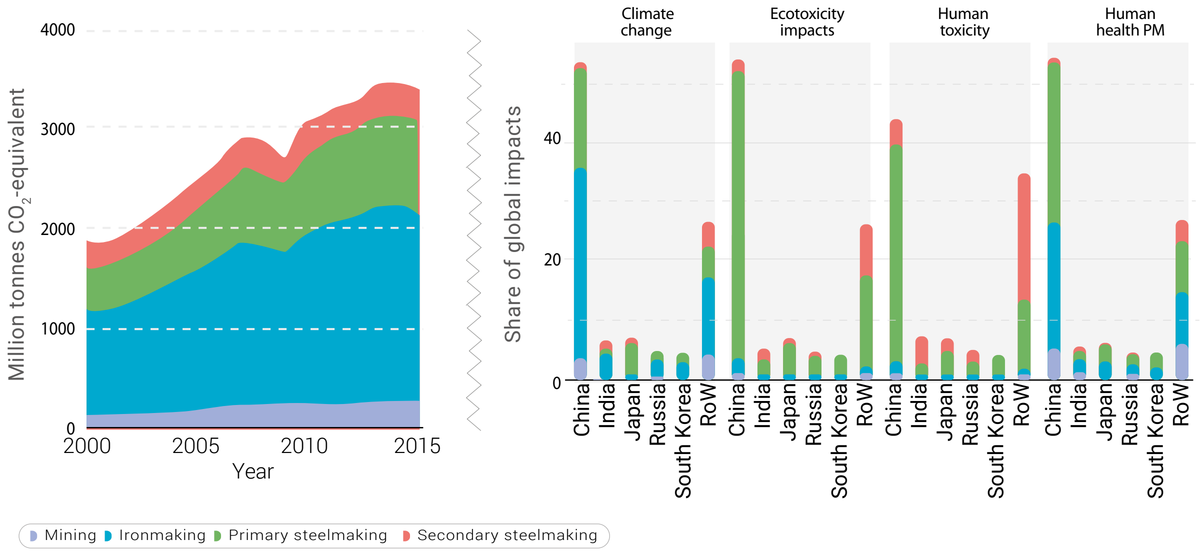
FIGURE 3.14 **Climate change impacts of metal recycling versus primary production**



The uncertainty bar captures the variation in CO2-emissions of electricity mixes of the producing countries (see annex). Country-adapted cradle-to-gate impacts from ecoinvent 3.4.

In the primary production route of steel, the first processing steps account for more impacts than the iron ore extraction phase for all indicators. The overall energy efficiency of iron- and steel-making rose considerably in the last few decades of the 20th century, but plateaued in the course of this century (IEA, 2014; World Steel Association, 2018). Today, blast furnaces are the most widely used technology, but some outdated open-hearth furnace plants still exist. The latter have much larger climate change impacts compared to all other technologies. In a blast furnace, the heat and elemental carbon required to smelt iron from raw materials is primarily provided by the combustion of carbon coke (Hasanbeigi et al., 2014). This process step accounts for most of the climate impacts of the primary steel value chain. Alternatives to the blast furnace production route offering lower carbon intensity exist or are at varying stages of development. Some of these technologies were developed to avoid sinter iron and coke production, for instance relying on the direct reduction of solid iron (DRI) and using non-coking coal or gas as a reducing agent. The potential for using plastic waste as a reducing agent has been tested in some plants that have included this secondary feedstock to partially replace coke or coal in their operations (Vadenbo et al., 2013). While these innovative solutions promise reductions in the climate change impacts of primary steel production, commercial adoption is low (Hasanbeigi et al., 2014). The International Energy Agency estimates that the energy intensity of iron and steel production can still

FIGURE 3.15 **Impacts of the iron- and steelmaking sector (primary and recycled steel)**



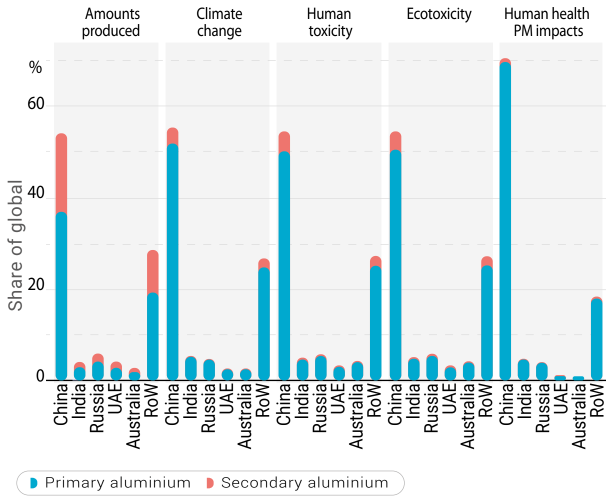
Notes: Left: Temporal evolution of global greenhouse gas emission;. Right: Distribution of impacts (reference year 2015). The top 5 countries in terms of impacts are shown and the remaining regions are summarized in the category RoW (rest of world).
Data sources: BGS, global MFA database, ecoinvent 3.4, World Steel.

be lowered by 20 per cent compared to the current status if best available technology (BAT) is applied (IEA, 2014). Based on the Energy Technology Perspectives 2014 of the International Energy Agency (IEA, 2014), the Science Based Targets Initiative (Pineda et al., 2015) quantified the total CO$_2$ emission budget between 2011 and 2050 for the iron and steel sector to be 112 Gt CO$_2$, in order to stay within the safe operating space for climate change. Considering that global steel demand is projected to increase (IEA, 2014), such an absolute reduction in climate change impacts is a challenge.

Following steel, aluminium production is the metal industry with highest climate change impacts on the global scale. Most of the impacts come from the energy consumption of fuel and electricity, which are the respective drivers of the refining bauxite ore into alumina and of the subsequent smelting of aluminium via electrolysis. In 2017, average energy intensity for alumina refining and aluminium smelting were 23 per cent and 8 per cent lower than in 2000, respectively (International Aluminium Institute, 2018). Further energy savings of around 10 per cent are still possible on a global scale by phasing out outdated production facilities and adopting the best available technology. This point has been demonstrated by China in the last couple of decades, where production capacity has rapidly increased, providing the opportunity to install the newest technology and enabling the country to be at the forefront of aluminium smelting energy efficiency, with around 4 per cent lower electricity intensity compared to the global average (International Aluminium Institute, 2018). On the other hand, climate change and PM health impacts of aluminium production are highest in China because of the large amounts produced (54 per cent of global primary production in 2015 (International Aluminium Institute, 2018), but also due to the large carbon intensity of the electricity mix, which relies heavily on coal power.

For metals where the key input is electricity, such as primary aluminium and secondary steel, a shift towards an electricity mix with a higher share of renewables and a lower share of fossil fuels (in accordance with the Paris Agreement) will also favourably influence the impact. Moreover, if future growth in aluminium demand slows down, recycling can cover increasing shares of production (Van der Voet et al., 2018)· which may substantially reduce the impact of metal production. Since recycled aluminium is currently the main form used in certain applications (mainly motor engines) and does not meet the quality standards of many other applications due to alloying elements, concerns have been raised that there may even be a scrap surplus in the coming decade if aluminium scrap continues to be processed as a mixed fraction (Modaresi & Müller, 2012). This scenario of a scrap surplus may be unlikely as other uses for low-grade aluminium may be found (replacement of other materials),

FIGURE 3.16 **Share of global production amounts and environmental impacts of the aluminium production chain**



Coupling data from BGS/global MFA database with regionalized ecoinvent 3.4 background data; reference year 2015

but these substitutions may result in fewer benefits than the substitution of primary aluminium. Therefore, attention should be paid to better sorting of scrap materials (Modaresi & Müller, 2012), with a view to producing high-quality secondary metals that can substitute the same primary metals.

While the above discussion refers to the industrial production of metals, there are also informal small-scale activities, especially in the mining sector in developing countries, which do not necessarily meet the technology standards assumed in the above figures. One of the most prominent examples is gold mining. To date, elemental mercury is still frequently used in (informal) artisanal and small-scale gold mining (ASGM) to extract gold (WHO, 2016). Artisanal and small-scale gold mining is estimated to be the largest anthropogenic source of mercury emissions, contributing approximately 37 per cent of the annual emissions in 2010 (AMAP/UNEP, 2013), and with an upward trend displayed in recent years (1,000 tons of mercury in 2008 versus 1320 tons or more in 2011 (Seccatore et al., 2014)). Recent estimates show that about 16 million miners (including around 4 to 5 million women and children) in over 70 countries, (mainly South America, Africa and Asia) may be directly affected by mercury exposure in ASGM (Pirrone & Mason, 2009; WHO, 2016). Such exposure may cause various health issues including kidney dysfunction, neurological disorders/symptoms and immunotoxicity/autoimmune dysfunction (Gibb & Leary, 2014; WHO, 2016), with the global burden of disease associated with ASGM miners estimated to be 1.22 to 2.39 million DALYs (Steckling et al., 2017). In addition to miners, their families as well as nearby and downstream communities may also be severely exposed to mercury via inhalation and/or ingestion of contaminated food items. As a response to the global concern over mercury, governments adopted the Minamata Convention in 2013, including objectives to reduce, and where feasible eliminate, the use of mercury in ASGM (Minamata Convention on Mercury, 2009).

Many alternative methods have been developed and are available on the market. For example, using “concentrate” amalgamation instead of “whole ore” amalgamation may reduce the use of mercury by a factor of up to 50 per unit of gold recovered (Ban Toxics!, 2010; Sousa et al., 2010; WHO, 2016). In addition, mercury in ASGM only yields about 20 to 30 per cent efficiency in recovering gold compared to 60 to 90 per cent from other methods (GEF, 2017). Therefore, miners have a financial incentive to switch, besides protecting their health. However, the sector’s general informality is one of the root causes of mercury use, and results in difficulties for the miners to apply alternative methods (GEF, 2017): (1) miners often do not know about the alternatives; and (2) they have difficulty in accessing capital to finance the initial investments for switching to alternative methods. Formalizing the sector and supporting miners with knowledge, training and capital (for instance through micro-loans or income from higher prices of certified gold) may be promising actions in the combat against mercury emissions.

3.3.1 Impacts of Non-Metallic Minerals

Although non-metallic mineral resource extraction makes up more than 45 per cent of the total mass of extracted resources and displays one of the highest growth rates of all resource groups (figure 2.7 in chapter 2), its contribution in terms of impacts to climate change and other impact categories remains limited (<2 per cent of the total resource impacts, figure 3.2, bottom). The majority of impacts of non-metallic minerals come from the processing stage, particularly from the production of cement and fertilizers (figure 3.17) (which are discussed in detail below). Extraction impacts are distributed among many different mineral resources. The main non-metallic minerals in terms of mass, namely sand/gravel and limestone, are of minor importance in terms of environmental impacts.

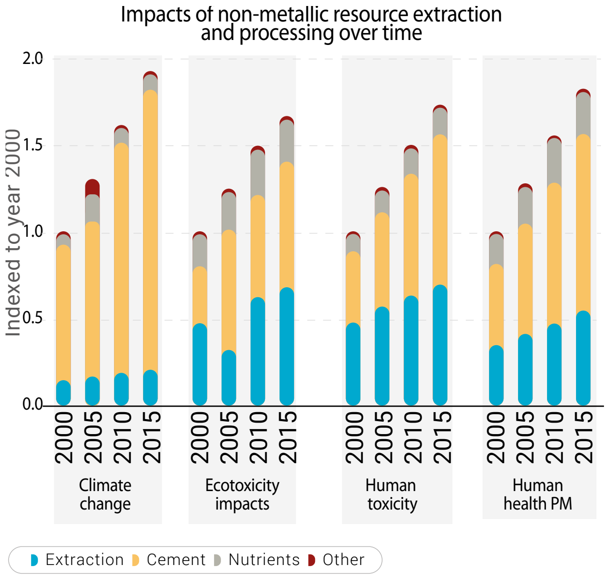
Nevertheless, mining activities may have local impacts on ecosystems. In particular, sand is mined in large amounts from rivers and marine sources, causing damages to local ecosystems. This is mainly a consequence of bad management practice, which calls for the attention of policymakers. Using land-based sand mines (as long as not from living riverbeds) or mining rock and crushing it to gravel and sand are viable options for many countries (the additional energy demand for crushing stone is small in comparison to the total impact of non-metallic minerals).

Climate change impacts and PM health impacts increased with the mass of minerals extracted over time and were mainly spearheaded by cement production (figure 3.17). By contrast, the increase in toxicity impacts is smaller than the mass increase. In addition to cement, emissions from the application of phosphorus fertilizer are also relevant for toxicity (discussed in the box later in this section). Nitrogen fertilizers were not included in figure 3.17 (only phosphorus and potassium nutrients used as fertilizer or as feedstock), because nitrogen fertilizers are not produced from mineral resources but from nitrogen in air. However, note that the production of nitrogen fertilizers is energy intensive, consuming fossil resources, and would contribute more than 15 per cent to the total of each impact category shown in figure 3.17. Other neglected processes include the production of glass and ceramics (adding approximately 10 per cent to the total climate change impacts in Figure 3.17) and the processing of building stone.

The production of clinker, the main ingredient of cement, is responsible for the greatest share of climate change impact and a substantial (> 40 per cent) share of the other impacts (figure 3.17). Greenhouse gas emissions are primarily due to the direct release of CO_2 in the process of decarbonation of the raw material during calcination in the clinker kiln, and secondly due to the use of fuels to cover the high heat demand necessary for the calcination process.

Similar to the impacts of steel and aluminium, the biggest shares of cement impacts occur in China and India (> 50 per cent and 13 per cent of global production in 2015, respectively; see annex for data), due to the large build-up of infrastructure in the past several decades.

FIGURE 3.17 **Development of impacts from non-metallic minerals extraction and processing (values from 2000 indexed to 1)**



Calculations based on data from IRP MFA database, WBSCD, FAOSTAT, ecoinvent 3.4 (processing impacts include cement, fertilizer and brick production; glass and ceramics production were disregarded).

Since energy inputs represent roughly one third of the total production costs of cement, economic incentives have fostered early innovation in clinker kiln technology. Thermal efficiency has greatly improved in the last decades, thereby reducing the greenhouse gas emissions per kg of clinker. For instance, the heat demand of a modern precalciner kiln is only half of the heat demand of the now outdated, long-wet kiln technology. As the technology reaches a state of maturity, the thermal requirements of modern kilns have plateaued in recent years and the adoption of efficient kiln technology stands at over 85 per cent of current installed capacity. While this is good news, it also means that the potential for further thermal efficiency gains is limited.

Another area for improvement of clinker production lies in the substitution of primary fuels and raw materials for waste materials. As part of the “Getting the Numbers Right” Project, the World Business Council for Sustainable Development (20 per cent coverage of global cement production) found that alternative fuels, biomass and mixed waste increased from a global share of 4 per cent of the heat demand of clinker kilns in 2000 to 15 per cent in 2015 (WBCSD, n.d.). Further increases can realistically be expected (IEA, 2018). Clinker production can accommodate alternative fuels and raw materials substituting primary fuels (such as coal or other fossil fuels) and raw materials (such as limestone), as long as requirements concerning chemical composition and heat demand are met. In most cases, the co-processing of waste materials (old tires, solvents and so forth) lowers the climate change impacts and, depending on the waste material and its introduction in the combustion process, may further decrease or increase other impacts, such as toxicity effects from airborne emissions. For example, clinker kilns can represent a viable way to treat organically polluted waste fuels because organics are destroyed due to the high kiln temperature. This is highly valuable, particularly in countries without proper dedicated infrastructure to treat hazardous waste. By contrast, waste raw materials such as organically contaminated soil are otherwise introduced at the "cold end" of the kiln and may be volatilized before they reach the hot zones, forming dioxin emissions. A careful evaluation of the types of waste materials to be co-processed is therefore necessary in the light of the kiln technology, the entrance point in the kiln and the gas purification system.

The increased demand for cement has overcompensated the reductions of greenhouse gas emissions per kg of clinker, leading to an absolute increase in overall impact (figure 3.17). Therefore, additional changes are necessary to decouple environmental impacts from economic growth. While improvements in the clinker production process are constrained by the fact that over half of the CO_2-emissions come from the unavoidable calcination emissions of the raw material, the use of sustainable construction materials and an improved design could also represent important technology innovation pathways in the near and medium term. Often, a portion of clinker is substituted with other materials that have lower environmental impacts, like industrial by-products or waste materials (such as ash from coal power plants and blast furnace slag). Another option is to reduce the volume of concrete needed for a given construction process by using high-performance concretes (see, for example, Habert & Roussel, 2009).

Although these strategies can help the cement industry meet the near- and medium-term CO_2 emission reduction objectives, worldwide demand for concrete is expected to continue rising and at least partially offset the gains in CO_2 intensity (WBCSD, 2018). Moreover, despite best efforts and technology, the fact that a large share of the CO_2 emissions is related to calcination means that these associated emissions cannot be avoided. This is why the greatest share of future greenhouse gas savings is expected to come from installing carbon capture and storage, followed by a reduction of the clinker content in materials (IEA, 2018). Initial results have shown that a CO_2 capture rate of 90 per cent is technically feasible with currently available technology, but it is also estimated to increase electricity demand (Cembureau, 2018).

Advances in materials can be combined with innovative production methods and technologies such as digital fabrication and construction. Concrete and steel can also be substituted with cross-laminated timber in the construction of mid-rise buildings. Furthermore, while the recycling of construction materials usually constitutes downcycling with little environmental benefit, this could change in the future if direct reuse of building components is introduced. Finally, urbanization design plays a key role in material demand for infrastructure. "Strategic intensification", as recommended in the IRP report (IRP, 2018c) can reduce material demand by establishing a "well-articulated networked hierarchy of high-density nodes that are interconnected", densifying cities and providing services to citizens at short distances, reducing mobility demand.

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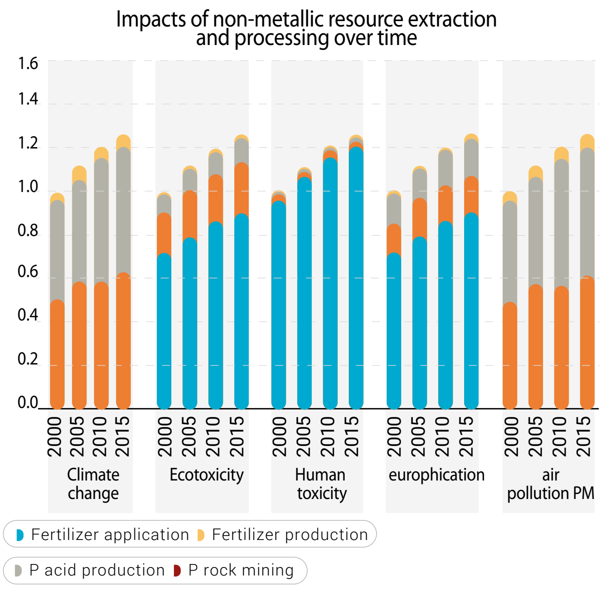
BOX 3.2 Cradle-to-grave assessment of phosphorus fertilizer

Fertilizer minerals play an important role in the context of global food security (IFA, 2002). In the case of phosphorus, a large proportion of globally applied fertilizer originates from phosphate rock resources. The main producing countries are the People's Republic of China, Morocco and Western Sahara, the United States of America and the Russian Federation (80 per cent of the total globally produced phosphate rock in 2015) (USGS, 2017). Initially alarming studies suggesting an upcoming phosphorus shortage and a threat to the global food supply have been put into perspective by a reclassification of phosphate reserves (USGS, 2012). Nonetheless, from an environmental viewpoint, it is vital to consider resource quality and the management of phosphorus resources.

FIGURE 3.18 **Environmental impact of phosphate fertilizers (mining, fertilizer production and application)**



Cradle-to-grave analysis, based on updated ecoinvent 3.3 data (values from 2000 indexed to 1). Phosphate fertilizers included are diammonium phosphate (DAP), monoammonium phosphate (MAP), triple superphosphate (TSP), single superphosphate (SSP) and P fertilizers not elsewhere covered (P nec), based on (FAO, 2018); (FAO and World Bank, 2018).

Figure 3.18 shows a cradle-to-grave analysis of the global production and application of phosphate fertilizers involving phosphate rock mining, phosphoric acid production, fertilizer production and fertilizer application on agricultural fields. Climate change and particulate matter impacts result mainly from the production phase of fertilizer. Eco- and human toxicity effects are primarily caused by the contaminants in the fertilizer such as cadmium, uranium, chromium and other heavy metals. Application of contaminated phosphate fertilizers can lead to long-term accumulation of these metals in soil systems, where they may impact soil health and fertility, be taken up by crops or leach into water bodies (Kratz et al., 2016). Contaminants in the phosphate rock, such as heavy metals and radioactive substances, often end up in manufactured mineral fertilizers, while cleaner resources are mostly used as feedstock in the chemical industry. Improving the quality of applied fertilizer and reducing the application rate in countries with current over-fertilization are key to lowering the environmental impact. Pollutant thresholds for mineral fertilizers could be a suitable way of improving fertilizer quality. Resource-quality considerations (especially for cadmium and uranium) should also play a key role in future phosphorus mining activities. Contaminated production residues, such as phosphogypsum, are an additional source of environmental impacts (Tayibi et al., 2009). They are mainly disposed of in large stacks, where wind erosion and groundwater leaching may spread contaminants, or they are directly discarded in rivers or the sea. Moreover, fertilizer production requires numerous chemicals and has high material and energy needs.

Over-fertilization in agriculture causes eutrophication of rivers and lakes through runoff and leaching. Erosion is affected by land use change and agricultural management practices, but its eutrophying effects depend largely on the phosphorus content in the soil, which is increased through fertilizer applications. These human causes are often combined, and it is therefore difficult to separate the two effects. Phosphorus concentrations build up especially in agricultural areas that have been intensively managed for long periods. As a result, past fertilization leads to eutrophication through current erosion, which depends on current management practices (Scherer & Pfister, 2015).

Table 3.1 summarizes the indices of phosphorus fertilizer use and related eutrophication impacts on a regional scale (FAO, 2018; FAO and World Bank, 2018; Scherer & Pfister, 2016a). Results show that the relative eutrophication impact tends to be higher in developed and emerging economies (higher application rates), as well as in regions with vulnerable climate, soils and ecosystems such as the tropics. Latin America and the Caribbean and Asia and the Pacific show the biggest regional overall eutrophication impact of fertilizer application (table 3.1).

Both eutrophication and toxicity impacts could be lowered by avoiding over-fertilization. The high relative impact in Latin America results from the vulnerable ecosystems and high application rates. By contrast, in Sub-Saharan Africa soil nutrient depletion (or lack of fertilizers) is common (Sutton et al., 2013)· and yields could be increased by appropriate fertilization. Future projections point to a major increase in fertilizer use due to population growth. Increasing urbanization may additionally lead to nutrient flows far away from production areas and may thus limit reuse and recycling options (UNEP, 2016a).

TABLE 31 **Indices of phosphate fertilizer application and related eutrophication effects. The relative impact shows the magnitude of aquatic species loss per area of arable land (Azevedo et al., 2014; FAO, 2018; FAO and World Bank, 2018). Highest value per index is in bold. PDF: potentially damaged fraction of species (regional species loss). CF: impact assessment characterization factor**

REGION	APPLICATION RATE	AREA OF ARABLE LAND	APPLIED AMOUNT	CF FOR SOIL EMISSIONS	RELATIVE IMPACT
	[KG P2O5/HA]	[HA]	[T P2O5/YR]	[PDF/KG P2O5]	[PDF/HA]
Africa	4.34	227'982'370	988'628	2.79E-13	1.33E-12
Asia and the Pacific	51.44	478'296'130	24'604'563	2.12E-13	8.51E-12
EECAA	4.83	124'872'800	603'660	4.98E-14	2.31E-13
Europe	18.03	169'859'620	3'062'363	5.00E-14	9.89E-13
Latin America and the Caribbean	33.89	166'857'520	5'654'719	3.84E-13	1.20E-11
North America	23.14	194'637'300	4'503'709	9.00E-14	2.20E-12
West Asia	24.28	32'005'710	777'105	8.72E-14	1.36E-12

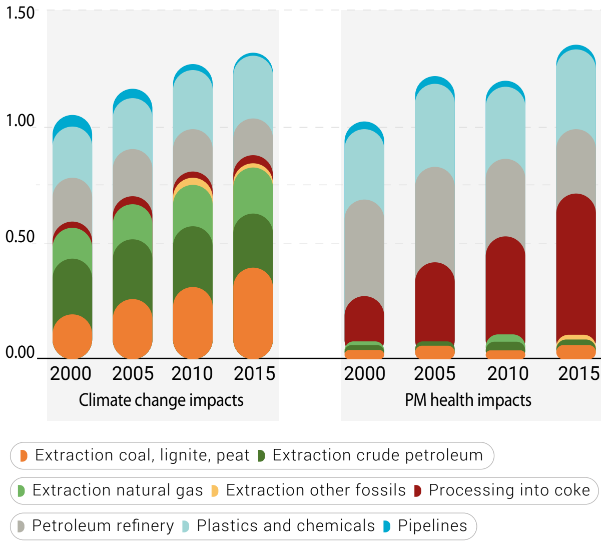
Regarding innovation, technologies exist to purify phosphogypsum and therefore to enable it to be used (for example in the building sector) instead of being disposed of. However these are mostly not yet economical (Tayibi et al., 2009). Potential alternative sources, such as phosphate seabed mining (which is on an advanced planning stage in Namibia and South Africa) could lead to unknown damage in the marine ecosystem. Technologies that recover phosphorus from sewage sludge (ash) are being developed (Egle et al., 2016). Some of these technologies produce fertilizer that is cleaner than conventional mineral fertilizer and saves the extraction of primary phosphorus resources at the same time (Mehr & Hellweg, 2018). Other measures include the recycling of organic wastes by anaerobic digestion or composting, in a circular economy approach, which is already currently practiced around the world (while retaining large upscaling potential). Depending on the wastewater infrastructure, urine separation could be a another way to recycle phosphorus for agricultural uses (Wu et al., 2016). Finally, many countries have made improvements in fertilization efficiency, leading to lower application rates and less eutrophication and ecotoxicity impacts without a reduction in yields. Precision agriculture is likely to further improve agronomic phosphorus efficiency in the future (Iho & Laukkanen, 2012; Mallarino & Schepers, 2005).

3.3.2 Impacts of Fossil Resources

Coal, oil and natural gas provide various forms of energy while also constituting the raw materials for numerous chemicals like pharmaceuticals, plastics, paints and many more. Extraction, processing, distribution and use are all major contributors to environmental pollution - especially in air.

A key pollutant in the extraction of fossil fuels is methane, as it contributes to climate change impacts. Coal extraction has particularly large impacts (figure 3.19), and is therefore discussed in more detail below. Generally, larger amounts of methane are bound in coal at greater depths, so underground mining releases more coalbed methane than open cast mining. Underground methane is vented to prevent the formation of explosive methane-air mixtures, but still causes human casualties throughout the world. In addition to flaring methane and converting it to CO_2, recent technological advances enable methane to be captured and fed into local natural gas networks or used in gas turbines to supply mining equipment with electricity.

FIGURE 3.19 **Climate change and PM health impacts of fossil resource extraction and processing**



From Exiobase 3.4 (Exiobase, n.d.; Stadler et al., 2018). Impacts of the year 2000 indexed to 1.

Polluting dust emissions occur from coal mining activities such as digging, blasting, coal handling and stockpiling, but also from increased wind erosion. This is relevant for underground and open-pit mining. The resulting emissions represent a health risk to workers and residents due to fine particulate matter release. Wet dust suppression and agglomerating agents are applied to the coal to reduce these emissions. Coal handling and stockpiling is increasingly taking place inside enclosures, which also helps to prevent leaching, keep coal dry and reduce noise pollution. In comparison to the particulate emissions from coal power plants, the share of health impacts from these emissions is small (figure 3.20), but may still have major local effects.

Crude oil and natural gas are recovered from deep wells. Moreover, unconventional extraction methods like shale oil and shale gas production (as well as production from oil sands) have gained interest in recent years due to technological innovation and the decline of conventional reserves. Overall, the total greenhouse gas emissions for oil and gas are in a similar range to that of coal extraction and processing impacts (figure 3.19). Mostly, they arise from venting, flaring and local energy supply, as well as from leaks and other sources of fugitive emissions (IPCC, 2006). Mercury is released into the environment during oil and gas extraction with wastewater and solid waste streams. These emissions are judged to be major sources of mercury contamination in oceans but currently lack quantification (AMAP/UNEP, 2013). Additionally, some of the mercury is separated after the extraction of fossil fuels and then released to the environment during artisanal and small-scale gold mining (see section 3.3.1). Environmental impacts from extraction of fossil fuels may also come from the release of other toxic compounds (such as those in drilling fluids) to air, soil and water bodies, as well as from seismic surveys and the construction of extraction infrastructure like ocean-floor pipelines.

The recent increase in unconventional oil and gas extraction in North America has brought additional environmental challenges that have not yet been fully quantified. Unconventional oil extraction, such as from shale or tar sands, is found to be on the higher end of greenhouse gas emissions in comparison to conventional deep-well extraction (IHS Energy, 2014). Natural gas fracking from shale may lead to gas leakage and methane migration into drinking water reservoirs. Additionally, the injected slickwater (a solution of water and chemicals) for enhanced recovery may reach upper layers of the earth and local aquifers, as well as consuming large amounts of water. Concerns about biodiversity loss from surface mining of tar sands have also been raised (Rooney et al., 2012).

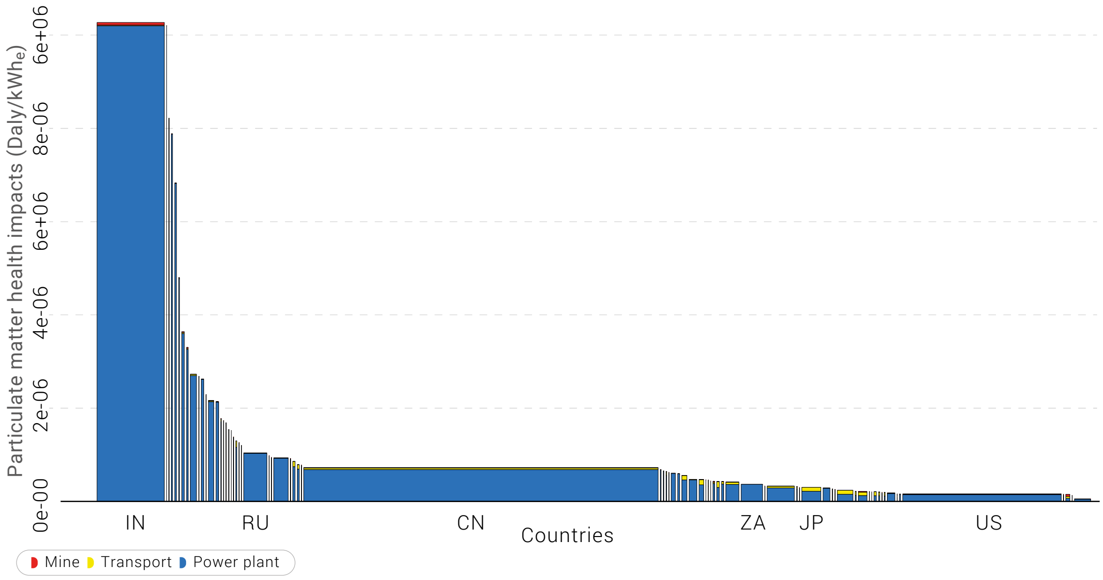
The most impactful fossil processing step in terms of climate change impacts is the refining of crude oil into useful products (such as chemicals and fuels) (figure 3.19), primarily due to the large heat demand of this process. A key for human health effects and environmental impacts of acidification is the removal of sulfur from crude oil, which may cause acid rain and health effects from particulate matter formation during fuel combustion. A current technical challenge for global refineries is the new regulation on heavy fuel oil combustion for ships that will force refiners to produce ship fuel with 0.5 per cent sulfur by 2020, instead of the current level of 3.5 per cent. Several technical alternatives are being discussed to either produce compliant ship fuel or shift production to other products.

Fossil fuels, and coal in particular, are the main goods involved in global freight transport (UNCTAD, 2017). Global transportation of coal via ocean vessels has become more significant in recent years. The resulting environmental impacts are limited on the global scale but can be substantial on the local scale: for example, 28 per cent of Japanese coal particulate matter health impacts come from transport (figure 3.20). Improvements of related pollution impacts can be achieved with larger, more efficient ships and cleaner fuel. In addition to ship transport, oil and gas are distributed by pipelines, which can be problematic when causing fugitive emissions or spills. Maintenance, especially in remote regions, is essential to avoid leakages. Altogether, pipelines cause 3 per cent of the total greenhouse gas emissions from fossil fuel extraction and processing (figure 3.19), due to the energy demand for pumps and compressors and their fugitive emissions (particularly methane).

BOX 3.3 Use phase emissions and impacts of fossil fuel combustion

Environmental and health impacts from the final use of fossil fuels play a crucial role in their life cycle. These impacts depend on the extracted resource quality, intermediate processing steps and the location of emissions, in addition to technical measures (for example flue gas cleaning equipment). Any mitigation actions must therefore consider the entire life cycle. Fuel properties vary largely (see coal in figure 3.21), and pollution therefore differs just as widely. For example, sulfur in fuel is converted into acidic SO_2, and nitrogen is converted into NOx (fuel NOx). Both these air emissions act as precursors of secondary particulate matter, which leads to human health impacts, as well as causing terrestrial acidification. In the case of coal, part of the coal ash forms particulate matter and leaves the boiler with the flue gases. Coal washing and coking, typically applied to coal for the steel industry, remove impurities (for example sulfur), do prevent subsequent pollutant emissions in the use phase but come with trade-offs, such as increased energy demand and related emissions. Additionally, some power plants use the impure washing rejects and other waste coal (gangue), thereby simply shifting the point of emission to power plants near mines without leading to a total net reduction in pollution.

FIGURE 3.20 **Health impacts from primary and secondary particulate matter from coal electricity generation**

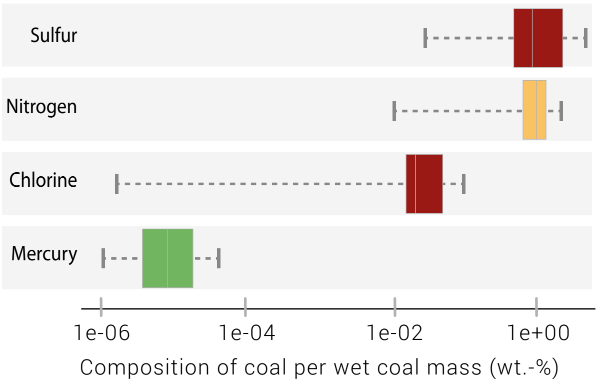


The x-axis shows the electricity generation, with the width of bars being proportional to the kWh of coal electricity generated within each country. The y-axis shows the average health impacts caused by the coal power production of each country related to electricity from coal power plants (in DALY/kWh). The area of the bars is proportional to total particulate matter health impacts from each country. Reference year: 2012. Regionalized health impacts were calculated with (Verones et al., 2016). Emissions of closed mines and spontaneous coal fires were not included due to lack of data.

Coal contributes 35 per cent to the anthropogenic emissions of mercury (Pirrone et al., 2010). There is large variation in the mercury share within raw coal composition (figure 3.21), and emissions can thus be prevented by sourcing coal with a low mercury content. Once released, mercury reversibly cycles between its different forms (two oxidation states and various organic forms, of which methylmercury is particularly toxic) and between environmental compartments globally. Post-combustion flue gas treatment eliminates considerable fractions of all forms of mercury pollutants, but health impacts from the fossil fuel use phase remain the highest in the entire supply chain (even in countries with modern flue gas cleaning systems) (figure 3.20).

Pollution prevention from fossil fuels is largely driven by environmental legislation (Lecomte et al., 2017). In the past few years, there have been major reductions of allowable emission concentrations in China and India, which are now two of the countries with the world's strictest emission limits. However, these emission limits are sometimes only applied to the newest plants (commonly the case in the United States of America and India), which may discourage innovation and modernization. In contrast, the Chinese government completely overhauled its electricity generation sector within one decade by shutting down old power plants and coal mines and replacing them with state-of-the-art ones. Furthermore, China equipped all its power plants with real-time monitoring devices to trace sources of pollution. Urban PM concentrations in China have dropped by 32 per cent in the last four years (Greenstone, 2018), but remain high due to the large amounts of coal used.

FIGURE 3.21 **Distribution of key constituents of coal from 1464 global coal samples (Finkelman, 1999)**



The boxes show the median as well as the lower and upper quartile, and the whiskers indicate the highest/ lowest datum within 1.5 times the interquartile range (Tukey boxplot; log-scale). Outliers are not shown.

Similar improvements would be possible in India, where power plants are often old and use outdated and incomplete flue gas treatment. This is particularly urgent as the population density in India is very high, meaning there is high exposure. An effective way to avoid placing unnecessary burdens on plant operators can be to adapt emission thresholds for pollutants with mostly local effects based on the surrounding population, such as in the case of SO_2 in Japan, where emission limits are based on population densities for 19 different regions.

While there have been improvements in fossil power plant emission standards throughout the world, there has also been a dramatic increase in fossil electricity generation capacity in recent years, which contributes to increased access to affordable energy but has environmental and health trade-offs. Globally, the capacity increased by 73 per cent from 2000 to 2015, with even higher increases in certain regions of the world (Lecomte et al., 2017). Due to high capital costs and long power plant lifetimes (sometimes exceeding 50 years), this poses the threat of a “lock-in” to environmentally harmful technologies. The construction of the least efficient subcritical coal power plants, which still make up the major share of new installations, has to be stopped to avoid compromising the achievement of global climate goals (World Steel Association, 2018), in line with SDG targets 7.3 and 7.a. Carbon capture and storage (CCS) is being discussed as an intermediate way to force the reduction of CO_2 emissions from fossil fuel combustion, but comes with efficiency losses that will in turn push up fuel demand (Schakel, 2017) and increase other pollutant emissions for supply chains and facilities. Therefore, even with appropriate flue gas cleaning systems and CCS, fossil energy systems are bound to have substantial health and environmental impacts (UNEP, 2016c). Substitution of coal and other fossils with renewables appears to be the most effective way to lower the various types of environmental impacts (UNEP, 2016a, 2016c).

BOX 3.4 Plastics – A Global Challenge and Opportunity for Sustainable Consumption

Due to their low weight, durability and low cost, plastics have become one of the most used human-made materials. Global annual production increased from 2 million tons (Mt) in 1950 to 380 Mt in 2015, roughly 2.5 times the average annual growth rate of global gross domestic product in the same period (Geyer et al., 2017). In contrast to the rapid increase in the production and diverse uses of plastics, the current management of plastics - particularly after the use phase - lags way behind: according to recent estimates from 2015, out of 6300 Mt of all plastic waste historically generated, only around 21 per cent has been either incinerated (12 per cent) or recycled (9 per cent), whereas the rest (79 per cent) has accumulated in landfills or the natural environment (Geyer et al., 2017). This major loss of plastics from value chains not only reduces overall resource efficiency (4 to 8 per cent of oil was estimated to be used annually for global plastic production (Hopewell et al., 2009; World Economic Forum, 2016)), but has also led to substantial marine pollution (with recent estimates suggesting that 4.8 to 12.7 Mt of plastic waste entered the ocean in 2010), particularly in the coastal areas of developing and transition countries in Asia (Jambeck, 2015). The adverse effects of plastics on marine ecosystems has been recently reviewed elsewhere (for example Thevenon & Carroll, 2015; UNEP, 2016d; Worm et al., 2017).

Table 3.2 summarizes the major causes of the current mismanagement of plastics along their life cycle, highlights major (upcoming) challenges and outlines some opportunities for future actions and examples of existing initiatives for the sustainable consumption and production of plastics. Various factors in every stage of the plastic life cycle contribute to the current global mismanagement and resulting issues such as marine debris pollution. Therefore, holistic, transformative approaches throughout the entire value chain from production to waste management, in a circular economy approach, are needed. For example, one may argue that legal instruments that prohibit and/or use economic penalties to discourage microbeads and carrier bags, including those in operation in over 60 developing and transition countries in Africa, Asia, Oceania (including some islands states) and Central and South America (UNEP, 2018c; Xanthos & Walker, 2017), may be extended to all countries and to other single-use plastics.

The common practice of trading plastics for recycling is problematic, as it may result in higher environmental impacts when materials are sent from countries with a high technological level to countries using technologies with lower efficiencies, or even to informal recycling sectors in developing countries. Due to a lack of consistent characterization and reporting of traded waste, it is not currently possible to assess these additional environmental impacts associated with plastic waste trade. In 2016, about half of all plastic waste intended for recycling (14.1 Mt) was estimated to be exported by 123 countries, approximately half of which (7.35 Mt) was taken by China (Brooks et al., 2018). Since January 2018, China has implemented a new import ban on low-quality plastic waste, resulting in great pressure on countries exporting waste plastics. It remains to be seen if this change will lead to the build-up of more recycling infrastructure in the previously exporting nations or whether it will simply result in a shift of exports to developing or transition countries. One starting point for addressing the plastic waste trade may be the Basel Convention, which provides a framework for knowledge transfer and promotes the proper management of waste. While it is mainly hazardous waste that is regulated within this framework, plastics waste could also arguably be included, including the harmonization of technical standards and practices for treatment (Brooks et al., 2018).

TABLE 3.2 **An overview of major causes, additional (upcoming) challenges and opportunities for future actions relating to the current mismanagement of plastics throughout their life cycle**

LIFE CYCLE STAGE	MAJOR CAUSES OF PLASTICS MISMANAGEMENT	MAJOR (UPCOMING) CHALLENGES	OPPORTUNITIES FOR FUTURE ACTIONS AND EXAMPLES
Plastic production	▪ Rapid increase in production, diversity, and complexity of virgin plastics (and additives therein) (UNEP, 2016d). ▪ Difficulties in identifying and separating different plastics to ensure quality, purity and safety, thereby limiting plastic's circularity. ▪ Cheap prices linked to a low oil price contribute to a steady demand for virgin plastics (Kramer, n.d.).	▪ Plastics production may further increase ▪ Expansion into new markets and new uses for plastics (Dauvergne, 2018)	▪ To develop and foster: ▪ Best production practices, including (1) reduction of harmful substances and waste, (2) prevention of plastic pellet loss, (3) take back, reuse and recycling of plastic products (i.e. transition to a circular economy), and (4) transparency about ingredients and production process, for example via clear global labelling, to enable the sorting of plastics after use into high-value resource streams (GESAMP, 2015) ▪ Prevention and reduction (for example by light weighting and new materials) to do more with less plastic ▪ Expansion of existing initiatives to constrain fossil fuel supply, for example the World Bank ending their support for new oil, gas and coal extraction (SEI 2018)
Materials and product design	A large portion of plastics (36 per cent in 2015; (Geyer et al., 2017) is designed for single use. Some uses lead to direct releases of (micro)plastics into the environment, for example, the wash-off of microbeads in personal care products and synthetic fabrics in textiles (Browne et al., 2011), plus wear and tear of tires.		To establish incentives (and disincentives) for: ▪ Reduction/elimination of single-use plastics, using, for example, existing prohibition and discouragement via economic penalties for microbeads and carrier bags in over 60 developing and transition countries in Africa, Asia, Oceania (including some islands States), and Central and South America as models (Xanthos & Walker, 2017) ▪ Design of new materials and products for a circular economy (for example minimized loss during use; easily reusable / recyclable; more durable; streamlined variations of plastics types and additives, using PET as a model)
Waste generation	A disposable / throwaway consumer culture		To educate and incentivize consumers to reduce plastic waste generation, for instance by using instruments such as bottle deposits to increase collection of recyclables and by fostering responsible disposal of non-recyclables.
Waste management	A lack of adequate management systems for most plastic waste worldwide (including collection, sorting and recycling). In addition, much of the plastic waste generated in developed countries is exported to developing and transition countries (87 per cent of all exports of plastic waste since 1988 (Brooks et al., 2018).	The import ban of waste plastics by China since 2018 puts great pressure on many developed countries that previously exported plastic waste for recycling (Brooks et al., 2018).	▪ Combine waste reduction methods with proper waste collection, disposal and treatment methods worldwide. ▪ Follow up and document trade flows of waste, similar to the regulation of hazardous waste through the Basel Convention. ▪ Plastic landfill bans in 11 European countries to enhance recycling (Worm et al., 2017). ▪ Define a set of clearly defined collection and sorting categories ▪ Extended Producer Responsibility (EPR), such as Norwegian Regulation 1289/2017.

3.3.3 Impacts of Biomass Resources

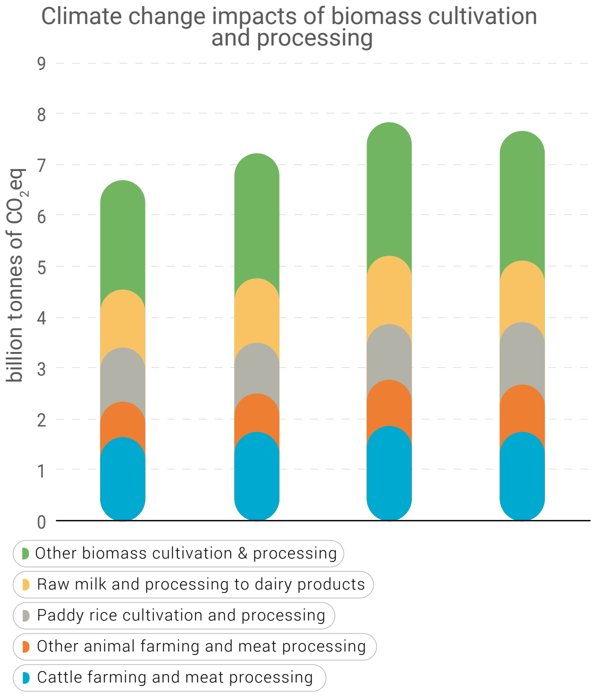
Biomass resources are used for food, material feedstock and for energy. Food is the most essential biomass extracted, as it is vital for humans and for SDG 2.4 (to end hunger). However, food production is also responsible for the majority of biodiversity loss, soil erosion and a large share of anthropogenic greenhouse gas emissions (UNEP, 2016a). Sustainable and productive agriculture is included in the SDGs in the form of indicator 2.4.1.

Food is mainly provided in the form of crops but also as animal products, which might be either wild catch (highly important for fish and SDG 14 but also wild game, insects and honey), from pastures (mainly ruminants) or feed-based production systems (mainly fish, chicken and eggs, pork and ruminants - including those bred for milk). Other animal biomass, such as insects or insect products (for example honey or silk), or mushrooms and algae can also be regionally important sources of biomass.

Crop yields per area have increased considerably over the last few decades (green revolution). However, growing population and increasing demand for high-quality food (including luxury products with a large biodiversity and water stress impact, such as coffee or cocoa) and cotton put pressure on water and land resources and add to eutrophying and toxic impacts through agrochemicals and fertilizer application (UNEP, 2016a). Land- and water-related impacts are further discussed in section 3.3.5 and freshwater eutrophication and toxicity from heavy metals from phosphorus fertilizers in box 3.2.

In terms of climate change impacts, biomass extraction and processing account for more than 30 per cent of greenhouse gas emissions related to resources, not including emissions from land use change. Cattle farming has the highest share of direct emissions, mainly from enteric fermentation (CH_4 emissions) and N_2O emissions, which also relates to the high impacts of the dairy sector. Rice production includes the highest CH_4 emissions besides ruminants and has the highest impacts from crop production (figure 3.22). The upstream impacts of cattle meat, dairy products and paddy rice production account for 60 per cent of climate change impacts of biomass production and processing (without land use change). Direct greenhouse gas emissions of all biomass extraction and processing have the following causes: 53 per cent by CH_4, 26 per cent by CO_2 and 21 per cent by N_2O. Note that N_2O emissions are highly variable and thus difficult to quantify on a global level, which leads to high uncertainties. Climate impacts of land use change are difficult to account for and allocate to sectors, but data from 2010 indicate that land use change potentially doubles the climate change impacts of biomass production (UNEP, 2016a).

FIGURE 3.22 **Climate change impacts of biomass cultivation and processing, excluding land use change**



Exiobase 3.4 (Exiobase, n.d.; Stadler et al., 2018). Land use change is estimated to double the climate change impacts (to a total of 10.6-14.3 gigatons CO2 equivalents for the food sector) (UNEP, 2016a).

From the production perspective, decoupling can be achieved through increased yields, as achieved in the previous century during the “green revolution”. In many developing countries in particular, there is still a large potential for yield increases by using state-of-the art crop management, including optimized fertilization and irrigation practices (UNEP, 2016a). Genetically modified organisms (GMOs) are used to enhance yield and to save labour and agrochemicals, while at the same time being perceived as a potential risk to humans and ecosystems, as well as to production through the resulting herbicide tolerant weeds (UNEP, 2016a). Precision agriculture, new breeds and drone applications are promising technologies with the potential to further increase biomass production efficiencies globally. An example of precision agriculture technologies is found in chapter 5 (section 5.2.3.4).

Greenhouse production can also increase yields by providing controlled and optimized growing conditions, especially for vegetables. Additionally, the efficiency of food production with regard to land and water resources (as well as emissions of agrochemicals) can be increased, but appropriate monitoring is still needed, since any efficiency gains can be offset by greater water depletion in some regions due to intensification (Ward & Pulido-Velazquez, 2008). Increased irrigation efficiency can facilitate large-scale intensification of greenhouses, leading to an increase in total water demand in a region (for example Lake Naivasha in Kenya or southern Spain), even if the water demand per crop decreases. Moreover, greenhouse production requires additional material and, depending on the climate conditions, energy inputs. While the latter are often based on fossil fuels, there are greenhouses that run on renewable energy (such as heat pumps, geothermal heating, renewable electricity from wind and photovoltaics and so on). Some greenhouses also draw waste heat from industrial processes in the surrounding area.

Another important food category is the wild catch of fish and other aquatic species. Per capita fish consumption has increased by more than a factor of two since 1960. In the last few decades, this increase has mainly been covered by aquaculture as wild catch levels had stagnated due to depleted fish stocks (see FAO, 2016b for a discussion of overfishing impacts).

Consumption patterns are relevant in terms of demand, as current diets vary considerably between people and cultures. For the first time in history, however, the number of overweight people exceeds those experiencing hunger (partly due to a tendency for kilocalorie overconsumption). This overconsumption can be associated with additional resource use for both the additional, unnecessary food production and for dealing with the resulting health impacts. Meat and milk demand have increased largely over the last decades and has been responsible for higher environmental impacts. Higher-income countries consume on average five times more meat per capita and year than lower-income countries (McMichael et al., 2007). There might be benefits for nutrient cycling through some livestock activities, however these would be realized at a lower extent than current production levels. With reductions in the consumption of certain types of foods, such as processed foods containing trans fatty acids and red and processed meat products or paddy rice, both fewer environmental impacts and improved health can be realized simultaneously (Walker et al., 2018). However, this requires consumer knowledge about food choices and government policy to incentivize change.

Regional impacts of diets can vary depending on growing conditions, food preferences and season, which means diets optimized for an individual will be different depending on location (especially in the case of subsistence farming and limited trade activities, which is still the case for a large share of the global population in emerging and developing economies). In other areas, trade allows more independence from local conditions and could also help to improve global food production efficiency in case production is moved to the most suitable areas. However, global trade also leads to increased consumption of luxury products such as coffee, tea and cacao, which only grow in tropical regions and often induce considerable biodiversity impacts (Chaudhary et al., 2016a; Scherer & Pfister, 2016b). Furthermore, trade among regions with unequal incomes and subsidies leads to distorted food prices, which do not reflect the full prices. This can lead to increased demand for food quantities or food types (such as meat) beyond nutritional requirements and thus add to food waste and overconsumption of calories or proteins. Note that personal dietary habits are a consequence of price, as well as other factors such as quality and taste (Glanz et al., 1998; Lappalainen et al., 1998). The role of culture strongly influences an individual's food choices as well, though their awareness of this influence may be limited (Kittler et al., 2012). While inducing changes in personal diets may be difficult to implement, they could help to mitigate the various environmental impacts of biomass resources and lead to health benefits at the same time.

Non-food biomass, such as wood, can also serve as feedstock for materials and energy. Material utilization ranges from the construction sector and furniture to packaging and various chemical applications, while the energy uses of wood include the residential and industrial sectors. Although wood is a renewable resource, its sustainable availability is limited. While overuse and deforestation are the norm in some countries, afforestation, reforestation and increasing wood stocks in existing forests are commonplace in others. This is often done intentionally to increase carbon storage in forests and mitigate climate change. The important role of afforestation (planting new forests) and reforestation (restocking of clear-cut forests) in carbon sequestration is undisputed, but the long-term success of harvesting less wood from forests by reducing forest management is debated in the literature (Werner et al., 2010; Krug et al., 2012): while initially the carbon pool in the forest increases, the rate of carbon uptake eventually declines, mortality increases in the long run and less wood is harvested and used in the economy to substitute other materials and fuels. Overall, models indicate that long-term carbon sequestration is highest when forests are harvested around their increment-optimized sustainable growth rate (for example Werner et al., 2010; Krug et al., 2012), and the harvested wood is used as a material or fuel (for example Seidl et al., 2007; Werner et al., 2010). Deforestation, on the other hand, results in severe environmental impacts due to loss of biodiversity, an increased risk of land degradation and carbon emissions (with deforestation causing up to 17 per cent of global carbon emissions (IPCC, 2007)). A main driver of deforestation is agricultural production, especially animal farming and soy/palm oil plantations, which cause between 70 per cent and 80 per cent of total deforestation globally. Other reasons include resource mining, infrastructure development, as well as timber logging itself. Illegal logging is assumed to account for 15 per cent to 30 per cent of all wood traded worldwide (Nellemann, 2012), a share that in the main tropical producer countries reaches 50 per cent to 90 per cent.

The biodiversity impacts of wood extraction depend largely on the intensity of forest management. While for extensive management systems (such as selection and retention forestry) no change in species richness is observed, intensive forestry (like clear-cut or slash and burn systems) can cause a loss of up to 50 per cent of local species (Chaudhary et al., 2016b). For the latter, biodiversity impacts in terms of species extinction is several orders of magnitudes higher in tropical regions than in Europe. It is therefore recommended to source wood from certified, extensively managed forests. However, only 8 per cent of forests worldwide are certified as sustainably managed, and over 90 per cent of these are located in Europe and North America (Nellemann, 2012). The climate targets of the Paris Agreement may result in increased bioenergy use (with or without carbon sequestration and storage) and intensification of forestry could increase, thereby impacting biodiversity.

The versatility of wood raises the question of how wood resources should be used in order to achieve an optimal environmental benefit. If sourced sustainably, the use of wood as a construction material or as material feedstock for products generally performs better in terms of climate change impacts compared to other material alternatives (Sathre & Gustavsson, 2006; Sommer & Kratena, 2017). Wood use is especially beneficial when high-impact products (like steel) are substituted and if a proper energetic use at the end of the life cycle is warranted (like replacing heating oil) (Suter et al., 2017). Furthermore, products with a long lifetime, such as buildings and furniture, store and thereby delay the emissions of carbon to the atmosphere, thereby reducing climate change impacts (Heeren et al., 2015; Mehr & Hellweg, 2018). Although wooden buildings tend to have an increased space heating or cooling demand due to less thermal mass (and therefore less heat buffering capacity) than other materials such as brick or concrete, the overall life cycle impacts tend to be substantially smaller than those of massive buildings (Heeren et al., 2015). This is due to the environmental benefits of the material (carbon storage capabilities and less embodied energy) for impacts of climate change, but also for many other environmental indicators. It is now possible to construct modern multi-story buildings of (mainly) wood, which increases the application options in the building sector. A cascade use of wood in various successive product cycles can increase the efficiency and the environmental benefits of wood, especially when other materials and fossil energy sources are substituted (Höglmeier et al., 2015). Wood can also be beneficial if used as a fuel, but complete combustion and adequate flue gas cleaning must be ensured. Otherwise, outdoor exposure to pollutants such as particulate matter can be elevated, as for example measured in cities and municipalities with large shares of wood heating (Fuller et al., 2013). From a health perspective, indoor exposure from biomass use in households is even more relevant and represents one of the leading global health risks. On a worldwide level, approximately 3 billion people do not have access to clean fuels and cook with solid fuels (WHO, 2018b) such as wood, coal, charcoal and agricultural residue. This leads to unhealthy indoor pollution exposure and severe health impacts. The World Health Organization estimates that 3.8 million people die prematurely every year due to inefficient cooking practices and related exposure to pollutants (WHO, 2018b). This problem is addressed by SDG 3.9, which aims for a substantial reduction of the number of deaths and illnesses from pollution. Improved ventilation and a switch to clean cooking fuels are technical solutions to mitigate this problem.

Biomass plays a large role as an energy source in future climate scenarios. However, wood should preferably be used firstly as a material before exploiting it as an energy source, as focusing on wood as an energy source alone would miss opportunities to make better environmental use of this resource. A comprehensive management strategy is needed, including a careful assessment of the environmental benefits and impacts of each biomass use, considering substitution effects of replacing other materials and fuels, cascade use and temporary carbon storage, in order to make optimal use of limited renewable biomass resources.

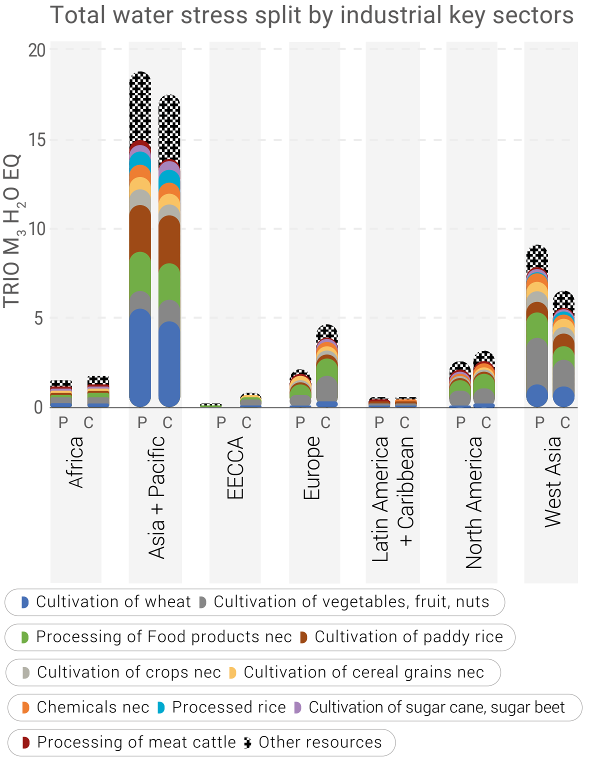
3.3.2 Water Resource Impacts

Freshwater is a vital resource for humans and ecosystems and thus a special case among abiotic resources. SDG 6 identifies several sub-goals for human access to freshwater, and under SDG 15.1 freshwater ecosystems ought to be sustainably used. The majority of water consumption occurs from renewable sources (rain, soil moisture, rivers, lakes and groundwater). Water scarcity is therefore mainly a function of demand and availability, which has been the basis for most approaches that quantify impacts in LCA (Kounina et al., 2013). If demand exceeds availability, non-renewable resources such as fossil groundwater reserves are tapped. In order to account for water scarcity beyond the common use-to-availability ratio (for example SDG indicator 6.4.2), the recent "AWARE" method, which was developed within a UNEP initiative (UNEP SETAC, 2016), includes natural scarcity and calculates the area required to sustainably supply a volume of water consumption in each of the >11,000 watersheds globally. In a subsequent step, the result is normalized to global equivalents, applying thresholds of 0.1 and 100 m^3-eq/m^3 (with the indicator ranging over three orders of magnitude).

Water resources are mainly impacted by agricultural activities, but also by electricity production. Overall, cultivation and processing of biomass are responsible for almost 90 per cent of global water stress impacts (figure 3.2, right column). Interestingly, the regions with the largest water-stress production impacts (West Asia and Asia and the Pacific) have a higher water scarcity footprint for production than for consumption, which means they "export" scarce water mainly through food and cotton products to other regions such as North America, Europe and Africa (which are net importers) (figure 3.28). Increased efficiency in biomass extraction (yields) and supply (as discussed in section 3.3.4) will generally translate into reduced impacts on water. However, if a yield increase requires additional irrigation, water impacts will increase (but create benefits in terms of area decrease of land use and other impacts). Similarly, shifts in production areas might increase or decrease water consumption-related impacts, usually as a trade-off with land use impacts (section 3.3.7), as naturally productive areas can reduce water consumption but increase land use impacts, while increasing irrigated agriculture can reduce land use change and deforestation.

Besides agriculture, power production and iron making cause high shares of water consumption-related impacts. In thermal power and iron making, water is often consumed for cooling purposes and thus efficiency gains in production decrease water consumption. Furthermore, cooling technologies can be water efficient (or even, as in dry/air cooling, involve near to no water consumption at all), which might, however, decrease the efficiency of the system if its cooling power is reduced, leading to

FIGURE 3.23 **Resource-related water stress split by most contributing resource sectors (mostly agriculture)**

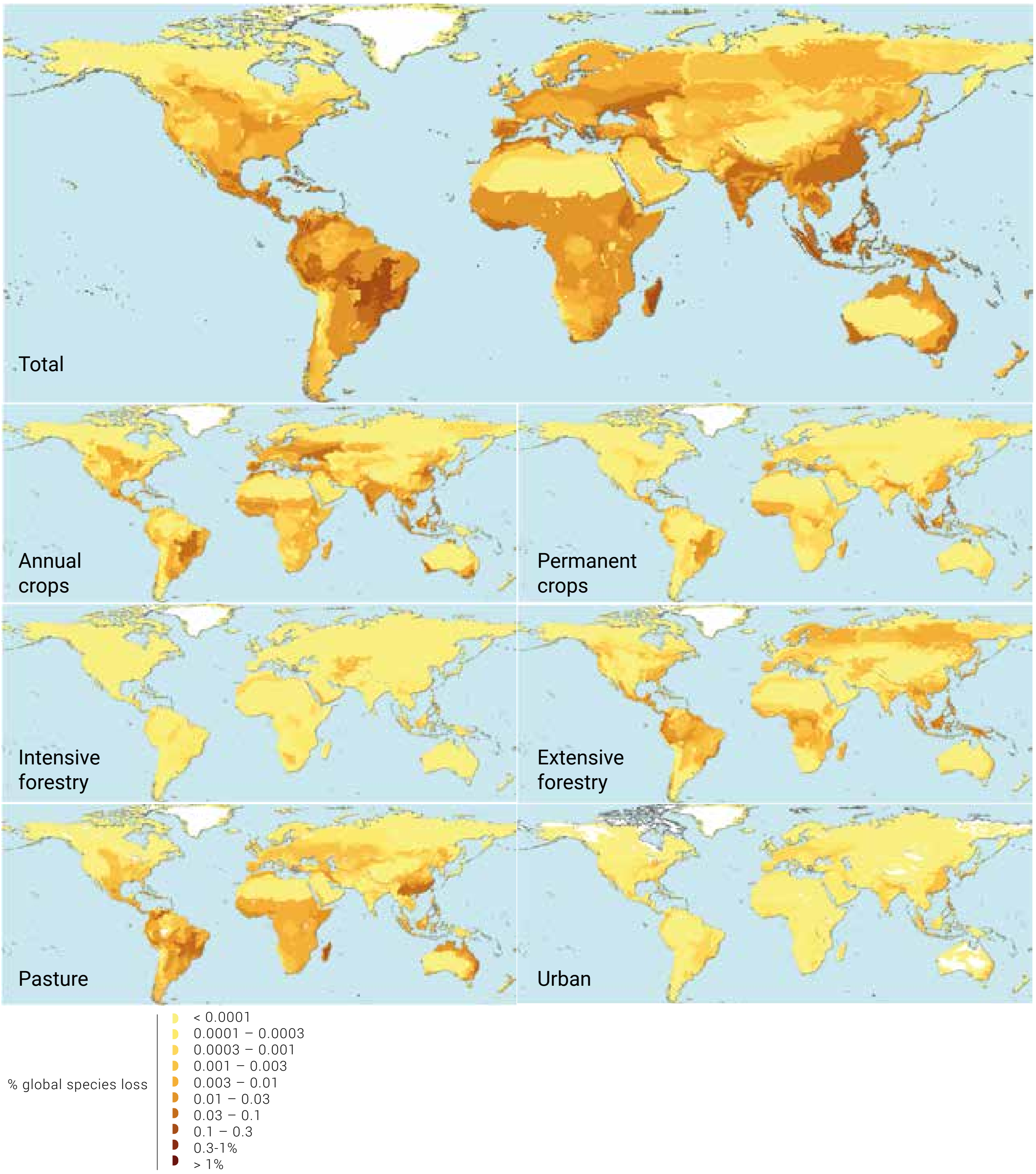


Assessed with the "AWARE" method (Boulay et al., 2018) per region and sector from a production (left column for each region) and consumption perspective (right column).

trade-offs with other impacts associated with thermal power production or iron making.

Hydropower has also been shown to play a major role in water consumption impacts. However, proper management of hydropower dams can even help to mitigate water scarcity (which is not accounted for in figure 3.23). This also applies to water-storage systems other than hydropower (for example irrigation ponds). Additionally, fragmentation of the river and run-off regime changes may have a larger impact on aquatic ecosystems than water consumption (Scherer & Pfister, 2016b).

FIGURE 3.24 **Biodiversity impact of land use in 2010 in per cent global species loss, summarized per ecoregion**



The impacts are calculated for total human land use (top map), as well as individual land use classes. Land use data from chapter 2 combined with biodiversity assessment
Data sources: Chaudhary et al., 2015; UNEP SETAC, 2016

3.2.3 Land Resource Impacts (Biodiversity Loss)

Land use gives rise to various environmental impacts including the destruction of natural habitats and biodiversity loss, as well as soil degradation and loss of other ecosystem services. The protection of terrestrial ecosystems is highlighted in various sub-goals of the SDGs (Wiedenhofer et al., 2018), and therefore efficient use and proper planning are required for land use change and management (Minx et al., 2013; UNCCD, 2017).

Land use caused global species loss of approximately 11 per cent by the year 2010. Figure 3.24 shows that the impact of total land use is highly correlated with agricultural activities. Islands and tropical areas have a high share of impacts due to their high endemic species densities, meaning higher shares of global species loss per local species loss. For total cropland use, annual crops have a higher share of the impact (2.9 per cent of global species loss) and are distributed over the globe, but particularly large losses of biodiversity are observed in the Indian sub-continent, Brazil, Central America, South East Asia, Eastern China, the Western Mediterranean region, Northern Black Sea shores and various parts of Australia. Permanent crop production (such as multiannual crops like coffee) causes total global species loss of 1.1 per cent. Pastures have a particularly high impact in South America, Africa, Madagascar, Australia and Southern China, and cause 2.8 per cent of global species loss in total. The highest impacts of forestry occur in Indonesia and the Philippines, as well as different parts of Latin America (2 per cent of global species loss). Urban areas have generally smaller land use-related biodiversity impacts (0.2 per cent of global species loss in total, figure 3.24) due to their limited extent compared to agriculture and forestry, but urbanization may alter consumption patterns and hence indirectly lead to changes in land impacts. Pasture-related impacts are highly uncertain, as the actual associated extent is difficult to estimate. Similarly, the extent and intensity of extensive forestry are uncertain. The impact of mining is small in comparison to other land uses (IRP, 2017a), but it can lead to local biodiversity loss, especially because some mining sites are located in valuable and vulnerable ecosystems. This includes large mining projects as well as informal mining activities in rainforests. In addition to direct land use, there are also biodiversity impacts from building streets and cities in remote mining areas. Furthermore, increasing resource demand and depletion of easily accessible reserves pushes up mining activities in remote areas, including tropical forests and fragile areas (Allegrini et al., 2015; IRP, 2018a).

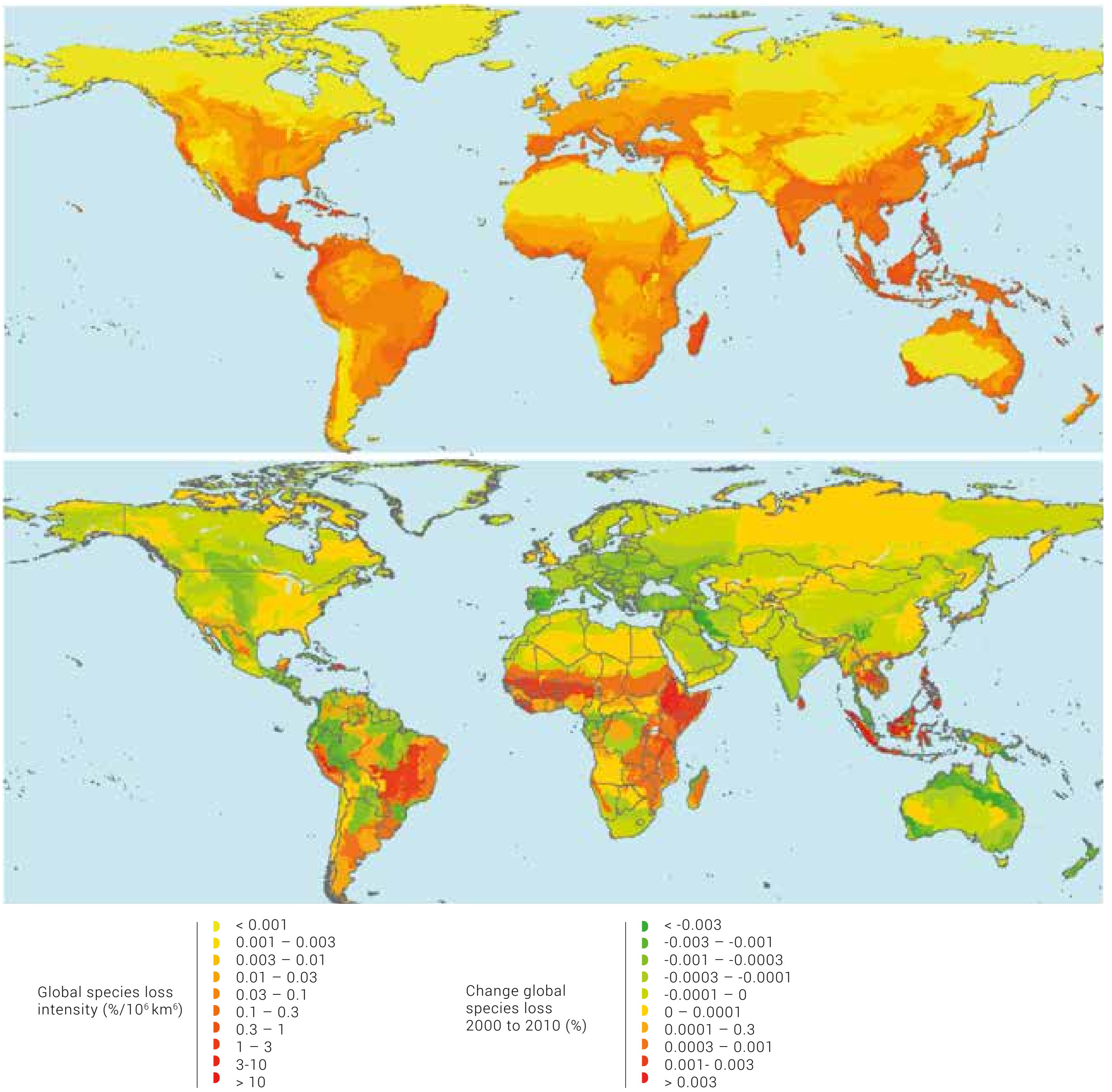
Many industrialized regions such as Europe, parts of the United States of America and Australia show decreasing land use impacts (figure 3.25), while others regions such as Indonesia, the Philippines, Brazil, tropical Africa and Peru see increasing land-use impacts. Many of these expansions occur in ecoregions with high species loss intensity (measured as per cent global species loss per km^2 in each ecoregion, see figure 3.25). Note that biodiversity loss and recovery are processes in time. Long-term species loss at steady state was assessed here, but species loss from additional land use may not occur right after the change. Biodiversity recovery is also not instantaneous and may occur over long time periods (Curran et al., 2014). Between 2000 and 2010, while overall biodiversity impacts due to land use were fairly stable in the present analysis (based on chapter 2), the effects on regions with increased and decreased biodiversity (figure 3.25) do not necessarily outweigh each other. In fact, the significantly increased losses in many regions are alarming. Calculations based on other land-use data show that global biodiversity losses increased between 2000 and 2010, as documented in the previous edition of this report (IRP, 2017a). The reason for the discrepancy in assessing the trend of biodiversity loss lies in the uncertainty in land-use data, which can be based on statistics (for example of FAO), remote sensing data or a combination of both (as used in chapter 2). Remote sensing can provide a detailed assessment of total extent, but changes over the years are affected by high uncertainty due to the resolution of the image and the varying climate. Note that agricultural management intensity also influences biodiversity, which was not considered in the present section and impacts are therefore underestimated in this respect. On the basis of all the above, it is evident that continued attention and efforts are required to achieve the goals of SDG 15.5 to halt biodiversity loss, as well as the Aichi goals of the Convention on Biological Diversity to reduce the direct pressures on biodiversity and promote sustainable land use. Resources, especially biomass extraction, play a central role in this endeavour. Since the impact per m^2 of land use varies geographically and by management intensity, Maron et al. (Maron et al., 2018) proposed to set up a series of area-based, quality-specific area targets for land use, which address protected areas and also used areas.

The results of this analysis support the findings of IPBES for the four world regions (Africa, Americas, Asia and the Pacific, and Europe and Central Asia (IPBES, 2018): in general there is a strong decline of biodiversity related to land use, but several regions have also been able to recover biodiversity. The high variability requires detailed assessments, including into vulnerability to loss of ecosystem services (which is especially high in Africa).

Land use also affects soil systems. Soils are important environmental assets, particularly given the need for additional food for a growing future population and for the achievement of the SDGs (IPBES, 2018). SDG 15.3 addresses this need by establishing land degradation neutrality as a global objective to be addressed at local to national levels. The United Nations Convention to Combat Desertification is promoting a number of initiatives to address SDG 15.3, in addition to its related ongoing work on drought and desertification. Land Degradation Neutrality has been defined by the Parties to the Convention as: "A state whereby the amount and quality of land resources, necessary to support ecosystem functions and services and enhance food security, remains stable or increases within specified temporal and spatial scales and ecosystems" (UNCCD, n.d.). Achieving land degradation neutrality requires an evaluation of the land potential (UNEP, 2016e). The recommendation is to adapt land use and management to this potential, such that the crops and production systems need to correspond to soil properties so they provide optimal yields with minimal degradation impacts. Systems, strategies, and tools for land evaluation are reviewed and presented in a previous IRP report (UNEP, 2016e). Land/soil degradation includes several degradation processes (for example erosion, compaction, salinization or acidification) and harms biotic productivity and the capacity of the land to deliver other ecosystem services (UNEP, 2016e). While land evaluation helps to predict which types of production systems are likely to cause such harm on which types of land (UNEP, 2016e), the environmental impacts of soil degradation have not yet been adequately quantified, for example by Life Cycle Impact Assessment methods (Vidal Legaz et al., 2017). Nevertheless, on a case study level, results show that productivity losses can be substantial. Compaction, for example, can lead to relative yield losses of up to double-digit percentages in the first few years after compaction stress and losses remain in the order of one-digit percentages in the long term (Håkansson & Reeder, 1994). Crops and production requiring intensive tillage and frequent tractor impacts associated with fertilizer and pesticide application (for example large scale potato production), increase compaction risk, particularly on soils with high clay and moisture content (Stoessel et al., 2018). Technological innovation therefore potentially leads to higher compaction risk, due to the trend towards more and larger machinery use. On the other hand, some innovations, such as those applied through precision farming, can reduce machinery passes on the field, and, in the future, agricultural robots could substitute the use of heavy machinery while lowering fertilizer and pesticide inputs (which are essential in no-till farming).

Other forms of degradation that have been shown to cause significant yield reductions include erosion-driven soil organic matter losses, salinization, soil acidification and reductions in soil fertility driven by removal in crops and crop residues. Few other degradation processes have been strongly linked to yield or productivity losses but remain at the level of proxy indicators. The main single indicator used for soil "quality" in LCIA is soil organic carbon or soil organic matter (Milà i Canals et al., 2007), but this has not yet been applied to global agriculture, although it is one of the three indicators selected by the UNCCD to quantify SDG 15.3. Since productivity losses due to various soil degradation processes have not yet been consistently assessed at the global level, they are not assessed in this report. However, some of the existing tools for quantifying degradation, for example the Revised Universal Soil Loss Equation (RUSLE), give a clear indication about good agricultural practices: Panagos et al., 2015, estimate that contour farming may reduce (water) erosion rates by up to 40 per cent, while no-till practices may reduce them by up to 75 per cent on some soils and slopes. Prevention of soil erosion is mentioned alongside prevention of overgrazing, maintenance of soil organic matter content and maintenance or introduction of landscape elements providing ecosystem services as an option for more sustainable land use in a previous IRP report (UNEP, 2016a).

FIGURE 3.25 **Biodiversity impact of total human land use in 2010 normalized to area (in per cent global species loss per million km2), summarized per ecoregion**



Land use data from Chapter 2 combined with biodiversity assessment (UNEP-SETAC 2016a).

3.4 Conclusions

This chapter has described the impacts of natural resource extraction and processing and, in selected cases, extended this coverage to economy-wide impacts. Natural resource extraction and processing make up approximately 50 per cent of total GHG emissions. For water stress and biodiversity loss due to land use, the share resource-related impacts of the total economy-wide impacts are even larger than 90 per cent, mostly driven by agriculture. An estimated 11 per cent of global species were lost by 2010 due to global land use, while the consumption of water contributes to water stress, thereby threatening the sustainable supply of freshwater to humans and ecosystems (UNEP SETAC, 2016). In addition, while some low-income regions suffer from soil nutrient depletion, the overuse of fertilizers leads to eutrophication as well as ecotoxic effects in many other regions (with both ultimately leading to biodiversity loss).

Between 2000 and 2015, there was a relative decoupling of resource-related environmental impacts from GDP and also a moderate relative decoupling of impacts from the extracted mass of resources. However, impacts still increased on an absolute scale, as did global average per capita climate change and health impacts. Climate change impacts increased by a factor of 1.4 between 2000 and 2011, following a similar trend to that of total extracted mass of resources (increasing by a factor of 1.6). During the same time, water- and land use-related impacts also increased, but by a lesser degree (by a factor 1.2 for water stress) due to increased productivity in food production, whereas resource-related value added doubled. If the rising trend in resource-related impacts persists, the goals of the Paris agreement will become difficult to meet and the achievement of the Sustainable Development Goals, including SDG 15.5 to halt biodiversity loss, will be put at risk.

The impacts and value creation are not equally distributed around the globe. Per capita impacts of high-income regions are between three and six times larger than those of low-income regions. This is reinforced by trade. For example, Europe and North America outsource environmental impacts, such that a part of the total environmental impacts of consumption occurs abroad. At the same time, the value created through these traded materials in the countries of origin is relatively low.

Capital investments for the build-up of infrastructure were the main driver of resource use in emerging economies, while in industrial countries consumer goods dominate final demand. While general trends exist, such as increased impacts with increased income, there are also cases of low-emission households within high-income segments - showing that decoupling is possible.

Environmental impacts are not always correlated with each other, indicating that a set of indicators is needed to assess resource-related impacts in a comprehensive manner and avoid problem shifting. Potential measures of the simultaneous reduction of several impacts include food waste reductions and shifts in diets towards less meat and animal products from intensive livestock systems. Phasing out coal as a fuel reduces climate change impacts and also other impacts related to resource processing. Focusing on long-term material use of sustainably grown wood, in particular in the construction sector, can lead to co-benefits in terms of climate change and biodiversity loss. Similarly, conserving valuable forest ecosystems and avoiding deforestation contribute to reducing climate change and biodiversity impacts. However, if climate policy leads to increased use of bioenergy (combined with Carbon Capture and Storage as a negative emission technology), as foreseen in many climate scenarios, additional biodiversity loss may occur through an increase in intensive biomass production. Special attention is therefore needed to avoid problem shifting from mitigating climate change to accelerating biodiversity loss.

Overall, this chapter illustrates that further action is needed to reach absolute decoupling and remain within planetary boundaries. While improvements in processing technologies have greatly reduced impacts in the past, this trend has plateaued in recent years for some key materials and further efficiency gains are limited in potential. Therefore, a systemic change is needed. The future of innovation lies particularly in the efficient design and use of materials, following circular economy principles. Chapter 4 will explore scenarios for a sustainable future, and chapter 5 will discuss policy measures to foster this development.

04

Two outlooks for resource use

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Back to the content

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Main findings

- Resource efficiency and sustainable consumption and production policies can achieve significant decoupling, while achieving increased economic growth and a more equal distribution of income and resource use.
- We find incomes and resource-based services increase significantly in the *Towards Sustainability* scenario across all groups of countries, while environmental pressures and impacts fall dramatically (as shown in figure 4.24 below).
- This contrasts starkly with the outlook under *Historical Trends*, which has similar projected increases in income, but higher resource extractions and escalating and clearly unsustainable environmental pressures – including rising greenhouse gas emissions, reductions in the quality and area of forests and other native habitat and increasing pressures on water sensitive ecosystems.
- Material resource extraction more than doubles globally by 2060 under *Historical Trends*, with per capita resource use increasing from 11.9 tons to 18.5 tons per person.
- Water extraction by industry and municipalities increases by at least 50 per cent, more than doubling in many outlooks. Competition for water between cities and agriculture may become a serious problem.
- The area of agricultural land increases by more than 20 per cent, reducing forests by more than 10 per cent and other habitat (such as grasslands and savannahs) by around 20 per cent. As water withdrawal is often for agriculture and energy production, competition for water and land transformation could also be substantially reduced by enhanced material and energy efficiency in production and consumption.
- This scale of growth in resource use – without improvements to managing the impacts of extraction, use and disposal of materials and resources – would result in substantial stress on resource supply systems and unprecedented levels of environmental pressures and impacts.
- *Towards Sustainability* policies and actions result in slower growth in global resource use, as well as supporting more equal per capita resource use across countries.
- Resource efficiency and sustainability actions are projected to result in slower growth of global natural resource use, with strong growth rates in emerging and other developing economies balanced by absolute reductions in per capita resource use in high-income countries. Global resource extractions are 25 per cent lower in 2060 than under a continuation of *Historical Trends*, equal to 47 billion tons of avoided resource extractions in that year alone. This reduction in growth would help take pressure off resource supply systems, and make it easier to avoid resource extraction and use that has relatively high social and environmental impacts per unit of resource throughput.

- Well-being indicators grow faster than resource extraction, with improved resource productivity and relative decoupling of well-being from resource use.
- Resource efficiency and sustainability actions are projected to achieve substantial relative decoupling of natural resource use from income and essential resource-based services, which we define for this purpose as average income (GDP per capita), energy use per person and food consumption per person.
- Environmental pressures fall, with absolute decoupling of environmental damage from economic growth and resource use.
- Resource efficiency and sustainability actions are projected to achieve absolute decoupling of economic activity and resource use from environmental impact, so that income and other well-being indicators improve, while key environmental pressures fall – including dramatic reductions in greenhouse gas emissions and substantial restoration of forests and native habitat from 2015 levels.
- Sustainability measures promote stronger economic growth, boost well-being and help support a more equal distribution of income and reduced use across countries.
- Implementing an integrated package of resource efficiency, sustainability and climate policy actions results in net economic benefits globally from 2030 onwards, with global GDP 8 per cent above *Historical Trends* in 2060, as projected gains from resource efficiency outweigh the near-term economic costs of achieving ambitious reductions in net greenhouse gas emissions. The suite of policies also supports more equal distribution of GDP per capita, increasing economic growth relatively more in low- and middle-income nations (11 per cent on average) than in high-income nations (4 per cent on average) relative to *Historical Trends*.

4.1 Introduction: Two Contrasting Outlooks for Resource Use, Well-being and Environmental Pressure

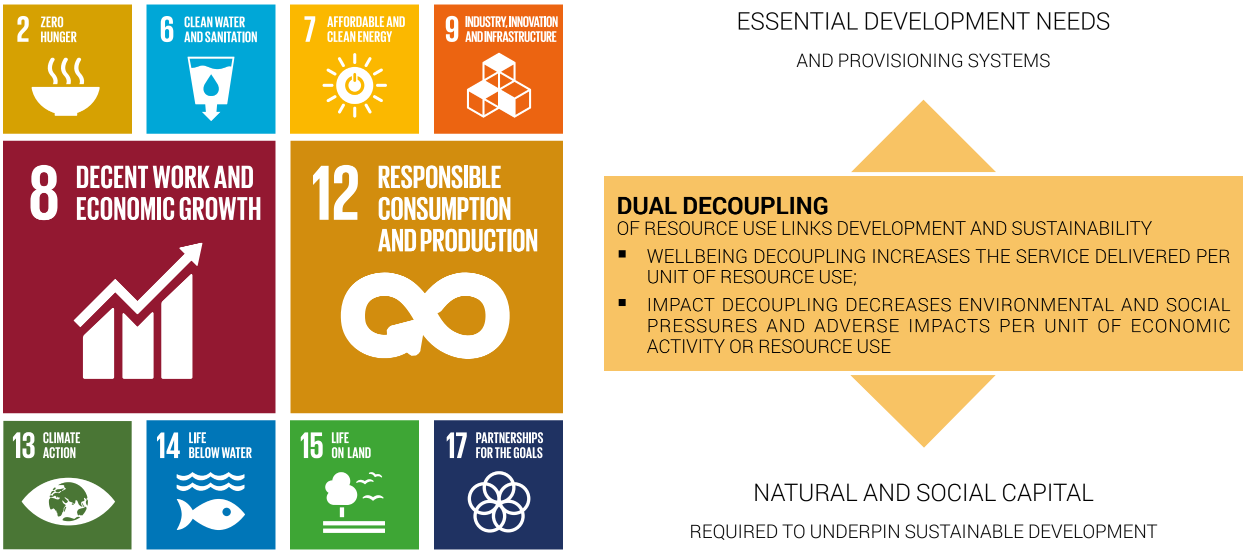
Patterns of natural resource use – including extraction, transformation, distribution and disposal of resources – are central to the dynamic links that connect human well-being and essential natural and social capital.

Past achievements in human development and rising standards of living in many parts of the world came at a cost of rapidly increasing environmental pressures (see chapter 2) and associated environmental impacts (see chapter 3). Problems of natural resource depletion, climate change, water shortages, biodiversity loss and environmental degradation have been increasing at an unprecedented pace, and are becoming increasingly intertwined and mutually reinforcing. In this chapter, we use scenario analysis and modelling to analyse two potential futures: a continuation of *Historical Trends* and a *Towards Sustainability* pathway, enabled by ambitious actions to promote resource conservation, greenhouse gas abatement and sustainable production and consumption.

In the context of the Sustainable Development Goals, natural resource use connects essential material needs for food, water, energy and shelter (represented by SDGs 2, 6, 7, and 9) and natural and social capital (represented by SDGs 13, 14, 15, and 17) that underpin all life and earth system functions.

Decoupling resource use from well-being and from adverse social and environmental impacts is thus central and essential to achieving sustainable development, as shown in figure 4.1. SDG targets 8.4, 12.1 and 12.2 recognize this, calling for resource efficiency and decoupling of economic growth from environmental degradation, sustainable consumption and production and the sustainable management and efficient use of natural resources.

FIGURE 4.1 **Dual decoupling to promote sustainable development**



DUAL DECOUPLING
OF RESOURCE USE LINKS DEVELOPMENT AND SUSTAINABILITY

- WELLBEING DECOUPLING INCREASES THE SERVICE DELIVERED PER UNIT OF RESOURCE USE;
- IMPACT DECOUPLING DECREASES ENVIRONMENTAL AND SOCIAL PRESSURES AND ADVERSE IMPACTS PER UNIT OF ECONOMIC ACTIVITY OR RESOURCE USE

We refer to the two dimensions of this task as ‘well-being decoupling’, which increases the service provided or satisfaction of human need per unit of resource use, and ‘impact decoupling’, which decreases environmental pressures and impacts per unit of economic activity or per unit of resource use.

This chapter explores these issues through two potential outlooks for resource use, well-being and environmental pressure, drawing on world-leading integrated modelling and analysis. It begins by describing the baseline *Historical Trends* scenario, focusing on projections for resource extractions and use. Additional projections for water and land follow. It then outlines the policy and other assumptions for the *Towards Sustainability* scenario, and presents the key results for resource use, human well-being and environmental impacts and implications for economic performance. Essential technical information is provided at the end of the chapter, with additional material provided in a separate Technical Annex.

Resource efficiency and sustainable consumption and production policies can achieve significant decoupling, while achieving increased economic growth and a more equal distribution of income and resource use.

As set out in more detail below, the modelling and analysis find that decoupling of economic growth, resource use and environmental impacts is possible, so that human well-being improves while resource use and environment impacts reduce (see figure 4.24 below). Specifically, the modelling and analysis find that decoupling results in slower global growth in resource use, and a decrease in per capita resource use in high-income countries. Incomes (GDP per capita) and resource-based services (particularly energy and calories per person) increase significantly in the *Towards Sustainability* scenario, across all groups of countries. This occurs while environmental pressures and impacts fall dramatically. In addition, the package of policies and actions provides an overall boost to economic growth, across all groups of countries. This projected decoupling contrasts starkly with the outlook under *Historical Trends*, which has similar projected increases in income, but higher resource extractions and escalating and clearly unsustainable environmental pressures – including rising greenhouse gas emissions, reductions in the quality and area of forests and other native habitat and increasing pressures on water-sensitive ecosystems.

While possible and economically attractive, shifting from our historical – and unsustainable – patterns of resource use and environmental impact towards ‘a future we want’ would require decisive action by governments and business around the world to support innovation for environmental challenges and sustainable consumption and production practices.

4.2 Overview of the *Historical Trends* Baseline Scenario

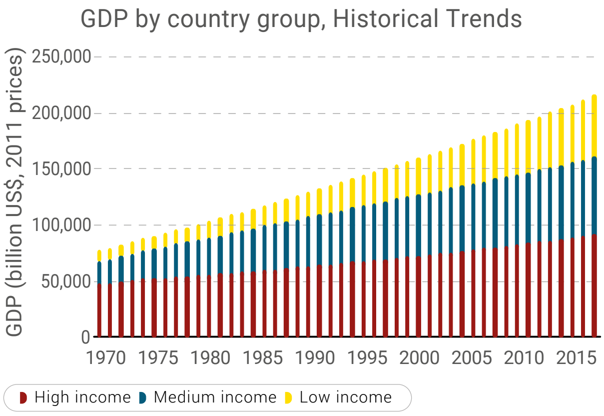
The *Historical Trends* scenario provides projections of resource use, economic activity, essential services (such as per capita energy and protein supply) and key environmental indicators (such as greenhouse gas emissions and loss of native habitat) on the assumption that observed trends and relationships over the decades to 2015 continue into future decades. These driving trends include population growth and per capita economic growth (both sourced from parallel OECD work), along with trends in the material intensity of economic activity, rates and patterns of urbanization, technological change within sectors and climate policy outcomes. Population data and data for GDP were sourced from the OECD and are compatible with the trends used in the OECD's RE-CIRCLE project (OECD, 2018) to facilitate comparability between the modelling results of the OECD and the IRP. Climate policy outcomes assume only partial implementation of Paris commitments.

The analysis uses two models to provide scenario projections for land use under *Historical Trends*, while the projections for water are based on existing literature.

4.2.1 Population and Economic Growth

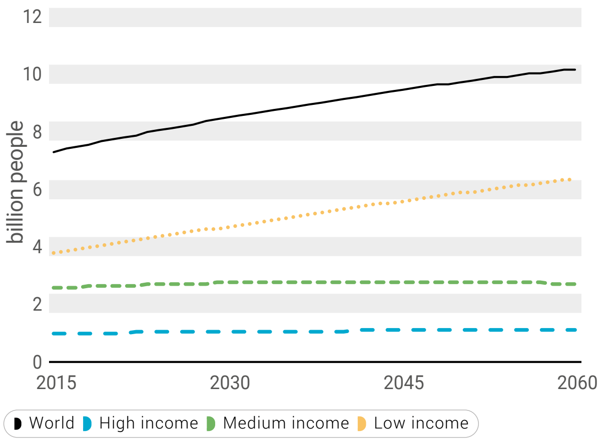
All scenarios, including *Historical Trends*, assume population grows from 7.3 billion people in 2015 to 10.2 billion people in 2060, an average annual growth of 0.7 per cent. This is slower than growth seen in previous periods, reflecting the slowdown in the rate of population growth. Consistent with observed trends, growth is slowest in middle-income countries including transition countries (averaging 0.3 per cent per year to 2040 before stabilizing), and quite low in high-income countries at an average of 0.3 per cent per year to 2040 and then 0.1 per cent per year to 2060, while remaining relatively strong in low-income countries, which grow by an average of 1.3 per cent per year to 2040 and 0.9 per cent per year to 2060. Population is contracting in a number of high-income countries and in some developing countries. Population is projected to grow strongly in Africa.

FIGURE 4.3 **Economic activity (GDP) by country group, Historical Trends, 2015 – 2060**



Data sources: OECD Resource Efficiency and Circular Economy Project, 2018

FIGURE 4.2 **Population, all scenarios including Historical Trends, 2015 – 2060**



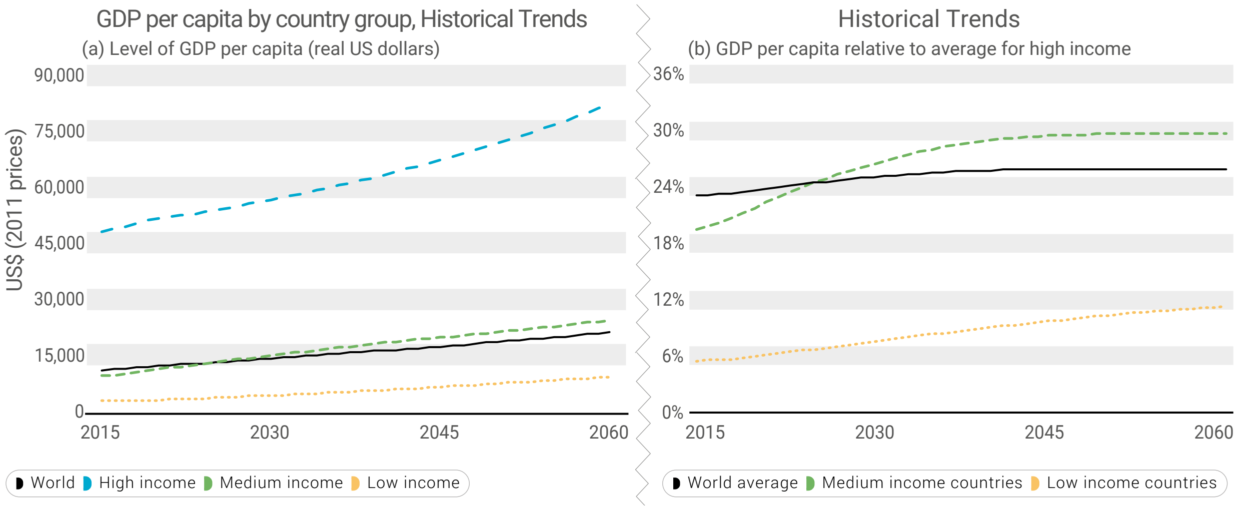
Data sources: OECD Resource Efficiency and Circular Economy Project, 2018. Note: in the scenarios, only three income groups are modelled.

Global living standards and GDP are projected to grow strongly from US$ 82 trillion in 2015 to US$ 216 trillion dollars in 2060 (real 2011 dollars), at an average rate of 2.2 per cent per year. The OECD growth forecast points to a certain convergence of living standards between countries, with growth highest in low-income countries at 4.0 per cent average yearly growth. Economies in middle-income countries are projected to grow by 2.3 per cent per year, with high-income countries experiencing the slowest growth in GDP at 1.4 per cent yearly growth.

4.2.2 *Historical Trends* Outlook for Materials

Projections of *Historical Trends* show that global material use would grow by 110 per cent from 2015 levels to reach 190 billion tons by 2060, if the material demands of a growing world economy and population are delivered

FIGURE 4.4 **Average income (GDP per capita) levels and relativities by country group, 2015 – 2060**



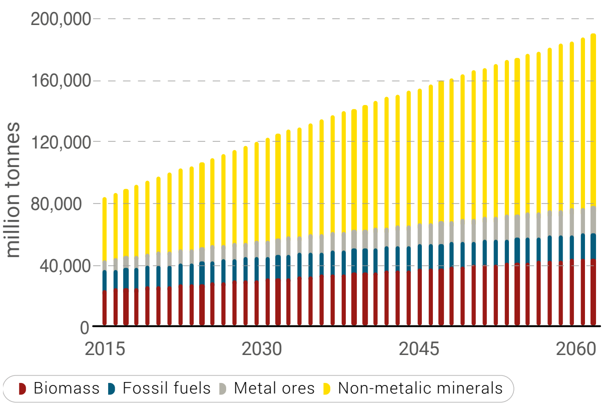
Note: Values based on market exchange rates (MER) not purchasing power
Source: OECD Resource Efficiency and Circular Economy Project, 2018

with current patterns of production, consumption and associated policies and infrastructure. This would see resource use rising from 11.9 tons per person to 18.5 tons per capita in 2060. This scale of growth in resource use – without improvements in managing the impacts of extraction, use and disposal of materials and resources – would result in substantial stress on resource supply systems and unprecedented levels of environmental pressures and impacts.

Resource extraction more than doubles by 2060 under *Historical Trends*.

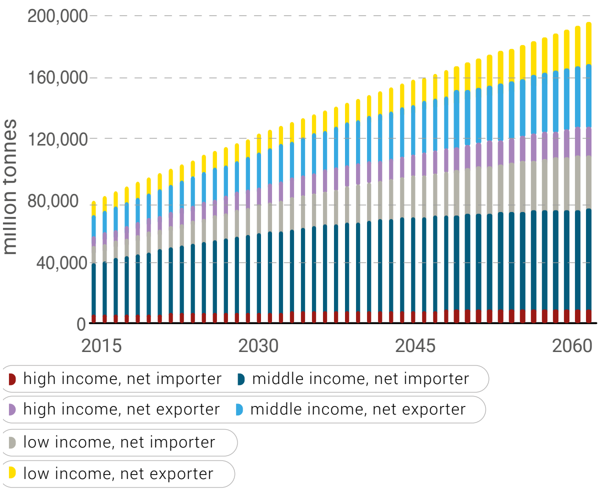
Under current trends, global domestic extraction would grow from 88 billion tons in 2015 to 190 billion tons in 2060, a yearly average growth of 1.8 per cent driven by strong growth in GDP and population. Non-metallic minerals for construction would see the strongest yearly growth of 2.2 per cent, reflecting the additional needs of buildings and infrastructure. Metal ores would grow at a yearly average of 1.7 per cent, biomass by 1.4 per cent per year and fossil fuels at 0.2 per cent. The share of non-metallic minerals would grow to 59 per cent of overall extraction in 2060, biomass would have a share of 23 per cent, followed

FIGURE 4.5 **Global material extraction by material categories, Historical Trends, 2015 -2060**



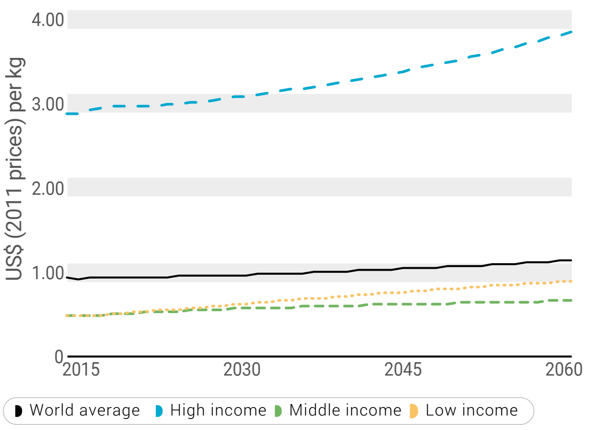
Source: CSIRO/IIASA (GTEM/GLOBIOM) 2018.

FIGURE 4.6 **Global material extraction by country group, Historical Trends, 2015 -2060.**



Source: CSIRO/IIASA (GTEM/GLOBIOM) 2018.

FIGURE 4.7 **Resource productivity (dollars GDP per ton of resource extraction), world and three country groups, 2015-2060**



Source: CSIRO/IIASA (GTEM/GLOBIOM) 2018

by fossil fuels at 9 per cent and metal ores at 9 per cent of total global extraction.

The group of middle-income countries focusing on imports continue to have the highest share of global materials extraction and reaches 65 billion tons by 2060, or a third of overall extraction. The highest rate of growth is expected for low-income countries focusing on exports of primary materials at 3 per cent annual growth (figure 4.6).

Global material productivity improves marginally from 0.93 US$ per kg of material use in 2015 to 1.14 US$ per kg in 2060, increasing by 0.4 per cent per year on average under *Historical Trends*, as shown in figure 4.7. Material productivity improves most in low-income countries by a yearly average of 1.4 per cent, compared with an average improvement of 0.7 per cent per year in high- and middle-income countries. In 2015, high-income countries used materials six times more productively in generating goods and services compared to low-income countries. There is some degree of convergence in material productivity, with high-income countries being just four times more productive than low-income countries in 2060.

4.2.3 *Historical Trends* Outlook for Water

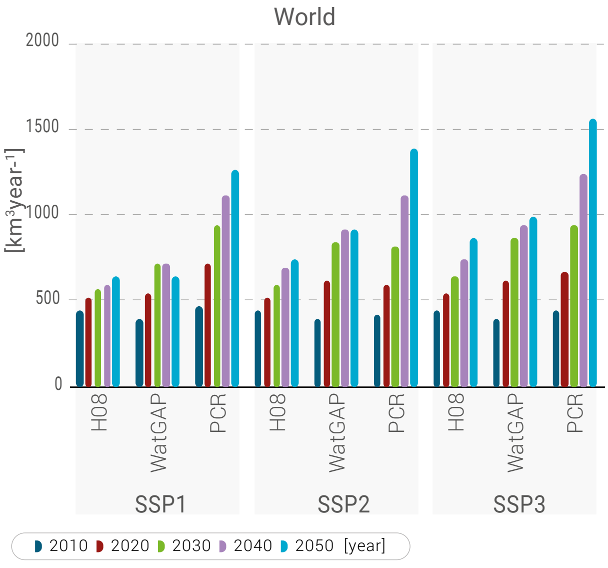
Future water withdrawal by industries and for domestic purposes has been modelled extensively. Modelling future water use in agriculture – which is the dominant consuming sector – is still under way, while expected use for irrigation shows diverging options.

A set of three global water models was used to model global and regional water withdrawal by the industrial sector under three shared socioeconomic pathways (SSP) scenarios (Wada et al., 2016). Depending on which scenario is used, the level of 2010 (850 km^3/year) may more than double and reach nearly 2000 km3/year or become reduced by about one third (figure 4.8).

Under the trend scenario (SSP2), industrial water withdrawal is expected to increase by at least three quarters to more than double the level of 2010. Assuming isolationist policies leading to reduced international trade (SSP3), the increase may range from 50 per cent to more than double. Only under more sustainable conditions (SSP1), in particular when – as in H08 model results – a significant shift to more water efficient technologies is assumed, could a decrease of industrial water withdrawal be expected.

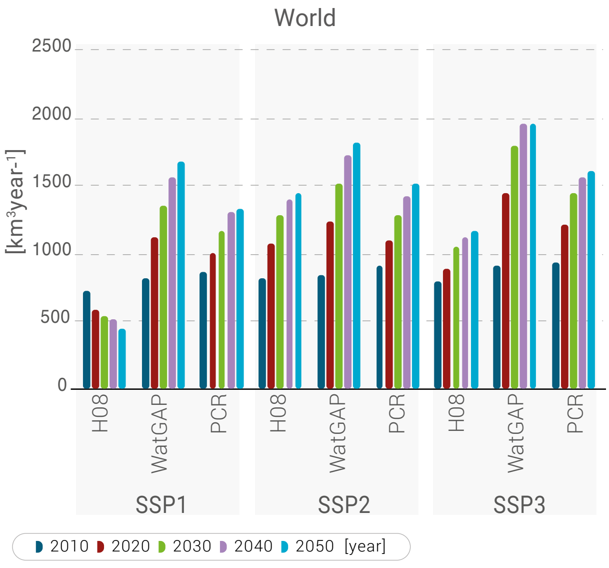
Depending on the technological development, the dynamics of industrial water withdrawal exhibit high variability. Whereas the models largely converge to project a declining or at least stabilizing trend for countries like the United States of America and Germany, they differ widely across SSP scenarios with regard to possible developments in emerging economies. For the trend scenario (SSP2), they jointly point to an expected increase

FIGURE 4.8 **Global industrial water withdrawal projections modelled by three water models (H08, WaterGAP, and PCR-GLOBWB (PCR) under three SSP scenarios (Wada et al. 2016)**



Source: UniKassel/CESR

FIGURE 4.9 **Global domestic water withdrawal projections modelled by three water models (H08, WaterGAP, and PCR-GLOBWB (PCR) under three SSP scenarios (Wada et al. 2016)**



Source: UniKassel/CESR

in withdrawal, although this can range from a one-third increase to more than tripling the level of 2010 by 2050.

Municipal (domestic) water withdrawal is expected to increase due to population growth and rising demands (figure 4.9). The level in 2010 was 400 to 450 km^3/year. Depending on the scenario, global withdrawal is projected to reach 700 to 1500 km3/year (an increase of between 50 per cent and 250 per cent).

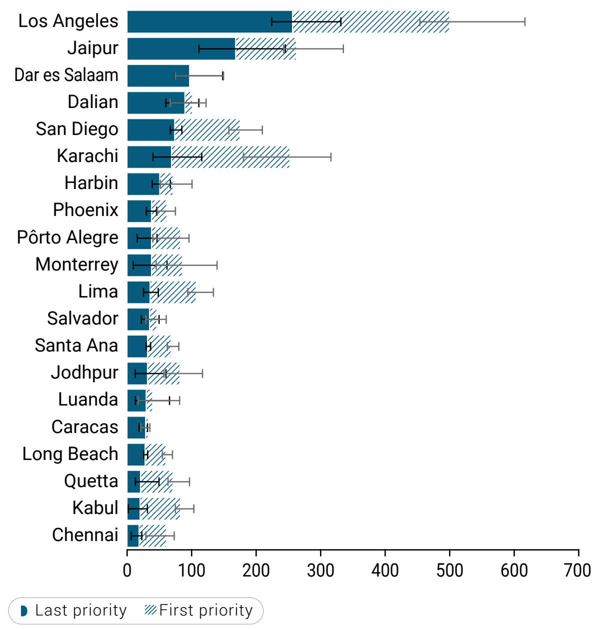
For domestic water withdrawal, the three models project similar orders of magnitude and trends between moderate increase or decrease to stabilization for countries like the United States of America and Germany. For some major developing countries, however, the projected level of municipal water withdrawal in 2050 differs by between a factor of 2.5 and 4.5. The models jointly point to an increase, but project the trend between moderate and severe. The results depend on varying assumptions. The results indicate the value of using a suite of models (Wada et al., 2016) in order to cover potential ranges of future developments.

BOX 4.1 Growing Water competition between cities and agriculture

Urban water demand will increase by 80 per cent by 2050, while climate change will alter the timing and distribution of water availability. Flörke et al. (2018) quantify the magnitude of these twin challenges to urban water security, combining a data set of urban water sources in 482 of the world's largest cities with estimates of future water demand (based on the IPCC's Fifth Assessment scenarios) and predictions of future water availability (using the WaterGAP3 modelling framework). The authors project an urban surface-water deficit of between 1,386 and 6,764 million m^3 in 2050. More than 27 per cent of cities studied, containing 233 million people, will have water demands that exceed surface-water availability. An additional 19 per cent of cities, which are dependent on surface-water transfers, have a high potential for conflict between the urban and agricultural sectors, since both sectors will not be able to obtain their estimated future water demands. In 80 per cent of these high-conflict watersheds, improvements in agricultural water use efficiency could free up enough water for urban use.

This indicates that the pressure of growing competition for water resources could be reduced not only by investing in improving agricultural water use as an important global change adaptation strategy, but also through an efficient use of biomass (including a reduction of food waste).

FIGURE 4.10 **Top 20 cities under urban surface-water deficit affected by climate change and socio-economic development (including urbanization).**



Two scenarios were analyzed: (1) urban surface-water supply gets first priority; or (2) cities receive the remaining water after water demand of other sectors has been fulfilled (last priority). Median urban surface-water deficit is shown; error bars represent the range of uncertainty resulting from the climate forcing data of five global hydrological models. Only withdrawal points located in sub-basins ≥ 10 grid cells (> 800 km2) are considered.
Source: Florke et al., 2018.

Future water withdrawal for agriculture is currently being modelled and has not yet been available for this report. Although the expansion of irrigated land has been diminishing over past decades, relevant projections are still being developed. First results for the water demand from the area already under irrigation were obtained by multi-model projections under climate change assumptions (Wada et al., 2013). The authors forced a set of seven global hydrological models with climate projections from five global climate models to project water demand and water consumption by irrigation. Although most models indicate a rising trend, the uncertainties of the model outcomes are substantial. In this case, the ensemble mean values may not be reliable: only one of the global hydrological models (LPJmL) considers CO_2 fertilization effects on crop synthesis and transpiration, and as a result projects decreasing trends of water demand for irrigation, while all other models that neglect this effect project increasing trends.

Altogether, one may expect rising water withdrawal globally for industries and municipalities, and probably growing risks resulting from uncertainties in water supply and distribution in agriculture due to climate change. These trends might be associated with an increasing competition for water between sectors, such as between expanding cities and neighbouring agriculture – particularly in water-scarce regions (see box 4.1).

4.1.4 *Historical Trends* Outlook for Land Use

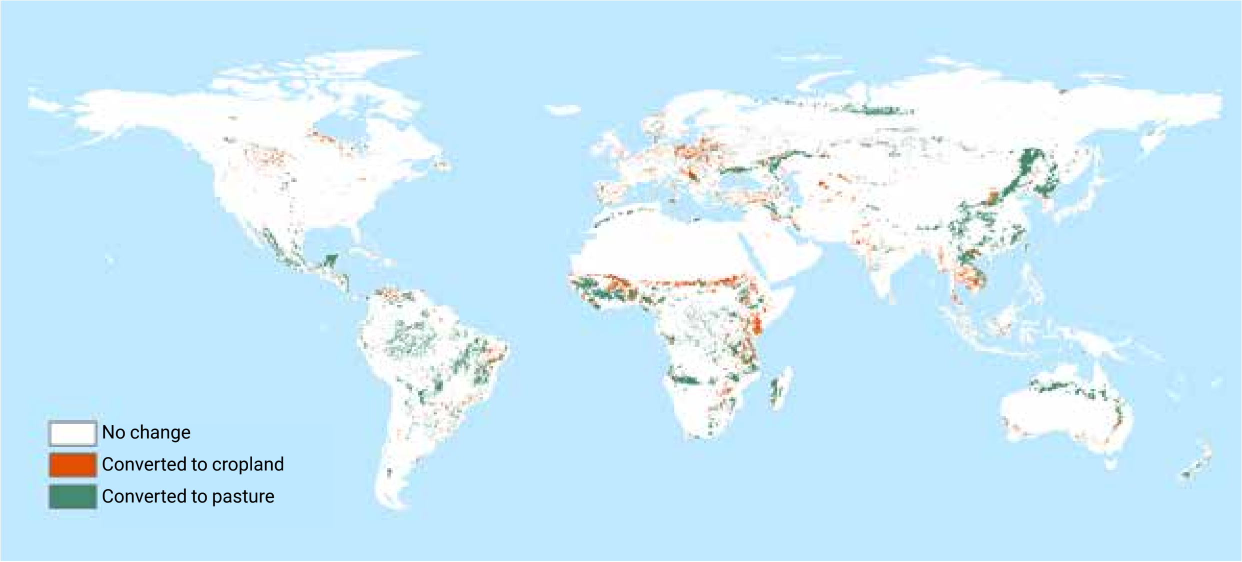
The analysis of land use and the loss of forests and other natural habitats uses two modelling frameworks: Land SHIFT (as described in sections 4.7.3 and 4.7.5 below) and the CSIRO/IIASA GNOME3 framework (used for all other analyses in this chapter, except water use). More details are provided in the separate Technical Annex.

Earlier studies have shown that uncontrolled expansion of settlement and infrastructure area may lead to a coverage of up to 5 per cent of total land in 2050 (UNEP, 2014 and references therein). By 2030, urban expansion is expected to result in a 1.8 to 2.4 per cent loss of global croplands, with about 80 per cent of the loss taking place in Asia and Africa where the lost area has twice the productivity compared to national average (d'Amour et al., 2017).

From 2010 to 2060, significant land-use change is expected in the *Historical Trends* scenario. In particular, shrubland, grassland and savannahs are converted to cropland and pasture (figure 4.11).

Under the *Historical Trends* scenario between 2010 and 2060, the LandSHIFT analysis finds total global cropland area increases by 21 per cent from 15.4 million to 18.6 million km² (figure 4.12). The largest increases are in Africa, Europe (including all countries in the former Soviet Union) and North America. An important reason for this area expansion is that the projected yield increases are

FIGURE 4.11 **Land conversion to cropland and pasture between 2010 and 2060 under the Historical Trends scenario as calculated by the LandSHIFT model**



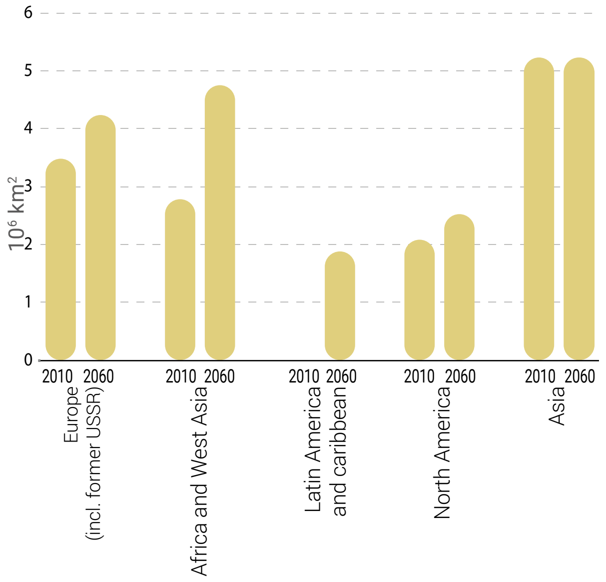
Source: UniKassel/CESR.

not sufficient to compensate the production increases necessary for food provision, especially in Africa.

Global pasture area increases by 25 per cent, from 30.9 million km² in 2010 up to 38.6 million km² in 2060. The largest increases are located in Africa and Latin America. Only in North America do pasture and rangeland areas decrease slightly (figure 4.13). Worldwide, the share of intensively used pasture increases from 52 per cent in 2010 to 60 per cent in 2060.

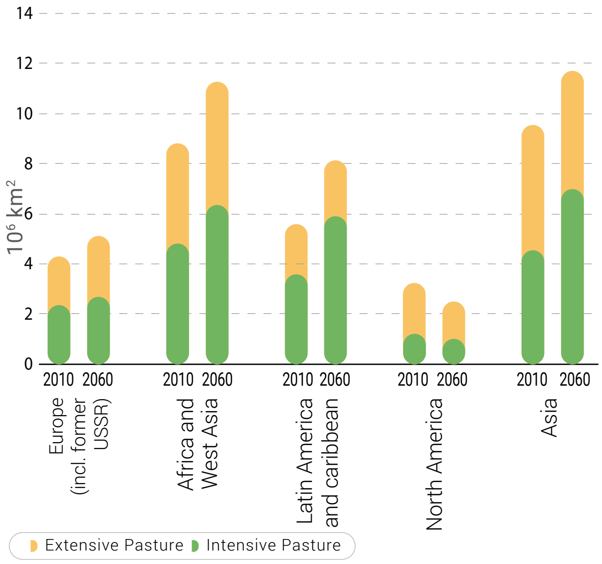
Considering only drivers outside the forest sector, relatively small net forest losses are modelled on all continents. Total forest area would decrease from 42.8 million km² in

FIGURE 4.12 **Cropland expansion under the Historical Trends scenario between 2010 and 2060 (LandSHIFT)**



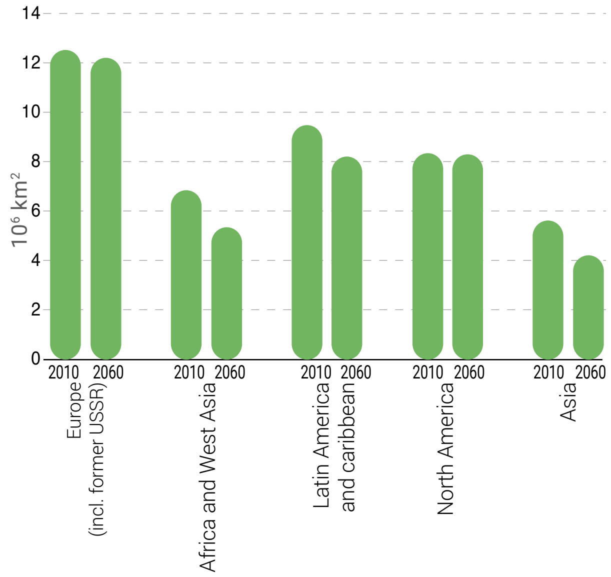
Source: UniKassel/CESR

FIGURE 4.13 **Development of pasture area under the Historical Trends scenario between 2010 and 2060 (LandSHIFT)**



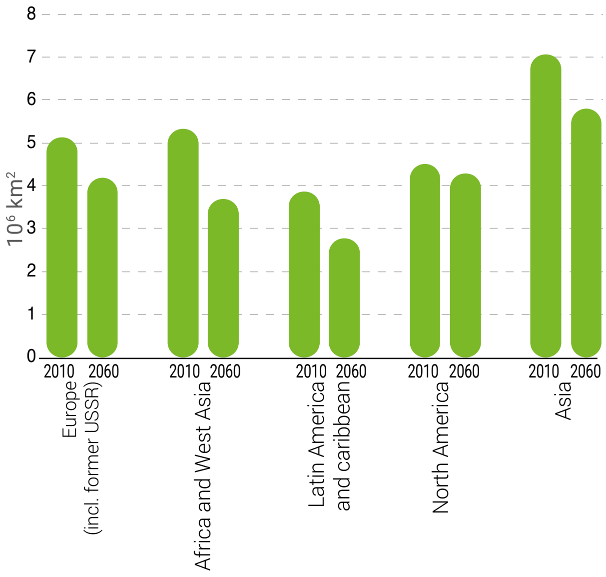
Source: UniKassel/CESR

FIGURE 4.14 **Loss of forest area under Historical Trends (LandSHIFT)**



Source: UniKassel/CESR

FIGURE 4.15 **Loss of grassland, shrubland, and savannahs under Historical Trends scenario (LandSHIFT)**



Source: UniKassel/CESR

2010 to 38.3 million km² in 2060 (figure 4.14). Hot spots of deforestation are located in Africa, Latin America and Asia.

Figure 4.15 shows the development of grassland, shrubland and savannahs. Their total area decreases by 20 per cent, from 25.8 million km² to 20.7 million km² in 2060. The largest losses are in Africa, Latin America and Europe. This trend seems most alarming, as those natural ecosystems harbour a significant share of terrestrial biodiversity (MEA, 2005).[7]

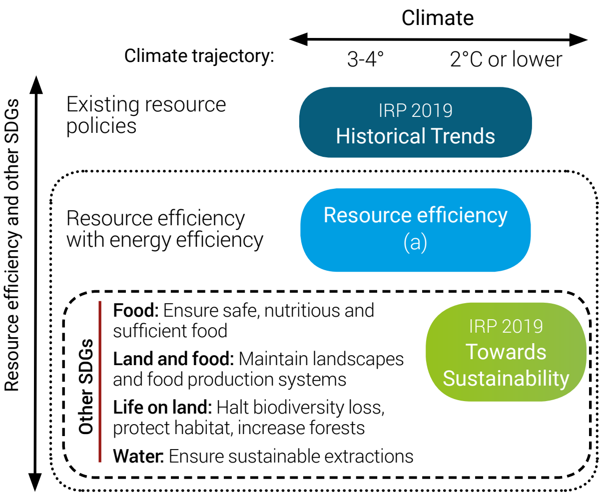
The analysis based on the GNOME3 modelling framework also found significant shifts, with agricultural land projected to increase by 8 per cent, while forest area reduces by about 80 million hectares (2 per cent) and other natural habitat reduces by about 320 million hectares (9 per cent) from 2015 to 2060 (see figure 4.22(b) and figure 4.23 below).

4.3 Overview of the *Towards Sustainability* Scenario

The *Towards Sustainability* scenario presents an ambitious and broad-based suite of actions by government, business and households to improve resource efficiency, decouple economic growth from environmental degradation and promote sustainable production and consumption, as called for by SDG 8.4 and SDG 12.1. We contrast the results for the *Towards Sustainability* scenario with the baseline *Historical Trends* scenario.

Sustainable Consumption and Production is interpreted broadly, with the analysis covering key aspects of resource efficiency (SDGs 8 and 12); food (SDG 2), water (SDG 6), energy (SDG 7), climate (SDG 13), and life on land (SDG 15) as shown in figure 4.8 below. The resource efficiency and sustainability action policies that underlie the *Towards Sustainability* scenario are described in the next section, with more details on scenario definitions and modelling assumptions provided in the next section and in table 4.1 below in the technical notes.

FIGURE 4.16 **Scenarios for resource efficiency and sustainable consumption and production**



Notes: More details of scenario assumptions are provided in Table 4.1 below. While broad definitions for Historical Trends and Resource Efficiency are similar to the 2017 analysis, results vary dues to differences in implementation including updated base year data and baseline economic growth assumptions. (a) This scenario applies the Resource Efficiency modelling treatment and no others.

The modelling builds on previous analysis by the International Resource Panel for G7 leaders (Hatfield-Dodds et al., 2017; UNEP, 2017), which was more closely focused on resource efficiency rather than SCP, and potential synergies with reducing greenhouse gas emissions. The new analysis for this report builds on this to assess actions to promote sustainable and productive food, water and landscape systems – along with better protection of biodiversity and native habitat. It also assumes a greenhouse emissions pathway consistent with 1.5°C rather than 2.0°C, involving a more rapid decline in net greenhouse gas emissions in the climate action scenarios than the 2017 analysis, reducing the need for net negative emissions later in the century while achieving a similar cumulative emissions budget to 2100. While the modelling also accounts for some economic impacts of climate change, particularly in relation to agricultural production, these impacts are not well represented in this analysis.

We describe the scenario as *Towards Sustainability* because the modelling framework focuses on the extraction and use of natural resources, as well as two major environmental issues – greenhouse gas emissions and protection of terrestrial biodiversity. Each of these

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[7] See also regional assessments of IPBES: https://www.ipbes.net/deliverables/2b-regional-assessments [accessed 8 Nov. 2018].

has well-understood drivers, dynamics and linkages to economic activity and supply of key resource-based services such as stationary energy, transport, land use and production of food and fibre. We anticipate being able to extend and deepen the scope of the analysis over time to include issues such as air quality, mobility, urban design, water use, aquaculture and ocean fisheries. We are also already working to improve our analysis of resource use, particularly in relation to urban systems, resource recovery and the circular economy.

4.4 Policy Packages and Societal Shifts that Underlie the *Towards Sustainability Scenario*

The modelling assumes three policy packages and one shift in societal behaviour that combine to produce the *Towards Sustainability* scenario outcomes relative to *Historical Trends*.

4.4.1 Resource Efficiency Policies

The resource efficiency policy package (RET in table 4.1) uses three measures to reduce global resource extraction and use, thereby achieving absolute reductions in per capita resource use (DMC) in high-income countries and slower growth of resource use in low- and medium-income countries. Resource efficiency innovation and improvement reduces the amount of virgin resources required to produce basic materials (including iron and steel, non-ferrous metals, chemicals/plastics and forestry products), as well as the amount of basic materials required in manufacturing (machinery and durable goods) and construction (buildings and infrastructure). In practice this measure could be implemented through policies such as public research programmes, incentives for private research and development (R&D); support for demonstration projects, business incubators and other incentives for innovation and technology adoption. This reduces resource inputs per unit of output, and thus reduces the supply cost of manufactured goods, buildings and infrastructure – generating a significant 'rebound effect' that offsets much of the potential reduction in virgin resource demand. The second suite of measures involves changes to regulations, technical standards, planning and procurement policies that act to progressively lower resource intensity of economic activity while maintaining or improving the services or amenity provided (such as the space and comfort provided by buildings). These measures are modelled as promoting manufactured items and buildings that require lower inputs of basic materials and associated raw resource inputs, without inducing increased overall demand. Finally, to manage the rebound effect, a range of policies is implemented to ensure resource scarcity is reflected in economic decision-making, including avoiding environmental damage from resource extraction (such as mining), use and disposal. These policies are modelled as a progressive increase to the cost of resource extraction, encouraging more efficient use and higher recycling rates, through a modest shift of taxation from income and consumption (including wages, payroll and sales taxes) to resource extraction.

Modelling implementation builds on previous IRP analysis, with the same approach to resource efficiency innovation and improvements in technical standards implemented from 2020 to 2060 (see Hatfield-Dodds et al., 2017). Policies to signal resource scarcity, represented by the extraction tax, are implemented in the same way in medium- and low-income nations, but set 25 per cent higher in high-income nations.

Consistent with previous analysis, the effectiveness and economic impacts of resource efficiency measures crucially depends on the relative weight given to each of these three measures, and on the detailed design and implementation of the policies used. While the package of resource efficiency measures implemented in the modelling boosts economic growth and provides net economic benefits, poorly designed and badly implemented strategies could slow growth and result in net economic costs.

It is also important to note that the modelling of the current *Towards Sustainability* scenario does not explore the full potential of circular economy policies, including ambitious resource recovery and recycling, which would be expected to deliver greater reductions in resource use (relative to *Historical Trends*) than presented in this report.

4.4.1 Climate Policies to Reduce Greenhouse Gas Emissions and Remove Atmospheric Carbon

The climate policy package involves two measures.

A global emissions reduction policy is implemented through a carbon levy and dividend (referred to as CPT[1] in table 4.1). For simplicity and transparency, the levy is modelled as applying equally to all countries and to all emissions sources, including emissions from land clearing. Equity issues associated with emissions reductions are dealt with through returning all net carbon revenues as a uniform per capita global dividend, regardless of where the revenue is raised. This is simpler and more transparent than implementing differentiated emission targets and tradable emissions rights, and is consistent with evidence that using revenues to provide a carbon dividend payment to households could promote equity objectives and help ease some of the political challenges associated with implementing ambitious emissions reductions (see Klenert et al., 2018). Sequestration from biodiversity plantings and reafforestation receives a subsidy at the same rate per ton of carbon as the levy. To maximize biodiversity outcomes, monoculture plantings are not eligible for the carbon subsidy.

The level of the levy is set to achieve an emissions pathway consistent with limiting climate change to 2°C (matching the cumulative emissions budget for RCP2.6), in a world with medium population and no resource efficiency measures. This mitigation effort is similar to the climate policy settings in previous analysis by the International Resource Panel for G7 leaders. Consistent with the climate policy literature (summarized by Stern & Stiglitz, 2017), the levy begins at US$15/t$CO_2$e in 2020, rising rapidly to US$100/t$CO_2$e in 2030, after which it increases by 5 per cent per year above inflation.

An additional carbon removal policy (referred to as CPT[2] in table 4.1) builds on the emissions reductions policies above, responding to growing attention to the benefits of keeping global warming *well below* 2°C (see IPCC, 2018), through more rapid decarbonization and limiting the extent of emissions 'overshoot'.

This policy package supports early deployment of two carbon dioxide removal (CDR) technologies: bioelectricity with carbon capture and storage (BECCS) and direct air capture (DAC) of CO_2 (see Obersteiner et al., 2018). Implementation is supported by a technology subsidy that covers capital and operating costs of BECCS and DAC, with deployment ramping up from 2020 to 2030 to achieve 1.2 GtCO_2e of CDR per year from 2030 through to 2100. Like any 1.5°C scenario, this assumes that a range of technical challenges will be overcome to allow large scale deployment of technologies that have not yet been demonstrated (IPCC, 2018). To manage concerns about competition for land and upward pressure on food prices, BECCS accounts for one quarter of total CDR, contributing 0.3 GtCO_2e per year and 17,250 TWH of 'negative emissions' energy once mature, while DAC contributes 0.9 GtCO_2e per year from 2030. The cost of the subsidy declines gradually after 2030, as technology costs fall. The subsidy is funded by high-income countries in proportion to per capita GDP above US$15,000 (in real 2011 dollars), consistent with capacity to pay and general notions of historical responsibility.

Policies to support resource efficiency and increased biodiversity (beyond the carbon subsidy) and societal shifts to reduce food waste and lower meat consumption all reduce emissions even further.

The combined result of the emissions reductions and carbon removal policy packages, as well as the contributions of other policies and societal shifts, result in cumulative emissions in the *Towards Sustainability* scenario well below the benchmark IPCC 2°C pathway (RCP2.6), with a 50 per cent chance of limiting global warming to 1.5°C above pre-industrial levels in 2100.

4.4.1 Policies to Protect Landscapes and Life on Land

The third policy package adopts an integrated approach to protecting landscapes and biodiversity (referred to as LBT in table 4.1). This ensures climate mitigation and energy policies are aligned with land and food system goals, and minimizes the additional actions required to achieve desired biodiversity outcomes. Applying the carbon levy to emissions from land clearing helps avoid deforestation, and payments for land sector sequestration are only provided where this contributes to improvements in biodiversity. To reduce competition for land and avoid upward pressure on food prices, policy incentives for crop-based biofuels are phased out by 2020, and bioenergy for electricity generation is focused on BECCS (with carbon capture and storage) - on the basis that this contributes to net negative emissions.

Additional conservation policies are implemented, where required, to ensure the Aichi target of a least 17 per cent of each ecoregion is protected. This is modelled through preventing loss of native vegetation in areas identified as key biodiversity areas (BirdLife International, 2017) or wilderness (Watson et al., 2016) and providing additional incentives where required for land use change providing biodiversity benefits (Leclère 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), and reduced barriers to agricultural trade.

Together, these policies limit the extension of agricultural land and promote dramatic improvements in biodiversity outcomes, so that the area of forests and natural land increases by 11 per cent rather than falling by 5 per cent from 2015 to 2060 under *Historical Trends*. This prevents the loss of around 400 million hectares and re-establishes around a further 800 million hectares of forests and natural land, including 430 million hectares of reafforestation. The smaller area of agricultural land in the *Towards Sustainability* 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.

4.4.1 Healthy Diets and Reduced Food Waste

The *Towards Sustainability* scenario assumes a shift in societal behaviour towards healthy diets (consistent with international dietary guidelines) and reduced food waste throughout the food supply chain. This shift is referred to as FDT in table 4.1. The shift towards healthy diets is supported by rising average incomes, reduced poverty and improved public understanding of the long-term benefits of a healthy diet and lifestyle. Reduced food waste provides savings to producers, processors and consumers, as well as increasing food availability and reducing environmental pressures.

The shift in diets is modelled as a shift from animal to plant protein, involving a 50 per cent reduction in meat consumption relative to *Historical Trends* by 2050, except in regions with a low share of meat in diets. The modelling assumes that total losses in harvest, processing, distribution and final household consumption decrease by 50 per cent relative to *Historical Trends* from 2020 to 2050, and then remain stable.

4.5 Towards Sustainability Outlook for Resource Use, Well-being and Environmental Impacts

This section reports our key findings for resource use and the potential for resource efficiency and sustainable consumption/production actions to decouple economic growth, resource use and environmental impacts, so that human well-being improves while environmental impacts reduce. We report our findings on resource use, well-being (and resource-based services) and environmental impacts, with a focus the distribution of each of these across countries. This is followed by a discussion of the economic impacts of the decoupling policies modelled.

4.5.1 *Towards Sustainability* Policies and Actions Result in Slower Growth in Global Resource Use, and Support More Equal Per Capita Resource Use Across Countries

Resource efficiency and sustainability actions are projected to result in slower growth of global natural resource use, with strong growth rates in emerging and other developing economies balanced by absolute reductions in per capita resource use in high-income countries. Global resource extractions are projected to increase by 1.6 per cent per year from 2015 to 2060, around one quarter below the average for *Historical Trends* (and the observed increase from 2000 to 2017), to reach 143 billion tons in 2060. This is 25 per cent lower in 2060 than under a continuation of *Historical Trends*, equal to 47 billion tons of avoided resource extractions in that year alone (figure 4.17). This reduction in growth would help take pressure off resource supply systems, and make it easier to avoid resource extraction and use - with their relatively high social and environmental impacts per unit of resource throughput.

Non-metallic minerals (used primarily in construction) account for two thirds (65 per cent) of total resource extractions and four fifths (82 per cent) of the growth from 2015 to 2060 (figure 4.17) - a little higher than their proportion in *Historical Trends*. Extractions of fossil fuel resources are projected to decline from current levels in the *Towards Sustainability* scenario, as renewable energy technologies outcompete non-renewable options in both electricity and transport, supported by concerted action to reduce greenhouse gas emissions. Resource efficiency policies result in substantially slower growth in the extraction and use of metal ores, which grow by 10 per cent to 2060 in this scenario, compared to 111 per cent growth under *Historical Trends*. Reductions in per capita biomass extractions associated with reductions in food waste are outweighed by population growth and uptake of bioelectricity with carbon capture and sequestration – a crucial potential 'negative emissions' technology. These factors combine to produce a 40 per cent increase in global biomass extractions by 2060, compared to 88 per cent under *Historical Trends*.

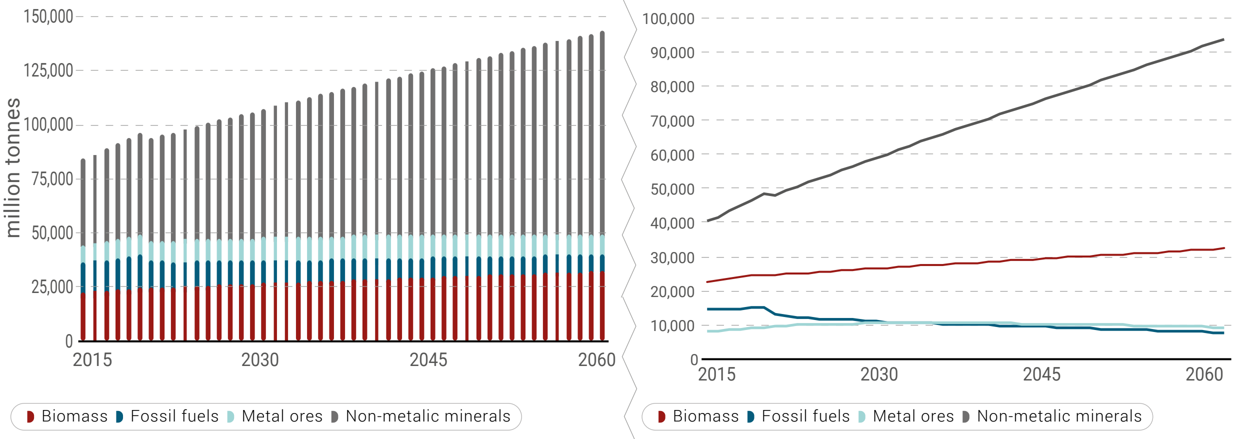
Resource use (DMC) adjusts resource extractions (DE) in each country or region by accounting for physical trade in basic resources. Resource use is thus equal to resource extraction at the global level in each year, but is not equal for individual countries and regions.

Resource efficiency and sustainable consumption and production measures slow the growth of resource use significantly, without impacting negatively on income and other well-being indicators (see below). The *Towards Sustainability* scenario sees world resource use reach a level that is 25 per cent lower in 2060 than under *Historical Trends*. Per capita resource use in the *Towards Sustainability* scenario converges across different country groups by 2060: falling by 17 per cent from 2015 levels (in absolute

FIGURE 4.17 **Global material extractions (DE) by major categories, Towards Sustainability and other scenarios, 2015-2060**

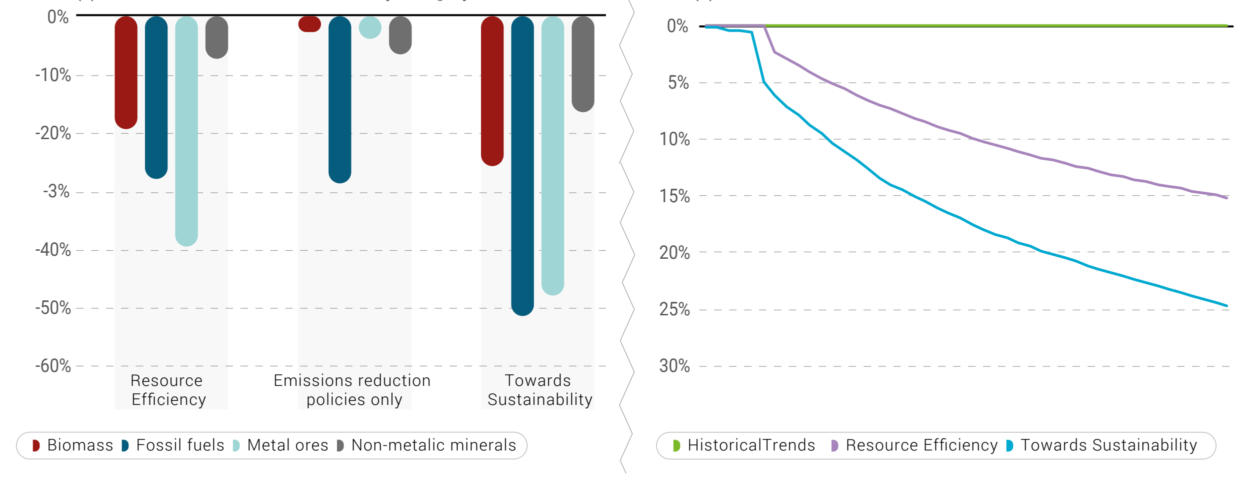
(a) Extractions by major category (stacked)

(b) Extractions by major category (individual)



(c) Deviation from Historical Trends by category in 2060

(d) Deviation from Historical Trends, total extractions

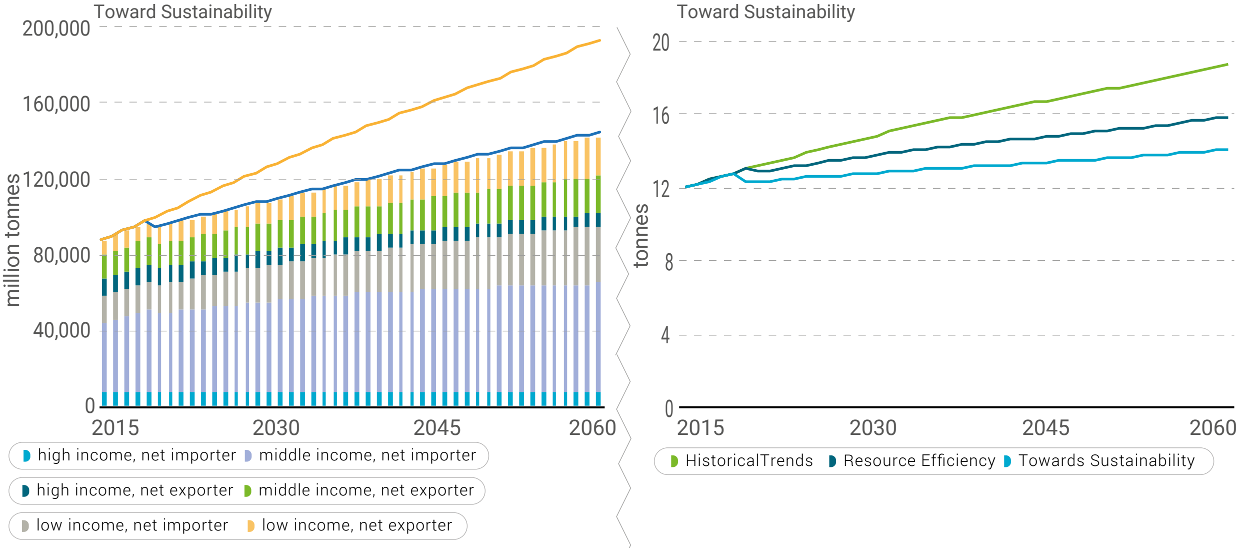


terms) to an average of 13.6 tons per capita in high-income countries, and increasing 44 per cent to an average of 8.2 tons per capita in low-income countries. Global demand for manufactured products drives strong growth in resource use (DMC) per capita in the case of resource importing middle-income nations, which increase from high current levels in all scenarios. Although this results in higher apparent per capita use in medium-income countries, a substantial portion of these resources is likely to be exported as manufactured products. Sustainability measures have smaller impacts on per capita resource use in lower income nations and on net resource importing nations, as shown in figure 4.18.

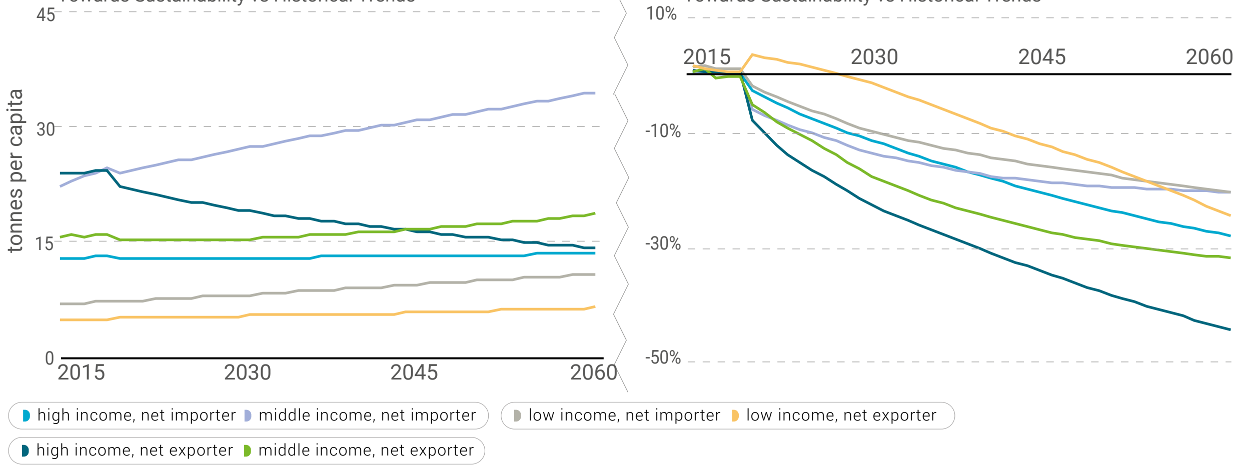
4.5.2 Well-being Indicators Grow Faster than Resource Extraction, with Improved Resource Productivity and Relative Decoupling of Well-being from Resource Use

We find resource efficiency and sustainability policies are projected to achieve substantial relative decoupling of natural resource use from income and essential resource-based services, including average income (GDP per capita), energy services and food. Global resource productivity (resource extractions per dollar of economic activity) increases by 27 per cent 2015 by 2060, while average GDP per person doubles. Energy productivity more than doubles, as electricity generation decarbonizes. It is also important to note that substantial improvements in energy efficiency will result in increased 'energy services' (such

FIGURE 4.18 **Global resource use (DMC), total and per capita for six country groups, Towards Sustainability and other scenarios, 2015-2060**


(a) Levels of economic activity and resource services, Toward Sustainability

(b) Measures of resource productivity, Toward Sustainability


(c) Deviation in economic activity and services, Towards Sustainability vs Historical Trends

(d) Deviation in economic productivity, Towards Sustainability vs Historical Trends as indoor comfort or vehicle passenger mobility) per unit of energy use – which is not reflected in the chart below.

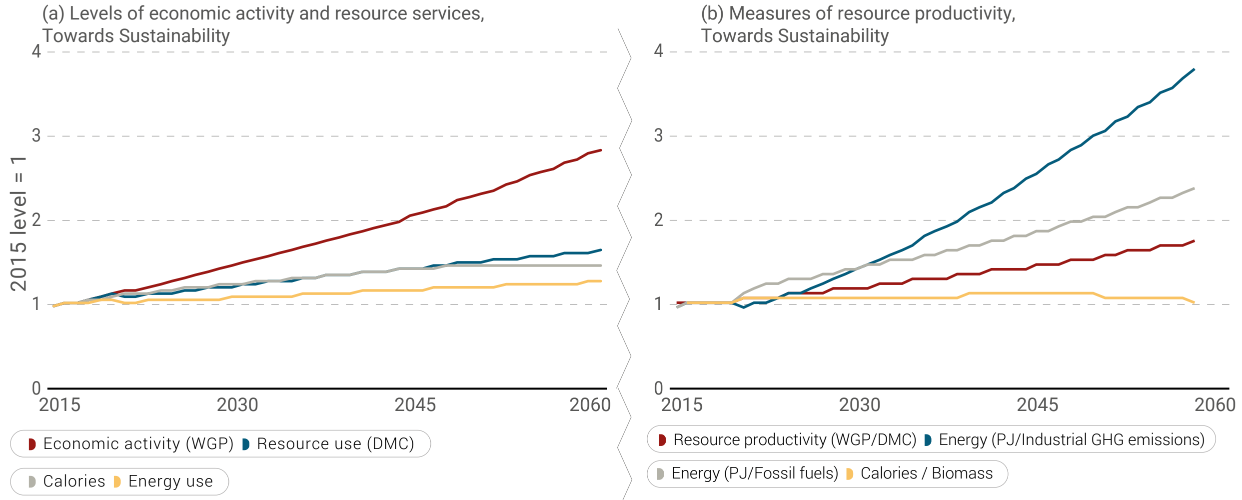
The analysis finds that reductions in food system waste improve food access and prevent declines in the supply of calories per capita (which would otherwise be adversely impacted by measures to reduce greenhouse emissions from agriculture). This results in per capita calorie intake increasing modestly from 2015 levels. Supply tracks the baseline projection for *Historical Trends* to 2045, but grows more slowly than the baseline from 2045 to 2060. Improved diet, air quality (from reduced fossil fuel use) and more active mobility (supported by sustainable urban systems) would deliver additional health benefits and economic gains, although these are not fully accounted for in the analysis.

4.5.3 Environmental Pressures Fall, with Absolute Decoupling of Environmental Damage from Economic Growth and Resource Use

Resource efficiency and sustainability actions are projected to achieve absolute decoupling of economic activity and resource use from environmental impact, so that incomes and other well-being indicators improve, while key environmental pressures fall – including dramatic reductions in greenhouse gas emissions and substantial restoration of forests and native habitat from 2015 levels.

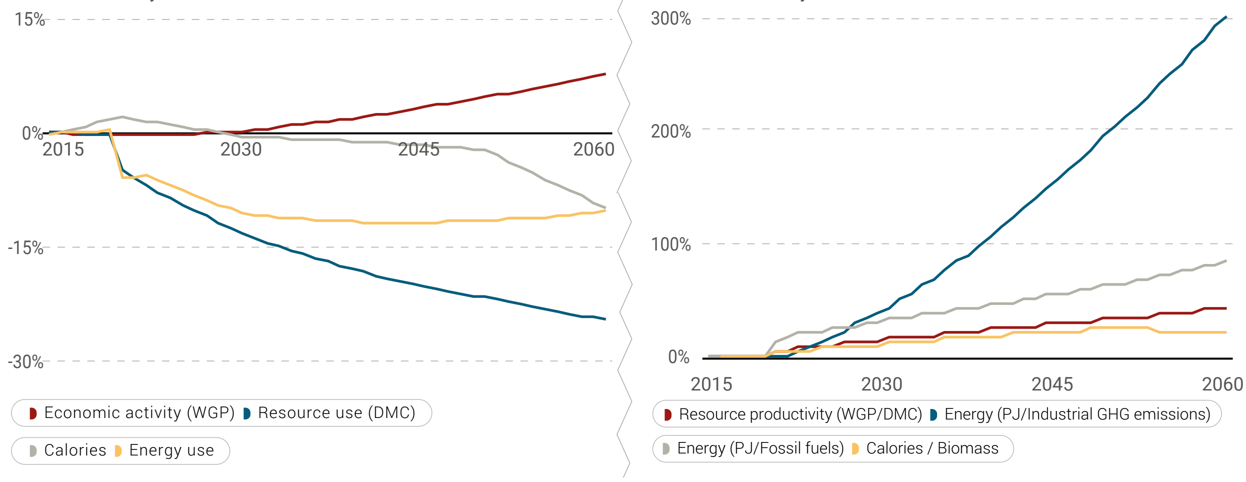
Ambitious emissions reduction and carbon removal policies, along with other scenario assumptions, see global greenhouse gas emissions fall by 5 per cent per year from 2015 in the *Towards Sustainability* scenario. This sees annual emissions fall by 90 per cent to 4.8 GT CO$_2$e in 2060, rather than rising 43 per cent to 70 GT CO$_2$e in

FIGURE 4.19 **Global resource productivity for materials, energy, and food, 2015-2060**



(a) Levels of economic activity and resource services, Towards Sustainability

(b) Measures of resource productivity, Towards Sustainability



(c) Deviation in economic activity and services, Towards Sustainability vs Historical Trends

(d) Deviation in resource productivity, Towards Sustainability vs Historical Trends

FIGURE 4.20 **Resource-based wellbeing indicators for country groups, 2015-2060**

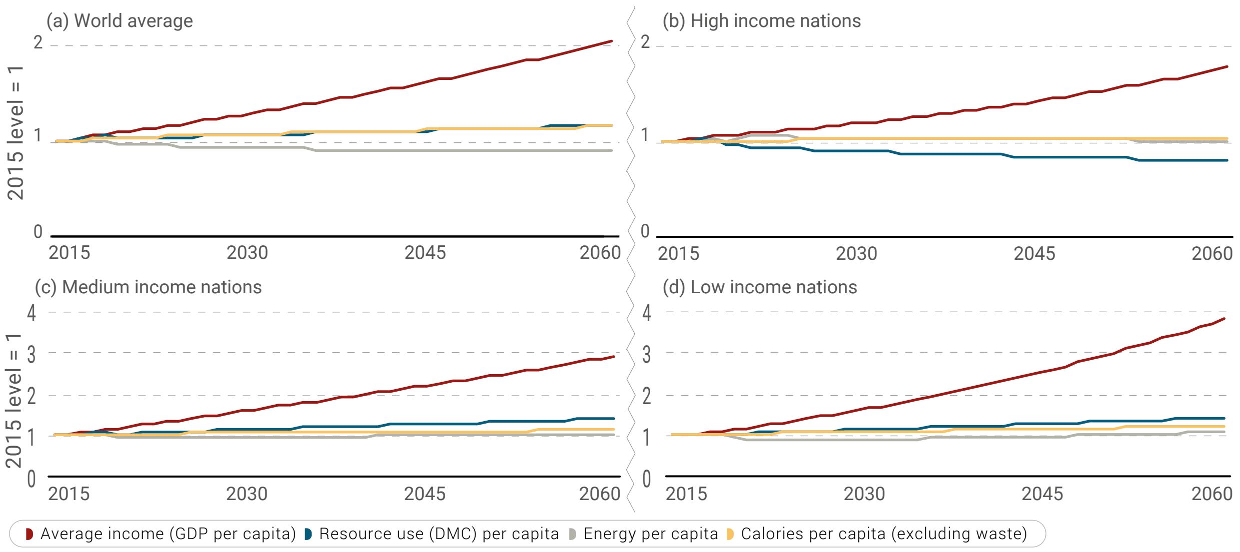
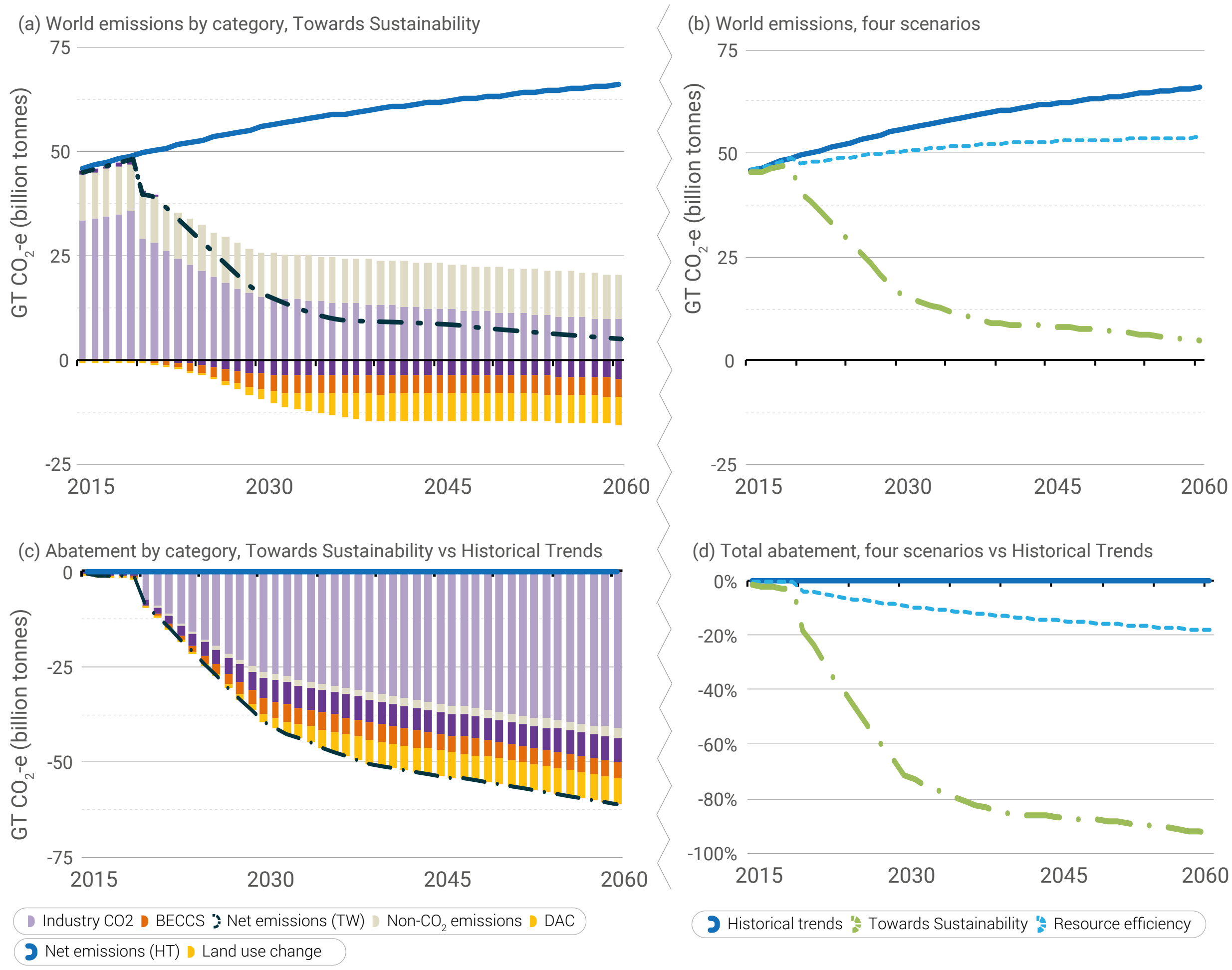


FIGURE 4.21 **Greenhouse gas emissions and abatement, Towards Sustainability and other scenarios 2015-2060**



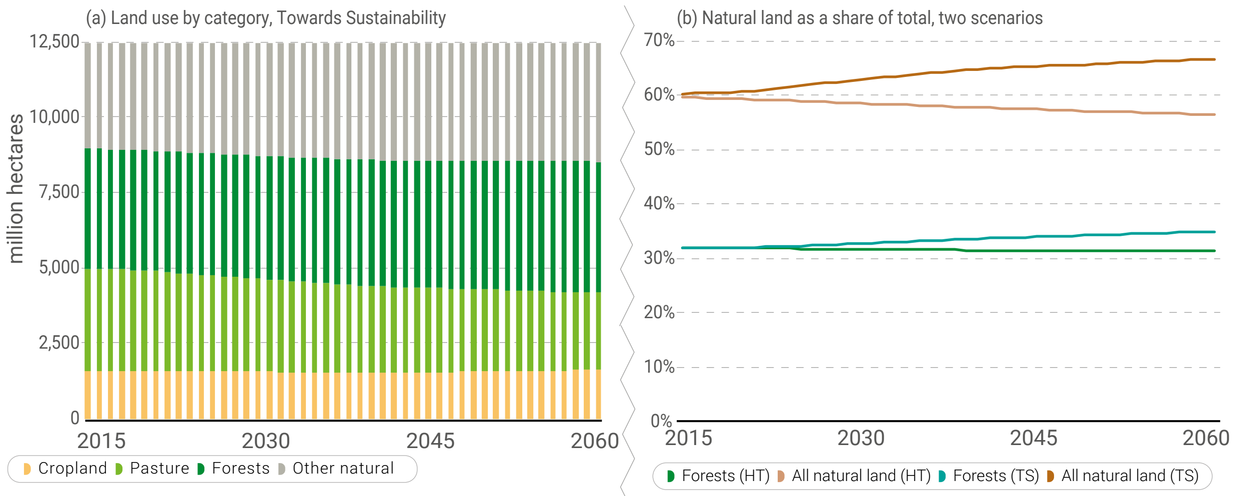
2060 under *Historical Trends*. (One GT CO_2e is one billion tons of CO_2-equivalent emissions.) In practice, the climate mitigation policies would be expected to achieve even greater emissions reductions, but the modelling framework does not account for expected electrification of industrial heat or substitution of renewable energy based synthetic gases, and so the modelling assumes continued reliance on natural gas. Resource efficiency policies are projected to reduce GHG emissions by 19 per cent compared to *Historical Trends* by 2060, in the absence of other climate policies (shown as the difference between *Historical Trends* (dark blue) and Resource Efficiency (dotted light blue) lines in figure 4.21 panels (b) and (d)).

This results in the *Towards Sustainability* scenario having cumulative emissions well below benchmark IPCC 2°C pathway (RCP2.6), with a 50 per cent chance of limiting global warming to 1.5°C above pre-industrial levels and a much better chance of limiting warming to 2°C or lower.

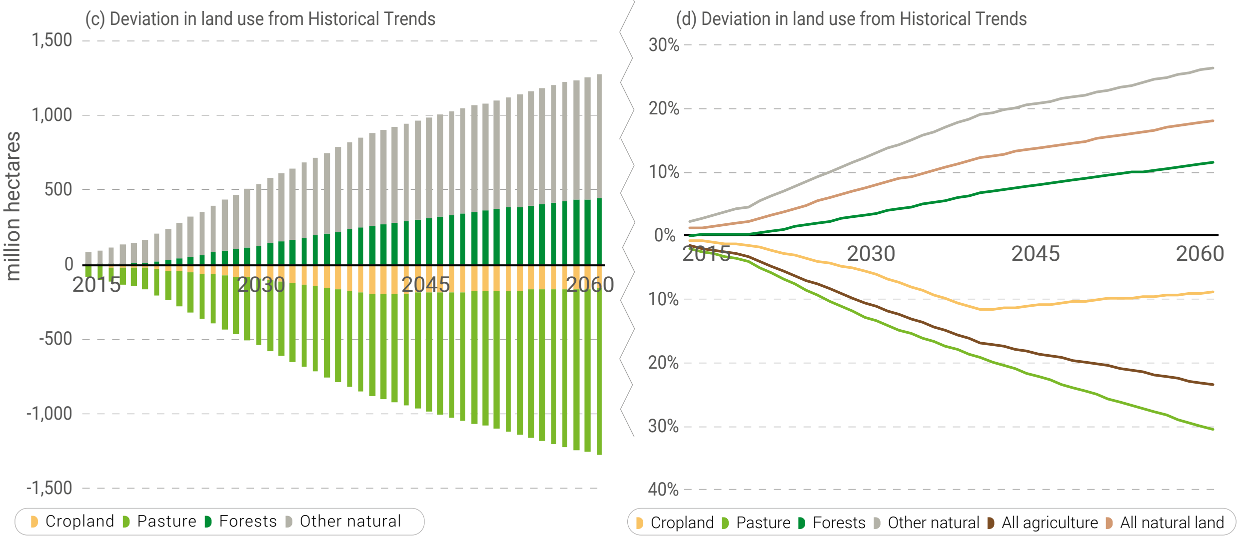
BECCS, reafforestation and direct air capture of CO_2 emissions (using artificial trees and soda lime processing) accounts for around one third of the total abatement achieved by the *Towards Sustainability* scenario relative to *Historical Trends*.

The *Towards Sustainability* scenario delivers outcomes for land use that meet the food and fibre requirements of a growing population, while increasing the area of forest and other natural land to enable carbon capture and limit biodiversity loss through delivering additional habitat for species. Global habit loss is reversed, thereby preventing the loss of 1,300 million hectares of forests and other native habitat and restoring a further 450 million

FIGURE 4.22 **Land use and land use change for two scenarios, 2015-2060**


(a) Land use by category, Towards Sustainability

(b) Natural land as a share of total, two scenarios

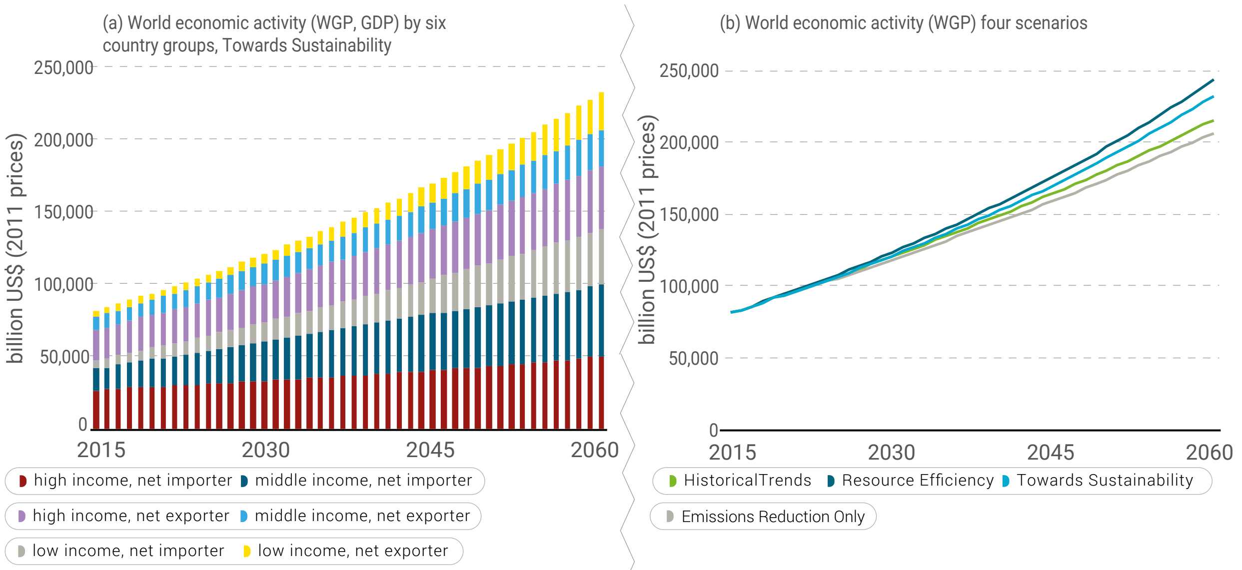

(c) Deviation in land use from Historical Trends

(d) Deviation in land use from Historical Trends hectares of forests by 2060, while per calorie consumption increases by 4 per cent globally and 19 per cent in low-income countries from 2015 levels (after accounting for reduced food system waste). This is achieved without increasing agricultural water extractions in water-stressed catchments. The area of cropland in the *Towards Sustainability* scenario is 9 per cent below *Historical Trends* in 2060, while the area of pastureland is 30 per cent below. This sees the area of natural land increasing by 11 per cent from 2015, with 11 per cent more forest and 26 per cent more natural land than *Historical Trends* in 2060 (figure 4.22).

4.5.5 Sustainability Measures Promote Stronger Economic Growth, Boost Well-being and Help Support More Equal Distribution of Income and Reduce Resource Use Across Countries

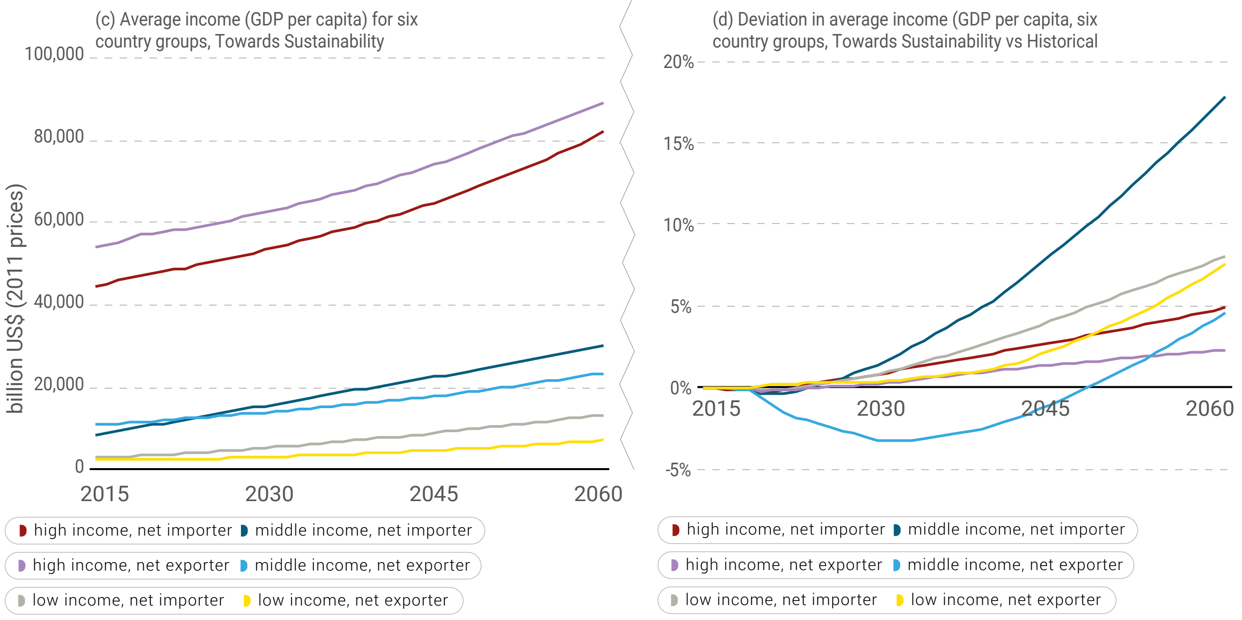
We find implementing an integrated package of resource efficiency, sustainability, and climate policy actions results in net economic benefits globally from 2030 onwards, with global GDP 8 per cent above *Historical Trends* in 2060, as projected economic gains from resource efficiency outweighing the near-term economic costs of achieving ambitious reductions in net greenhouse gas emissions. The suite of policies also supports more equal distribution of GDP per capita, increasing economic growth relatively

FIGURE 4.23 **Economic impacts of resource efficiency and sustainability actions, 2015-2060**



(a) World economic activity (WGP, GDP) by six country groups, Towards Sustainability

(b) World economic activity (WGP) four scenarios



(c) Average income (GDP per capita) for six country groups, Towards Sustainability

(d) Deviation in average income (GDP per capita, six country groups, Towards Sustainability vs Historical more in low- and middle-income nations (11 per cent on average) than in high-income nations (4 per cent on average) relative to *Historical Trends*.

As shown in figure 4.23, in *Historical Trends* GDP per capita increases from 2015 to 2060 in every income group: increasing 3.8 times (275 per cent) on average in low-income countries, 2.9 times (192 per cent) in middle-income countries and 1.8 times (76 per cent) in high-income nations. Sustainability measures reinforce this trend, increasing GDP and GDP per capita in every country group: lifting average incomes by an average of 8 and 13 per cent in low- and medium-income countries respectively by 2060, and by an average of 4 per cent in high-income countries. Middle-income resource exporting nations are the most adversely affected by the suite of sustainability actions, particularly the slower growth in world resource demand, and only become net beneficiaries in around 2050 as the longer-term benefits mature. These results do not account for likely second round economic benefits of improved diets, air quality and mobility, and only consider limited aspects of avoided climate change impacts.

Various aspects of the *Towards Sustainability* scenario have different economic effects, with improved resource efficiency and reduced food waste overcoming the near-term dampening effects of emissions reductions on GDP and GDP per capita (see figure 4.23b). Resource efficiency measures in particular impact differently across different groups of nations, with less positive effects on net resource exporters and on higher income nations (see figure 4.23d).

4.6 Conclusions

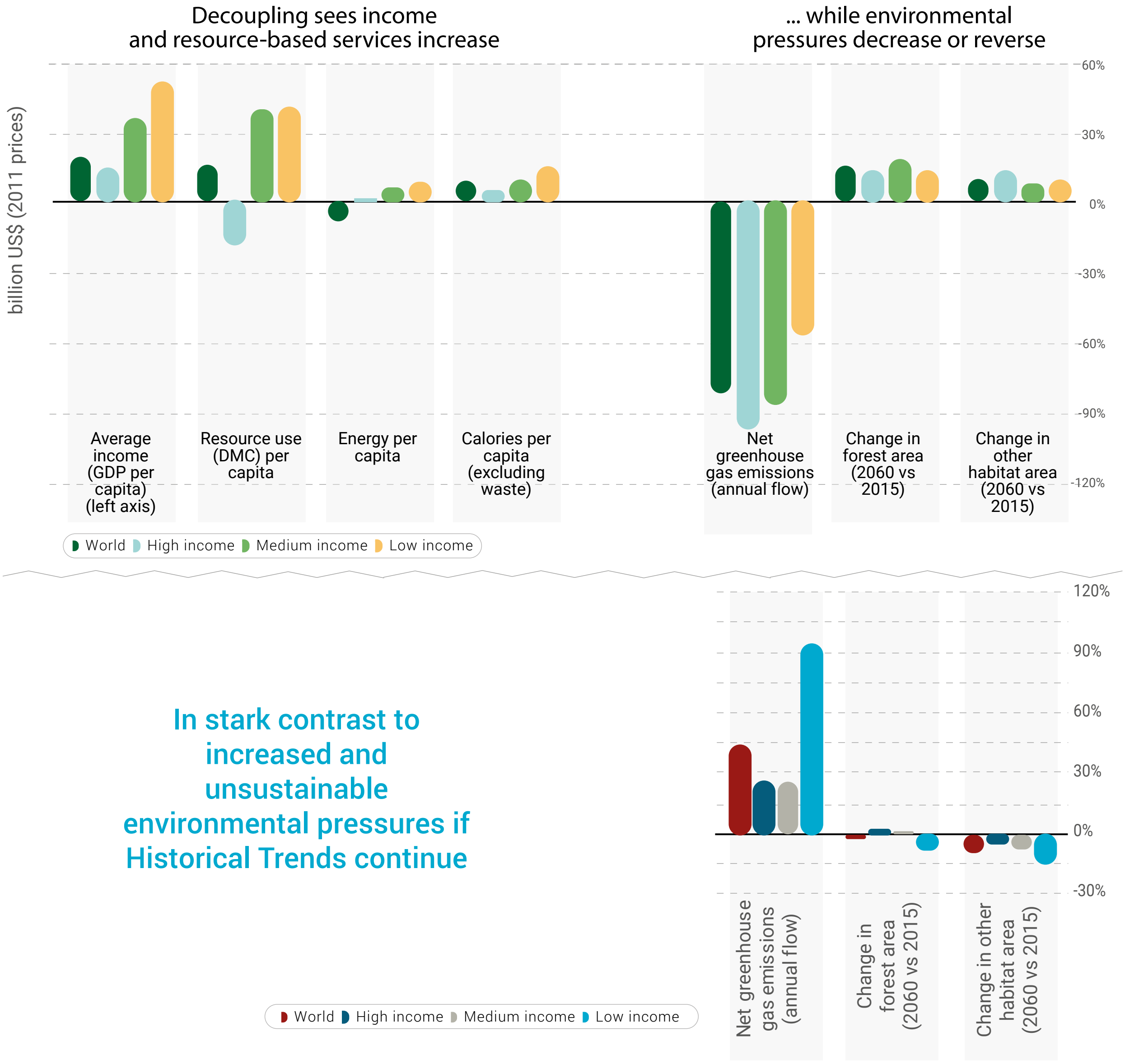
The analysis and modelling results presented in this chapter represent a first attempt to develop coherent scenario projections for resource efficiency and sustainable production and consumption that decouple economic growth from environmental degradation as called for by SDG Target 8.4 and SDG Target 12.1. This decoupling seeks to meet essential human needs for food, water, energy and shelter (represented by SDGs 2, 6, 7 and 9), while protecting the natural and social capital (represented by SDGs 13, 14, 15 and 17) that underpins all life and earth system functions.

Our central finding is that well-chosen and coordinated sustainability actions – particularly resource efficiency and sustainable consumption and production policies – can achieve significant decoupling, while achieving increased economic growth and a more equal distribution of income and resource access. Ambitious actions modelled in the *Towards Sustainability* scenario see incomes and resource-based services increase significantly across all groups of countries, while environmental pressures and impacts fall dramatically. This contrasts starkly with the outlook under *Historical Trends*, which has similar projected increases in income, but higher resource extractions and escalating and clearly unsustainable environmental pressures – including rising greenhouse gas emissions, increasing pressures on water sensitive ecosystems and reductions in the quality and extent of forests and other native habitats (see figure 4.24).

While possible and economically attractive, shifting from our established – and unsustainable – patterns of resource use and environmental impact towards 'a future we want' would require decisive action by governments and business around the world to support sustainable consumption and production practices.

An integrated analysis of this scale is complex, and is subject to many assumptions and caveats. We consider, however, that the insights generated are both important and robust. We hope that the methods and results presented will generate interest and debate, along with suggestions for improving and extending the analysis of these issues in the future.

FIGURE 4.24 **Resource efficiency and sustainable consumption and production (SCP) achieve significant decoupling to 2060**



Decoupling sees income and resource-based services increase

... while environmental pressures decrease or reverse

In stark contrast to increased and unsustainable environmental pressures if Historical Trends continue

Note: Change in average income shown against left hand axis; all other variables shown against right hand axis.

4.7 Technical Notes

4.7.1 Overview of Scenario Definitions and Assumptions

The analysis extends previous modelling of resource efficiency to assess the broader concept of Sustainable Consumption and Production, which is referenced in the title of SDG 12, and in SDGs 8.4, 12.1 and 12.a (UN, 2015). We make this broader approach tangible by interpreting resource efficiency and SCP through the lens of related SDG targets for food (SDG 2), water (SDG 6), energy (SDG 7), climate (SDG 13) and life on land (SDG 15), as detailed in table 4.1 below.

The baseline *Historical Trends* scenario has been constructed to align with the 'middle of the road' shared socioeconomic pathway narrative (SSP2) (O'Neil et al., 2017), with updated economic and population parameters. Population growth and per capita GDP projections are based on, or calibrated to, OECD (2018), thereby facilitating comparisons with current and future OECD analysis.

TABLE 4.1 **Summary of scenario treatments and assumptions**

	HISTORICAL TRENDS	TOWARDS SUSTAINABILITY SCENARIO	TREATMENTS*	SDG
Resource use and efficiency	Historical trends in per capita resource use and resource intensity.	Policies achieve a step change improvement in resource efficiency, slowing the growth of global resource extractions and use.	**RET**	8.4
Sustainable production and consumption (SCP)	*No specific measures*	*Towards Sustainability* interprets SCP as resource efficiency plus action on food, water, energy, climate, life on land food and water, and ensuring levels of non-renewable resource extraction are consistent with managing environmental impacts.	**all**	12.1 12.2
Climate and GHG emissions	Scenario calibrated to RCP6.0 cumulative emissions, with historical trends in greenhouse gas emissions	Emissions reductions calibrated to achieve RCP2.6 cumulative emissions (with medium population and no resource efficiency). Carbon removal (reducing atmospheric concentrations) through early deployment of BECCS and DAC technologies, avoiding the need for large scale negative net emissions later in century. Note other treatments also contribute to lower net emissions, as described in text.	**CPT**[1] **CPT**[2]	13 plus Paris
Energy	*No specific measures*	Emissions reductions actions substantially increase renewable energy share relative to HT. Bioenergy is limited to BECCS, and other biofuels not allowed. Rate of energy efficiency improvement at least doubles by 2030, relative to HT.	**CPT**[1]	7.2 7.3
Land	*No specific measures*	Limit the extension of agricultural land. Eliminate crop-based biofuels by 2020, reducing competition for land and food price pressures. Ensure zero net global deforestation by 2030, with net restoration of native habitat supported by payments for carbon biosequestration. Ensure Aichi target of at least 17 per cent of each ecoregion protected globally by 2030.	**LBT**	2.4 15.2 15.5 15.9
Water	*No specific measures*	Eliminate or substantially reduce irrigation-related water stress.	**LBT**	6.4 15.1
Food	*No specific measures*	Consumer driven shift to healthy diets (including access to safe, nutritious and sufficient food), supported by higher incomes and public policies. Reduce food waste per person 50 per cent by 2030.	**FDT**	2.1 12.5
Population	Medium: 10.2 billion in 2060, matching OECD reference scenario.		n.a	n.a
Shared Socioeconomic Pathway	SSP2: Historical trends continue, with uneven development and a weak focus on sustainability.	SSP1: The world shifts to a more sustainable path, emphasizing inclusive development and respecting environmental boundaries. Assumptions generally align with *Towards Sustainability* scenario. Diet and bioenergy assumptions go beyond SSP1.	n.a	n.a
Economic assumptions	Calibrated to OECD reference scenario.	*Towards Sustainability* accounts for economic impacts of policies and actions set out above, with no additional economic assumptions.	n.a	n.a

Notes: * Treatment codes are RET = Resource Efficiency Treatment; CPT = Climate Policy Treatment; [1] reducing greenhouse gas emissions, [2] removing atmospheric carbon; LBT = Land and Biodiversity Treatment; FDT = Food and Diet Treatments. SDG refers to SDG goal and target number.

The *Towards Sustainability* scenario is developed through four modelling treatments that together shift the world from *Historical Trends* to a well-rounded SCP-compatible pathway, broadly consistent with the narrative for the 'sustainability' shared socioeconomic pathway (SSP1) (O'Neill et al., 2017). The four treatments involve policy packages supporting resource efficiency, reduced greenhouse gas emissions and protection of landscapes and life on land, along with a societal shift towards healthy diets and reduced food system waste. The scenario assumptions and links to the SDGs are summarized in table 4.1 above, with detailed explanations provided in the main chapter text above.

More details on the contributions and impacts of the modelling treatments are provided in the separate Technical Annex.

4.7.2 Modelling Regions and Country Groups

Reporting and discussion of results is based on the 28 regions, aggregated into three economic and geopolitical groups (based on GDP per capita), each of which is divided into net importers versus net exporters based on physical trade balance in 2030. Each of these groups shares substantial common features and patterns of consumption and production, notwithstanding considerable variation across regions. Details of the 28 regions, including the countries within each, are provided in the separate Technical Report.

Table 4.2 provides summary statistics for economic groupings and net resource importers and exporters, based on projected results for 2030 under *Historical Trends*.

TABLE 42 Projected GDP per capita and shares of economic activity and population in 2030 by country groups

ECONOMIC / FUTURE INCOME GROUP	GDP PER CAPITA (REAL US$ 2011)	WGP SHARES	POPULATION SHARES
Developed / high			
all	**56,700**	**49 per cent**	**12 per cent**
importers	52,300	27 per cent	7 per cent
exporters	61,700	22 per cent	5 per cent
Emerging and transition / medium			
all	**15,000**	**34 per cent**	**32 per cent**
importers	14,900	23 per cent	21 per cent
exporters	14,100	11 per cent	11 per cent
Developing / low			
all	**4,100**	**17 per cent**	**55 per cent**
importers	5,100	11 per cent	29 per cent
exporters	3,100	6 per cent	26 per cent
World			
all	**14,200**	**100 per cent**	**100 per cent**
importers	15,100	61 per cent	57 per cent
exporters	13,000	39 per cent	43 per cent

Notes: Projections for *Historical Trends* in 2030. Average GDP per capita is real USD 2011, and rounded to three significant figures. WGP = World Gross Product, the global equivalent of GDP. Percentages may not add to total or subtotals shown due to rounding.

The economic groupings are based on projected real GDP per capita in 2030 under *Historical Trends*: high spans US$ 35,000 to US$ 85,000; medium spans US$ 10,000 to US$ 25,000 and includes emerging economies (except India) and transition economies; while low spans US$ 1,000 to US$ 8,500 in real US$ 2011). There are no countries with GDP per capita between US$ 25,000 and US$ 35,000 or between US$ 8,500 and US$ 10,000 in 2030. At the boundary between medium- and low-income, the GDP per capita of the lowest member of the medium-income group (South Africa) is 8 per cent lower than the next highest region in that group and 26 per cent higher than the highest member of the low-income group, in 2030 under *Historical Trends*.

4.7.3 Integrated Assessment and Modelling Framework

The analysis uses GNOME3 (Global and National Outlooks for Materials, Energy, Emissions and Environment): a multi-model framework developed by CSIRO and IIASA that links a multi-sector multi-region global computable general equilibrium (CGE) economic model (GTEM) to several sectoral models of electricity supply, road transport and land use (including agriculture, forestry and nature conservation) to a simple climate model. Model linking and coordination is implemented through a linking engine, coded in python, which also automates version control and archives input and output data files. An urban settlements and built assets model is under development, but not used in this analysis. The multi-model approach builds on the strengths of CGE economic models, including the analysis of second round employment and investment effects across sectors and regions, with improved representation of sectors where activity is strongly shaped by stock dynamics and asset turnover (Allen et al., 2016; Kelly et al., 2013).

Multi-model frameworks are able to leverage the established capacity and track record of all component models, which are familiar to a pre-existing research and policy community. Implementation requires up-front collaborative investment by the teams who operate each of the models, to establish appropriate cross-model linkages and identify any adjustments to the component models, such as to align sectors or regional structures. Once established, the multi-model framework allows considerable flexibility in how it is used and applied. In most cases, each component model can continue to be used on a stand-alone basis, and improvements within each model automatically become available to the framework as a whole.

More details on the component models and linking arrangements are provided in the separate Technical Report.

4.7.4 Material Flows and Resource Use Projections

Projections for natural resource domestic extractions (DE), physical trade balance (PTB) and use (domestic material consumption, DMC) are developed using the methods demonstrated in our previous analysis (Hatfield-Dodds et al., 2017; McCarthy et al., 2018). The method derives physical volume indexes from the CGE model for sub-categories of natural resources and applies them to base-year data from the UNEP International Resource Panel in order to generate scenario projections. This is consistent with methodological guidelines and international standards for material flow indicators (EUROSTAT, 2013) and national and global material flow accounting (Fischer-Kowalski et al., 2011). More details are provided in the separate Technical Report.

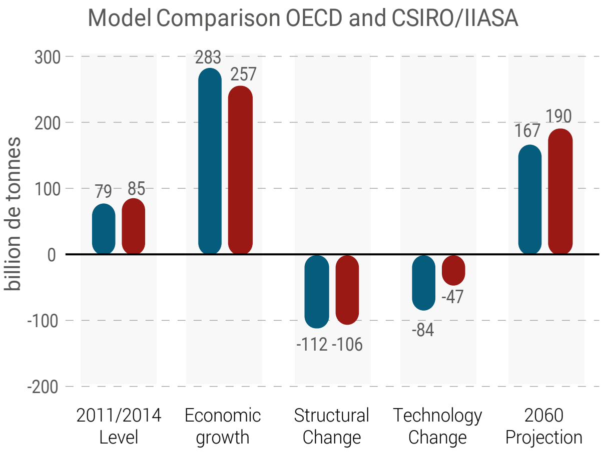
Resource extractions in the baseline scenario are driven by three main factors: economic growth (from OECD, 2018), structural change and the pace of technological change within each sector – particularly material intensive sectors. Structural change (the relative size of different economic sectors) is driven largely by rising incomes, which change the relative demand for different types of goods and services, along with demographic changes. For *Historical Trends*, the CSIRO/IIASA modelling calibrated technological change to observed trends in material intensity of sector output at the country and sector level, based on econometric analysis of historical IRP material flows data. As shown in figure 4.25, the major difference between the OECD and CSIRO/IIASA baseline projections of resource use relates to different views of the likely future within sector technological change, with our projections being less optimistic about technological change than the OECD baseline.

4.7.5 Modelling of Land Use in *Historical Trends*

Scenarios for land use change under *Historical Trends* were developed using two modelling frameworks: GNOME3 (described above) and the LandSHIFT global land system model (Schaldach et al., 2011). The LandSHIFT model does not include the forest sector, and dynamics of logging and changes in forest composition are not considered. The shown trend results for forest area reflect changes mainly driven by agriculture.

Model drivers used as input data for the LandSHIFT simulations were derived from a study conducted with the GLOBIOM model (Havlík et al., 2011) for a scenario that follows the Shared Socioeconomic Pathway 2 (SSP2). This SSP describes a world that "follows a path in which social, economic, and technological trends do not shift markedly from historical patterns" (Riahi et al., 2017; p. 5).

FIGURE 4.25 **OECD and CSIRO/IIASA baseline projections of material flows and resource use**



Source: OECD (2018) and CSIRO/IIASA modelling

4.7.6 Limitations of the Analysis

The modelling has a number of limitations that are relevant to interpreting the results.

The scenarios represent combinations of stylized policy settings and are intended to assess the economic and environmental implications of broad alternative future directions and governance choices, with a particular focus on the period from 2030 to 2060. The scenarios are not intended to assess detailed specific real-world policies or proposals, or related near-term transition or adjustment pathways. For transparency, input assumptions for population growth (in all scenarios), GDP growth per capita (in *Historical Trends*) and the carbon price trajectory (in CPT and the *Towards Sustainability* scenario) are each based on authoritative sources, while cumulative greenhouse gas emissions are benchmarked to the IPCC representative concentration pathways (RCP6.0 in the HT scenario and RCP2.6 in the CPT treatment).

Scenario modelling is intended to provide insights into impacts of different events or courses of action by comparing the results of different scenarios. Each scenario represents a plausible and internally coherent future pathway, and is not a prediction of the future (Allen et al., 2016; Wilkinson & Kupers, 2013). The modelling and analysis assume smooth future pathways, and do not account for variability and instability – such as 'booms and busts' in global economic markets; weather and climate related events; or wars, social unrest and geopolitical disturbances.

The analysis does not quantify the extent of improvements in diet, air quality or active mobility that would be expected to occur as part of the scenario definitions, nor does it account for or quantify the flow of social and economic benefits of these changes (Heal, 2009; West et al., 2013).

While the modelling accounts for some near-term impacts of climate change, it does not explore the full range of plausible impacts (New, 2011; OECD, 2015; World Bank, 2012) or provide a comprehensive analysis of climate risk and uncertainty (including potential catastrophic climate impacts (Fisher & Ley, 2014; Stern, 2013) or positive climate feedbacks that might trigger 'runaway climate change' (Steffen et al., 2018).

Lastly, the modelling framework is focused on the physical economy and selected environmental and earth-system interactions, and does not attempt to represent the evolution of social systems (Allen et al., 2016; Hatfield-Dodds et al., 2015), including social relations or the distribution of access and entitlements within and across nations (central to issues of poverty, inequality and gender, reflected in SGDs 1, 4, 5, and 10).

Additional limitations of the modelling are discussed in the separate Technical Annex.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05. A Societal Response to Determine our Shared Future

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Authors

Bruno Oberle and Jessica Clement

Main findings

- Decoupling environmental impacts and resource use from economic activity and human well-being is a key strategy that can support the achievements of the Sustainable Development Goals while remaining inside the planetary boundaries. This strategy further contributes to the achievement of the United Nations Framework Convention on Climate Change Paris Agreement, the Aichi Targets of the Convention on Biological Diversity and the Land Degradation Neutrality objectives supported by the United Nations Convention to Combat Desertification.

- Achieving decoupling is possible and can deliver net positive gains environmentally, socially and economically. Innovative solutions to achieve decoupling can address environmental challenges and drive fundamental transformations towards sustainable consumption and production.

- Indicators and targets used at all levels of governance can help monitor natural resource flows and guide transitions towards sustainability. These indicators and targets include both the production and the consumption perspectives.

- National plans for the sustainable use of natural resources would enable governments to identify priorities and proceed in a coordinated way to achieve the set targets. National plans are typically backed by scientific work and accompanied by the engagement of important stakeholders across specific action areas. Engaging in dialogue to connect with citizens, civil society and the private sector builds consensus and facilitates the development of an optimal set of measures.

- Achieving sustainable transitions will not happen spontaneously, but rather requires well-designed and concerted policy packages. The scope and context of each set of instruments will depend on the national situation. Innovation and capacity building are necessary drivers of SCP. The concept of the circular economy operationalizes SCP ambitions and promotes value-retention and environmental impact reduction, while simultaneously reducing costs and creating economic opportunities. Leapfrogging can be harnessed for decoupling by policymakers and decision makers. For some countries, a redistribution policy that shifts resources toward the poor and vulnerable in society is an appropriate tool to use when implementing policies for decoupling and sustainability.

- International exchanges and cross-country cooperation can accelerate transitions towards sustainability. They also can support national decisions and help to creating a level playing field for international businesses and traded goods. These exchanges make it easier to navigate obstacles, promote shared experiences and find ways to leapfrog. While it is clear that resource, well-being and impact decoupling and resource efficiency improvements should be internationally pursued efforts with the involvement of all countries, due consideration will have to be given to the different responsibilities and capabilities of countries. These different aspects call for a global discussion.

5.1 Introduction

Any response to the increasing use of natural resources and the corresponding impacts involves influencing the key drivers of the use and enabling fundamental changes throughout the entire socioeconomic system. The findings from the previous chapters in this report support an integrated response to transforming the way natural resources are used in our economies and societies.

5.1.1 The Current Use and Management of Natural Resources are Unsustainable

Trends leading up to 2017 have indicated a glaring increase in natural resource use. Since the 1970s, the annual global extraction of natural resources grew from about 27 billion tons to 92 billion tons. This increase is linked to various factors, including higher consumption due to changing consumer habits and purchasing power, population growth and out-dated business models embodying inefficient production technologies.

The *Historical Trends* scenario shows that this use will continue to grow by 110 per cent, reaching 190 billion tons of natural resource extracted per year in 2060, unless a fundamental change is achieved that drives natural resource use away from the status quo.

5.1.2 With Increasing Use Come Increasing Negative Impacts

The extraction and processing of material resources (biomass, fossil fuels, metals and non-metallic minerals) currently contribute more than 90 per cent to global biodiversity loss and water stress impacts, and around 50 per cent of global greenhouse gas emissions (not including climate impacts related to land use change). Additionally, land use caused global species loss of approximately 11 per cent up to 2010.

There was a relative decoupling of resource-related environmental impacts from GDP and a moderate relative decoupling of impacts from extracted mass of resources from 2000 to 2015. However, negative environmental impacts and global average per capita climate and health impacts still increased on an absolute scale.

While the analysis in this report extends only to the extraction and processing of natural resources, the use phase of natural resources is also causing increasingly serious impacts. Both outdoor and indoor air pollution are linked to the use phase of natural resources (WHO, 2018a; WHO, 2018b). The World Health Organization states that 4.2 million premature deaths occurred in 2016 due to outdoor air pollution, with 91 per cent of these premature deaths in low- and middle-income countries (WHO, 2018a). An additional 3.8 million deaths per year are attributed to indoor exposure to smoke from dirty cookstoves and fuels (WHO, 2018b).

5.1.3 Natural Resource Use and the Related Impacts are Unevenly Distributed Around the World

Low-income countries with agriculturally based economies are not typically driving the increased consumption of natural resources that is leading to negative environmental and human health impacts around the world. The billion richest individuals account for 72 per cent of the consumption of global resources, while the poorest 1.2 billion consume only 1 per cent (IRP, 2017a). Moreover, in 2017, the material footprint per capita of high-income nations was approximately 27 tons, while the material footprint per capita was around 17 tons for upper-middle income countries, almost 5 tons for lower-middle income countries, and only 2 tons per capita for low-income countries. While the material footprint per capita is increasing for upper-middle income countries, it is remaining stagnant for low-income countries. Per capita material footprints are the largest for high-income countries, but the striking growth in domestic materials consumption since 2000 can be attributed to the upper-middle income group, with very little growth seen in low-income countries.

The per capita climate impacts of low-income countries are four times lower than the global average. The per-capita environmental impacts generated by consumption of high-income countries are between three and six times larger than those impacts in low-income countries. A picture is emerging where the richest in global society are consuming the most natural resources and facing the fewest consequences.

This situation stems from an increasingly connected global economy, with high-income countries specializing in high value-added product development and management activities while resource-intensive added manufacturing is located in low-cost countries. This calls for stronger global partnerships in sharing the benefits and mediating environmental impacts of resource extraction and processing.

The following sections in this chapter provide a response to mitigate the above-mentioned trends by describing the policy actions that drive the *Towards Sustainability* scenario presented in chapter 4, providing relevant examples of action and suggesting eight elements for multi-beneficial policymaking.

5.2 Reaching a Sustainable World: Implementing the Policy Actions Adopted in the *Towards Sustainability* Scenario

5.2.1 Innovative Solutions and Sustainable Consumption and Production

Innovative solutions are not necessarily specific technologies, but rather they are novel or noteworthy approaches. Simply put, innovative solutions can be thought of as “business unusual” ways to achieve sustainability (UNEP, 2018a). These innovative solutions include policy interventions, implementing environmentally sound technologies, sustainable financing schemes, capacity building and private-public partnerships. Innovative solutions also include new business models that focus on selling a service instead of products – such as lighting instead of lightbulbs. Where relevant, examples of these solutions are flagged throughout this chapter.

Sustainable consumption and production promotes decoupling natural resource use from negative environmental and health impacts (see chapter 4; One Planet Network, 2017). Within SCP, the entire life cycle of economic activities is considered from the extraction of resources to the reuse, recycling or disposal of products made from material resources. Innovation and systemic changes within this life cycle promote SCP and directly mitigate the negative impacts linked with environmental challenges (UNEP, 2018a). Therefore, achieving decoupling is possible through innovative solutions for environmental challenges and sustainable consumption and production.

The *Towards Sustainability* scenario in chapter 4 included technical assumptions that enabled absolute impact decoupling and relative resource decoupling. After providing a brief summary of the *Towards Sustainability* scenario, this section explains how these assumptions can be translated into real actions using innovations and policy solutions.

5.2.2 A Summary of the Towards Sustainability Scenario

The *Towards Sustainability* scenario is based on a collection of actions by governments, the private sector and households aimed at improving resource efficiency, decoupling economic growth from negative environmental impacts and promoting sustainable consumption and production.

Under this scenario, global resource use grows but at a decreasing rate compared to *Historical Trends* (which provides an outlook to 2060 based on historical and current patterns of natural resource use). The lower growth rate is attributed to a slowdown in natural resource use in high-income countries, despite the increasing use in emerging and developing economies. Annual global extraction is 25 per cent lower than the estimate under *Historical Trends*, reaching 143 billion tons in 2060.

In addition to a decrease in natural resource growth rates, well-being indicators grow faster than resource use. This leads to a sizable relative decoupling of natural resource use from income and essential services such as GDP per capita, energy and food. The *Towards Sustainability* scenario also shows an absolute decoupling of negative environmental impacts from economic growth and increasing resource use, meaning total environmental pressures fall in this scenario. These results indicate a dual decoupling of both well-being and impact.

The absolute impact decoupling and relative resource decoupling achieved in this model are not at the expense of economic growth. The policy packages implemented in this scenario lead to net global economic benefits from 2030 onwards. Global GDP is 8 per cent above *Historical Trends* in 2060, and economic growth increases relatively more in low- and middle-income countries at 11 per cent on average compared to high-income nations at 4 per cent on average (which represents a more equitable distribution of GDP per capita,) while all country groups still benefit from economic gains.

5.2.3 Policy Packages and Changes in Societal Behaviour

The *Towards Sustainability* scenario shows that changes in policies and behaviours can achieve decoupling. The model assumes three policy packages and one shift in social behaviour that, when implemented together, lead to a relative decoupling of natural resource use from GDP per capita and an absolute decoupling of environmental damage from economic growth and resource use. This section explains which policies and actions are adopted, and provides insight into their real-world implementation.

Resource efficiency policies

Measures implemented in the model

The *Towards Sustainability* model embodies a resource-efficiency policy package that includes three measures to reduce global natural resource extraction and use. This amounts to absolute reductions in domestic material consumption in high-income countries and slower growth rates of DMC in low- and medium-income countries.

The first suite of measures are innovative policies and actions for resource efficiency, including public research programmes; incentives for private research and development; and support for demonstration projects, business incubators and other incentives that drive the adoption of innovation and technology. These initiatives lead to a reduction in resources needed per unit of output, thereby reducing the overall amount of resources used and leading to an overall reduction of supply costs. However, the cost reduction causes a ‘rebound effect’ that offsets the achievements of resource-efficiency policies, thereby pointing to the need for additional policies to counteract this effect.

The second suite of measures encompasses changes to regulations, technical standards and planning and public procurement policies. These measures help reduce the demand for materials and associated raw inputs without increasing the demand for manufactured items and infrastructure because they can actively lower the resource intensity of economic activity while maintaining or improving the service or amenity provided. Innovative public-private partnerships (such as Peru’s ‘Works for taxes’ law presented in box 5.1) are an example of how governments can implement new regulations and engage with the private sector to support sustainable projects.

Finally, the third suite of measures is implemented to compensate for the rebound effect. This includes a combination of policies that introduce resource scarcity in economic decision-making, signalling a tax shift from income and consumption to resource extraction. Such a tax leads progressively pushes up the cost of resource extraction and encourages the efficient use of materials and recycling.

Real examples of implementation

Resource efficiency policy packages can take the form of R&D tax incentives, including tax credits, tax allowances and payroll withholding tax credits for R&D wages, to name but a few. Research shows that tax incentives for R&D help support innovation (Westmore, 2014). Many countries across Europe already have R&D tax incentives. For example, France has an R&D tax incentive for operations related to prototype designs by small- and medium-sized enterprises, while Romania has a personal income tax exemption for the salaries of researchers and employees working in R&D. These policies are also seen in South Africa, where an R&D tax incentive was introduced to offer a 50 per cent tax deduction on qualifying R&D revenue expenditure in 2006 (KPMG International, 2017).

Such R&D incentives can actively promote sustainability to drive change. Germany implemented programmes targeted at improving R&D in the private sector to align domestic action with the Europe 2020 strategy for ‘smart, sustainable, and inclusive growth’. One notable programme to improve innovative technologies was introduced for biotechnology and sustainable agricultural production (KPMG International, 2017). Countries can aim to not only promote sustainable innovations but also to ensure that R&D respects ecological limits. Belgium provides tax deductions for fixed assets that aim to promote new technologies with no effect on the environment or that aim to minimize the negative effect on the environment (KPMG International, 2017).

BOX 5.1 Alternative Mechanism for Public Projects Funding: "Works for Taxes - Peru"

By: Marcos Gabriel Alegre Chang

Law No. 29230, "Works for Taxes" (Ley de Obras por Impuestos), is a regulation adopted by the Peruvian government in 2008 that seeks to accelerate the implementation of priority public infrastructure projects across the country. By using the Works for Taxes mechanism, the public entities of national, regional and local governments enter into funding agreements with private companies. This mechanism facilitates the financing and implementation of public investment projects that are considered to be a priority by the authorities, and that have a national, regional or local impact.

The law allows a private company, individually or in a consortium, to fund and implement public projects chosen by regional and local governments, and then to later recover the total amount of investment from its tax. In 2017, 76 projects with a US$ 300 million budget were funded using the Works for Taxes mechanism in Peru. These projects were across several sectors, including water and sanitation, roads, health and education. The Ministry of Environment is actively promoting Work for Taxes mechanisms in environmental projects including forestry, biodiversity conservation and solid waste management. The first projects on solid waste management with the Works for Taxes mechanism began in 2018.

Climate Policies to Reduce Greenhouse Gas Emissions and Remove Atmospheric Carbon

Measures implemented in the model

Two measures are included in this package. First, policy packages for climate mitigation to lower greenhouse gas emissions. These policy packages include a carbon levy and dividend, which are modelled as applying equally to all countries and to all emission sources. Biosequestration from reforestation and afforestation, such as biodiversity plantings, receives a subsidy at the same rate per ton of carbon as the levy. The level of this levy is consistent with limiting climate change to 2 degrees Celsius[8]. Notably, all net carbon revenues are returned as a uniform per capita global dividend, regardless of where the revenue is raised.

The second measure focuses on carbon removal to reduce concentrations of greenhouse gases in the atmosphere. The carbon removal policy package builds on the aforementioned policies to support a faster rate of decarbonization and efforts to limit the extent of emissions 'overshoot'. This policy package is in response to efforts to keep global warming well below 2 degrees Celsius. In particular, the early deployment of two carbon dioxide removal technologies is supported by this package. The first technology is bioelectricity with carbon capture and storage, and the second is direct air capture of CO_2. In order to support these interventions, a technology subsidy is introduced that covers capital and operating costs of BECCS and direct air capture. In the model, the cost of the subsidy begins to decline gradually in 2030 as technology costs fall. The subsidy is funded by high-income countries in proportion to per capita GDP above US$ 15,000 (in real 2011 dollars). This duty is consistent with ability to pay and the general notions of historic responsibility.

Real examples of implementation

Until climate mitigation policies are implemented at a global scale, countries can consider carbon taxes at the national level. In 2008, the province of British Columbia, Canada, introduced the first fully comprehensive carbon tax in North America. Although this tax was initially opposed by the public, within three years of implementation public opinion shifted to support the measure. The concept of the carbon tax is to be revenue neutral, which means that - instead of raising taxes - the revenues obtained through the carbon tax are used to reduce business and personal income taxes (specifically aimed at poorer households), as well as to provide direct grants to rural households. Between 2008 and 2015, the carbon tax generated C$6.1 billion (Canadian dollars) in revenue while tax cuts equalled more than C$7.1 billion. Therefore, while the tax is not completely neutral, it did enable reductions in personal income tax, corporate taxes and GHG emissions despite an increasing population. The GHG emissions have decreased 5 to 15 per cent compared to the counterfactual level (Murray & Rivers, 2015). Moreover, since 2010, British Columbia has been carbon neutral across public sector organizations. To achieve this, the government buys offsets, including emission reductions from project investments in the province. The portfolio of offset projects for 2017 included sequestration in forest conservation projects, energy efficiency in the oil and gas sector and fuel switching to less GHG-intensive or renewable sources (B.C. Government, 2017).

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[8] The analysis for the scenario models was undertaken prior to the release of the International Panel on Climate Change report advocating a 1.5 degrees Celsius limit to warming . That report demonstrates the necessity and urgency of putting in place the policy practices described in this report.

It is important to note that, at this stage, carbon removal technologies are not currently widely used. In fact, in 2018 the Illinois Industrial Carbon Capture and Storage fermentation plant in Decatur, Illinois (United States) was the only BECCS system functioning well at a large scale (approximately 1 Mt CO_2yr -1) (Haszeldine et al., 2018). This highlights the space for governments to step in with domestic support for this technology and similar methods of carbon dioxide removal, while requiring caution in terms of promoting the ability of these technologies to mitigate climate impacts. However, emerging companies are stepping up to offer solutions. Climeworks successfully tested a Direct Air Capture and Storage technology in Iceland and found that capturing CO_2 and subterranean sequestration is feasible. Climeworks is currently working to expand their operations (Climeworks, 2018).

Landscapes and life on land policies

Measures implemented in the model

The final policy package protects landscapes and biodiversity by ensuring that climate mitigation and energy policies are consistent with land and food system goals. Applying the carbon levy to emissions from land clearing helps avoid deforestation, while payments for land sector sequestration are granted only where this contributes to enhancing biodiversity. Phasing out the incentives for crop-based biofuels by 2020 leads to a reduction in land competition and helps avoid food price hikes. These objectives are further supported by focusing bioenergy for electricity generation on BECCS, as this contributes to negative net emissions.

Additional conservation polices are included in this package to meet the Aichi target of protecting at least 17 per cent of each ecoregion. Polices include those aimed at preventing loss of native vegetation in key biodiversity areas, increasing agricultural productivity and reducing barriers to agricultural trade. This policy package limits the increase of agricultural land and promotes improvements in biodiversity outcomes, leading to an increase of 15 per cent in forests and natural land area from 2015 to 2060 (compared with a decrease of 5 per cent in the *Historical Trends* scenario). In total, the cumulative effects of these policy packages prevent the loss of 400 million hectares, and further lead to an increase of 800 million hectares of forests and natural land.

Real examples of implementation

An example of existing conservation polices can be seen in the European Union (EU). The EU is home to the largest coordinated network of protected areas in the world, encompassing 18 per cent of EU's land area and approximately 6 per cent of its marine territory. The EU developed Natura 2000, a system of privately and publicly owned lands that works to conserve valuable and threatened species and habitats by mandating that Member States manage the sites in an ecologically and economically sustainable way (EC, n.d.). While land conservation is designated as a top priority, marine resources must also be protected. Box 5.2 describes planned regulation to protect marine resources.

BOX 5.2 Marine Resources and Their Management in Areas Beyond Natural Jurisdiction

By: Steve Fletcher

Areas Beyond National Jurisdiction (ABNJ) occupy more than 60 per cent of the surface of the global ocean (UN Environment, 2006; Rogers et al., 2014) and 95 per cent of its volume (Katona, 2014). The deep waters in these areas underpin many of the Earth's life support systems including climate regulation, nutrient cycling and biological production, as well as containing key natural resources such as fish, metals and genetic material. Until the mid-twentieth century, their remoteness and challenging conditions provided deep-sea ecosystems with some degree of protection from human activities. This is no longer the case. Fishing, bioprospecting, tourism, waste disposal and deep-sea mining are all under way or planned (in the case of mining) in the deep ocean ABNJs. At present, resource use is either controlled by activity- and location-specific regulation or is entirely unregulated. It has therefore been argued that the current sectoral framework leaves legal, governance and geographical gaps in management of activities within ABNJ and is insufficient to address the cumulative impacts of the wide range of sectoral activities (Gjerde et al., 2016; Ringbom & Henriksen, 2017; UN, 2017b). However, this may be set to change. The United Nations General Assembly has initiated a process to develop a new legally binding instrument under the UN Convention on the Law of the Sea to manage:

- Marine Genetic Resources (including issues of benefit sharing);
- Area-Based Management Tools (including Marine Protected Areas);
- Environmental Impact Assessments; and
- Capacity building and the transfer of marine technology.

This process is planned to conclude in 2020 and, if successful, will for the first time provide a framework for the conservation and sustainable use of marine biodiversity and associated resources in areas beyond national jurisdiction.

As mentioned in the policy package, increasing agricultural productivity supports life on land. Agriculture is crucial for life, as global society depends on crops for food, fuel and feed, as well as being required to meet certain SDGs such as SDG 2.4 to end hunger. However, some regions are suffering from soil nutrient depletion and could benefit from increased fertilization to increase yields, which can lead to decoupling. Other regions have overused fertilizer, which has led to an oversupply of nutrients with serious environmental consequences. Striking a balance, especially in situations with poor infrastructure, is a difficult task. Precision farming, using satellite images, weather forecasts and soil sensors can facilitate crop management. A Nigerian precision farming company, Zenvus, analyses the soil and provides farmers with the information needed on how to use fertilizer for their farms. Zenvus is paired with a web application for easy use. Other start-up companies are using ICTs to link farmers with pricing data for their crops or to provide farmers with the weather forecast. Some of these initiatives use simple SMS messages, such that they are accessible to farmers who have only the most basic technological capabilities (Ekekwe, 2017).

Other agricultural innovations include agroforestry systems (AFS), which are agricultural techniques that combine trees and crops (and in some cases, pastures/cattle) on the same parcel of land. Practising AFS can increase productivity, while also maintaining biodiversity and providing positive benefits to the farmer. AFS further helps mitigate climate change through carbon sequestration that occurs in woody components of the system and in soils. The benefits of AFS can be seen through the lens of the SDGs. To name but a few synergies, AFS promotes SDG 2 on hunger, SDG 5 on gender equality, SDG 13 on climate action and SDG 15 on sustainable forestry and reforestation (Montagnini & Metzel, 2017).

The AgFor Sulawesi Project, which lasted from 2012 to 2017, was deployed across multiple provinces on Sulawesi island in Indonesia to support agroforestry and forest livelihood systems in rural communities. The AgFor project promoted mixed AFS involving cacao and other tree crops to build agricultural resilience. *Nurseries of excellence*, which helped farmers produce superior seedlings and provide AFS training, were established to further support this initiative. As a result, over 25,000 people improved their knowledge of sustainable agriculture and natural resource management through workshops, training and meetings, as well as 286 individual or group nurseries producing over 1.3 million seedlings. Importantly, AgFor places a strong emphasis on gender equality. By 2016, an impact survey found that over 630,000 people - of which 52 per cent were women - improved their incomes after adopting AgFor-promoted technologies. This survey also found that 738,000 hectares on the island were secured under improved sustainable management (Montagnini & Metzel, 2017).

Shift in societal behaviour

Measures implemented in the model

In addition to the implementation of three complementary policy packages, the *Towards Sustainability* scenario assumes changes in societal behaviour. The changes include adopting healthier diets that are consistent with international dietary guidelines and reducing food waste throughout the food supply chain. Healthier diets are envisioned through a 50 per cent reduction in meat consumption relative to *Historical Trends* by 2050, except in regions with a low share of meat in their diets. This reduction involves replacing animal protein with plant-based proteins. Higher average incomes, reduced poverty and improved public knowledge contribute to the change in diets.

Real examples of implementation

Social norms have been identified as a major component in transitioning away from meat-rich diets, and major gains can be made with societal level diet changes. In many cultures, however, social norms around heavy meat consumption act as a barrier to reducing number of animals and dairy products consumed in daily life. Shifting these social norms can help change a society's overall caloric make-up to a diet that emphasizes less intensive food products. Well-known ways to shift the norms surrounding meat consumption include providing information about the environmental impacts of eating meat (Stoll-Kleemann & Schmidt, 2017). For example, while 83 per cent of the respondents of one international study agreed that human activity contributes to climate change, in the same study a mere 30 per cent of respondents agreed that meat and livestock are significant contributors (Garnett et al., 2015). Increasing public knowledge about the links between animal products and environmental damage helps drive the needed shift in behaviour.

5.3 Eight Elements for Multi-Beneficial Policymaking

Achieving sustainable transitions will not happen spontaneously, but rather will require well-designed and concerted policy packages to effect the desired changes. Using eight elements, this section identifies policy solutions for stimulating fundamental changes in consumption and production systems that enable economic growth and improvements in human well-being without putting unsustainable stress on the environment. Innovative solutions, such as novel policy interventions, progressive environmentally sound technologies, sustainable financing, novel capacity-building ideas and new forms of public-private partnerships can also help drive these changes.

FIGURE 5.1 **8 ELEMENTS FOR MULTI-BENEFICIAL POLICY MAKING**

8 elements for multi-beneficial policy-makding

1. Use targets to achieve objectives
2. Develop a national plan
3. Implement a policy mix
4. Enable access to finance
5. Unlock the resistance to change
6. Promote innovation for a circular economy
7. Take advantage of leapfrogging
8. International exchanges and cooperation

Source: Based on IRP 2017a

5.3.1 Set Targets and Use Indicators to Measure Progress

Targets and indicators used at all levels of governance can help monitor material flows and guide transitions towards sustainability. Regular reporting on the metrics of resource use and efficiency that is consistent across different entities can raise the profile of these measures, thereby mobilizing support to improve them. Box 5.3 provides one example of why monitoring improvements are necessary.

National natural resource-efficiency targets

Natural resource-efficiency targets can guide policy and provide context for a progress-monitoring framework. By setting objectives at the national level, complementary policy packages can be implemented to achieve these defined goals. Having a defined target to achieve facilitates the policymaking process, as policymakers know which direction to move in to reach the goal. To measure progress, a country can track the indicators used to measure resource efficiency. Targets help shape national plans.

One category of indicators is based on domestic material consumption, while another category is based on the material footprint. The indicators for domestic material consumption highlight the production side. Footprint indicators are used to measure environmental impacts beyond the production perspective by quantifying environmental impacts caused by domestic consumption inside and outside a country. It is recommendable to use both types of indicators.

Eight European Union Member States (Austria, Estonia, France, Germany, Hungary, Latvia, Portugal and Slovenia) have adopted national material resource-efficiency targets related to resource productivity. These targets, in most cases, are formulated by the ratio of GDP to DMC, which is the main productivity indicator in the EU. For example, France has a two-fold goal to have a 30 per cent increase in resource productivity (GDP/DMC) along with a decrease in per person DMC between 2010 and 2030 (EEA, 2019 forthcoming; IRP, 2017a).

The use of targets for industry and business

In addition to national and regional targets, industries and individual companies can develop their own targets to steer their activities. For instance, EDP is an electricity generator, distributor and supplier with 9.8 million electricity and 1.5 million gas customers across 14 countries that has worked with the Science Based Targets initiative (SBTi) to introduce resource targets. The company committed to reduce direct and indirect GHG emissions from electricity production by 55 per cent per TeraWatt hours (TWh) by 2030 (compared with 2015 levels). Over the same time period, EDP has committed to reducing absolute value chain emissions by 25 per cent. The overarching goal for EDP is to reduce CO_2 emissions by 75 per cent by 2030, compared to 2005 levels (Science Based Targets, 2017).

Global targets for resource use

Although resource-efficiency targets at the national level are an important first step to improving resource use, international targets for sustainable levels of global resource use will also be needed (IRP, 2017a). To guide transitions towards sustainability, targets for biodiversity, climate change and land degradation neutrality are already in place at an international level, and the 17 goals of the SDGs include 169 associated targets. Natural resources are within the scope of many current targets, but a direct process to monitor resources and guide resource use is still lacking.

Developing new science-based targets for natural resources would support the mitigation of impacts that are being felt around the world. The process for science-based targets for resource use should consider how to limit impacts and guarantee human well-being. Targets developed in this way refer to direct limits in stocks of resources and to 'indirect' limits focused on mitigating negative impacts.

Generally speaking, in order to be useful for policymakers and decision makers, targets on impacts will need to be translated into a meaningful resource-use target paired with applicable indicators applicable at a global scale. In this way, the benefits of targets can be shared across borders and modified for domestic circumstances. Other concerns that can be addressed by resource targets include scarcity for certain resources (such as water), or ensuring that future generations have access to "high-quality" resources.

The development of global resource targets is still in its infancy. Individual countries can lead the way by implementing targets at a national level. The Netherlands, for example, set an interim objective to achieve a 50 per cent reduction in the use of primary raw materials by 2030 (Government of Netherlands, 2016). Until decisions on targets are accepted internationally, the International Resource Panel will continue to provide research, analysis, and policy options that support resource and impact decoupling.

BOX 5.3 Impact of Sand Mining on the Environment

By: Pascal Peduzzi and Janyl Moldalieva, United Nations Environment Programme

Sand and gravel are mined worldwide and account for the largest volume of solid material extracted globally. Formed by erosive processes over thousands of years (John, 2009), they are now being extracted at a pace far greater than their renewal rate. Sand is being used mostly by the building sectors, for sea reclamation and beach nourishment, as well as for many other applications (electronics, agriculture, cosmetics, glass and so forth). With an estimated 40 to 50 billion metric tons per year, extraction of such large volume has a major impact on rivers, deltas and coastal and marine ecosystems. It results in loss of land through river or coastal erosion, lowering of the water table and decreases in the amount of sediment supply. Despite the colossal quantities of sand and gravel being used, our increasing dependence on them and the significant environmental impact of their extraction, the issue has been mostly ignored by policymakers and remains largely unknown by the general public.

There is a need to generate environmental and social standards on how sand is mined, as well as to consider how to reduce the demand for this resource. Currently, there is no monitoring system in place, and legislation is either insufficient or not adequately enforced - leading to significant environmental and social impacts.

Photo credit: TomDiTOm, Flickr.

5.3.2 Establish a National Plan to Create a Feasible Pathway for the Sustainable Use of Natural Resources

National plans allow governments to identify priorities and proceed in a coordinated way toward the targets set. National plans are typically backed by scientific work and are accompanied by the engagement of important stakeholders across specific action areas. A national plan includes two aspects. The first step involves an evaluation of a country's situation. The second step is to develop an action plan for decoupling.

Evaluate the domestic situation

An evaluation of the domestic situation provides the factual foundation for the national plan. This includes an analysis of the natural resources extracted and processed within the borders of a country, the natural resources traded internationally, whether the country is a net exporter or a net importer of resources, how natural resources play a role in the overall economy and what the impacts of natural resource use within the country. A full understanding of natural resources in the national context can help to identify leverage points for action and to develop national programmes relevant to domestic circumstances.

Kenya's Vision 2030 is a long-term development plan that aims to achieve economic growth and promote a prosperous society while ensuring environmental protection, including the sustainable extraction, use and management of natural resources. Vision 2030 has successive five-year plans and three pillars: economic, social and political. As natural resources are a key component of this plan, Kenya sought to identify the most relevant challenges related to resources and its domestic situation. This process identified six challenges: continued deforestation and poaching; human-wildlife conflicts; increased occurrence of alien and invasive species, depletion of marine resources; lack of an effective policy, regulatory, and institutional framework; and environmental degradation and encroachment in fragile ecosystems. With clear challenges identified, Kenya is now developing targeted approaches to overcome obstacles. Notably, this includes a focus on increasing resource efficiency through technological progress, conservation efforts and pollution and waste management (UNIDO, 2016). The Kenyan process serves as an example of how countries can evaluate their national situation for targeted action.

Construct a national plan for decoupling

After leverage points are identified, countries can formulate a national plan for decoupling. Such a national plan identifies relevant areas to be covered by actions and programmes for resource efficiency and sustainable consumption and production.

Resource efficiency programmes can help strategically coordinate national institutional arrangements and policies. Countries in Europe, such as Austria, Finland and Germany, are already pursing national policy programmes that focus on natural resource management and resource efficiency (IRP, 2017a). Progress is also observable in emerging and developing economies. In India, for example, an Action Plan for resource efficiency was introduced in 2017 to outline policies to be pursed at a domestic level up to 2020. This plan begins by developing a multi-stakeholder, inter-departmental group, then sets up a task force to support institutional development and highlights the need for resource efficiency education and awareness programmes. In the following years, it outlines resource efficiency promotion strategies and public policies. The recently established Indian Resource Panel will help drive these comprehensive national resource efficiency objectives and pursue decoupling (NITI Aayog & European Union, 2017).

In addition to resource efficiency, fundamental changes to the current patterns of consumption and production are needed. Within Latin America and the Caribbean, Brazil designed and implemented a national action plan for SCP. The first in this region, the Brazilian SCP national plan worked with 26 institutions (including ministries, government offices and NGOs) to monitor, guide and encourage activities that adhered to the SCP plan. From this cooperation, six areas were identified as top priorities for change. As an example outcome from this plan, local shops were supported in collaborating to pursue sustainable retail and consumption practices. This led, among other achievements, to the collection of 70,000 litres of cooking oil each year, which is transformed into biodiesel. The first cycle of the national plan ran from 2011 to 2014, and the second cycle is under way and will continue until 2020 (One Planet Network, 2018).

5.3.3 Develop an Integrated Policy Mix for Natural Resource Management

Policy mixes are comprised of instruments that a government uses to achieve national targets and the objectives from the national plan. Using a broad toolbox with aspects of multiple approaches leads to beneficial decision-making. Consider the successful strategy by the EU to combat plastic waste that incorporates a combination of elements such as enforcing rules, partnerships and market-based instruments. The fusion of different governance styles embodies 'metagovernance', which is the combining or switching between governance styles to develop an effective combination for a particular situation. A variety of tools builds more resilient approaches (Meuleman, 2018). Public policies, notably when backed by broader society, can influence producer and consumer choices through incentives, regulations and improved knowledge.

Moreover, the *Towards Sustainability* scenario embodied three policy packages on resource efficiency, climate mitigation and carbon removal and the protection of landscapes and biodiversity. The success of the overall strategy to improve resource efficiency, decouple economic growth from environmental degradation and promote SCP is contingent upon the combined actions represented in these policy actions.

There is no one-size-fits-all solution

Achieving a sustainable transition requires multiple, complementary measures. A policy package needs to be feasible and relevant to the targets set and the national plan developed. Policies can be seen as instruments to reach domestic and international goals, and the set of instruments required will differ in context and scope depending on the national situation.

One option for policymakers to drive innovative solutions in their country's policy mix is by integrating legislation on natural resources with biodiversity and climate policies. This innovative solution is important because the improved use of natural resources, including enhanced resource efficiency, will be necessary to achieve national and international objectives on climate, biodiversity and land degradation neutrality. Developing integrated resource, climate and biodiversity policies can drive coordination and collaboration across government ministries, leading to further policy innovations.

A recent IRP report (UNEP, 2017) modelled four different scenarios: an *Existing Trends* scenario based on historical resource trends and a climate commitment broadly consistent with the Paris pledges to 2030; a *Resource Efficiency* scenario that assumes the same GHG setting as *Existing Trends* but also a package of tools to promote resource efficiency; *an Ambitious Climate* scenario that assumes the world follows historical trends for resource use but shifts to a 2 degree Celsius climate pathway, indicating global GHG emission abatement policies; and an *Efficiency Plus* scenario that combines the measures of *Resource Efficiency* and *Ambitious Climate.* The results of this report show that the combination of climate policies and resource efficiency policies is better at reducing resource use per capita and global GHG emissions than each package separately at a global level. Bundling the policies also led to a higher Gross World Product compared to *Existing Trends.* The same overall trends held true for the Group of 7 countries. This analysis shows that pursuing policies that abate emissions and increase resource efficiency together leads to a more advantageous outcome.

Effective and efficient policy mixes

The policy package used needs to be effective in achieving the domestic objectives outlined by the targets and national plan. Implementing policies in steps can help reduce the burden of a drastic policy shift. In this way, even if the final target is not reached in the short term, progress towards defined goals is nonetheless achieved.

In addition to effectiveness, the policy objectives should be designed to be efficient in their use of personnel and resources (including money, materials and energy). Efficiency can be increased by taking advantage of shared domestic experiences from actors across sectors, and also internationally by collaborating with individuals in different countries.

One way to ensure effectiveness and efficiency is through adaptive management. Adaptive management is one form of natural resource management that promotes learning and consequent management changes in based on discoveries during the policymaking process. Depending on the outcome, the course of action is adjusted. It is an iterative process that helps reduce uncertainty, develop knowledge and ultimately improve the management of natural resources (Allen et al., 2011).

Capacity building will support policymaking

Policymakers, decision makers and those supporting them need training to devise informed and effective policy mixes. Capacity building acts as a catalyst for change (UNEP, 2006) and equips these actors with the information and know-how to make substantial improvements in policy. Innovation in education and capacity building have been flagged up as ways to mitigate environmental challenges and drive SCP.

The Building Capacity to Use Research Evidence (BCURE) ran from 2013 to 2017 and supported six projects across 12 countries to focus on building skills, networks and organizational systems for evidenced informed policymaking (EIPM) during this time. In Bangladesh, the BCURE programme developed EIPM guidelines in three ministries, one of which was the Ministry of Environment and Forests. A pilot EIPM training course was designed to teach technical skills to evaluate policy formulation, and BCURE further collaborated with national training institutions to integrate EIPM training in existing civil servant training courses. The pilot training course was predicted to reach 400 civil servants during the programme, and has the potential to reach thousands of civil servants per year (Vogel & Punton, 2018).

5.3.4 Enable Access to Finance for Decoupling Oriented Businesses and Projects

Innovative sustainable financing schemes can be leveraged to promote SCP. It has been estimated that financing a sustainable transition, by achieving the SDGs and the Paris Agreement commitments, will require investment amounting to trillions of US$ per year for the next decade or more (UNEP, 2018b). Governments are called on to help finance sustainable projects, but private sources will need to provide much of the funding.

Innovative financing tools

A specific instrument for financing projects that provide environmental and climate benefits, or “green projects”, is the green bond. Each type of green bond specifies what the proceeds from the bond sale will be used for, and how the debt will be repaid to the investor. However, at the moment there is no common framework to define a “green bond”. This motivated the European Commission to present its Sustainable Finance Action Plan in March 2018 to provide transparency about what is sustainable or not through a common taxonomy and then to develop labels for financial products (EC, 2018b).

The green bond market has gained strong traction as a funding instrument. In 2017, US$ 157 billion was issued, up from US$ 37 billion in 2014 and US$ 11 billion in 2013. Local and national governments, along with private companies and international organizations, have been involved in issuing green bonds for sustainability projects around the world (Climate Bonds Initiative, n.d.). Other stakeholders include Climate Action 100+, a group of institutional investors that aim to secure decarbonization of the most carbon intensive companies (UNEP, 2018b). An example of a green bond is the “Climate Awareness Bond” issued by the European Investment Bank (EIB) (Climate Bonds Initiative, n.d.). The EIB agreed to provide US$ 100 million through green bonds to support sustainable development in emerging markets by investing in the “Amundi Planet – Emerging Green One” Fund (EIB, 2018).

Another example of adapting the bond market for sustainability is from the multi-stakeholder initiative Tropical Landscapes Finance Facility (TLFF). In 2018, TLFF announced that a US$ 95 million sustainability bond issued by BNP Paribas (one of the partners) would be used to fund a sustainable natural rubber plantation in Indonesia. The plantation will protect a national park in Indonesia and provide around 16,000 fair-wage jobs. This type of investment shows how the private sector can become involved in sustainability projects backed by trustworthy organizations and ultimately deliver a profit (TLFF, 2018).

Ensuring access for local actors

Financing tools must be accessible to local actors. Multinational organizations and domestic governments can engage with local actors to encourage green supply chains, innovation and resource efficiency at the local level. In order to connect global institutional investors to small businesses and entrepreneurs on the ground, these institutional investors can open local offices in developing and emerging economies to create accessible solutions in local markets.

Other mechanisms to help financing reach the local level include tax incentives, such as preferential withholding tax rates to entice foreign investors into domestic bond markets. A preferential withholding tax rate was deployed in India to attract infrastructure investment. This policy was one of the first to use the preferential withholding tax rate incentive for green bonds. At an international level, existing organizations such as the Financial Stability Board, the G20 or OECD can help encourage support for local green bond markets or other green financing instruments (Climate Bonds Initative, 2015).

5.3.5 Unlock the Resistance to Change

Addressing the resistance to change that may arise during a sustainable transition is another key element, in addition to capacity building, that will help policymakers and decision makers support their national strategy for decoupling.

Provide transition support for vulnerable groups

The policies adopted in a policy mix to drive a sustainable transition will probably entail phasing out certain industries and sectors to move toward less polluting and more efficient economic activities. New policies and incentives can encourage new labour opportunities, but those individuals who are negatively affected during the transition stand to benefit from targeted government support. This support can take the form of education and training programmes that help people adjust to the changing labour market. Notably, if environmental taxes are included in conjunction with support programmes, the revenue raised from taxes can be used to fund training or, more broadly, mitigate distribution impacts that arise from a transition (OECD, 2017).

Indeed, for some countries a redistribution policy that shifts resources toward the poor and vulnerable in society is an appropriate tool to use when implementing policies for decoupling and sustainability. In these situations, suitable tools include cash transfers or supplementary social safety nets to support redistribution.

Engage in dialogue and listen to concerns

Engaging in dialogue to connect with citizens, civil society and the private sector provides these members of the public with a way to share concerns and participate in the policymaking process. The R&Dialogue project across Europe promoted ten low-carbon dialogues between different groups, including those in energy, the low-carbon R&D community and social actors. National Dialogue Councils were developed to host multiple meetings from 2014 to 2015. These meetings focused on a range of issues, including economic aspects of the energy transition and how to bridge the divide between scientific findings and society. Some dialogues took the form of a round-table discussion, to stimulate listening and increase interaction among participants (Øye et al., 2015).

A panel in Scotland serves as a specific example from this project to show how dialogue can work in action. A citizen's panel organized on energy technologies in 2014 found that participants were open to accepting higher taxes to fund the development of renewable energy technologies if the taxation process was fully transparent (Øye et al., 2015).

The R&Dialogue project can be used as a model of how to collaborate with society during a sustainable transition. Both formalized and informal dialogue – through social media, for example – enables members of society to share their fears, express concern and inform policymakers about their priorities. Dialogue is a critical aspect of the political process between the government and citizens, while strong communication with society helps policymakers garner support for change.

Provide scientific information

In both the private sector and the public sector, informing citizens and private businesses of all sizes about how to improve their natural resource consumption can go a long way towards improving the current state of natural resource use and management.

Businesses can also develop innovative solutions and tools to promote resource-efficient practices. For example, Winnow is a company working to prevent food waste (Magoni, n.d.). Stopping food waste is a global priority, as it represents a large portion of global waste and causes more than 3.3 Gt of CO_2-equivalent emissions annually (FAO, 2013). In developed countries, 40 per cent of the total estimated food waste occurs at the retail and consumer level, equalling out to around 222 million tons. The total net food produced in sub-Saharan Africa alone is around 230 million tons (UNEP, 2016a), so preventing this waste has huge implications. Notably, SDG 12.3 focuses on halving food waste, which if achieved would contribute to the prevention of climate change, water stress and biodiversity impacts.

The Winnow Waste Monitor collects data on food waste in commercial kitchens by putting the waste receptacles in the kitchen on scales. Food is weighed as an employee throws it away and a pre-programmable system allows the employee to categorize the food (lasagne, lunch buffet and so forth). The results are compiled into reports, which are then sold to the organization using the Winnow system. Kitchens using Winnow have cut food waste by 40 to 70 per cent. As an estimated US$ 100 billion of food is thrown away by the hospitality industry, these reductions in food waste translate into significant financial savings for commercial kitchens. In addition to the prevention of food waste, an unanticipated result is that employees working in these kitchens are more aware of food waste. After Ikea began using Winnow in their kitchens, it was found that around 50 per cent of workers involved in food production wanted to reduce food waste (Magoni, n.d.).

Winnow simply informs its customers of their food waste, and from there they are able to more efficiently manage their food resources.

Leverage social norms

Leveraging social norms is another way to change behaviours regarding natural resource use. Social norms refer to either imagined or real knowledge of how another person would act in one's own situation. When an individual believes or knows that their neighbours and friends are using resources more responsibly than them, this can trigger a change in resource consumption. Peer behaviour and social norms are a strong predictor of environmental behaviours for energy and water use, and can sometimes be more influential than changes in the price of a natural resource (Stoknes, 2015). Governments can also lead the way through their own behaviour.

A concrete example of leveraging norms to achieve change is provided by the company Opower, which provides electricity utilities to households. Opower began giving customers easy access to their power consumption and also enabled customers to compare their energy-saving performance with their neighbours through an online application. Opower states that during their start-up phase from 2007 to 2013, its services could power a city such as San Francisco for one year with the energy saved. This service leverages the influence of social norms to change behaviours (Stoknes, 2015).

5.3.6 Promote Innovation for a Circular Economy to Reduce Material Demand and Increase Resource Security

Promotion of the circular economy by decision makers and policymakers can complement the other components of an integrated policy-mix.

The concept of the circular economy

Historically, linear models of production and consumption have characterized economic systems. Raw materials are extracted, processed and then transformed into manufactured goods. These goods are consumed and then disposed of, effectively taking natural resources from the earth as virgin material and putting them back as waste. Throughout the linear production process, value is lost through inefficiencies and waste (EMF, 2015).

According to the Ellen MacArthur Foundation, an organization dedicated to the circular economy, the circular economy rests on three principles: preserving and enhancing natural capital by controlling finite resource stocks and balancing renewable resource flows; optimizing resource yields by circulating products, components, and materials at the highest utility possible; and fostering system effectiveness by revealing and designing out negative externalities. By adhering to these principles, firms have the potential to realize lower input costs or create new profit streams, while decreasing their dependence on commodity imports (EMF, 2015). Effectively, firms that strive to adopt the circular economy principles "close the loop" of the production system by creating products that can be broken down and replaced by new pieces or products that can be reverse engineered to recover used materials.

The circular economy promotes value-retention and environmental impact reduction, while simultaneously reducing costs and creating economic opportunities. Value retention processes (which include direct reuse, repair, refurbishment and remanufacturing) also offer additional options for consumers. Remanufacturing has the highest value retention potential of the processes previously mentioned, as it restores the end-of-life goods to their original working condition. By embracing remanufacturing and refurbishing processes in the United States, manufacturers of industrial printers, vehicle parts and off-road equipment saved up to 98 per cent in new materials input. They further reduced production waste by 90 per cent, embodied material emissions by up to 99 per cent and process emissions by up to 87 per cent. The remanufactured products are of the same quality as new products, and moreover led to cost savings per unit of up to 44 per cent (IRP, 2018b).

The circular economy model often involves innovative technologies and processes that help close the loop. Selling services instead of products is one emerging solution to promote circularity. Philips recently began offering Light as a Service, with contracts for LED lighting and a service and warranty solution where Philips maintains ownership until the product's end-of-life, thus facilitating refurbishment, parts harvesting and recycling (Phlips Lighting, 2015). New environmentally sound technologies are also highlighted as innovative solutions that promotes circularity and additionally SCP. Box 5.4 provides an example of an innovative technology to develop a circular wastewater system.

BOX 5.4 Helio Pure Technologies

Helio Pure is an environmental engineering company with the principal idea that 100 per cent of water is reusable with the right treatment, if it is correctly sorted and recuperated. The current water management model used in most systems around the world is single use. Water flows from the tap, is used once, and then – irrespective of water source – is disposed of in a common sewer. This practice results in water waste and unnecessary energy lost due to the common application of water purification techniques applied to all water in the shared sewer. Helio Pure proposes a new method. First, water is sorted at source. Then, improved environmentally friendly treatment methods are applied to the sorted water. Subsequently, the water is put back into the system, depending on the next use of the water. This type of recycling already exists for materials, and this model can be applied to water with decentralized action: the end user must participate in sorting the water, because water can no longer be sorted after it flows into a sewer.

To purify the water, Helio Pure developed Bio-Solar Purification (BSP). This is a scientifically tested process that converts water with high organic and nutrient loads into purified water suitable for irrigation, water or industrial uses using solar energy (de La Rochebrochard et al., 2016).

This integral solution can be applied for industry, agriculture and residential areas. Water management solutions are already deployed in water stressed areas in Algeria, France, Saudi Arabia, Spain and the United States. The new method of wastewater management is especially appropriate for areas affected by water stress, high water prices or conflict driven by water competition.

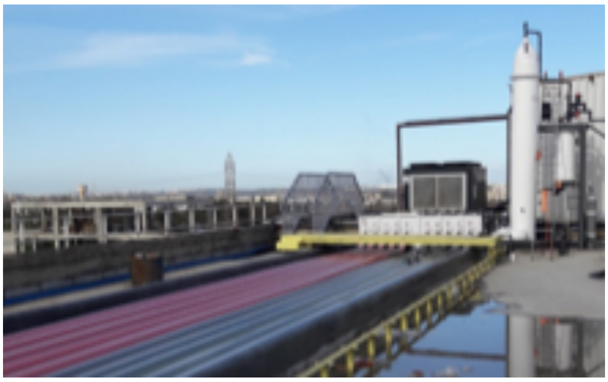

Photo: Helio Pure operation in Algeria, printed with permission from Helio Pure.

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Policies tailored to supporting a circular economy

Policies for the circular economy should be designed to defeat the present throw-away culture seen in both consumer and producer behaviour, and to keep value within the production and consumption system. An initial step is to establish effective waste management and recycling infrastructure, though decision makers will need to look to the whole life cycle of products to encourage sustainable design, longevity of use and re-use and finally disposal to waste. Policymakers can further assess their existing policies to ensure that the current regulations do not create barriers to the development of value-retention processes by producers or the adoption of these processes by consumers (IRP, 2018b).

The EU has actively been promoting this since the Action Plan for the Circular Economy, which established concrete objectives to drive circularity and measures to address the life cycle of economic activities in Europe. It further seeks to increase global competitiveness and create new jobs. A 2018 update states that, within only two years of adopting the Action Plan, over 50 per cent of the planned initiatives have been delivered. Along with this plan, revised legislation establishes targets for waste reduction and improved waste management. For example, common EU targets include recycling 65 per cent of municipal waste by 2030 and recycling 75 per cent of packaging waste by 2030 (EC, 2018a). Another example of policies aimed at driving circularity from China is described in Box 5.5.

BOX 5.5 Circular Transformation of Industrial Parks in the People's Republic of China

By: Bing Zhu, Dingjiang Chen and Bomin Liu

The "Circular Transformation of Industrial Parks (CTIP)" Programme is a policy from the Chinese Government to push and support various types of Industrial Parks (IPs) to follow circular economy principles (such as "reduce", "reuse" and "recycle", with priority given to "reduce"). The parks optimize spatial layout, adjust industrial structure, develop key technologies for linking various components of a circular economy, extend the industrial chain appropriately and link its various parts into a circular loop. They further build infrastructure and public service platforms, and renovate organizational and administrative mechanisms to implement an efficient and circular utilization of resources and "zero discharge" of wastes, thereby continuously strengthen the Industrial Park's capacity for sustainable development.

In order to tackle the resource and environmental problems during rapid economic growth, China has been implementing CTIP since 2011 to promote resource efficiency during production. China has 2,543 national or provincial-level Industrial Parks. They are an important pillar of the Chinese economy, and engage in the highly concentrated use of raw materials and energy. According to the Chinese Government, by 2020 CTIP will be implemented in 75 per cent of all national Industrial Parks and 50 per cent of all provincial Industrial Parks. Currently, the government has supported the establishment of 129 National Demonstration Industrial Parks for Circular Transformation. An evaluation of the 30 earliest national demonstration or pilot IPs has shown that, in aggregate, the 30 Industrial Parks have utilized approximately 23 million tons of solid waste and reduced carbon emission by 30 million tons.

FIGURE 5.3 **SPATIAL DISTRIBUTION OF CHINA'S INDUSTRIAL PARKS PARTICIPATING IN CTIP DURING 2011-2017**

Source: Bing Zhu, A Good Practice Example on Resource-Efficient Solutions from China: Circular Transformation of Industrial Parks (CTIP), presentation at Inaugural Meeting of the G20 Resource Efficiency Dialogue, 27-28 November 2017, Berlin, Germany.

5.3.7 Take Advantage of Leapfrogging Opportunities

Leapfrogging possibilities for decoupling

The concept of leapfrogging embodies the idea that industrializing countries can bypass the resource-intensive conventional pathway of development paved by high-income, industrialized countries to "leap" to the most advanced technologies (Gallagher, 2006). One leapfrogging example is the off-grid solar industry in sub-Saharan Africa with the pay-as-you-go solar home system (PAYG SHS), explained in box 5.6.

Leapfrogging can be harnessed for decoupling by policymakers and decision makers. Developing countries that are not yet locked in to long-term infrastructure, industry or cities have an opportunity to leapfrog and satisfy demands using substantially fewer natural resources with new technologies. Even in developed countries, opportunities exist for regions, businesses and households to take advantage of new technologies or organization patterns to drive a sustainable transition.

5.3.8 International Exchanges and Cooperation

The previous seven approaches depend on international exchanges and cross-country cooperation. Three topics warrant particular attention: a level playing field, exchanges to navigate obstacles and share experiences and the currently unequal burden sharing.

Exchanges to navigate obstacles

Exchanges between countries can help navigate obstacles by sharing experiences. Countries can exchange among themselves to share examples and best practices in their country that may be relevant and helpful to other countries. This transfer of experiences and knowledge is especially beneficial to encourage leapfrogging processes and technologies.

The Resource Efficient and Cleaner Production (RECP) programme supported by the United Nations Industrial Development Organization (UNIDO) and UNEP was developed to encourage the adoption of RECP around the world. From this programme, RECP*net* (a voluntary network that connects members across the globe) was created in 2011 to encourage knowledge and expertise sharing. RECP*net* members include organizations or initiatives delivering RECP services in developing or transitioning countries. RECP*net* further collects and

BOX 5.6 Pay-As-You-Go Solar Home Systems (PAYG SHSs)

In sub-Saharan Africa, 612 million people (62.6 per cent of the population) have no access to electricity (IEA, 2017). The kerosene lamp is the primary lighting option for households that are not connected to an electricity grid (Wogan, 2013). Using kerosene lamps leads to carbon dioxide and black carbon particle emissions, which contribute to climate change and have negative health impacts (Lam et al., 2012).

To provide electricity, companies are developing leapfrogging technologies using mobile phones. PAYG SHSs are solar panel devices for individual households that are paid for using an initial down payment and subsequent small incremental mobile payments, making them affordable for an increasingly large population. PAYG SHSs can be small simple lanterns for lighting at night, or an extensive bundle of products including multiple charging stations for mobile phones, a television or other small devices such as fans.

The adoption of PAYG SHSs has avoided at least 26.8 million tons of GHGs, and one study found that 63 per cent of solar light owners who had previously used kerosene before adopting a solar home system saw an improvement in their health (GOGLA, 2018).

Governments can encourage PAYG SHSs by eliminating or reducing duties on renewable energy hardware imports. Kenya and Tanzania adopted policies similar to these, and are credited with supporting the PAYG SHS industry (Amankwah-Amoah, 2014; Pailman et al., 2015).

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shares information about its operations to a larger set of stakeholders (RECP*net*, 2015). At the Central University of Nicaragua, the implementation of RECP measures, including energy efficiency methods and using renewable energies, led to annual savings of US$ 34,450 and a yearly reduction of 26.78 tons of CO_2 (UNIDO, 2017).

Moreover, international exchanges can enhance global governance of a particular resource. For example, if carefully managed, particularly in low-income countries, the extractive sector can provide opportunities to advance sustainable development through the generation of taxes for governments, creation of jobs and transfer of technology (Pedro et al., 2017). However, effective governance is key for mitigating the negative impacts from resource extraction and maximizing the benefits from the sector. Numerous extractive resource governance policies and initiatives have emerged across geographical locations, or even at global levels. These range from comprehensive policy frameworks to platforms for dialogues; from legally-binding instruments backed by UN sanctions and national laws to voluntary instruments; and from single stakeholder-led to multi-stakeholder platforms. These initiatives play an important role in the extractive sector, but still face limitations. As an example, some instruments are voluntary in nature, which results in low compliance. In order to address the governance gaps, an international agenda is required to ensure impacts are limited and benefits are maximized within the sector. This agenda can consider resource security, resource efficiency, limiting negative impacts and promoting sustainable development in the sector. An emerging concept called the Sustainable Development Licence to Operate, which will be included in an upcoming IRP report, aims to support governance in this sector.

Collaboration to create a level playing field

Actors, governments and businesses should reflect together about how to ensure level playing fields for the competition between businesses in international trade. These will have to consider the existing international settlements and agreements, such as those on trade, intellectual property rights and environmental goals.

International cooperation to share burdens

Although internationally pursued efforts with the involvement of all countries can help achieve the goals of impact decoupling and improving resource efficiency, due consideration must be given to the different responsibilities and capabilities of individual countries.

High-income countries have enjoyed a more significant use of resources (thereby contributing to the related negative environmental impacts) and access to finance and technology. As such, they have often stepped forward to take the lead in resource efficiency policies (UN, 2014). High-income countries still have high capacity to act, but their share of consumption is decreasing. The material footprint per capita is still the most pronounced in high-income nations, but it is growing for upper-middle income countries. Moreover, this report found that the share of global domestic material consumption in the upper-middle income group surpassed those of the high-income group by 2012.

5.4 Conclusions

This chapter has shown that obstacles (such as environmental challenges and fundamentally driving change in the current consumption and production systems) go hand in hand with opportunities. In particular, improvements in how natural resources are extracted, processed, used and disposed of around the world can be harnessed through collective action by governments, the private sector and civil society organizations.

The forward-looking scenario developed for this report –*Towards Sustainability*– shows that fundamental changes to policy packages used by governments and societal behaviour can lead to a relative decoupling of natural resource use from income (GDP per capita) and an absolute decoupling of environmental damage from economic growth and increasing resource use. This chapter helps actualize the assumptions made in the *Towards Sustainability* scenario in a useful way for policymakers and decision makers.

Indicators and targets that inform national plans for a sustainable use of natural resources at all levels of governance enable governments to identify priorities and proceed in a coordinated way. Achieving a sustainable transition will require complementary measures that combine to achieve domestic objectives. The context and scope of the instruments will depend on the domestic circumstances of each country. In all cases, the policy mixes developed to improve the use and management of natural resources should be closely coordinated with policies for climate mitigation and biodiversity protection.

Engaging in dialogue to connect with citizens, civil society and the private sector builds consensus. International exchanges and cross-country cooperation can accelerate transitions towards sustainability and support national decisions, thereby helping to create a level playing field for businesses and goods, navigate obstacles, promote shared experiences and find ways of leapfrogging. Although impact decoupling and improving resource efficiency should be an internationally pursued effort involving all countries, due consideration must be given to the different responsibilities and capabilities of countries involved.

These different aspects call for a global discussion.

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06 The Road Ahead

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This report has evaluated the historical trends of natural resource use and the impacts of their use on the environment and human well-being. In this report, only the impacts of resource extraction and processing are analysed, as additional research is needed to fully understand the use phase of natural resources. In addition to this analysis, this report presents two scenarios: *Historical Trends* and *Towards Sustainability*. The *Historical Trends* Scenario shows that the current trajectory of natural resource use and management is unsustainable, while the *Towards Sustainability* scenario explores a transformative global society that achieves large gains in resource efficiency and absolute impact decoupling.

The analysis of natural resource trends, impacts and the two diverging scenario pathways underscores the urgency for a new era of multi-beneficial and innovative policymaking. The previous chapter offers examples and novel ideas for policies. In the effort to embark on a sustainable transition to achieve decoupling, fulfil the SDGs and abide by international agreements such as the Paris Agreement on climate change, each country will need to construct its own pathway and set of policies. A unique policy mix is needed, as every country faces unique circumstances.

Having said that , a handful of essential strategies and tools will be useful for all countries. First, indicators and targets used across governments and sectors can help monitor material flows and guide sustainable transitions. After these targets are set, a national plan for the management of natural resources can be developed to provide a framework for progress. The policies and best practices suggested can help achieve resource and impact decoupling, leading to environmental improvements, economic gains and benefits for human health and well-being. Developing policy mixes must consider the need to build capacity at a national level, mitigate resistance to change by making provisions to those who experience hardship during the transition, discover ways to promote circularity in the economy and find opportunities to leapfrog over outdated technologies or models. These strategies for a national transformation will greatly benefit from international exchanges and cooperation. Sharing ideas, best practices, technology and basic knowledge will support a systemic shift in global society.

Throughout this process, policymakers and decision makers can engage with stakeholders across sectors to motivate action and promote these strategies. This includes a continued collaboration with international organizations to accelerate the improved use and management of natural resources, such as the International Resource Panel. Academics and research departments can also reach out to policymakers to ensure a dynamic conversation. While national policymakers are focused on their domestic natural resource targets, a discussion is needed at the international level to develop global science-based targets for natural resource use. This report, as it provides a scientific analysis of natural resource use and related impacts and policy suggestions, serves as an overarching body of knowledge that can be used to help promote the idea of targets at a global level. Building on this knowledge will further strengthen the collective drive for internationally applicable natural resource use targets.

Much is at stake as global society approaches the final decade before the SDGs are set to be achieved in 2030. A world without resource efficiency and improved impacts will create a future featuring potentially irreversible damage to the environment, ongoing dramatic inequalities between countries and increasing stress on human health. This report has reviewed the dangers of inaction. Human actions place extreme burdens on the Earth system. Respecting the planetary boundaries reduces the risk that human activities could lead to an alteration of the Earth system toward a much less hospitable state (Steffen et al., 2015). This catastrophic outcome would benefit no one. As our global society becomes increasingly complex and interconnected, we must be aware that negative changes across the world can have serious implications at home.

A recent IPCC report on climate change helps drive home the urgency of this situation and the importance of understanding what is at stake for our environment and our livelihoods. The IPCC reported with high confidence that biodiversity loss is projected to be lower at a 1.5 degrees Celsius increase in global temperatures compared to a 2-degrees increase. There is also a high confidence that limiting global warming to 1.5 degrees Celsius above pre-industrial levels will lower the impacts on terrestrial, freshwater and coastal ecosystems (IPCC, 2018).

The IPCC report further details the differences between a world with a 1.5 and 2 degree Celsius-increase. Limiting global warming by 0.5 degrees increases projected food availability, decreases exposure to water stress, decreases health risks (including vector-borne diseases such as malaria) and decreases the risks of climate-change related impacts to global aggregated economic growth (IPCC, 2018).

The results of this Global Resources Outlook complement these findings, and further extend the scope to focus on the role of natural resources and actions in terms of environmental degradation and human well-being. It is worth remembering that extracting and processing material resources is currently responsible for approximately 50 per cent of the global greenhouse gas emissions (not including climate impacts related to land use change) and more than 90 per cent of global biodiversity loss and water stress impacts. Solving the current problems faced by global society requires a fundamental change in how we use natural resources.

The final message of this report should be one of hope and optimism. While additional research is needed, there is an extensive knowledge base about natural resources use and their impacts. Existing or feasible technologies can be applied in the short term across all sectors and countries to improve natural resource use and management. Emerging business models and best practices that embrace the circular economy and leapfrogging technologies can generate enormous resource and economic savings, while still driving development. Policymakers and decision makers have tools at their disposal to advance transformative change. Importantly, this involves national actors working together across borders to achieve this change. Using the results from this report, multi-stakeholder collaboration and innovative solutions, we can resource the future we want.

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Much is at stake as global society approaches the final decade before the Sustainable Development Goals are fixed to be realized in 2030. The international community has set high ambitions for global prosperity, the protection of our biological diversity and land resources, and limiting global warming. Progress towards these ambitions is within our grasp – but a fundamental change in how natural resources are used around the world is necessary to succeed.

Since the 1970s, global population has doubled and global Gross Domestic Product has grown fourfold. These trends have required large amounts of natural resources to fuel economic development and the attendant improvements in human well-being this has brought across the globe. However, these gains have come at a tremendous cost to our natural environment, ultimately impacting human well-being and exacerbating inequalities within and between countries.

The analysis and modelling presented in this report are a first attempt to understand the impacts of our growing resource use, and to develop coherent scenario projections for resource efficiency and sustainable production and consumption that decouple economic growth from environmental degradation. A Historical Trends scenario shows that the current trajectory of natural resource use and management is unsustainable, while a Towards Sustainability scenario shows that implementing resource efficiency and sustainable consumption and production policies promotes stronger economic growth, improves well-being, helps to support more equal distribution of income and reduces resource use across countries.

The final message of this report is one of hope and optimism. While additional research is needed, an extensive knowledge base from the International Resource Panel about natural resources use and their impacts exists. Well-chosen and coordinated sustainability actions can achieve our international ambitions for prosperity within planetary boundaries. Using the results from this report, multi-stakeholder collaboration, and innovative solutions, we can resource the future we want.

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