UN environment

International Resource Panel

ASSESSING GLOBAL RESOURCE USE

A systems approach to resource efficiency and pollution reduction

Acknowledgements

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This interim report was written under the auspices of the International Resource Panel (IRP) of the United Nations Environmental Programme (UN Environment). We thank Janez Potocnik, the co-chair of the IRP, and the members of the IRP and its Steering Committee.

We also thank the United Nations Environment Programme Secretariat of the International Resource Panel:

Peder Jensen, Maria-Jose Baptista,Vera Gunther and, in particular Hala Razian, for assistance in the organization and editing of the report.

Recommended citation: IRP (2017). Assessing global resource use: A systems approach to resource efficiency and pollution reduction. Bringezu, S., Ramaswami, A., Schandl, H., O'Brien, M., Pelton, R., Acquatella, J., Ayuk, E., Chiu, A., Flanegin, R., Fry, J., Giljum, S., Hashimoto, S., Hellweg, S., Hosking, K., Hu, Y., Lenzen, M., Lieber, M., Lutter, S., Miatto, A., Singh Nagpure, A., Obersteiner, M., van Oers, L., Pfister, S., Pichler, P., Russell, A., Spini, L., Tanikawa, H., van der Voet, E., Weisz, H., West, J., Wiijkman, A., Zhu, B., Zivy, R. A Report of the International Resource Panel. United Nations Environment Programme. Nairobi, Kenya.

Design and layout: Anna Mortreux
Printed by: UNESCO
Photos: © Georgina Smith CIAT/Flickr, © Shutterstock, © Icaro Cooke Vieira CIFOR/Flickr

ISBN: 978-92-807-3677-9
DTI/2141/PA
UNEP 162

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List of Acronyms

10YFP — 10-Year Framework of Programmes on Sustainable Consumption and Production
ALA — American Lung Association
APCC — The Australasian Procurement and Construction Council
AQMD — Air Quality Management District
BioIS — Bio Intelligence Service
BREEAM — Building Research Establishment Environmental Assessment
BRICS — Brazil, Russian Federation, India, China and South Africa
C — Celsius
C2E2 — Copenhagen Centre on Energy Efficiency
CAAP — Clean Air Action Plan
CASBEE — Comprehensive Assessment System for Building Environmental Efficiency
CE — Cambridge Econometrics
CED — Cumulative Energy Demand (MJ)
CML-IA — Impact assessment proposed by the Institute of Environmental Sciences of Leiden University, Netherlands
CO_2 — Carbon dioxide
CO_{2e} — Carbon dioxide equivalent
COMTRADE — United Nations International Trade Statistics Database United Nations (COMTRADE)
CSIRO — Commonwealth Scientific and Industrial Research Organisation
DE — Domestic extraction
DG Environment — European Commission's Directorate-General for Environment
DMC — Domestic Material Consumption
DPO — Domestically processed output
DPSIR framework — Drivers-pressures-state-impacts-response framework
EEA — European Environment Agency
EECCA — Eastern Europe, Caucasus and Central Asia
EIO — Eco Innovation Observatory
EMF — Ellen MacArthur Foundation
EPD — Environmental Product Declarations
EPR — Extended producer responsibility
ESCAP — United Nations Economic and Social Commission for Asia and the Pacific
EU — European Union
EUROSTAT — European Statistical Office
EX — Direct exports
FAO — Food and Agriculture Organization of the United Nations
GDP — Gross Domestic Product
Gg — Gigagram
GGKP — Green Growth Knowledge Platform
GHG — Greenhouse gas
HK-BEAM — Hong Kong Building Environmental Assessment Method
HLPE — High Level Panel of Experts on Food Security and Nutrition
ICCA — Institute for Climate Change and Adaptation, University of Nairobi
IEA — International Energy Association
IHME — Institute for Health Metrics and Evaluation
IIASA — International Institute for Applied Systems Analysis
INDC — Intended Nationally Determined Contributions

IM — Direct imports
IMF — International Monetary Fund
IPCC — Intergovernmental Panel on Climate Change
Kg — Kilogram
LCA — Life cycle assessment
LEED — Leadership in Energy and Environmental Design
MCW — Municipal Waste
MJ — Megajoule
MNRE — Ministry of New and Renewable Energy, India
MoHURD — Ministry of Housing and Urban-Rural Development, China
MRIO — multi-regional input-output
MSW — Municipal solid waste
NAAQS — National Ambient Air Quality Standards
NAS — Net additions to stock
NCPC — National Cleaner Production Centres
NDRC — National Development and Reform Commission, China
NIH — National Institute of Health, United States
OECD — Organisation for Economic Co-operation and Development
PM2.5 — Particulate Matter < 2.5 micron diameter
POCP — Photochemical Ozone Creation Potential
PRC — People's Republic of China
PTB — Physical Trade Balance
PTI — Press Trust of India
RCPs — Representative Concentration Pathways
RME — Raw Material Equivalent
RMEEX — Raw material equivalent of exports
RMEIM — Raw material equivalent of imports
SCP — Sustainable Consumption and Production
SDG — Sustainable Development Goal
SEEA — System of Environmental-Economic Accounting
SETAC — Society of Environmental Toxicology and Chemistry
SHEE — Society for Excellence in Habitat Development, Environment Protection and Employment Generation (India)
SO_2 — Sulphur dioxide
SMCS — Sound Material Cycle Society
UBA — German Federal Environmental Agency
UN Habitat — United Nations Human Settlements Programme
UNDP — United Nations Development Programme
UNEP — United Nations Environment Programme
UN Environment — United Nations Environment Programme
UNIDO — United Nations Industrial Development Organization
USD — United States Dollars
US EPA — United States Environmental Protection Agency
USGS — United States Geological Service
VAT — Value Added Tax
WEEE — Waste electrical and electronic equipment
WHO — World Health Organization
WRAP — Waste and Resources Action Programme, United Kingdom
WRF — Water Research Foundation

Preface

At the Second Session of the United Nations Environment Assembly, nations not only recognized that fundamental changes in the way societies consume and produce are indispensable for achieving global sustainable development, but also acknowledged the importance of rigorous scientific evidence on the sustainable use of natural resources to inform policies to this end.

The International Resource Panel was honoured to be called upon at that session to make available information on the state, trends and outlook of sustainable consumption and production to the Assembly by 2019.[1] This interim report is the first step in responding to that request. It builds on ten years of research by the Panel to reassert the centrality of natural resource management to achieving sustainable development; to reiterate the urgency and imperative to decouple economic activity and human well-being from resource use; and to provide innovative solutions based on cutting-edge data to support the transformation of our linear production and consumption systems towards efficiency and circularity.

In line with the drive for a pollution free planet at the Third Session of the United Nations Environment Assembly, the research takes a step further to look at the relationship between resource use and pollution. The amount of natural resources used is closely linked to the amount of final waste and emissions generated through their use. Effective pollution control must therefore also look to minimize raw material use, thereby decreasing final waste and emissions. This link between natural resource use and management and pollution mitigation is explored in depth at the city scale in the special feature of this report. Using a systems approach to examine resources used in developing and emerging economy cities, strategies are being put forward to reduce pollution while also advancing human well-being.

Such innovative and multi-beneficial approaches to the complex social, economic and ecological challenges of our times can be revealed by measuring and monitoring the way we extract, use and dispose of our natural resources. The scientific evidence put forward in this interim report focuses on material resources, including - for the first time - results drawn from a database spanning fifty years up to 2017. Subsequent research of the Panel, including a report to be submitted to the Fourth Session of the United Nations Environment Assembly in 2019, will expand this analysis to include water, land and fossil fuel and emission footprints.

Through continued reporting on this information at regular intervals, the International Resource Panel aims to improve the evidence base for systemic monitoring and policymaking for sustainability. It is our hope that such regularly reported data in our Global Assessment series can support the efforts of nations to monitor natural resource flows and the work of policymakers to orient socio-economic transitions toward sustainability.

We wish to sincerely thank the lead authors and the members of the International Resource Panel working group for laying the groundwork for such important research through this interim edition of the Global Assessment series. Equally, we would like to thank the members of the United Nations Environment Assembly for their confidence in the International Resource Panel to deliver this important work.

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Co-Chair
International Resource Panel

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1 Second Session of the United Nations Environment Assembly, Resolution 2/8 on Sustainable Consumption and Production available at: http://wedocs.unep.org/bitstream/handle/20.500.11822/11184/K1607179_UNEPEA2_RES8E.pdf?sequence=1&isAllowed=y.

Foreword

The more natural resources that move through our economy, the more impact - including waste, emissions and hazardous pollutants - we can expect on our environment and, in turn, our well-being. While seemingly a straightforward proposition, the links between human well-being, economic prosperity and environmental resilience are complex and varied. This means that, unless all three dimensions are taken into consideration in policymaking, any progress in achieving ambitions across them may be hampered by unintended consequences and rebound effects.

This interim report of the International Resource Panel provides a first glimpse at a new evidence base that can inform precisely this kind of integrated policymaking. It presents up-to-date information on material resources that reveals where material resources are extracted and used, for what purpose and to what effect. This information can drive targeted policy interventions and the setting of long-term goals to transform how resources are used for the benefit of people and a pollution-free planet. Seven key strategies are proposed, and existing examples from across the globe shared, to drive the transformation of consumption patterns and production systems that contribute to human well-being without putting unsustainable pressures on the environment.

The implications of this type of integrated policymaking are potentially transformative. Using data on water, fossil fuels, air pollution and greenhouse gas emissions for Delhi, India, and over 600 cities in China, case studies demonstrate how information on natural resources can help identify policy bundles that deliver a significant improvement in human well-being with a relatively small investment in resources. For developing and emerging economies, this means that delivering well-being for all citizens can be achieved with only a modest increase in the amount of resources used. For developed economies, absolute levels of resource use and impacts can be reduced while still achieving high social and economic gains.

In the case example of Delhi, a policy bundle that requires only a 10 per cent increase in the city's energy and material (cement) resource demand was estimated to improve the well-being of 7 million underserved homes (while decreasing greenhouse gas emissions and the fine particulate matter emissions that are a dominant risk factor in air-pollution related premature deaths). In China, a mix of compact urban design and circular economy policies could contribute up to 35 per cent towards carbon dioxide mitigation compared to single-sector strategies, while also avoiding pollution-related mortalities. While every city faces its own unique challenges and circumstances, the case examples demonstrate the importance of this new evidence base in supporting impactful policy design.

The drive towards transformative, integrated approaches to sustainability must be founded on rigorous science - so that progress in one area reinforces advancements in others. Recognizing this, in Resolution 2/8 on *Sustainable Consumption and Production* the Second Session of the United Nations Environment Assembly invited the Panel to share scientific knowledge on the state, trends, and outlook of sustainable consumption and production. This report is the interim response to this request, with impressive results. I am sure you will join me in welcoming this contribution to the debates at the Third Session of the Environment Assembly, and in looking forward to the subsequent reports of this series that will expand its assessment to other natural resources including land, water and greenhouse gas emissions.

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Key Messages

1. Global material resource use is expected to reach nearly 90 billion tonnes in 2017 and may more than double from 2015 to 2050, with high-income countries currently consuming 10 times more per person than low-income countries and the planetary boundaries being pushed beyond their limits.

2. Environmental impacts – including climate change and pollution – cannot be effectively mitigated by focusing on emission abatement alone. The level of resource use determines the magnitude of final waste and emissions released to the environment, making resource management and efficiency key strategies for environmental protection.

3. Decoupling economic activity and human well-being from resource use – i.e. enhanced resource efficiency – is necessary to achieve the Sustainable Development Goals for all.

4. To achieve effective decoupling, today's linear material flows must become circular through a combination of intelligent infrastructure and product design, standardization, reuse, recycling and remanufacturing.

5. Resource efficiency and circular economy create jobs and deliver better socio-economic and environmental outcomes compared to business as usual over the long term.

6. Countries face differing circumstances and therefore have varying opportunities for decoupling wealth creation and resource use, including leapfrogging.

7. A systems approach that avoids burden shifting between sectors, regions, resources and impacts is needed to transform production and consumption systems toward the SDGs.

8. A systems approach can also be used to steer sustainable urban infrastructure transitions, transforming the way in which the basic needs of food, energy, water and shelter are met in order to develop inclusive, resource-efficient and low-polluting cities.

9. Targets and indicators, such as material footprints, are needed at all levels of governance to monitor material flows and steer socio-economic transitions toward the SDGs.

10. Technical, business and policy innovation across the whole product life cycle, as well as reform of financial instruments, will be crucial for the transition to resource efficient economies -as will policy learning, capacity building and knowledge sharing.

The International Resource Panel aims to improve the evidence base for systemic monitoring and policymaking, in particular through systems-based assessment of the resource related challenges and opportunities supporting the transition towards sustainable development.

Summary for Policymakers

Why a Global Assessment of Resource Use?

The way in which societies use and care for natural resources fundamentally shapes the well-being of humanity, the environment and the economy. Natural resources - that is, plants and plant-based materials, metals, minerals, fossil fuels, land and water - are the basic inputs for the goods, services and infrastructure of socio-economic systems from the local to the global scale. Research shows that, either directly or indirectly, natural resources and the environment are linked to all of the United Nations Sustainable Development Goals. Restoring and maintaining the health of the natural resource base is a necessary condition to achieving the ambitious level of well-being for current and future generations set out in these goals.

Improving the well-being of people while minimizing resource use and environmental impacts in particular through enhanced resource efficiency is an essential aspect of delivering on Sustainable Development Goal 12 on Responsible Production and Consumption, and also on almost all of the goals in a direct or indirect manner. To achieve such decoupling, today's linear material flows through the economy must become circular through intelligent design of products incorporating standardization, reuse, recycling/remanufacturing, development of efficient and inclusive infrastructure systems, and, a focus on delivering services rather than material products. Resource efficiency is also complementary to conventional pollution-control strategies. By lowering the amount of resources used, the amount of related emissions and impacts can also be reduced, and many of them at the same time.

Viable pathways exist for society to undertake such decoupling of economic growth from natural resource use and environmental impacts. Technically feasible and commercially viable technologies can improve water and energy efficiency by 60 to 80 per cent in construction, agriculture, food, industry, transport and other sectors, while also delivering economic cost savings of between USD $2.9 and 3.7 trillion each year by 2030. Essential infrastructure (energy, buildings, transportation, water supply, sanitation and waste management) and food supply sectors significantly contribute to global resource-use pollution and environment-related impacts on human health. These sectors also shape social equity in basic provisioning and impact multiple Sustainable Development Goals. With over 60 per cent of the urban infrastructure expected to exist by 2050 yet to be built, the opportunity exists to shape the future over the long term.

In this sense, decoupling is not the domain of environmental ministries alone, but rather cuts across all ministries and levels of government. This means that a mix of multi-level and multi-sectoral policies is needed to move beyond piecemeal changes to a profound transformation of how natural resources flow through society.

The foundation for this change is accurate information. Environmental and sustainability policy requires a solid evidence base that makes it possible to monitor the scale of the physical economy, that is - the amount of material, energy, water and land used and of emissions generated in making, using and providing goods, services and infrastructure systems. Data drawn from up-to-date information on the state, trends, and drivers of the physical economy can help to identify leverage points for targeted and effective policy intervention across sectors and geographical scales. This kind of regularly reported data, such as those drawn from a global assessment of natural resources, can inform the setting of long-term orientation goals, incentive frameworks and systems of engagement and mutual learning that will pave the way for transformational change.

Resource use and pollution

Better and more efficient production and use of natural resources can be one of the most cost-efficient and effective ways to reduce impacts on the environment and advance human well-being. Identifying efficiencies across the life cycle of natural resources means finding opportunities for improving how they are extracted, processed, used (including re-use, recovery and recycling) and disposed of to achieve the same - or greater - economic and social gains while minimizing negative environmental impacts (including pollution).

Approximately 19 million premature deaths are estimated to occur each year globally due to environmental and infrastructure-related risk factors that arise from the way societies extract and use natural resources in production and consumption systems, including essential infrastructure and food provision. About 6.5 million premature deaths (the vast majority in cities) are caused by air pollution related to energy supply and use in homes and industries, as well as transportation and construction sectors within cities.

Effective pollution control requires mitigation of substance-specific hazards and a reduction of raw material use through the economy, in order to lower the volume of final waste and emissions to air and water. Material demand has continued to shift from biomass and renewable materials to non-renewable materials, creating new waste flows and contributing to higher emissions and pollution. The global trend of moving from traditional to modern technologies, and from agriculture-based economies to urban and industrial economies (along with their fast-growing new material requirements), further accelerates global material use and creates significant challenges for sustainability policy.

Metal-ore extraction and metal production increased threefold from 1970 to 2010. The steepest increase occurred from 2000 to 2010, driven mainly by the industrialization and urbanization of emerging economies. Environmental impacts have increased over time, mainly as a result of increased production. Decreasing material and energy productivity is bad economically – it means reduction of potential economic growth – and also bad environmentally (as pressures and impacts upon the environment, including pollution, grow disproportionally faster than the production of goods and services). Investing in material and energy productivity is therefore a key area for improving the integration of economic and environmental objectives and reducing pollution. This is integral to Sustainable Development Goal 12, which aims to reshape consumption and production patterns by transforming resource use in a way that reduces pressures on the environment and climate while promoting human and economic development.

What can a systems approach to natural resources tell us?

Focusing on single resources, single economic sectors or single environmental and health impacts will not achieve the collective vision of the Sustainable Development Goals, and may instead cause harm if the interactions between each of the goals are not considered. Analysis linking the way natural resources are used in the economy to their impacts on the environment (pollution, deforestation, biodiversity loss and water depletion) and people (health, well-being, wealth and so on) across time requires the adoption of a systems approach. A systems approach connects the flow of resources - from extraction through to final waste disposal - with their use and impact on the environment, economies and societies at each stage of the life cycle. The approach can be used to identify key leverage points; develop resource targets; design multi-beneficial policies that take into account trade offs and synergies; and steer a transition toward sustainable consumption and production and infrastructure systems.

The International Resource Panel assesses natural resources from a systems perspective in keeping with the **DPSIR** analytical framework for human-nature interactions. The framework looks at multiple **drivers** of resource use and resulting **pressures** on the natural environment as determinants of the **state** of the environment. The state of the environment in turn **impacts** human wellbeing and socio-economic systems that rely on it, thus requiring a **response** strategy to influence key drivers, and direct the resulting pressure, state and impacts to desired levels through an iterative and continuous process.

The use of natural resources and their related impacts are increasingly transboundary, largely due to trade and globalization. As a result, national accounting metrics that focus solely on a nation's direct natural resource use do not fully represent the resources and associated impacts that contribute to economic activity. The concept of footprints that captures resource use across borders is therefore a critical tool in a systems approach. Footprints can measure different types of pressures, including resource use, pollution emissions and environmental impacts. Four footprints on resource use (materials, land, water and fossil energy) have been identified as determining the magnitude of most specific environmental impacts.

A Global Assessment of Material Resources

While subsequent reports of this series will assess footprints of all resources (materials, land, water and greenhouse gas emissions), the focus of this report is on material resources. Material resources are the biomass (such as wood and crops for food, energy and plant-based materials), fossil fuels (such as coal, gas and oil), metals (such as iron, aluminum and copper) and non-metallic minerals (including sand, gravel and limestone) that are used in the economy. Strong growth in the extraction of material resources continues to support the global economy, and also adds to global environmental pressures and impacts. Based on a material resources database that covers almost five decades (1970 to 2017) and 191 countries, existing trends forecast global material use to reach 88.6 billion tonnes in 2017 – more than three times the amount used in 1970. This is significant because, all else being equal, growing material extraction with subsequent material flows would lead to growing environmental pressures and impacts across the globe.

Growing material use is driven by expanding populations, consumption trends in mainly developed economies and the transformation of developing economies. Demand for materials has shifted from renewable to non-renewable resources, reflecting the global trend away from traditional towards modern technologies, and from agriculture-based economies to urban and industrial economies. This creates new waste flows - thereby increasing emissions and pollution. For example, data show that the steep increases in demand for metal ores, like iron, have contributed to sharp rises in greenhouse gas emissions, acidification, aquatic ecotoxicity and emissions of smog-forming substances.

New analytical tools provide insight into the amount of primary raw materials required along the entire supply chain of commodities.2 For imports, and measured on a per capita basis, the use of primary raw materials is four times the world average in Europe and North America. Global materials have historically been sourced from low-income and middle-income regions that bear the burden of local impacts of resource extraction, often for the sake of producing primary exports to high-income countries. Until the year 2000, high-income countries were net importers of materials while all other regions were net exporters. This has changed dramatically in 2017. High-income countries now export one billion tonnes of materials, mainly driven by the United States and Australia's fast growing exports, while upper-middle-income countries import around 750 million tonnes.

Material footprints add further depth to the picture of global materials use. In 2017, despite more than half of global material use being directed to final demand in Asia and the Pacific, the material footprint of the region is estimated at 11.4 tonnes per capita. North America recorded 30 tonnes of material per capita for final demand, Europe 20.6 tonnes and all other regions measured under 10 tonnes per capita. On a per capita basis, high-income countries continue to consume 10 times more materials than low-income countries.

The full report provides in-depth analysis of material resources to illustrate where materials are extracted, where they are used, what the impacts are and what has driven material use. Understanding these interactions facilitates the development of appropriate policy responses. Reigning in the total physical scale of the economy is one essential first step to reduce waste and emissions and to mitigate overall environmental impacts. A new economic paradigm is needed to improve resource productivity and allow for production and consumption systems to be run with lower material and energy requirements, as well as reducing waste and emissions while providing all services needed.

2 The raw material equivalents (RME) of trade flows, that is, the amount of primary raw materials required along the supply chain to produce commodities.

How resource efficiency can transform economies

The International Resource Panel modelled the combined economic and environmental consequences of ambitious resource efficiency and greenhouse gas abatement policies (UNEP, 2017) and found that there is substantial potential to achieve win-win outcomes that reduce environmental pressure while improving income and boosting economic growth.

By 2050, ambitious polices for resource efficiency could reduce global resource requirements by about a quarter and deliver global economic growth of 3 to 5 per cent above the existing trend. This would also have considerable co-benefits for climate mitigation efforts.

Resource efficiency policies and initiatives could:

- reduce natural resource use globally by 26 per cent by 2050, in combination with ambitious global action on climate change, as well as stabilizing per capita resource use at current levels in high-income countries;
- reduce greenhouse gas emissions by an additional 15 to 20 per cent by 2050 (for a given set of greenhouse policies), with global emissions in 2050 falling to 63 per cent below 2010 levels, and emissions in high-income countries in 2050 falling to 74 per cent below 2010 levels;
- more than offset the economic costs of ambitious climate action, so that income is higher and economic growth is stronger than in the 'existing trends' scenario;
- deliver annual economic benefits of USD $2 trillion globally by 2050 relative to existing trends, including benefits of USD $520 billion in high-income nations, while also helping put the world on track to limit climate change to 2°C or lower.

These projections can be treated as a reasonable minimum estimate of economically attractive physical resource efficiency potential. Further reports of this series will present in-depth scenario modelling to support informed policy and decision making. The level and mix of economic and environmental benefits achieved will depend, however, on the design of the policies and approaches implemented – suggesting that attention will be required to develop and test a smart and practical package of resource-efficiency measures.

Driving a profound resource efficiency transition

Efficiency in the way resources are extracted and manufactured by industry, used and re-used by people and recycled and disposed of by all is essential to efforts toward a sustainable and pollution-free planet. A long-term vision underpinned by evidence-based targets and incremental policy signals can combine to produce a profound transformation of the physical economy. It is crucial to ensure a coordinated and coherent approach to policymaking across ministries, as well as the participation of stakeholders capable of turning shared visions into reality and managing resistance to change by clarifying multiple benefits for the actors. This implies not only bottom-up changes in the way businesses create value and citizens access, use and dispose of resources, but also top-down changes in the way that policies steer the markets where businesses operate and build the social infrastructure in which citizens live.

To steer long-term and profound changes, four iterative steps across all levels of governance are required: (1) monitor current performance and use; (2) set targets and define future objectives in the light of international agreements; (3) test and innovate targets, regulation and voluntary approaches, subsidies and taxes for resource efficiency and integrated resource management; and (4) evaluate, learn and adapt.

At the national level, a bundle of strategies and tools is available to public authorities to support the shift towards inclusive, resource-efficient and pollution-free economies.

The overarching strategies manifest differently in terms of possible pathways depending on a country's level of natural resource endowment and its socio-economic context. **Absolute decoupling** is recommended as an aim for high-income nations, with the need to lower average resource-consumption levels, distribute prosperity equally (including for gender equality) and maintain a high quality of life. Strategies toward waste prevention, high-value resource recovery, circular resource flows and adjusting social norms are particularly relevant. **Relative decoupling** is a key strategy suited to developing economies and economies in transition to raise average income levels and eliminate poverty. These countries should strive to improve their resource efficiency even as their net consumption increases, until a socially acceptable quality of life is achieved. There is an opportunity to fast track sustainable development in such countries by learning from and leapfrogging traditional pathways.

Resource efficiency alone is not enough. Productivity gains in today's linear production system are likely to lead to increased material demand through a combination of economic growth and rebound effects. What is needed is a move from linear to circular material flows through a combination of extended product life cycles, intelligent product design and standardization, reuse, recycling and remanufacturing. Business models aiming at offering high-quality services as an alternative to selling more products would be another important component.

Seven policy strategies for multi-beneficial policymaking

Many policy tools have been successfully used for tackling aspects of the resource efficiency challenge in different parts of the world. This report proposes seven strategies for consumption patterns and production systems that contribute to human well-being without putting unsustainable pressures on the environment.

1. Set targets and measure progress

A set of resource efficiency targets for the use of key resources (materials, land and water, as well as greenhouse gas emissions) can guide policy development and inform a progress-monitoring framework. Targets should preferably be footprint-based to consider transboundary effects of product use and minimize the risk of shifting problems to other regions. Reporting on harmonized metrics of resource use and efficiencies at regular intervals across and within countries could raise the profile of resource efficiency and drive ambitions to increase it. Resource-efficiency targets are the first step forward, while national and international targets for sustainable levels of global resource consumption will also be needed.

2. Act on key leverage points across all levels of governance

To identify "hot spots" for policy action, national and international resource-efficiency programmes could play a strategic role in the coordination of monitoring to streamline institutional arrangements and promote synergies in national – and cross-sectoral – policy interventions.

3. Take advantage of leapfrogging opportunities

Many fast-growing cities and developing economies are not locked into current design and business models. They can benefit from a weaker bias[3] against resource-efficient investments, and the opportunity to avoid the resource- and energy-intensive design for new infrastructure. Taking advantage of these opportunities requires access to finance and international cooperation, in particular for low-income economies.

4. Implement a policy mix that builds incentives and corrects market failures

Aligning price signals and fiscal policies with the strategic goals of society can adjust the behaviour of firms and individuals, so that their investment and purchase decisions reflect those of society as a whole. Implementing a policy mix that builds incentives and corrects market failures for resource efficiency, including slowly shifting taxes from labour to materials in line with the pace of decoupling success, can have a strong steering effect and help to avoid rebounds.

5. Promote innovations toward a circular economy

A switch from consumption of finite resources to recycled materials and renewable resources (such as sunlight, wind and sustainably managed biomass) opens up the possibility of meeting the needs of more people over the long term. Before recycling, extending the lifetime of material resources through direct reuse, repair, refurbishing or remanufacture, as well as policies that encourage recycling to be considered as part of product design, are crucial to breaking through infrastructural lock-in of existing production and consumption systems.

6. Enable people to develop resource-efficient solutions

New types of alliances to collaborate, experiment and learn are critical to a successful transition. Initiating and participating in multi-stakeholder platforms, cross-cutting and expert networks and private-public partnerships will help promote cooperation and collaboration. Governments can provide skills training, improve education programmes and provide financial support to spread risk associated with potential breakthrough innovations.

7. Unlock the resistance to change

Any reduced revenues and job losses occurring during transformations to a resource-efficient and sustainable global economy must be addressed to overcome resistance to change and to support workers and businesses that are impacted. Upskilling training and education, recycling tax revenues back to affected industries and businesses to support transformation and protecting the very poor and vulnerable through policy packages that take their needs into account are some of the ways resistance to change can be mitigated.

3 This relates to the fact that vested interests may not be as set on defending the status quo, and that consumption habits may not yet be as tied to mass consumption with rapid obsolescence, thereby providing greater scope for new forms of consumption and leasing (Swilling and Annecke, 2012; Boston Consulting Group, 2010).

Special feature: mitigating air pollution and achieving the Sustainable Development Goals in cities through a systems focus on natural resources and infrastructure

Air pollution has emerged as one of the primary risk factors for premature mortality in the 21st century, linked with 6.5 million premature deaths annually, the majority of which are in global cities. Indoor and ambient air pollution in the form of fine particulate matter (PM2.5) is the dominant risk factor (accounting for 96 per cent of health impacts).

Addressing PM2.5 air pollution is challenging because it arises from multiple sectors within the city boundary (industry, transportation, household cook stoves, waste burning, construction and road dust) and outside city boundaries (agricultural burning, industrial emissions and natural sources). Furthermore, PM2.5 concentrations in air are influenced by local weather patterns in complex ways and exacerbated by climate change (particularly extreme heat and drought events).

Lessons learned from air-quality management experiences indicate that systems-based approaches complemented by end-of-pipe control strategies are important in addressing the multi-faceted sources of PM2.5. The Special Feature presents a systems approach anchored in the use of natural resources, with a focus on essential infrastructures and food supply in cities. The findings suggest pathways for reducing pollution while also providing multiple co-benefits that advance Sustainable Development Goals for economies at differing stages of development.

For developing economies, strategic pathways are identified for transforming cities with underserved populations, high inequality and high pollution levels to become inclusive, resource efficient and cleaner, thereby advancing the well-being of large urban populations. A case study of the National Capital Territory of Delhi, India (hereafter Delhi) demonstrates how a bundle of strategies (provision of transit services, in situ slum rehabilitation within the urban fabric, resource-efficient multi-storey building construction with low-polluting materials, energy efficiency among high consumers and replacement of dirty cooking fuels) can deliver basic services to about 7 million additional people while consuming a small fraction (less than 5 per cent) of the total amount of cement and electricity used in the city today, while avoiding over 22 per cent of greenhouse gas emissions and air pollution (PM2.5) emissions and preventing more than 2,500 premature deaths from dirty cooking fuel use alone. This case study indicates a significant improvement in human well-being, with a relatively small investment in resources, as a good example of the concept of decoupling.

For **emerging economies** undergoing rapid urbanization and industrialization, circular economy policies (combined with urban planning that enables beneficial exchange of materials and energy across different industry and infrastructure sectors in cities) are found to yield economic gains, natural resource conservation, greenhouse gas mitigation and air-pollution reductions. Using modelled energy use in different sectors (residential, commercial and industrial) in more than 630 Chinese cities, circular economy strategies in cities had a demonstrated collective impact on national sustainability and greenhouse gas emissions targets, while also showing local health co-benefits specific to each city's context. The models show that circular economy strategies applied in cities can collectively contribute an additional 15 per cent to 36 per cent towards national greenhouse gas mitigation compared to conventional single-sector strategies. Co-beneficially, about 47,000 (range 25,500 - 57,500) premature deaths are estimated to be avoided annually through air-pollution reduction.

Developed economies also benefit from a systems approach that systemically integrates resource efficiency in multiple sectors with air-pollution control, as has been demonstrated from experiences in air-quality management in countries including the United States. Air pollution is a worldwide challenge requiring a systems approach anchored in resource use and efficiencies, particularly in the infrastructure and food supply sectors.

For cities, the bundle of policy strategies listed below, when implemented together, can simultaneously reduce air pollution and advance human well-being, achieving multiple benefits in diverse world regions.

- Develop urban-rural market mechanisms and avoid urban area expansion to agricultural lands and lands that provide high-value ecosystem services to ensure preservation of lands and reduction of dust/air pollution emissions;
- Undertake strategic urban land-use and infrastructure planning within cities and urban areas to reduce travel demand;

- Invest in efficient transit systems to reduce vehicular emissions and congestion;
- Undertake inclusive development and in situ slum rehabilitation in multi-storey buildings within dense city areas that provide essential services and access to livelihoods while reducing the travel burden on the poor;
- Promote multi-storey resource-efficient building construction and energy efficiency for all buildings;
- Promote culturally-sensitive behavioural change strategies to reduce resource use, including a focus on resource substitutions for dirty cooking fuels and construction materials;
- Implement electricity grid transformations with high levels of renewable energy;
- Encourage business innovations to reduce agricultural and solid-waste burning.

Where to from here?

Sustaining and managing resource use is a cornerstone of sustainable development, particularly in terms of achieving environmental *and* socio-economic goals. A systems approach considering all phases of natural resources life cycles – from extraction through production, consumption, recycling and final disposal – has been shown to foster a better understanding of the physical basis of societies. This improved understanding can, in turn, inform the design of effective policy measures across all sectors and levels of the economy to promote resource efficiency and reduce pollution.

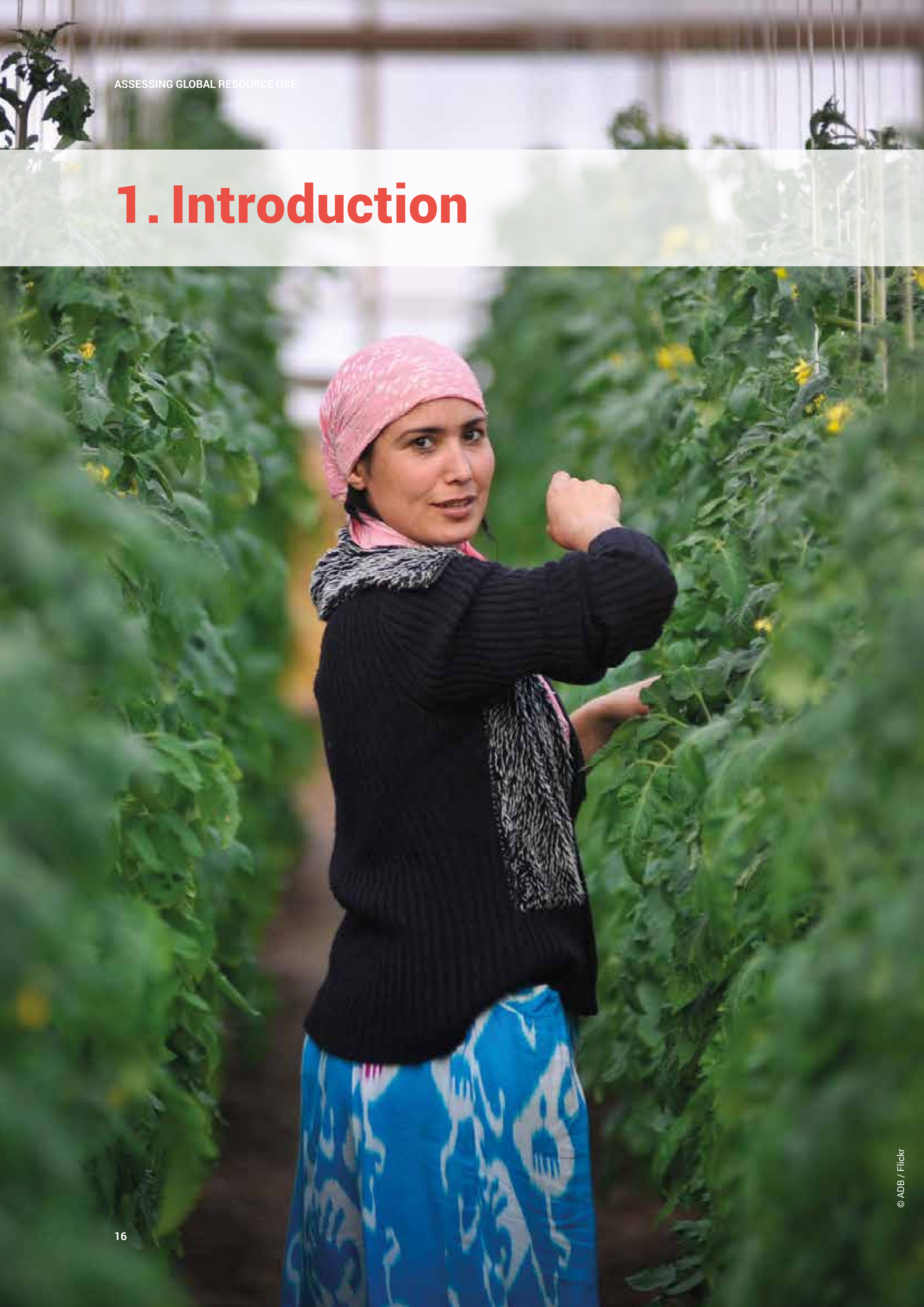
The twin issues of reducing overconsumption and waste of natural resources on the one hand, and providing secure access to natural resources and food on the other, must be addressed simultaneously to ensure that neither surpasses the thresholds of a global "safe operating space". Strategies and solutions should therefore be designed according to national circumstances, but in a globally consistent manner by approaching the Sustainable Development Goals without compromising other regions' progress towards this end.

Conventional pollution control by add-on technologies is bound to shift environmental problems and increase resource consumption. Keeping natural resource use and associated impacts within safe limits can only be achieved by significant increases in resource efficiency within production and consumption systems and infrastructure provision. Transformations toward resource-efficient urban infrastructures also have the co-benefit of increasing progress related to human health and well-being.

Overall, transformational policies are needed to enhance resource efficiency and sustainable resource use throughout the economy. There has been initial progress in establishing instruments that foster a more sustainable use of natural resources in production and consumption systems, including infrastructure management. Nevertheless, there remain huge opportunities for the future.

Improved information and scenario analysis on the state, trends and outlook of natural resource use, reported on a regular basis, can support effective and targeted policy design and evaluation. The Global Assessment of Natural Resource Use and Management series of the International Resource Panel aims to provide this knowledge base. All in all, this report can be taken as a pilot, providing strategic elements for regular reporting based on a new and authoritative database of the International Resource Panel on material flows. A report covering natural resources (water and land) and greenhouse gas emissions is expected to be released in 2019.

1. Introduction



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The way in which society uses and cares for natural resources fundamentally shapes the well-being of humanity, the environment and the economy. Effective pollution control requires mitigation of substance specific hazards *and* a reduction of raw material use throughout the economy, in order to lower the volume of final waste and emissions in air and water. This chapter introduces the challenges and opportunities for resource management and use towards sustainable development. From a material flow perspective, it argues that a systems approach to resource assessment is needed to provide the insight that policymakers need to steer development towards the ambitious level of well-being for 9 billion people articulated in the Sustainable Development Goals (SDGs).

This chapter also sets the overarching framework for this report. It describes the approach of the International Resource Panel to assess resource use from a systems perspective, presents the structure of the report and briefly introduces key concepts and terms for building a common understanding of the fundamental issues and methods involved.

1.1 Natural resources and sustainable development

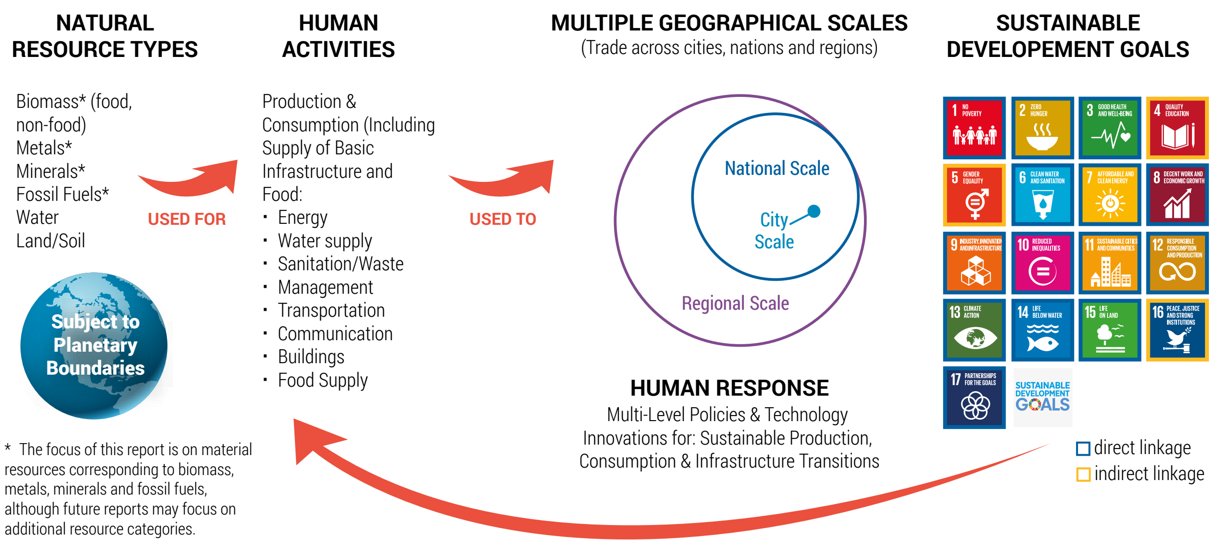
The Sustainable Development Goals aim to end poverty, protect the planet and ensure prosperity for all by the year 2030. They represent a collective vision of a better future that is ambitious, universally applicable and truly transformative. To this end, restoring and maintaining the health of the natural resource base is a necessary condition. Box 1.1 provides examples of the linkages between the use of multiple natural resources (materials, land and water) and environmental impacts (greenhouse gas emissions, pollution and biodiversity loss), economic development, human health and well-being. Understanding these linkages is essential to achieving the Sustainable Development Goals.

BOX 1.1 Challenges for resource management and use

- **Global material resource use has accelerated in the first decade of the 21st century, thereby increasing environmental pressures and impacts such as pollution**. An estimated four out of nine planetary boundaries have been surpassed, irreversibly changing the functioning of major Earth system processes (such as climate) (Rockström et al., 2009; Steffen et al., 2015). Over the last few decades, a combination of habitat loss, overexploitation and pollution has led to catastrophic declines in biodiversity – known as Earth's sixth mass extinction – in the form of damage to ecosystem functioning and services vital to sustaining civilization (Ceballos et al., 2017).
- **There is high inequality in the distribution, availability and use of natural resources and in exposure to environmental risk factors** across world regions and within countries and cities. For example, the 1.2 billion poorest people account for 1 per cent of the world's consumption, while the billion richest consume 72 per cent of the world's resources (United Nations, 2013). In many cities, more than 30 to 40 per cent of the population is living without access to basic services (United Nations Environment Programme (UN Environment and/or UNEP), 2012c), and the infrastructure deficit in water supply and sanitation, food supply and transportation places an undue burden on the poor and particularly on women (resulting in poverty, poor access to livelihoods and safety concerns) (United Nations Human Settlements Programme (UN Habitat), 2013).
- **Approximately 19 million premature deaths are estimated to occur globally each year** due to environmental and infrastructure-related risk factors that arise from the way societies use natural resources in production and consumption systems, including essential infrastructure and food provision (Ramaswami et al., 2016). About 6.5 million premature deaths (the vast majority in cities) arise from air pollution associated with energy supply and use in homes and industries, as well as transportation and construction sectors of cities (ibid).
- **Economic stability is reduced by volatile world market prices for natural resources**, as well as the financial, environmental and social limits of resource extraction adding to the pressure.
- **The cost of inaction is high**. Estimates indicate that the combined economic costs of air pollution and climate change will be nearly 5 to 6 per cent of Gross Domestic Product (GDP) in many nations by 2060 (Organisation for Economic Co-operation and Development (OECD), 2016).
- **Regionally, access to fresh water and availability of other resources (like sand from river beds) constrain both human and economic development**. By 2050, it is estimated that about 3.9 billion people will be living in water-insecure regions, thereby increasing vulnerability and costs (UNEP, 2012c). The boom in construction spurred by urbanization in emerging economies has created such excessive demand for sand that river beds close to urban areas are being depleted to meet it, causing acute water stress that harms humans and ecosystems alike (with additional impacts on the construction sector) (see Tejpal et al., 2014; Shaji and Anilkuar, 2014; and Ashraf et al., 2011).

One of the great strengths of the SDG framework is its recognition of the intimate links between human well-being, economic prosperity and a healthy environment. Either directly or indirectly, natural resources and environment are linked to all 17 SDGs - impacting poverty, health, hunger, gender inequality, food and agriculture, water and sanitation, human settlements, energy, climate change, sustainable consumption/production and oceans/terrestrial ecosystems (UNEP, 2016a). The linkage of natural resources and SDGs manifests in society-environment interactions in the form of consumption and production systems (such as infrastructure provisioning) that are played out at different scales – global, national, regional and city. Figure 1.1 depicts these links. **Analysis of these interactions at multiple scales provides a powerful means of understanding the drivers and potential pathways to achieving SDGs in different world regions, nations and cities**.

FIGURE 1.1 Natural resources flow through society via production, consumption and infrastructure provisioning - impacting Sustainable Development Goals at different scales



* The focus of this report is on material resources corresponding to biomass, metals, minerals and fossil fuels, although future reports may focus on additional resource categories.

1.2 The benefits of resource efficiency

Better and more efficient use of natural resources can be one of the most cost-efficient and effective ways to reduce impacts on the environment and to advance human well-being. Increased efficiency across the life cycle of resource use means more effective extraction and production, as well as smarter consumption (including a shift towards circular material flows requiring changes in business models, behaviours and products). Several recent international reports and global scenario analyses demonstrate **viable pathways for society to decouple economic growth from natural resource use and environmental degradation**. These reports present the opportunities for achieving economic benefits by promoting resource efficiency (UNEP, 2017a; Meyer et al., 2015; Cambridge Econometrics (CE) and Bio Intelligence Service (BioIS), 2014; and McKinsey Global Institute, 2011), urban infrastructure transitions (UNEP, 2017b) and a circular economy (Ellen MacArthur Foundation (EMF), 2015). For example, it is estimated that 60 to 80 per cent improvements in energy and water efficiency are technically possible and commercially viable in construction, agriculture, food, industry, transport and other sectors compared to conventionally used technologies - delivering economic cost savings of between 2.9 and 3.7 trillion USD each year by 2030 (UNEP, 2014b; UNEP, 2017a). Human well-being, measured by the Human Development Index,[4] demonstrates little improvement beyond a relatively low level of material consumption (UNEP, 2016c).

Nations, cities, companies and civil society are beginning to engage in large-scale supply and infrastructure transitions in the provisioning of energy, water, food,

4 Available at: http://hdr.undp.org/en/content/human-development-index-hdi.

transportation, communication, buildings and sanitation and waste management – sectors that form the fabric upon which other production and consumption activities are carried out. In the electric power sector, for example, renewable energy sources are becoming cost competitive with fossil fuels. New construction materials are the subject of experimentation, including innovative ways to re-use certain waste streams. Smart technologies and behaviour changes contribute to transforming transportation options in cities, with options such as shared taxis, on-demand bus services, bike lanes and pedestrian-only zones. **These infrastructure transitions create strategic opportunities.** The decisions taken during such transitions shape the future over the long term**.** They offer the opportunity to reimagine future cities, recognizing that 60 per cent of the urban areas expected to house 3.9 billion people by 2050 have yet to be built (UNEP, 2013a). At the same time, infrastructure in existing cities in the United States, Australia, the European Union and elsewhere is being replaced or refurbished. **Given the long lifespan of infrastructure, an urban infrastructure transition perspective offers a strategic opportunity for achieving resource efficiency and inclusive development in different world regions**. It has been estimated that a 30 to 60 per cent reduction in energy and material use can be achieved in cities through strategic intensification and critical infrastructure transitions, including energy-efficient buildings, district energy systems and transit systems built upon a compact and sustainable land-use plan (UNEP, 2017b). With more than 1 billion people in cities living in informal settlements with poor infrastructure provisioning, strategies toward resource-efficient and inclusive infrastructure system transformations are vital to achieving SDGs and reducing pollution.

1.3 The need for a systems approach

Focusing on single resources, single economic sectors or single environmental and health impacts will not achieve the collective vision of the SDGs, and may instead cause harm if these interactions are not addressed. For example, it will not be possible to achieve climate goals if society focuses solely on the energy sector: consideration of the “embodied” energy of materials has been found to be indispensable for mitigating greenhouse gas emissions (UNEP, 2017a). Likewise, agricultural intensification, forest/biodiversity conservation, climate change mitigation, soil health maintenance and freshwater protection are all included as fundamental goals in the SDGs, yet they all entail potential synergies and trade offs with other objectives. **A whole systems approach is essential to maximize co-benefits and anticipate and mitigate trade offs in the light of net effects on resource supply and demand** (UNEP, 2015b).

The world’s increasing reliance on trade makes it difficult to readily track progress toward the SDGs, particularly where impacts are transboundary. This means that those impacts are either displaced abroad (as in the case of polluting industries) or occur at regional or global scales (like when greenhouse gas emissions accumulate to change climate systems at a global scale and land-use change contributes to global biodiversity loss). National accounting metrics for resource efficiency that focus solely on a nation’s direct material consumption do not fully represent all the resources that contribute to economic activity in a given country. Thus, **the footprints concept – which captures resource use across borders – has become critical to assessing progress toward sustainability**. Transboundary material footprint assessments, for example, show that around 40 per cent of the total annual global material flows are linked to trade (Wiedmann et al., 2015). Furthermore, the indirect or embodied materials in trade far exceed the direct mass of goods traded across nations (by a factor of 4) (ibid).

Altogether, there is a need for robust monitoring data that are regularly updated and coherent across scales (global, regional, national and city). A systems approach is required for analysis to connect different types of material resources used in the economy (such as biomass, fossil fuels, metals and non-metallic minerals) to their impacts on the environment (pollution, deforestation, biodiversity loss and water depletion) and people (health, well-being and wealth) over time. Such a systems approach (a) takes the whole life cycle of resources used into account (b) uses material flow analysis to link resource use to environmental pressures (through footprints) and (c) considers interactions between human activities and the environment across scale, time and boundary dimensions. It can be used to identify key leverage points for designing multi-beneficial policies for achieving SDGs, in particular by considering trade offs and synergies between individual SDGs and providing the data foundation for developing resource-use targets to steer a transition toward sustainable consumption and production systems.

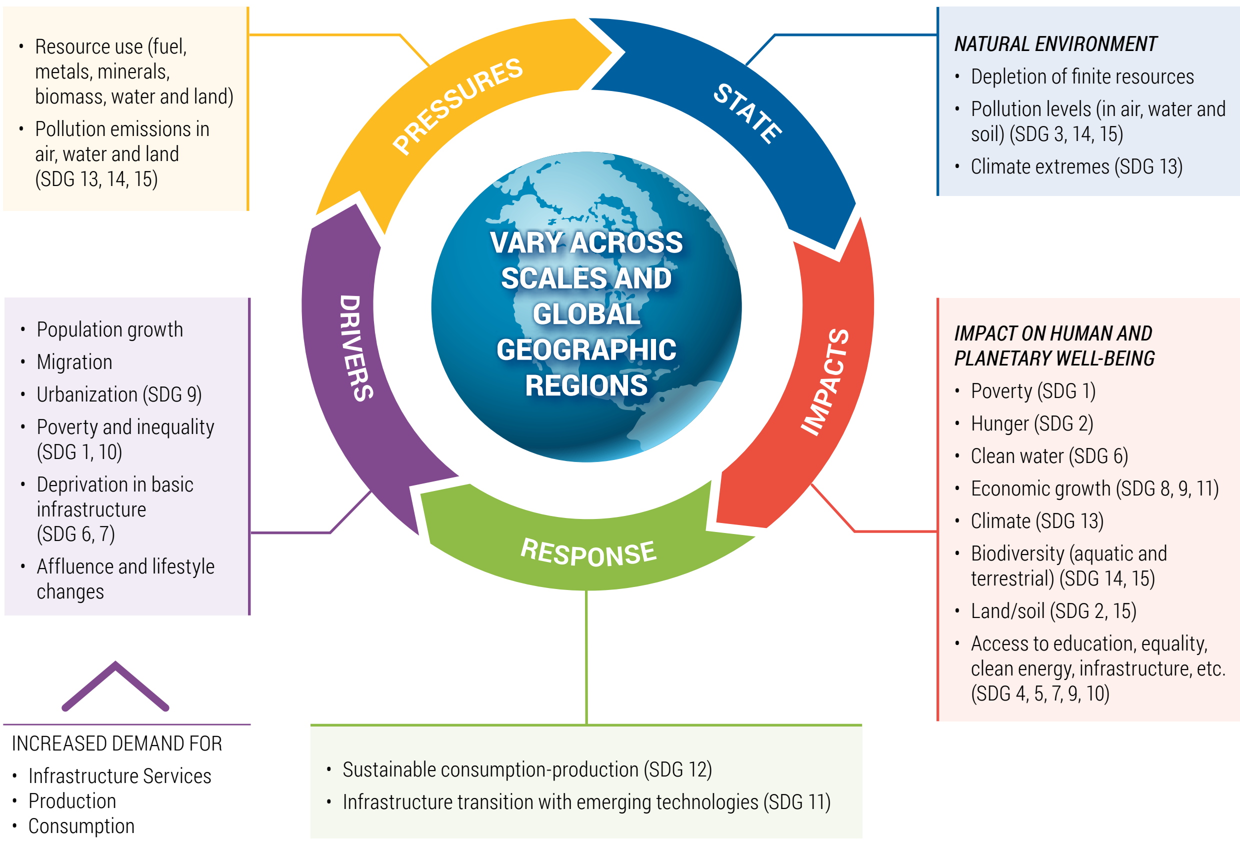
1.4 The International Resource Panel's vision for regular resource reporting

The International Resource Panel is hosted by the United Nations Environment Programme (UN Environment). It is tasked with building and sharing the knowledge needed to increase the sustainability of resource use worldwide. The International Resource Panel aims to develop better ways to promote human well-being and economic growth while minimizing environmental degradation and resource depletion. The Panel emphasizes systems thinking and a life-cycle perspective that takes the drivers-pressures-state-impact-response framework into account (see figure 1.2).

This report focuses on the state and trends of 'material' resource use (biomass, fossil fuels, metals and non-metallic minerals), with further types of resources (land/water) and greenhouse gas emissions remaining as major areas for future reports. These material resources are assessed from a systems perspective, in keeping with the analytical framework for assessing how human-nature systems interact:

- multiple **drivers** of resource use, including production/consumption patterns, urbanization, economic growth, population growth, lifestyle changes, emerging disruptive technologies, poverty and inequalities in basic services.[5]

FIGURE 1.2 Natural resource use linked to the Sustainable Development Goals via the Drivers-Pressures-State-Impact-Response Framework



5 Ending poverty in all its forms everywhere is Goal 1 of the SDGs. While providing essential services will contribute to increased resource use and thereby pressures, this represents a basic human right at the core of sustainable development. It increases the urgency of addressing drivers such as excessive consumption related to lifestyle and affluence.

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- **pressures** on the natural environment, represented in terms of both resource use (in material footprints) and environmental impacts.
- as a consequence, the **state** of the environment deteriorates: surface and groundwater become polluted, groundwater levels plummet, fertile soils are lost, forests are degraded, city air pollution grows, carbon emissions increase and so forth.
- these changes have various **impacts** on human and environmental health, leading to premature deaths, hunger, increased species extinction and climate change.
- a **response** strategy to keep resource use and the resulting impacts within acceptable levels would be to change production and consumption systems, including infrastructure systems.

The evidence generated can support socio-technical transitions towards the SDGs. Future reports of the International Resource Panel will continuously update the data sets and scenarios to provide a platform where different types of resource use are linked to impacts on the economy, environment and human well-being. All in all, this report can be taken as a pilot, providing strategic elements for regular reporting based on a new and authoritative database of the International Resource Panel on material flows.

1.5 Structure of the report

This interim report responds to a request at the Second Session of the United Nations Environment Assembly[6] to assess the state and trends of natural resource use and provide an outlook on sustainable consumption and production, in a manner that informs transitions toward sustainable development. **It aims, in particular, to provide an evidence base for policymaking and to enable monitoring of progress or regression in the interests of achieving SDGs.** It is intended to be a short report that highlights important trends, challenges and policies from the unique resource-based systems approach advocated by the International Resource Panel. The scope and depth of analysis shall be expanded in future. With a continued focus on trends and policies, each subsequent report is expected to include a focus issue that addresses an environmental challenge of significant concern, using a natural resource systems perspective. This report includes a special feature on air pollution in cities. In detail:

- **Chapter 2 presents new data and trends related to resource flows of biomass, fossil fuels, metals and non-metallic minerals** (including global extraction, environmental impacts, trade, material footprints, drivers and future outlook). It compares the performance of world regions and country groupings (such as low- and high-income countries) and identifies drivers of material extraction in different national contexts.
- **Chapter 3 presents resource-oriented strategies and policies integral to the success of the SDGs**. Seven transition strategies towards sustainable consumption and production systems are presented, including consideration of appropriate policy instruments and good practice examples from cities and countries around the world. Policy solutions related to food systems, the built environment, cities and urban infrastructure are examined in more detail.
- **Chapter 4 is a special feature that focuses on the link between resource use, infrastructure provisioning, air pollution and human health in cities**. It argues that resource-efficient urban infrastructure transformations will be instrumental in reducing air pollution and co-beneficially advancing multiple SDGs in cities. Two illustrative case studies of cities at varying stages of development faced with different infrastructure provisioning challenges are presented and a set of strategies identified that can combine to encourage diverse world cities to reduce air pollution while advancing broader sustainability goals.
- **Chapter 5 draws together strategic conclusions and summarizes key findings.**

All in all, this report will demonstrate the type of analysis possible at different scales to improve the knowledge base and support a common understanding of the challenges and opportunities for action in preventing further degradation of ecosystems across the world and preserving the resource base for generations to come.

6 Resolution 2/8, point 13 of the 27 May 2016 session, Nairobi; available online: http://www.unep.org/about/cpr/resolutions-adopted-un-environment-assembly-its-second-session.

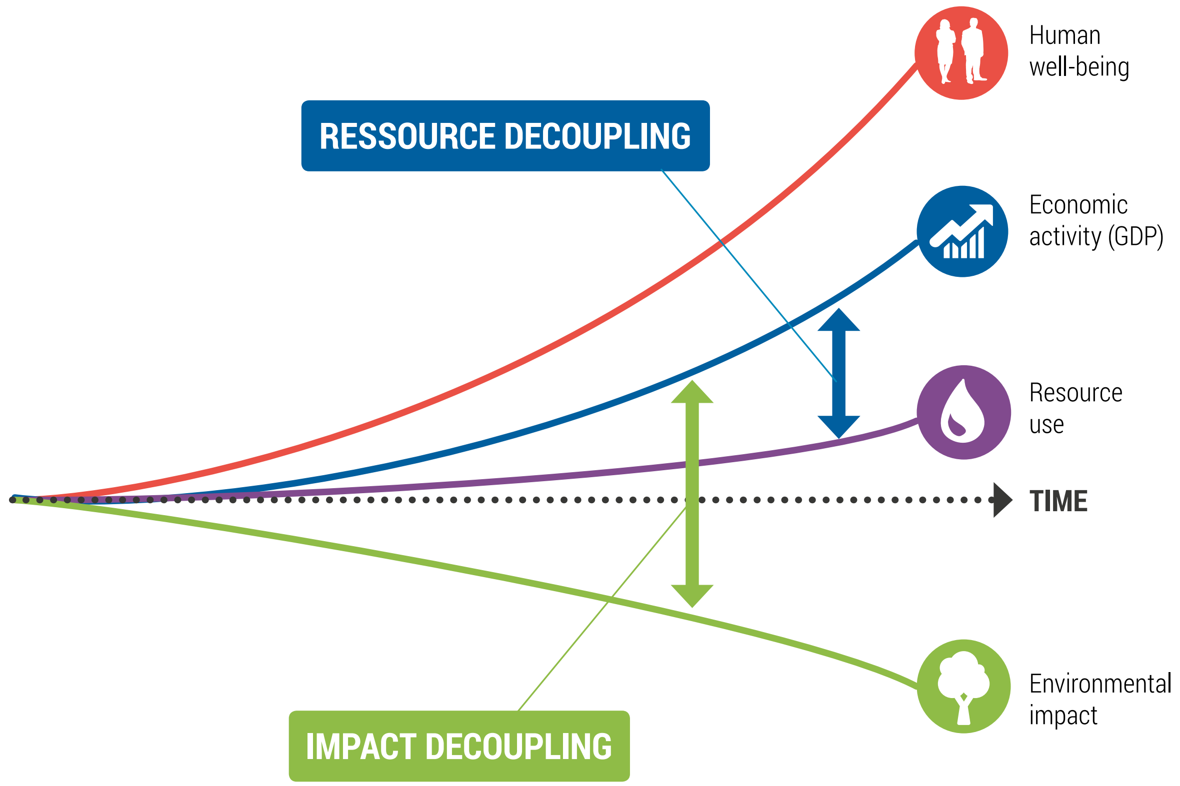
1.6 Key terms, concepts and approaches

This section describes the key terms, concepts and scientific approaches used in this report. It is largely based on the online glossary of the International Resource Panel,[7] as well as UNEP, 2016e.

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 1.3, which shows increasing trajectories for GDP and human well-being that could result from successful achievement of SDGs. The figure also shows that resource use can increase at a much slower rate than GDP (relative *resource decoupling*) and environmental impacts may actually decline (absolute *environmental 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). So far, there is evidence for resource decoupling at the national level, while decoupling of overall environmental impacts from resource use seems limited.

FIGURE 1.3 Concept of decoupling



Source: UNEP, 2011a.

7 Available at: www.resourcepanel.org/glossary.

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.

Footprints

Herein, the term footprints is mainly 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). The direct and indirect pressures can be assigned to different activity sectors, including (a) production (economic output in a nation or city), (b) final consumption (by households, government and business capital formation), and (c) community-wide infrastructure and food supply to the geographic area (including producers and consumers). 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 and biodiversity losses and so forth). Four footprints on resource use (abiotic non-energetic materials, land, water and fossil energy) have been found to determine more than 80 per cent of all specific environmental impacts (Steinmann et al., 2016). 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). Together with land, water and GHG emission footprints, these four footprints seem to account for most of the potential environmental impact. However, they must be supplemented by specific indicators to measure specific environmental impacts such as eutrophication. To compare footprints across cities or nations, some type of normalization is necessary (although this has been the subject of much debate). Normalization into per capita metrics follows consumption-based footprints quite closely. For community infrastructure, the normalization metrics can be either per unit GDP or per capita, and both have been discussed in the literature.

Infrastructure provisioning and food supply

This term describes the provisioning of essential utilities (water, energy, buildings, sanitation, transportation and waste management) and nutrition supply to communities. These sectors are of particular importance as they address basic needs and are at the core of SDGs related to resource access and inequality. These sectors are essential for human and economic development. They also dominate natural resource use at the global level: together they account for 80 per cent of global material use, over 90 per cent of water withdrawals and around 85 per cent of global greenhouse gas emissions. Furthermore, they represent the sectors where high-impact interventions to enhance resource efficiency have been shown to be possible, which encourages a concerted focus on these sectors (see UNEP, 2017a).

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. 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 rematerialization (reuse, remanufacturing and recycling) in a systems-wide approach to a **circular economy,** as well as infrastructure transitions within **sustainable urbanization**.

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. The focus of this report is on **material resources**. These include inputs from the environment into the economy such as **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, aluminum and copper used in construction and electronics manufacturing) **and non-metallic minerals (**used for construction, notably sand, gravel and limestone).

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 (see also figure 3.2 in chapter 3). **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.

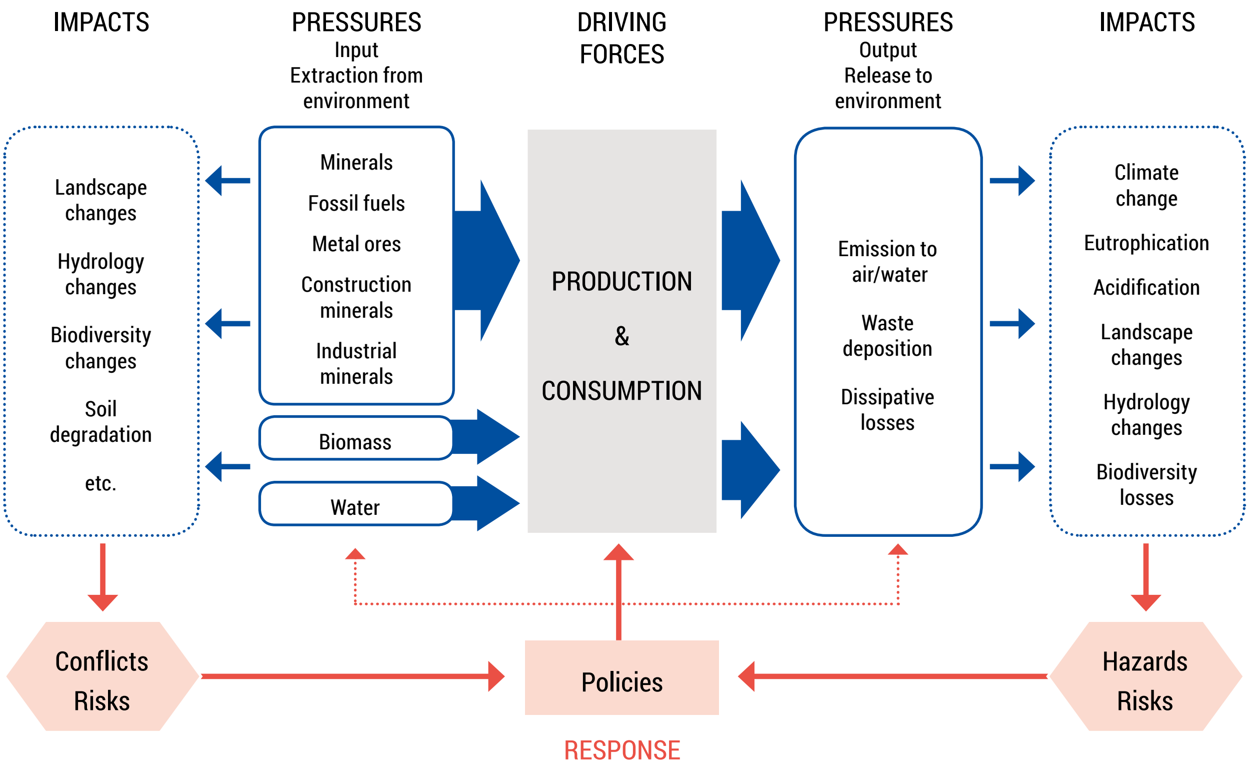
Systems approach

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 and Wade, 2015). This report applies the DPSIR Framework to assess the linkages between the use of natural resources in society, through production-consumption systems and essential infrastructure and food provisioning services, as they impact economic development, human well-being and the environment (as reflected in multiple SDGs). The system approach (1) considers the total material throughput of the economy from resource extraction and harvest to final disposal, and their environmental impacts (called "pressures" in the DPSIR framework, figure 1.4), (2) relates these flows to activities in production and consumption (driving forces) 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. Chapters of this report present different elements of a systems approach. Chapter 2 and chapter 4 identify metrics to track progress towards the SDGs. Chapter 3 identifies a suite of policies that support system transformations. Chapter 4 goes on to link infrastructure and natural resource use with economic development, pollution emissions and environmental quality (including air quality), to inform the goal of good health and well-being with reduced levels of resource use.

Transition

The International Resource Panel sees transition as a process of transformation from current systems of unsustainable production and consumption to sustainable ones. It describes long-term, structural changes occurring simultaneously in economic, political, cultural, technological and environmental areas - and may be steered by policies.

FIGURE 1.4 Systems approach considering material flows and their environmental impacts resulting from production and consumption activities



Source: Bringezu et al., 2016.

2. Global trends and outlook

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Environmental and sustainability policy require a new evidence base that enables the scale of the physical economy to be monitored, that is, the amount of materials and energy used and waste and emissions generated, connected to the production and consumption of goods and services and the provisioning of infrastructure services. This chapter presents trends in global material use and productivity. The purpose of this type of reporting is to provide an evidence base for policymaking and to enable monitoring of the SDGs. **The database made available by the International Resource Panel now covers almost five decades – 1970 to 2017 – and 191 countries.**[8]

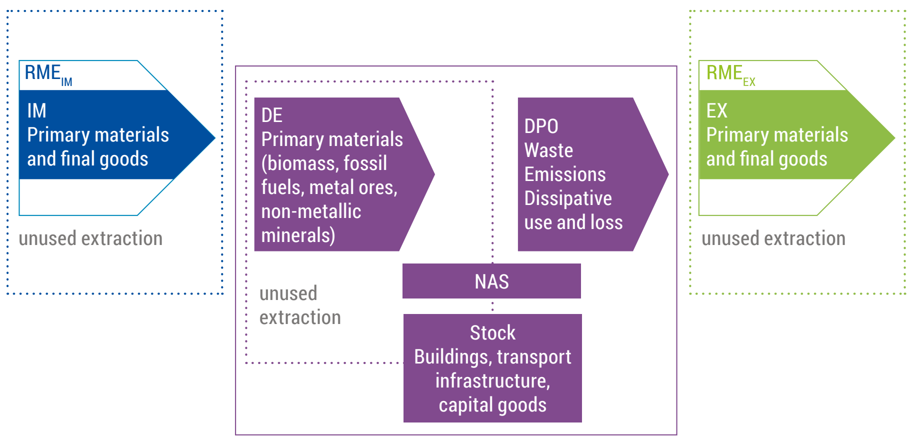
This chapter focuses on the total amount of natural resources extracted for further use in the economy, the associated environmental impacts of resource extraction and the economic efficiency of material use in global and regional economies. Trade flows and material requirements of final demand in different world regions are reported, and how these relate to the level of affluence in a country is described. The chapter illustrates where materials are extracted, where they are used and what has driven material extraction in the past. Finally, the chapter identifies the environmental and economic benefits of ambitious resource efficiency policies to conserve the global natural resource base, abate greenhouse gas emissions and reduce environmental impacts of resource use.

The analysis is guided by the methodology for national material flow accounts established at the European Statistical Office(European Statistical Office (EUROSTAT), 2001), in collaboration with the Organisation for Economic Co-operation and Development (OECD, 2008), and adopted by the United Nations Environment Programme (UNEP, 2016c). The analysis is based on a large and detailed database of material extraction, trade and use[9] compiled by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) of Australia; the Vienna University of Business and Economics, Austria; Nagoya University, Japan; and the Institute of Social Ecology in Vienna, Austria. Material footprints were calculated with the Eora multi-regional input-output (MRIO) framework of the University of Sydney (Lenzen et al., 2013).

This report has focused on direct material use and material footprints. There are plans to monitor other resource and emission footprints in subsequent reports. The material flow accounting approach is based on the notion of industrial metabolism (Ayres and Simonis, 1994) and provides a comprehensive overview of the material requirements and the resulting waste and emissions of national economies (figure 2.1). The approach is compatible with the System of National Accounts and the System of Environmental-Economic Accounting (SEEA) framework (Bartelmus, 2003).

The material flow accounting framework captures material inputs to the economy (whether imported or extracted domestically); net additions of materials in stocks of buildings, transport, communication and energy infrastructure; and outflows (disposal of waste and emissions and exports). It distinguishes direct flows, such as the amount of materials in traded goods, and indirect flows that include the raw material requirements of direct imports and exports (as well as unused extraction that may be related to domestic extraction or extraction abroad). This report focuses on direct flows and the raw material equivalents of imports and exports, but does not cover unused extraction.

FIGURE 2.1 Central framework of material flow accounting



Source: UNEP, 2016c.
Legend: DE: domestic extraction of materials; IM: (direct) imports; EX: (direct) exports; RMEIM: Raw material equivalent of imports, i.e. direct imports plus upstream material requirements for producing imports; RMEEX: raw material equivalent of exports; NAS: net additions to stock; Stock: assets in-use of buildings, infrastructure, capital and long-lived consumer goods; DPO: domestically processed output, such as waste and emissions generated within the domestic territory; and unused extraction: movement of materials without further economic use. The size of the arrows and boxes does not represent magnitudes.

8 Data are sourced from the international databases of reputable international organizations and adapted to the methodological guidelines of material flow accounting. Data sources include the Food and Agriculture Organization of the United Nations (FAO), the International Energy Agency (IEA), the United States Geological Service (USGS) and the United Nations International Trade Statistics Database (COMTRADE). Most dataset report data are up to 2014. Data for 2015-2017 are estimated based on existing trends. Data are expected to be updated on a yearly basis.

9 Available at http://www.resourcepanel.org/

2.1 Global trends in natural resource extraction

Strong growth in natural resource extraction of biomass, fossil fuels, metal ores and non-metallic minerals continues to support the global economy, and also adds to global environmental pressures and impacts. **Global material demand has increasingly been supplied by low-income and middle-income regions, indicating outsourcing of local impacts of resource extraction - often for the sake of producing primary exports to high-income countries.**

During the period 1970 to 2010, the annual global use of materials grew from 26.7 billion tonnes to 75.6 billion tonnes (see figure 2.2 and the annex).[10] In other words, the last three decades of the 20th century saw yearly average growth in global material use of 2.3 per cent. **Annual growth accelerated to 3.5 per cent in the first decade of the 21st century** – from 2000 to 2010 – and the 2008–2009 global financial crisis had a negligible impact on global material use. From 2010 to 2014, global material use grew again by an additional 7.3 billion tonnes, or an average of 2.3 per cent per year, to 82.9 billion tonnes. This report forecasts that, based on existing trends, global material use will reach 88.6 billion tonnes in 2017 – more than three times the amount observed in 1970. This is significant because, all else being equal, growing material extraction indicates growing environmental pressures and impacts across the globe. Reigning in the total physical scale of the economy is therefore an important first step to reducing waste and emissions and mitigating overall environmental impacts.

Material demand has continued to shift from biomass and renewable materials to non-renewable materials, creating new waste flows and contributing to higher emissions and pollution. The global trend of moving away from traditional to modern technologies, and from agriculture-based economies to urban and industrial economies (and their fast-growing new material requirements), further accelerates global material use and creates significant challenges for sustainability policy (Steinberger et al., 2010).

In 1970, **biomass** represented one third of all extracted materials, reflecting the large group of developing countries that relied on agriculture and renewable resources, especially in the global South. Biomass extraction grew from 8.8 billion tonnes in 1970 to 21.2 billion tonnes in 2014, and is expected to reach 22.5 billion tonnes in 2017. This is an average 2 per cent increase per year (which is slightly faster than average population growth of 1.5 per cent per year). The share of biomass in global material extraction had reduced to one quarter of the total by 2014, and is expected to remain at that level in 2017. The rate of growth has been slowest for those biomass sub-categories where non-biomass alternatives are most easily substituted (such as wood), and where there are hard limits on yields that are not easily improved by advancing technology (including wild-caught fish).

Fossil fuels have grown in absolute terms from 6.2 to 14.4 billion tonnes, but their share in global extraction decreased from 23 per cent in 1970 to around 17 per cent in 2014. They are expected to represent about 15 billion tonnes in 2017. They grew by an average of 1.9 per cent per year. Natural gas and coal had higher growth rates compared with crude oil, which mainly reflects the greatly expanded electricity-generation capacity of coal- and gas-fired power stations.

Metal ores had a share of 10 per cent in global material extraction (2.6 billion tonnes in 1970), which remained at 10 per cent (8.2 billion tonnes) in 2014, and is expected to slightly exceed 10 per cent (9.1 billion tonnes) in 2017. This is an average growth of 2.7 per cent per year.

The largest growth in relative terms was in **non-metallic minerals**, up from 34 per cent in 1970 to over 47 per cent in 2014 (with this expected to exceed 47 per cent in 2017), reflecting the large shift in global extraction from renewable to non-renewable natural resources. Non-metallic mineral extraction was 9.2 billion tonnes in 1970, and had reached 38.6 billion tonnes in 2014. It is forecasted to reach 41.7 billion tonnes in 2017. This is an average growth of 3.3 per cent per year.

Ferrous metals and non-metallic minerals for construction had the highest average growth rates of extraction of all materials, fuelling the major build-up of infrastructure in many transitioning countries (particularly China, India, Brazil and South Africa).

Over the past four decades, a large shift has occurred in material extraction from Europe and North America to Asia and the Pacific and West Asia (figure 2.3). This shift has ratcheted up environmental pressures of primary industries as well as resource flows in Asia and the Pacific, Latin America and the Caribbean and Africa (Schandl and West, 2010; West and Schandl, 2013). While increased material extraction in the South has underpinned poverty alleviation and growing material standards of living in some countries,

10 *Annex: Assessing Global Resource Use* – Tables and Figures for More Information is available at http://www.resourcepanel.org/reports/assessing-global-resource-use) and provides the specific breakdown in each category.

it is also associated with considerable environmental (Mudd, 2010) and social (Reeson et al., 2012) problems.

Additionally, a considerable share of material extraction has occurred for consumption in wealthy parts of the world, while low-income countries have fallen short of yielding the benefits of their resource base.

In 1970, 43.6 per cent of all material extraction occurred in Europe and North America, in other words extraction focused on high-income parts of the world at that time. Asia and the Pacific, also then the most populous world region by far, accounted for just one quarter of global material extraction, the former Soviet Union was at 14 per cent, Africa at 7.8 per cent and Latin America and the Caribbean at 7.2 per cent. Only 2.4 per cent of global material extraction occurred in West Asia.

This report forecasts that the shift in global material extraction share from Europe and North America to Asia and the Pacific will continue. Most of the growth in global material extraction over the four decades from 1970 to 2014 was driven by Asia and the Pacific and West Asia, which were growing at an annual 4.5 per cent and 3.4 per cent respectively. Some of this growth reverberated in the resource-rich region of Latin America, which has seen average yearly growth in material extraction of 3 per cent. In comparison, yearly average growth in material extraction was 0.5 per cent in Europe and 0.6 per cent in North America, perhaps reflecting a continuous process of outsourcing of resource extraction by the rich parts of the world to the fast-growing developing economies, which not only had to supply their growing populations with domestic resources but also have increasingly supplied the wealthy parts of the world (Bruckner et al., 2012).

In 2017, 58.5 per cent of all materials are expected to be extracted in Asia and the Pacific, 8.6 per cent in Latin America and the Caribbean, 8.3 per cent in North America and 8 per cent in Europe. The resource-rich region of Africa is expected to supply 7.3 per cent of all global materials, but most certainly will see large growth in coming decades.

FIGURE 2.2 Global material extraction in four main material categories, 1970–2017, million tonnes

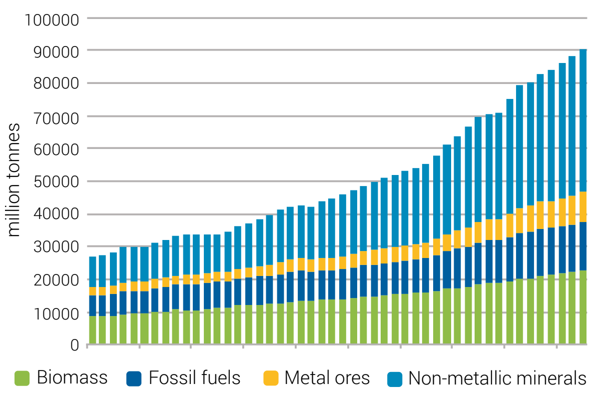
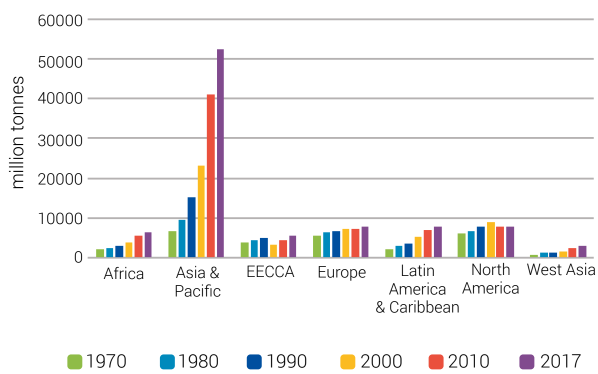


FIGURE 2.3 Regional shares in global material extraction, 1970–2017, million tonnes



Legend: Regional aggregates represent the United Nations Environment regional classification. EECCA refers to Eastern Europe, Caucasus and Central Asia.

2.2 Material productivity

Material productivity is seen as an important feature of managing natural resources sustainably, and yet the amount of economic value that we can extract from every kilogram of material and every megajoule (MJ)of energy has been decreasing or stagnant since about the year 2000 (Schandl and West, 2010).

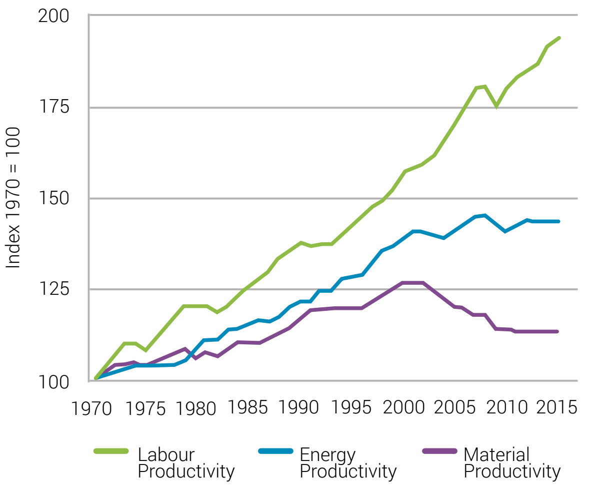
Over the last 45 years, the global average for labour productivity – USD per hour of work – has almost doubled. Energy productivity – USD per MJ – has risen substantially since the oil price shocks in the 1970s (at a lower rate than labour productivity), and has plateaued since about 2000. This has been caused by the energy transition in many developing economies, which involved steep increases in electricity supply and fuel use for transport and mobility. As a result, energy use has started to grow faster than GDP. **Improvements in material productivity – USD per kg - posted the slowest progress of all three factor**

productivities and started to decline around the year 2000. The decline in material productivity is attributable to a shift in the share of global output from highly material productive economies (such as Japan) to less productive economies such as the BRICS (Brazil, Russian Federation, India, China and South Africa) countries. Urbanization and industrialization in many developing economies have required large amounts of materials to build the infrastructure and manufacturing capacity to fuel economic growth, increase human well-being and reduce poverty. This has ratcheted up material use, which has grown faster than GDP. In 2015, the global economy gained 0.75 USD per kg of material and 0.10 USD per MJ of energy compared to 6.50 USD per hour of work on average.[11]

Decreasing material and energy productivity is bad economically – it means reduction of potential economic growth – and also bad environmentally as pressures and impacts upon the environment grow disproportionally faster than the production of goods and services. **Investing in material and energy productivity is therefore a main area for improving the integration of economic and environmental objectives** (UNEP, 2017a).

Improving material and energy efficiency is a necessary but not sufficient strategy for achieving environmental sustainability. In the past, labour productivity gains have been achieved against the backdrop of reducing resource productivity. This is an effect of substitution between labour and capital, where the latter relies on materials to establish new capital and energy to fuel it. A new economic paradigm is needed that improves resource productivity and allows for production and consumption systems to be run with lower material and energy requirements, as well as reduced waste and emissions. This would allow refocusing from a single objective of labour productivity to a multi-factor productivity objective.

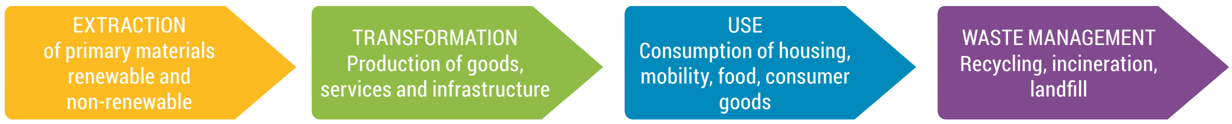
FIGURE 2.4 Global material productivity compared to labour and energy productivity



2.3 Environmental impacts of materials extraction

Environmental impacts occur at all stages of material utilization, as they result from extraction, transformation, product use and waste management (see figure 2.5 and figure 1.4). Some of the growth in negative environmental impacts may be offset by circular economy initiatives where virgin material input is replaced by recycled materials, remanufacturing and reuse (Allwood and Cullen, 2012). The objective of the International Resource Panel is to measure environmental impacts comprehensively. In this report, environmental impacts related to the extraction of specific (groups of) material resources over time are assessed. Nevertheless, it should be borne in mind that resource flows also determine the flow of materials through production and consumption and all subsequent waste and emissions released back to the environment, including various bundles of impacts.

FIGURE 2.5 The life cycle of resource use



11 Material productivity is calculated as global GDP at 2005 prices per unit of material extraction (global DE); energy productivity is GDP per energy use (global energy supply); labour productivity as GDP per labour hours (global labour volume).

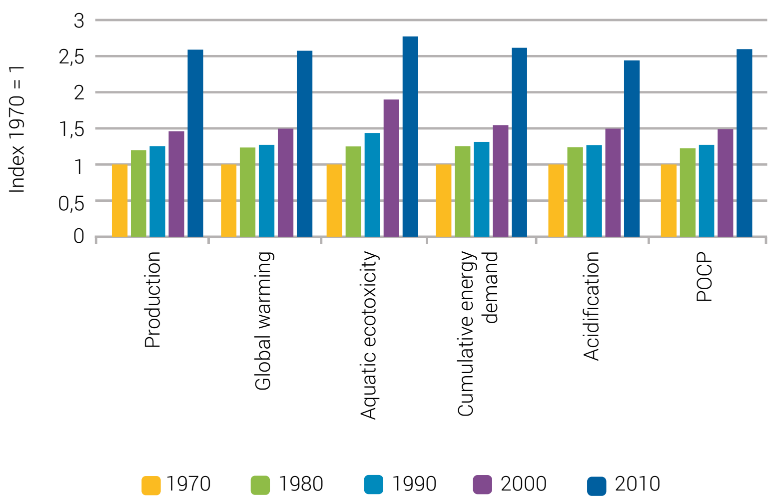
2.3.1 Environmental impacts related to metal extraction at the global level

Metal-ore extraction and metal production increased threefold between 1970 and 2010. The steepest increase occurred from 2000 to 2010, driven mainly by the industrialization and urbanization of emerging economies. Iron constitutes by far the largest flow. Figure 2.6 shows the development in production, together with developments in a variety of environmental impact categories.

Environmental impacts have increased over time, by and large as a result of the increased production. Aquatic ecotoxicity (mainly caused by copper) has increased more than production, the other impact categories (mainly caused by iron) slightly less.

Iron dominates greenhouse gas emissions, due to the sheer size of its production, although the impact per kilogramme of iron is lowest. Other metals, and especially aluminium, are particularly energy intensive. For iron, the development of emissions follows production trends to a large degree, since impacts per kilogramme have changed only slightly over the whole period. Aluminium, on the other hand, shows a clear decoupling of resource extraction from environmental impacts through improved technologies. This is attributable to energy efficiency improvements of aluminium production and changes in the background electricity system. More information on the environmental challenges of metal production can be found in UNEP, 2013b.

FIGURE 2.6 Global-level environmental impacts related to the production of seven major metals over time, relative to 1970 (=1)

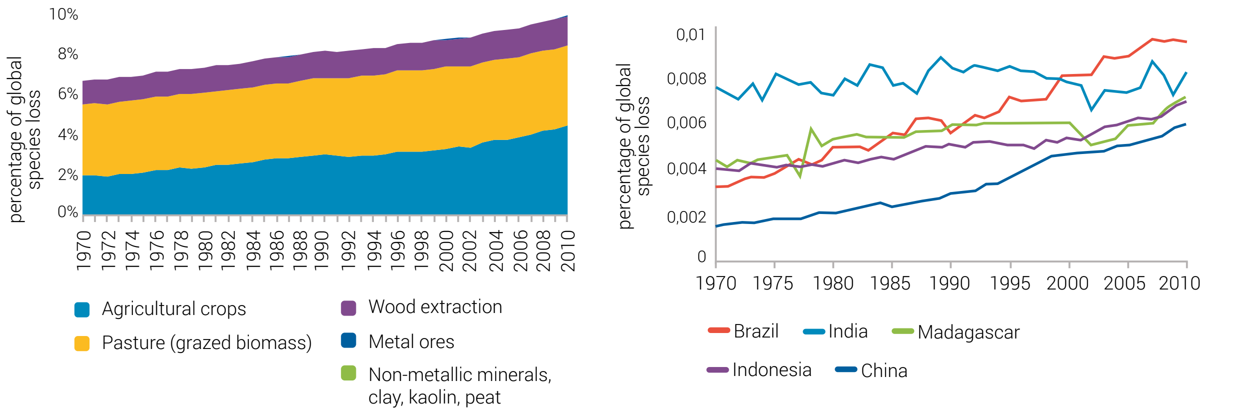


Legend: Metals included are iron, aluminium, copper, zinc, lead, nickel and manganese
The environmental impacts are expressed in terms of the Life Cycle Assessment (LCA) Impact Assessment midpoint impact categories as published in Guinée et al. (2002).
Impact categories according to CML-IA database v4.8, 2016: Global warming = Greenhouse gas emissions (kg CO_2-eq), Aquatic ecotoxicity = freshwater aquatic ecotoxicity (kg 1.4 DCB-equivalent); CED = Cumulative Energy Demand (MJ), acidification = emission of acidifying substances (kg SO2-eq); POCP = emissions of smog forming substances (kg ethylene-equivalent).

2.3.1 Water use, land use and biodiversity impacts of resource extraction

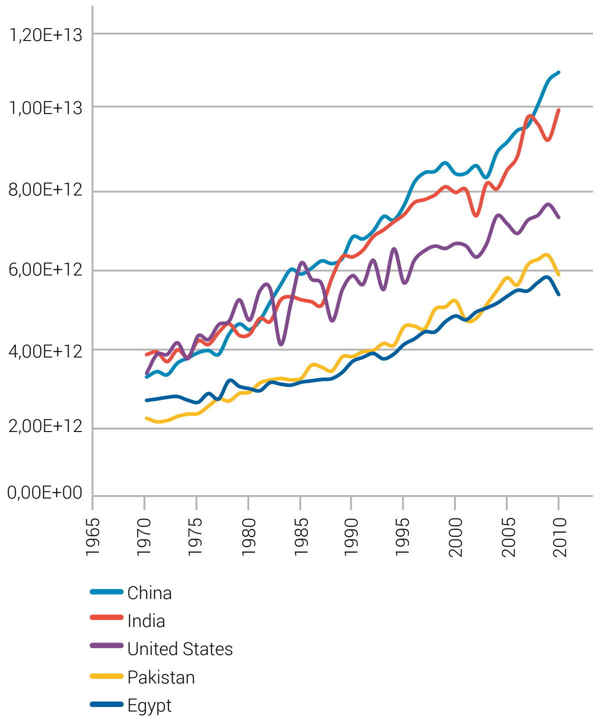
Globally and for the year 2010, approximately 10 per cent of species were lost because of agricultural crop production, wood extraction and pasture use (grazed biomass) (figure 2.7). The main crops and wood types include cereals, paddy rice, oil-bearing crops, timber (round wood and fuel wood) and wheat. Biodiversity impacts are especially relevant in the five countries shown in figure 2.7, and most of them display a rising trajectory. With regard to pastures, Madagascar suffers the strongest impact due to high endemism (which in turn affects global biodiversity loss), while Brazil and Australia are key contributors due to their large pasture areas. Although the mining of minerals and metals often takes place in ecologically sensitive areas (Murguía et al., 2016) and may have pronounced impacts locally, the area of land occupied and the resulting biodiversity impacts are small in comparison to the impact of biomass harvesting and are therefore not visible in figure 2.7. Globally, the demands placed on land and the resulting impacts on biodiversity have increased in the last 40 years. Impacts are particularly high in countries with significant levels of agricultural/forestry activity and high endemism.

FIGURE 2.7 Global biodiversity loss (proportion of species lost) due to land use associated with global resource extraction (left figure) and the top five countries in terms of impacts (right figure)



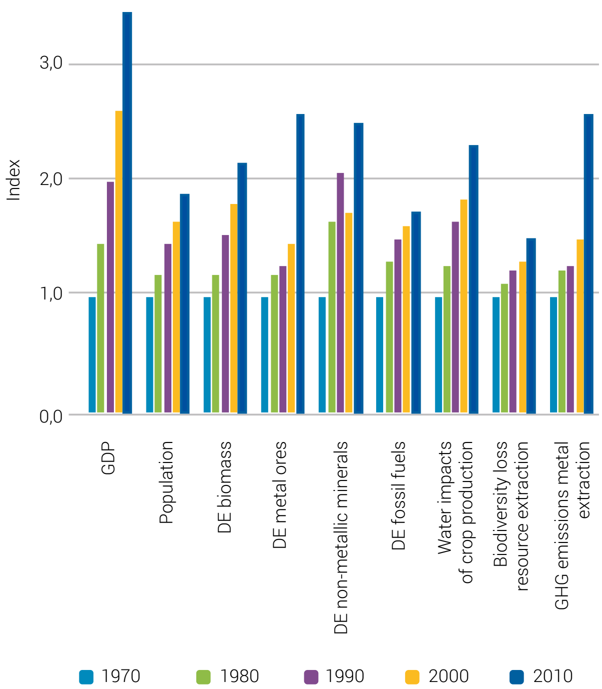
Note: The indicator for biodiversity loss (UNEP and Society of Environmental Toxicology and Chemistry (SETAC), 2016) due to land use measures the percentage of global species lost under steady-state conditions, in other words the global extinctions that will result as a consequence of current land use. Only direct land use (such as for mining sites and related infrastructure) was counted, while indirect land uses were ignored (such as settlements that form due to a new mining site). Therefore, the results should be understood as a lower-bound estimate of the impacts of resource extraction.

FIGURE 2.8 Trends of water consumption impacts [m³-eq.] for crop biomass production in the top five countries for water scarcity impact



Note: The unit of "m³-eq." denotes equivalents of water consumed under conditions of global average water stress (UNEP and SETAC, 2016).

FIGURE 2.9 Trends of GDP, population growth, amount of resource extraction and biodiversity impacts (1970 indexed to 1)



Sources: World Bank, United Nations and the Global Material Flows Database.

Although water scarcity[12] is mainly driven by wheat production, rice, other cereals, fruits and oil crops groups also contribute a high share. Water impact for crop production is particularly relevant in the five countries shown in figure 2.8. Water scarcity for crops increased globally by a factor of 2.3 from 1970–2010, with the greatest impact in China, where it increased by a factor of 3.4.

As depicted in figure 2.9, the amounts of resources extracted increased less than GDP, indicating decoupling. Compared with population trends, per capita water impacts have increased, while per capita land impacts on biodiversity decreased. Compared to GDP, decoupling of both water impacts and biodiversity land impacts can be observed. However, this decoupling should not distract from the fact that biodiversity loss is still increasing in absolute terms and represents one of the planetary boundaries that has already been exceeded (Steffen et al., 2015). The projected increase in global population will lead to a further increase in demand for food and other biomass, indicating that further decoupling is needed to limit biodiversity impacts.

For GHG emissions related to metals, figure 2.9 shows a relative decoupling between GDP and metal production in the 1970–2000 period, followed by a re-coupling in the decade to 2010. Greenhouse gas (GHG) emissions closely follow production of iron. For the metals group, it appears that the dynamics of demand development are not straightforwardly determined by GDP. **The decoupling during 1970–2000 probably has to do with stock saturation in OECD countries, and the recoupling afterwards with the rapid build-up of the infrastructure of emerging economies**. Demand, therefore, can be expected to continue to grow rapidly for the period to come. Impact decoupling for metals is also not straightforward. The transition towards a renewable energy system plays an important role in two ways. Initially, the build-up of such a system will require an additional input of metals, including major metals such as copper, aluminium and steel (UNEP, 2015). Emissions related to metal production will increase as well. In the end, energy-intensive metals can be expected to benefit from a transition towards a renewable energy system, as emissions of energy production will go down. For iron, however, impact decoupling can only be expected as a result of radical changes in technology and/or society: either the development of novel low-carbon production processes, or a significantly larger share of secondary production.

2.4 Trade of materials

Some primary materials (such as biomass, sand and gravel) are widely available in a large number of countries, while others (such as metal ores and fossil fuels) are concentrated in just a few. Trade in primary materials mitigates regional imbalances in resource availability and supports production and consumption systems worldwide. Markets for many strategic primary materials - such as oil, coal, iron ore and aluminum - have become global, and price volatility has become a dominant feature of resource trade between countries.

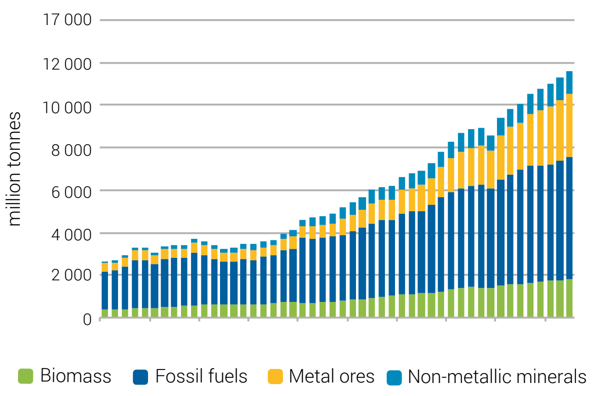
BOX 2.1 Does international trade improve or worsen the global efficiency of resource use?

The International Resource Panel report International Trade in Resources: A biophysical assessment (UNEP, 2015a) asked how trade affects the global efficiency of resource use. It found evidence that upstream resource requirements of trade are, for the most part, rising. Various factors may be driving this growth, including an increasing share of higher-processed goods in total trade and higher trade activities in general. At the same time, we see declining ore grades for metals and industrial minerals, as well as declining energy returns on energy investment for fossil fuels. The increasing consumption of fossil energy carriers for fuelling transport and increasing virtual water consumption, due to growth in demand for food from arid regions, also contributes to rising upstream requirements. Such factors may completely cancel out a potentially better allocation of extraction and production processes through world trade. As such, the answer to the question of whether trade leads to greater global environmental efficiency remains undetermined. It does appear, however, that **trade leads to a redistribution of environmental burdens towards resource-extracting and producing countries**. By depleting their natural resources, exporting countries have to deal with waste and emissions from primary processing, and may not be gaining high economic revenues. For instance, the export of biomass from regions such as Latin America, North America and areas in Sub-Saharan Africa has led to loss of forest cover, land degradation and other negative ecosystem changes. This makes mitigating such adverse environmental impacts a key role of policy. For example, regulatory framework changes accompanied by favourable advancements in process technologies and voluntary initiatives reduced harmful sulphur dioxide emissions from the mining of platinum by up to 90 per cent. Policy initiatives, such as the phasing out of fossil fuel subsidies, could act as a catalyst in discouraging extraction and consumption of fossil fuels, thereby reducing carbon dioxide (CO_2) and sulphur dioxide (SO_2) emissions and spearheading the urgently needed transition towards renewable resources.

Source: UNEP, 2015a.

12 The indicator for water impacts (UNEP and SETAC, 2016) is a measure of water scarcity and resulting water deprivation for humans and ecosystems. A m3 extracted in a water-scarce region is multiplied by a scarcity factor.

FIGURE 2.10 Global trade in materials, by material category, 1970-2017 (million tonnes)



Trade also redistributes incomes, employment and environmental pressures and impacts among countries, as well as spreading out the opportunities, risks and vulnerabilities of national economies. Exporting countries receive some of the trade revenues thorough royalties and tax revenues, but also accept environmental and social impacts related to significant export-oriented industries. Importing countries face issues of supply security and price volatility. **Trade also adds to the growth dynamic of global resource use.** Recent decades were characterized by increasing trade liberalization, leading to growing levels of globalization of financial, labour and natural resource markets. In the light of current global policy trends, however, it is questionable whether globalization will continue in a similar fashion to past decades (Bello, 2017). This may require countries to reassess their dependence on traded commodities.

Trade in primary materials, and commodities made from those materials, has grown strongly and surpassed growth rates in domestic extraction. **The global economy is now more dependent on material trade than ever before.** Although growth in global trade of materials and commodities stalled during the financial crisis in 2008–2009, it experienced a rapid recovery**. Trade volumes have been dominated by primary materials and basic commodities, with fossil fuels accounting for 50 per cent of the total global trade volume in 2014.**

Between 1970 and 2017, the quantity of traded materials more than tripled, growing from 2.7 billion tonnes to 11.6 billion tonnes. This amounts to an average annual growth rate of 3.2 per cent, outpacing the growth in global material extraction (which was on average 2.6 per cent per year during the same period). This roughly linear trend was only disrupted in 1975, 1980-82 and most recently by the 2008–9 global financial crisis, resulting in a 3.6 per cent drop in 2009 physical trade volume. While physical trade recovered to its pre-crisis level and growth trend in 2010, monetary trade growth has been sluggish ever since (International Monetary Fund (IMF), 2016). The material composition of trade was relatively stable over the last four decades with fossil fuels by far dominating the total quantity, followed by metal ores and biomass.

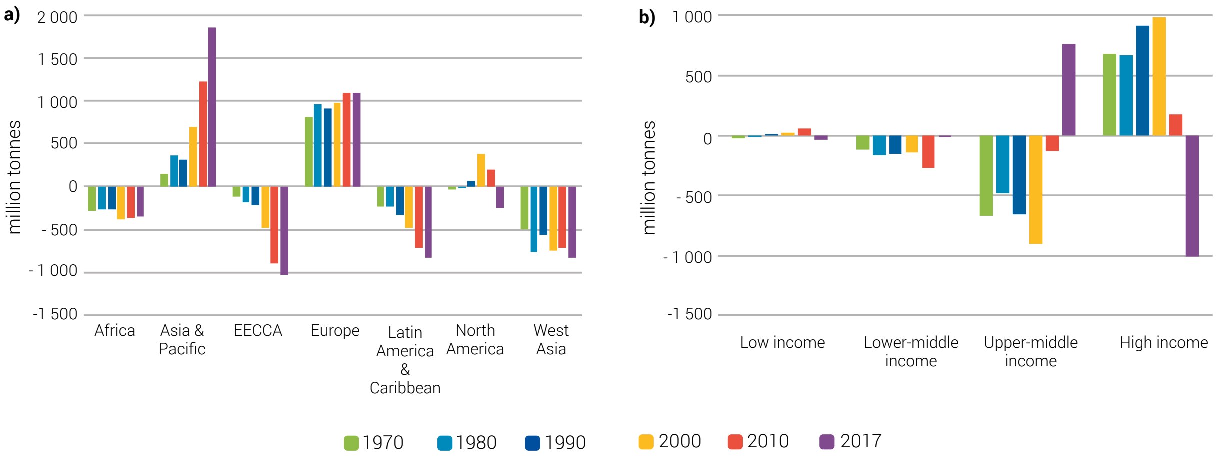
2.4.1 Which world regions dominate global imports and exports of materials? The rise of Asia

There are large differences in scale, dynamic and material composition of imports among the seven world regions. Asia and the Pacific experienced the highest growth rates and became the largest importing region. Overall, the three largest importing regions in 2017 are Asia and the Pacific (representing 48 per cent of all imports), Europe at 28 per cent and North America at 8 per cent. These three regions combined account for 84 per cent of all physical imports. In 1970, the group of high-income countries received 93 per cent of all imports. Today, the situation is more balanced with high-income countries receiving 52 per cent, upper-middle-income countries 34 per cent and lower-middle-income countries 13 per cent of all imports. Low-income countries are mostly excluded from physical trade flows (See also figure A1 in the Annex).

The regional balance for exporting regions is more even than that relating to imports. West Asia and Europe had the largest export share of around 20 per cent each in 1970. In 2017, Asia and the Pacific recorded an export share of 31 per cent, followed by Europe at 17 per cent. Differences in scale, dynamic and material composition of exports can be observed, but they are less pronounced than in the case of imports. Asia experienced the highest growth rates and has become the largest exporting region. China, India and the Russian Federation account for a large share of this effect. Fossil fuels dominate export volumes in all regions, with two exceptions: Latin America's export of metals and ores equalled its fossil fuel exports after the financial crisis. North America's fossil fuel exports overtook its biomass exports in 1999, and have dominated export composition ever since. Exports have been concentrated on high-income countries, with a 60 per cent share in 2017. Upper- and lower-middle-income countries combined exported 40 per cent of all exported materials. Exports from low-income countries were negligible in terms of the amounts involved (see also figure A.2 in the Annex).

In recent decades, Asia and the Pacific and Europe have been net importers of materials while all other regions were net exporters. North America turned from a net importer to a net exporter in 2011, but only by a very small margin.

FIGURE 2.11 Physical trade balance by (a) region and (b) country income groups, 1970-2017, million tonnes



Legend: Regional aggregates represent the United Nations Environment Programme's regional classification. EECCA refers to Eastern Europe, Caucasus and Central Asia. Income aggregates represent the World Bank classification scheme.

The physical trade balance (PTB) is calculated by subtracting physical exports from physical imports. Hence, net exporters export higher quantities than they import, net importers vice versa. Throughout the time period, six out of seven country groups maintained their respective "roles", with the only exception being North America (Figure 2.11). Asia and the Pacific experienced the highest growth in net imports. Net exporters show a complementary pattern of growing net exports, especially Latin America and the Caribbean (West and Schandl, 2013).

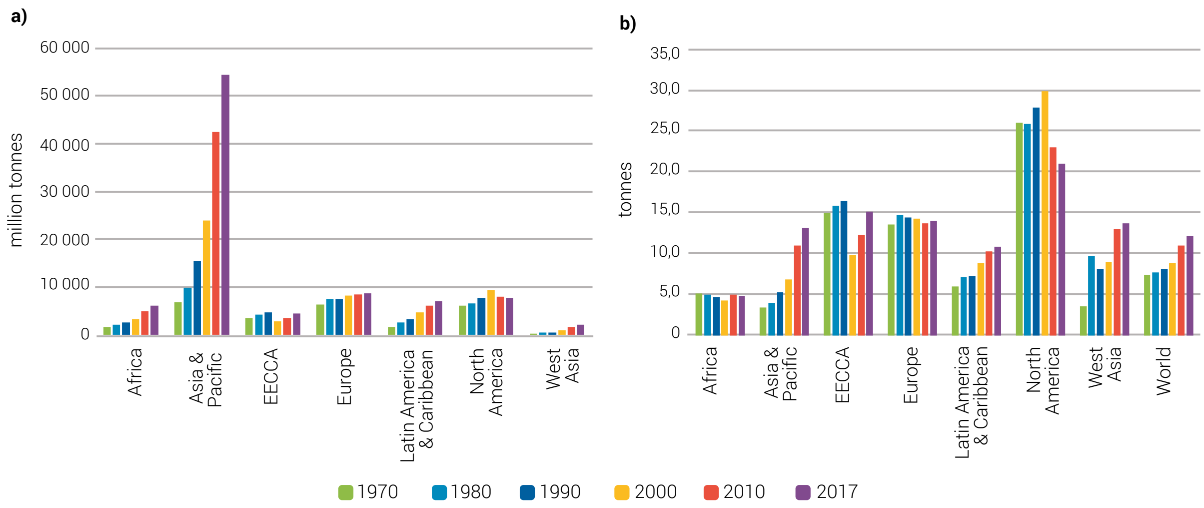
Since the year 2000, there has been a rearrangement in the global trade relations for primary materials. Until 2000, high-income countries were net importers of materials while all other regions (especially upper-middle-income countries) were net exporters. This has changed dramatically in 2017. High-income countries now export one billion tonnes of materials, mainly driven by the United States and Australia's fast growing exports, while upper-middle-income countries import around 750 million tonnes.

2.4.1 Territorial material use

The most widely applied indicator from material flow accounts is domestic material consumption (DMC). It is used in Eurostat's reporting of material flows for the European Union and for monitoring the Japanese government's progress in establishing a Sound Material Cycle Society (Takiguchi and Takemoto, 2008; see also box 3.2). In essence, domestic material consumption measures the apparent consumption of materials on a national territory (domestic extraction plus imports minus exports). It can be interpreted as a proxy for the related domestic environmental pressure and determines the amount of final waste and emissions in the long run.

Since the turn of the century, Asia and the Pacific have overtaken the rest of the world as the largest user of materials (Schandl and West, 2010). Material use in Asia has grown exponentially, and this growth reverberated in the resource-rich regions of Africa, Latin America and Australia (see figure 2.12a).

FIGURE 2.12 Domestic material consumption by region (a) totals, million tonnes and (b) per-capita



On a per capita level, North America remains the largest material user (albeit as part of a downward trend). Asia and the Pacific and West Asia have caught up with Europe in terms of territorial per capita material use. The global per capita average of material use has grown from 7.2 tonnes to 11.8 tonnes. This means that the environmental pressure of an average person globally has increased by 1.1 per cent per year between 1970 and 2017.

2.4.1 Supply chains underpin the material requirements of international trade

Trade flows are linked to upstream commodity production in the countries of origin of trade flows. This production requires material extraction, which often leads to environmental impacts where materials are extracted. New analytical tools allow assessment of the *raw material equivalents (RME) of trade flows*, that is, the amount of primary raw materials required along the supply chain to produce commodities.

The raw material equivalents of imports, measured on a per capita basis, are highest in Europe and North America, at four times the world average, reflecting these regions' high levels of affluence and consumption. The highest per capita raw material equivalents of exports are observed in the oil-exporting regions of West Asia and the Eastern Europe, Caucasus and Central Asia (EECCA). As a result, the raw material trade balance shows Europe and North America as net importers and West Asia and EECCA as net exporters of materials embodied in trade. Other regions have a low per capita raw material equivalent trade balance. However, within these regions specific countries show very large differences.

The raw material trade balance by income groups of countries demonstrates the extent to which high-income countries rely on the resource base of the rest of the world through trade relations. **The fact that the raw material trade balance for high-income countries is still growing shows that the dependence of affluent nations on the resource base and manufacturing capacity of the world is continuing to grow**.

FIGURE 2.13 Per capita raw material equivalents of imports and exports, and raw material trade balance, by region, 1990, 2000, 2010, 2017 (tonnes per capita)

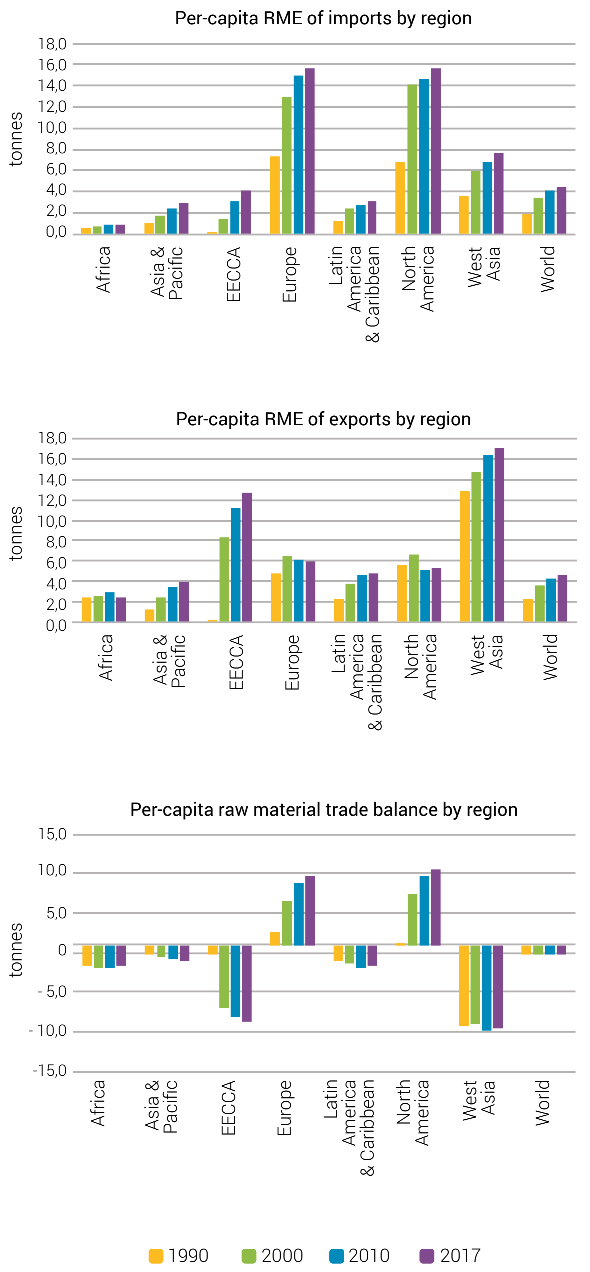
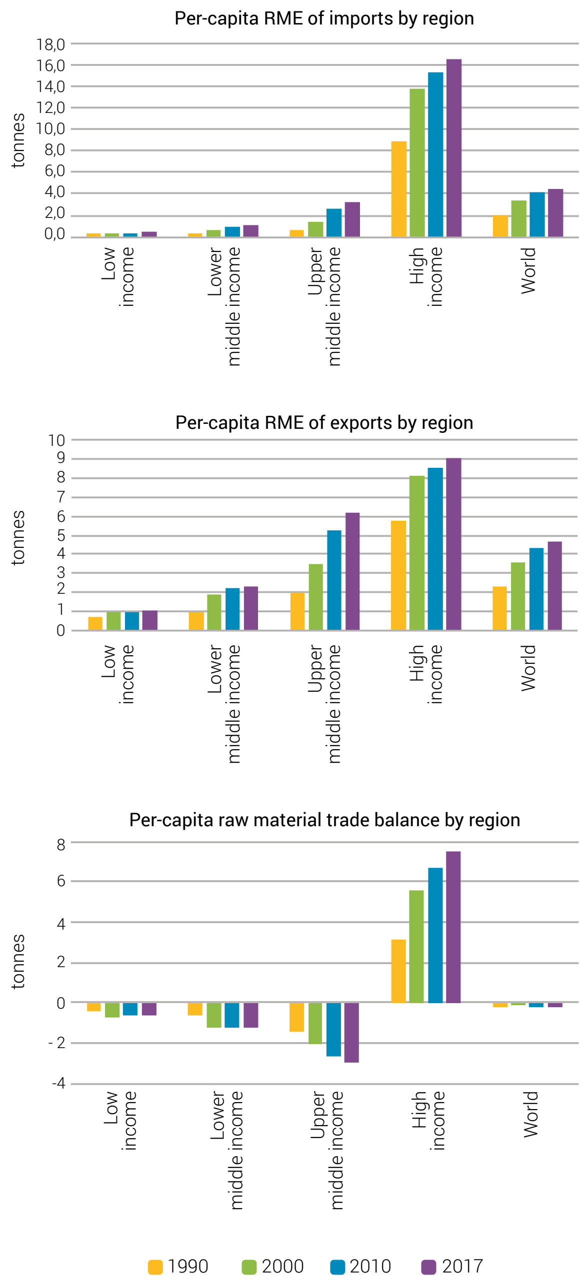


FIGURE 2.14 Per capita raw material equivalents of imports and exports, and raw material trade balance, by income group, 1990, 2000, 2010, 2017 (tonnes per capita)



2.5 Material footprints

The concept of a material footprint offers an additional perspective on a country's material use by attributing material extraction, wherever it may have occurred globally, along supply chains of different products and services to final domestic demand (Giljum et al., 2015). It is therefore a measure of the material requirement of the consumption and infrastructure system of a country (Wiedmann et al., 2015). Indirectly, it also indicates the material flow based environmental pressure of final consumption across the entire supply chain.

Material footprint developments differ significantly from indicators of direct material flows (such as domestic material consumption). For the period 1990–2008, Wiedmann et al. (2015) showed that, in many industrialized countries, domestic material consumption trends declined (by about 20 per cent in Japan and the United Kingdom), while material footprint trends increased (by about 30 per cent or even 60 per cent, respectively). On the other hand, in resource-extracting countries like Chile, Brazil and India, domestic material consumption and material footprints show similar developments.

Asia and the Pacific is the most populous world region and features a fast-growing and increasingly commensurate claim on global materials supply. **In 2017, more than half of global material use is destined for final demand (consumption and capital investment) in Asia and the Pacific.** Europe and North America are of similar importance and each requires around 15 per cent of the global material supply for their final demand.

An analysis of the material footprint per capita shows North America requiring about 30 tonnes of material per capita for final demand. Material consumption in Europe is more moderate, and the fastest growth has been occurring in Asia and the Pacific. **Africa, on the contrary, has seen no growth in per capita material supply for final demand over the past three decades, which coincides with a stagnating material standard of living of large parts of the population**. In other words, material and infrastructure supply is not keeping up with fast population growth.

The average per capita material footprint of Asia and the Pacific has grown from 4.8 tonnes per capita in 1990 to 11.4 tonnes per capita in 2017, a 3.2 per cent average yearly growth, which bears testament to rapid economic growth underpinned by the region's unprecedented industrial and urban transitions (in scale and speed). Average growth of the per capita material footprint in Europe, Latin America and the Caribbean and West Asia was half that of Asia and the Pacific, at around 1.4 per cent average growth per year. In 2017, Europe's per capita material footprint was around 20.6 tonnes, which was twice that of Latin America at 10.2 tonnes per capita and West Asia at 9.6 tonnes per capita.

Per capita material footprints in North America have seen a significant downward adjustment from 36.1 tonnes per capita in 2000 to 31.9 tonnes per capita in 2010, mainly as a result of the global financial crisis and the large decrease in consumption and investment that has been prevalent since that time. The EECCA region saw a very sharp downward adjustment after the break up of the Soviet Union, and has since recovered to reach 9.8 tonnes per capita material footprint in 2017. Africa continues to have the lowest level of materials available per capita for final consumption and investment, just below 3 tonnes per capita in 2017, and an overall yearly decline of 0.6 per cent since 1990, which points to a significant incentive for increasing material standards of living in this region. **While absolute material footprint levels are by far highest in Asia and the Pacific due to high population numbers, North America and Europe remain the top consumers with regard to per capita levels**.

In 2010, upper-middle-income countries were on a par with high-income countries in terms of their material requirements for final demand (around 30 billion tonnes). Growth in the material footprint has been moderate in high-income countries since about 2000, while upper-middle-income countries have seen a rapid overall increase over the past two decades. They have now overtaken high-income countries and require 40 billion tonnes in 2017 (compared to a little above 30 billion tonnes in high-income countries). Lower-income countries do not match the level or pace of material supply to final consumption and for building much-needed infrastructure, which perpetuates ingrained inequalities in resource distribution around the globe.

On a per capita basis, high-income countries still consume 10 times more materials than low-income countries. Material footprints have somewhat stabilized in high-income countries and have grown strongly in upper-middle-income countries (and to a lesser extent in lower-middle-income nations). Low-income countries rely on a very small per capita material footprint with no significant increase in per capita natural resource supply over the last 30 years.

FIGURE 2.15 Material footprint by region, 1990, 2000, 2010 and 2017 (million tonnes)

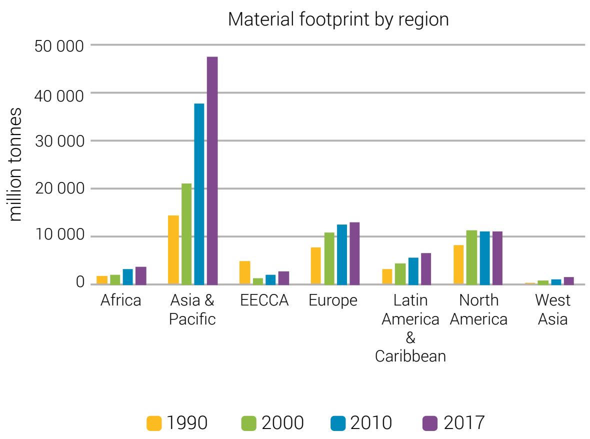


FIGURE 2.17 Material footprint by income group, 1990, 2000, 2010, 2017 (million tonnes)

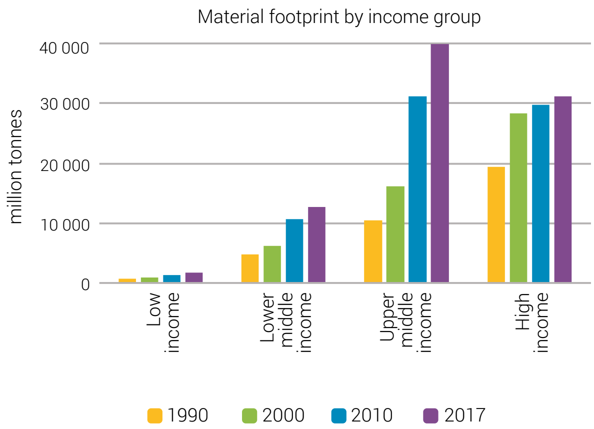


FIGURE 2.16 Per capita material footprint by region, 1990, 2000, 2010 and 2017 (million tonnes)

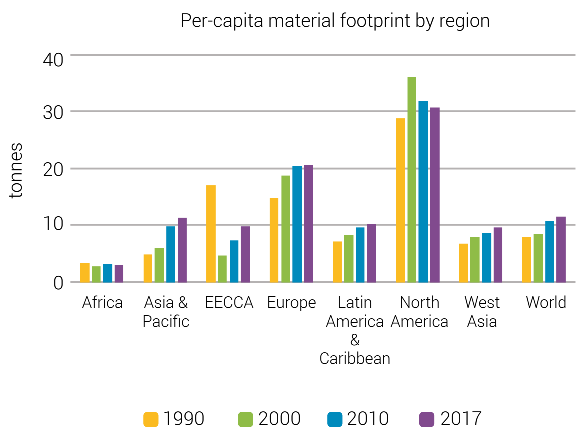
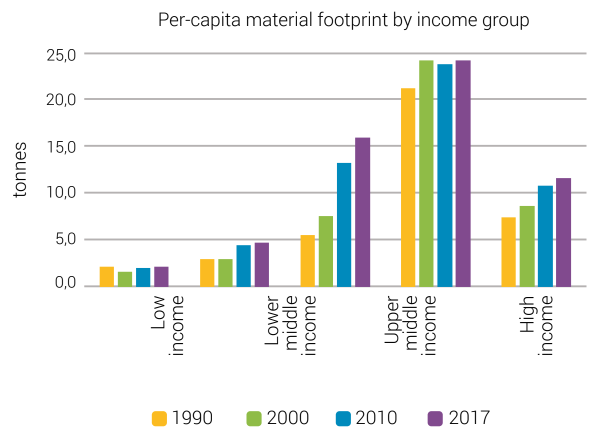


FIGURE 2.18 Per capita material footprint by income group, 1990, 2000, 2010, 2017 (tonnes)

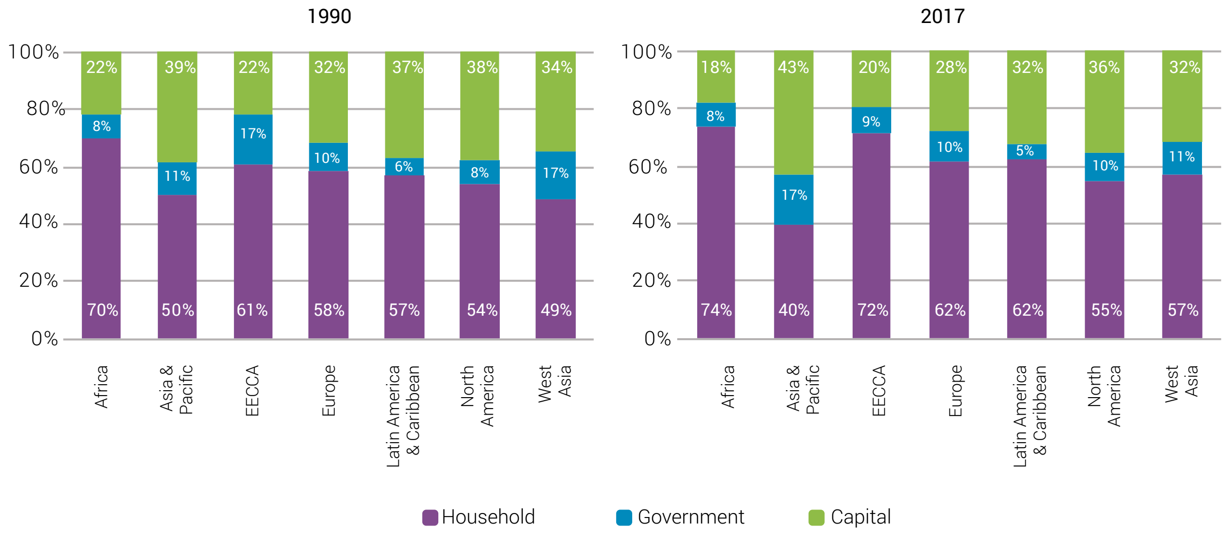


2.5.1 Material footprint by different domestic final demand sectors

Another strength of the material footprint is that it facilitates analysis of the contribution of different categories of final demand to overall material consumption. That links well to policy initiatives of the 10-Year Framework of Programmes on Sustainable Consumption and Production, such as green public procurement, environmentally responsible household consumption and green infrastructure investments (UNEP, 2011b). The shares of (private and public) consumption versus that of capital investments in the total material footprint differ widely across countries. **In some emerging economies, capital formation accounts for over 50 per cent of the material footprint due to rapid expansion of infrastructure (energy, transport, buildings and so on),** setting the country up for further expansion of urban population and manufacturing growth. In contrast, **in industrialized countries, private consumption accounts for around two thirds of their material footprint (with capital spending falling short of meeting maintenance requirements)**. As countries follow the path of industrial development, their per capita material footprint changes (as does the composition of investment and consumption). In China and other countries in Asia, rapid industrialization increased per capita material footprints and the share of investment in overall material footprints. Once the expansion of infrastructure slows down, the share of investment decreases, while per capita material footprints and the share of private consumption continue to increase.

These dynamics are reflected in how materials are used for different aspects of final demand across the whole supply chain. Various world regions have different shares of material supply for household and government consumption and capital investment. Africa, the EECCA region and North America have the highest share of material footprint of household consumption at around 70 per cent. The Asia-Pacific region has the lowest material supply to household consumption; this has been decreasing over time and is now at around 40 per cent of the total material footprint. The material footprint of government consumption is highest in the Asia-Pacific region. Africa and Latin America and the Caribbean, by comparison, have the lowest share of material footprint of government consumption. The Asia-Pacific region also has the highest share of material footprint for capital investment, which reflects investment by China and countries in Southeast Asia into urban and transport infrastructure.

FIGURE 2.19 Share of material footprint by final demand category of total material footprint by region, 1990 and 2015 (percentages)



2.6 Drivers of material extraction

A simple IPAT framework[13] (Ehrlich and Holdren, 1971) identifies the main drivers of change in material footprints as a result of changes in population, affluence (GDP per capita) and technology (material footprint per unit of GDP). This framework is applied to the analysis of material footprints to consider what has driven material footprints in different world regions since the 1990s.

Between 1990 and 2000, the material footprint grew fastest in West Asia and Asia and the Pacific, but was reduced in Eastern Europe, Caucasus and Central Asia (EECCA region) as a result of the break up of the former Soviet Union and the retirement of inefficient heavy industry (West et al., 2014). Population growth was the strongest driver in Africa and West Asia. In North America and Asia and the Pacific, growing affluence and consumption had a larger influence on expanding material footprints than population growth. Changes in technology, resulting in changes in material intensity of consumption, have mediated the impact of population and affluence that has driven growth in material extraction. Globally, population and affluence had a similar influence of the growth of material footprints (with technology compensating somewhat the growth impact).

13 IPAT refers to the multiplicative relationship of population (P), affluence (A) and technology (T) for any environmental impact (I). IPAT has become the most commonly used framework for analysing drivers of changing environmental impacts. Note that technology refers to all other factors combined, beyond population and affluence, and does not reflect an engineering notion of technology.

FIGURE 2.20 Drivers of material footprint, 1990–2000 (percentages)

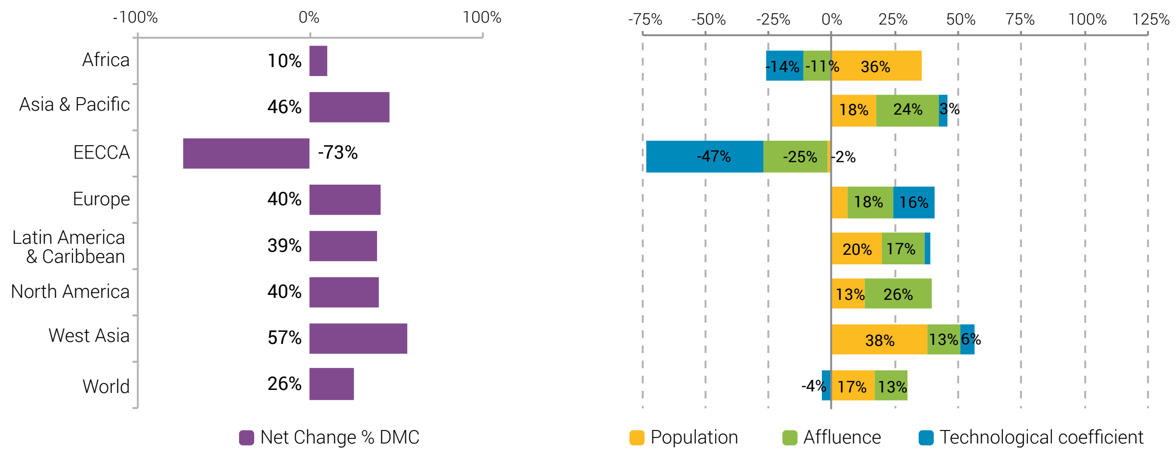


FIGURE 2.21 Drivers of material footprint, 2000–2010 (percentages)

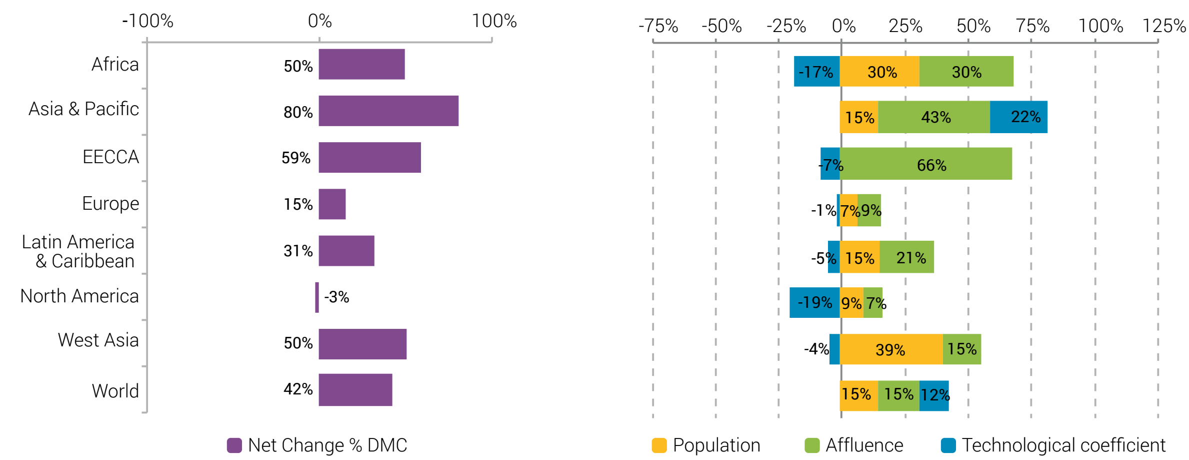
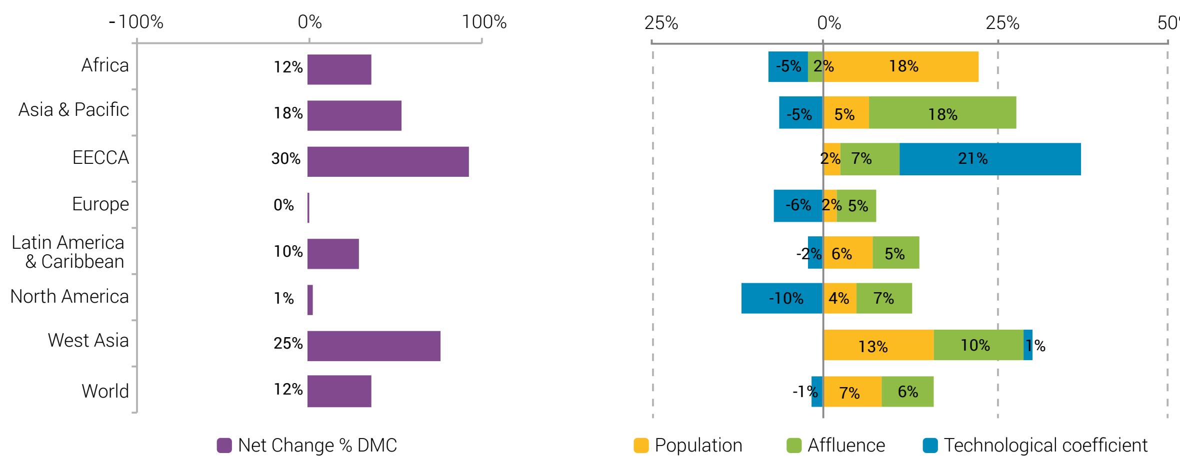


FIGURE 2.22 Drivers of material footprint, 2010–2015 (percentages)



The following decade to 2010 saw a decline in material extraction in North America and a very small increase in Europe, which is attributable to the impact of the global financial crisis. Asia and the Pacific, the EECCA region and West Asia became the most dynamic regions in terms of material footprint growth, and changes in technology added to material growth in Asia and the Pacific and also globally. Modern technologies replaced traditional technologies for buildings, transport and electricity generation infrastructure and added to the material intensity of consumption. Growing affluence replaced population growth as the main driver for material footprint growth in all world regions, with the exception of West Asia.

Since 2010, growth in the material footprint has been dominated by the dynamic Asian economies and Eastern Europe. North America and Europe have seen negligible growth in material footprints because of a slow recovery of economic growth in those regions after the global financial crisis. The environmental pressures of final demand have been reduced, not because of successful environmental policy but rather because of the economic slowdown. **As a result, population has become more important as a driver**. Technology improvements have mitigated some of the growth in material footprint in most regions, with the exception of the EECCA region.

This demonstrates that the material requirements of consumption and infrastructure are still growing strongly in developing economies to facilitate delivery of basic services and further economic growth, and more moderately in high-income countries due to the economic slowdown in many of these nations. **Population and affluence have both been strong drivers of material footprint growth, and innovation and technological change have done little to mitigate growth**. This signals the tremendous change that is required to current production and consumption systems in order to deliver higher material standards of living to more people with lower material use and associated environmental impacts of waste flows, pollution and climate change. Achieving the SDGs inclusively for the planet will require producing goods and services and delivering infrastructure using much lower material and energy throughput and at lower levels of waste and emissions.

2.7 Scenarios for future global material demand and Greenhouse Gas emissions, with ambitious policies

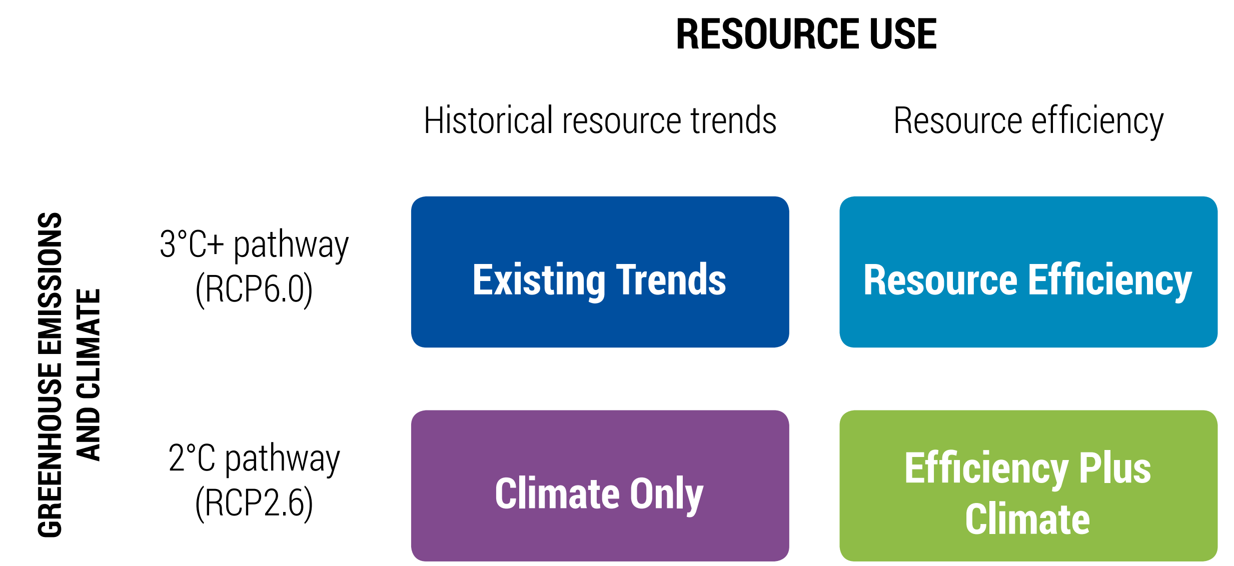
Modelling undertaken by the International Resource Panel shows ample evidence for economically attractive resource efficiency, leading to higher economic growth in the medium and long term and reducing pressures on the global resource base. Resource efficiency also contributes, all else being equal, to lower environmental impacts. The International Resource Panel modelled the combined economic and environmental consequences of ambitious resource efficiency and greenhouse gas abatement policies (see figure 2.23) (UNEP, 2017a).

Each of the four scenarios represents a specific combination of potential future resource use trends and future greenhouse gas emission pathways.

Existing Trends is calibrated to historical natural resource use trends and greenhouse policies that would see a 3°C increase in temperatures by the end of the century, rising to around 4°C after that. Natural resource use trends are applied across major world regions, accounting for changes in GDP per capita. *Existing Trends* is aligned with the “middle of the road” Shared Socioeconomic Pathway two (SSP) (O’Neill et al., 2015; International Institute for Applied Systems Analysis (IIASA), 2015) and greenhouse emissions match the trajectory for RCP6.0 (Rogelj et al., 2012), which is a little lower than most interpretations of the Paris pledges (the Intended Nationally Determined Contributions (INDCs) to 2030).

Resource Efficiency assumes the same climate pathway as *Existing Trends*, but introduces a package of innovations, information, incentives and regulations to promote ambitious but achievable improvements in resource efficiency, and reductions in total resource extractions. The model explores potential improvements in resource efficiency (lower resource intensity and slower growth in natural resource extraction) through three measures: (1) Technical resource innovation and improvements reduce the quantity of resource input required for a given volume of output; (2) a resource extraction tax increases the price of natural resources relative to other inputs; and (3) an exogenous resource demand shift changes the demand curve towards the origin. It mimics the effect of changes to regulations, planning and procurement policies that seek to progressively lower resource intensity while maintaining or improving the services or amenity (such as the space and comfort provided by buildings).

FIGURE 2.23 Scenarios for resource efficiency and greenhouse gas abatement



Source: Hatfield-Dodds et al., 2017.[14]

The three types of measures have very different impacts on natural resource extraction, resource prices, investment and overall economic activity. Technical resource innovation and improvements reduce prices and boost economic growth, but have only very modest impacts on extraction volumes (since lower unit costs promote higher direct and indirect natural resource use). A resource extraction tax increases prices and slows the growth of natural resource use, and also lowers the rate of economic growth. A resource demand shift causes a moderate and fairly even reduction in prices and extraction volumes, with a positive second-round impact on economic activity through increased investment (due to reduced expenditure on consumption of materials-based goods and services). The measures also impact differently across natural resource categories (biomass, fossil fuels, metal ores and non-metallic minerals).

Crucially, these different patterns imply that **the physical effectiveness and economic impacts of real-world resource-efficiency initiatives will depend on the mix, their respective intensities and detailed design of the measures employed**. While resource efficiency boosts economic growth and provides net economic benefits, it is possible that some resource-efficiency strategies could slow growth and result in net economic costs in some circumstances.

Ambitious Climate assumes the same natural resource use policies as *Existing Trends*, but that the world adopts ambitious greenhouse gas abatement policies capable of limiting likely global temperature increases to 2°C above pre-industrial levels. This goes beyond the specific pledges made in Paris for 2025–2030, with global greenhouse emissions to 2050 calibrated to match RCP2.6. The model represents the stronger greenhouse abatement policies for the *Ambitious Climate* scenario as a global carbon price, applied uniformly across all countries and all industrial and energy sectors, with the price level determined endogenously to achieve the year-on-year emissions trajectory for RCP2.6 (as a deviation from RCP6.0). The carbon price begins at USD $5 per carbon dioxide equivalent (CO_{2e}) in 2021 and rises 18.1 per cent per year to 2050, reaching USD $42 in 2035 and USD $573 in 2050.

While a uniform carbon price is an appropriate and transparent way of determining the extent and location of cost-effective abatement, it does not account for differentiated responsibilities for emission reductions or various forms of assistance that could be provided to lower-income nations (including financial assistance and potential trade in emissions credits). This implies that the analysis is likely to underestimate the value of economic activity in lower-income nations (particularly in the 'rest of the world' group), perhaps materially, and may overstate the value of economic activity in high- and future middle-income nations.

14 To measure greenhouse gas concentration (not emissions) trajectories the Intergovernmental Panel on Climate Change (IPCC), in its fifth Assessment Report in 2014, adopted the notion of Representative Concentration Pathways (RCPs). RCP 6.0 represents a global three degree warming pathway, while RCP 2.6 represents a two degree warming pathway.

Efficiency Plus combines the resource efficiency settings and greenhouse gas abatement settings to explore potential policy interactions. This scenario is found to have a higher chance of limiting climate change to 2°C than any other scenario. Greenhouse gas emissions in the *Resource Efficiency and Efficiency Plus* scenarios arise endogenously from interactions between scenario assumptions, and are not calibrated to RCP6.0 or RCP2.6. Cumulative emissions to 2050 in the *Efficiency Plus* scenario are 9 per cent (97 GT CO_2e) lower than in the *Ambitious Climate* scenario, implying a higher chance of limiting global warming to 2°C than under RCP2.6.

In an existing trend scenario, the global economy would require 180 billion tonnes of natural resources by 2050 or more than twice the level of 2017.

There is substantial potential to achieve economically attractive resource efficiency, providing win-win outcomes that reduce environmental pressure while improving income and boosting economic growth.

Ambitious polices for resource efficiency can reduce global resource requirements by about 25 per cent and deliver global economic growth of 3 to 5 per cent above existing trend. This would also have considerable co-benefits for climate mitigation efforts.

Resource-efficiency policies and initiatives could:

- reduce natural resource use globally by 26 per cent by 2050 compared to business-as-usual increases, in combination with ambitious global action on climate change, and stabilize per capita resource use at current levels in high-income countries;

- reduce greenhouse gas emissions by an additional 15-20 per cent by 2050 (for a given set of greenhouse policies), with global emissions falling to 63 per cent below 2010 levels by 2050, and emissions in high-income countries falling to 74 per cent below 2010 levels by 2050

- more than offset the economic costs of ambitious climate action, so that income is higher and economic growth is stronger than in the *Existing Trends* scenario;

- deliver annual economic benefits of USD $ 2 trillion globally by 2050 relative to *Existing Trends*, including benefits of USD $ 520 billion in high-income nations, while also helping to put the world on track towards limiting climate change to 2°C or lower.

These projections can be treated as a reasonable minimum (or 'lower bound') estimate of economically attractive physical resource efficiency potential.

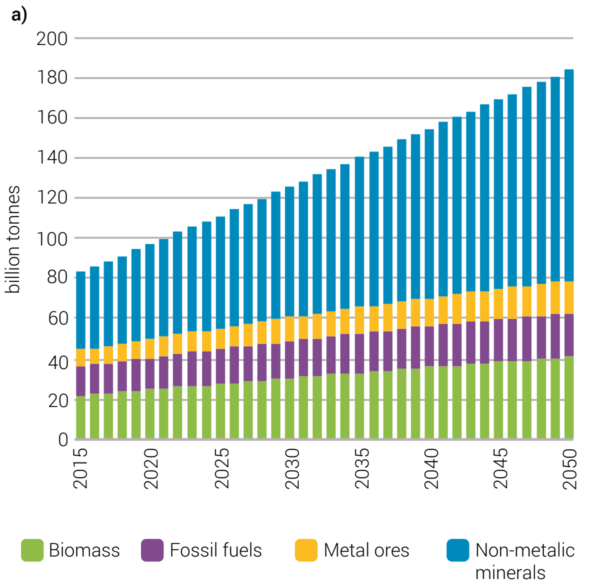
The level and mix of economic and environmental benefits achieved will depend, however, on the detail of the policies and approaches implemented – suggesting that there will be a need to focus on developing and testing a smart and practical package of resource-efficiency measures.

Domestic extraction under *Existing Trends* would grow to 184 billion tonnes in all world regions by 2050 - more than double the 2015 levels (with lower growth in Latin America and North America and lowest growth of all in Eastern Europe, Caucasus and Central Asia). The combination of resource efficiency and greenhouse abatement policies (Climate Plus) would trigger a significant reduction in material extraction to 132 billion tonnes. Reduced material extraction would be strongest in North America and Latin America, and material extraction would decline in the EECCA region. Even under *Climate Plus*, global material extraction would still expand by around 75 per cent by 2050 - demonstrating the inertia of current systems of production and consumption and lock-in with regard to important infrastructure with long-lasting legacies for material requirements.

While most countries would benefit economically from a global effort to reduce resource use through investment in resource efficiency, low-income countries that have invested mainly in primary sector activities would lose out. This would require a compensation effort, redistributing some of the economic gains of increased resource efficiency to countries that would carry the cost (in order to achieve a no-loser outcome).

Despite the beneficial outcome of the *Climate Plus* scenario for reducing greenhouse gas emissions, the 132 billion tonnes material requirement of the global economy of (around 75 per cent above 2017 levels) will nonetheless have huge environmental impacts, contribute to surpassing important global boundaries (Steffen et al., 2015) and increase the risk of pushing the Earth System into a different state that is less suitable for social and economic systems and that will make it harder, if not impossible, to achieve the SDGs comprehensively.

FIGURE 2.24 Global resource extractions (DE) by four categories (biomass, fossil fuels, metal ores and non-metallic minerals) (a) 2010–2050 for *Existing Trends*, and (b) change from 2015 to 2050 for four scenarios



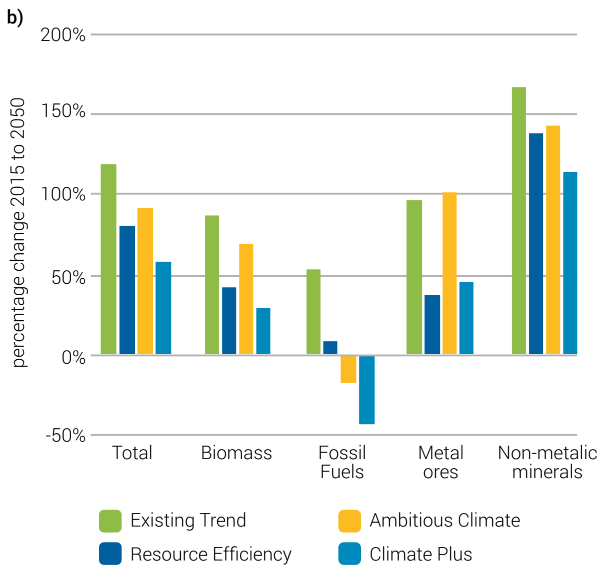
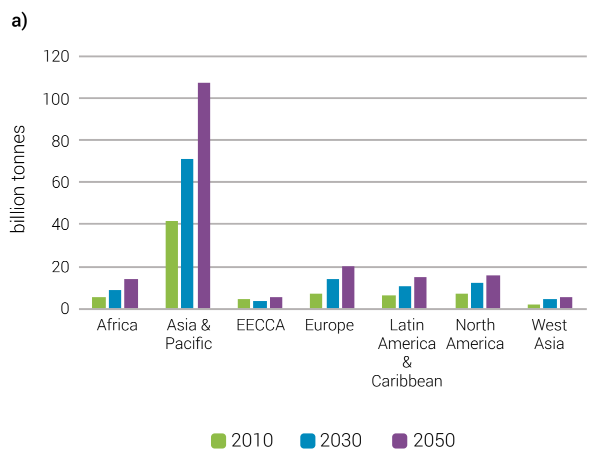
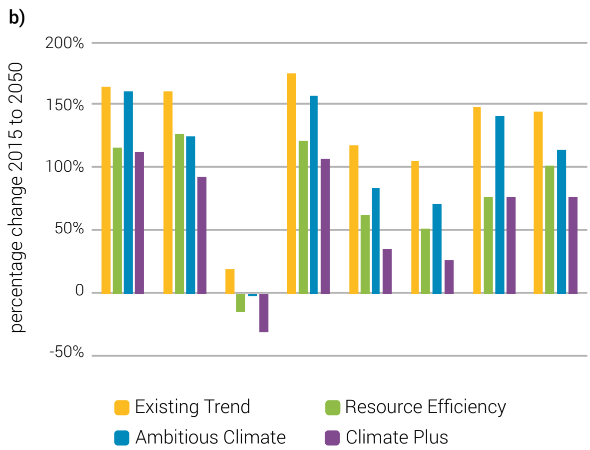


FIGURE 2.25 Global resource extractions (DE) by world regions (a) 2010–2050 for *Existing Trends*, and (b) change from 2015 to 2050 for four scenarios





3. Governance solutions

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Smart integration of the natural resource perspective across public and private governance operations and political strategies is needed if Sustainable Development Goals are to be achieved. Efficiency in the way resources are extracted and manufactured by industry, used and re-used by people, and recycled and disposed of by all are essential efforts towards a pollution-free planet.

This chapter pinpoints key strategies for system-wide pollution reduction and more sustainable resource use throughout the economy. It provides a long but non-exhaustive list of policies and instruments in action in different countries and regions of the world, and points to specific International Resource Panel reports for a more in-depth analysis.

3.1 Towards a new era of multi-beneficial policymaking

Nations are at the cusp of enormous challenge and opportunity. Environmental management and socio-economic development need to be pursued together if either is to be achieved. Sustainable prosperity for current and future generations requires the maintenance and restoration of ecosystem health across the globe. **A new era of policymaking can and must make simultaneous progress towards economic, social and environmental imperatives**. For environmental policies, this means a broadening of goals from managing to preventing environmental harm by creating the conditions that encourage investments in resource productivity. Economic and market-based policies encouraging eco-innovation (Machiba, 2010), green investments and sustainable business models (United States Environmental Protection Agency (US EPA), 2009) are particularly relevant (UNEP, 2014b; UNEP, 2017a). In this sense, **decoupling is not the domain of environmental ministries alone, but rather cuts across all ministries and levels of government**. From a systems perspective, **decoupling helps to lower emissions and reduce environmental impacts such as pollution, as well as lowering costs and enhancing security of supply (see**, **inter alia**, **UNEP, 2011a and UNEP, 2014b**). This goes hand in hand with policies to regulate and manage pollution. That means that a synergetic mix of multi-level and multi-sectoral policies are needed to move beyond incremental changes towards a profound transformation of how resources flow through society. Providing long-term orientation, setting the incentive framework rather than prescribing specific technologies, increasing public engagement and learning from past experiences (including beyond borders) will pave the way for change.

3.1.1 Paving the way to the Sustainable Development Goals through a systems approach[15]

Countries and their policies are faced with different environmental conditions and socio-economic contexts. Where high levels of air or water pollution and severe draughts exert proximate pressure, people's very survival is at stake. Where the living conditions for people and local environments have been secured, the effects of their activities on other regions and resulting repercussions, such as refugee streams[16], become relevant. Widening of this sphere is observable for each country and region over time.

A systems perspective connects material flows from resource extraction through to final waste disposal, in order to build a bridge between the environment and economy: (a) material flows are linked with a bundle of environmental impacts along the production-consumption chain, and (b) the resulting products, infrastructures and buildings provide the basis of material welfare. Two insights are of particular importance:

1. Environmental impacts – including pollution and climate pressure – cannot be mitigated effectively without reducing raw material inputs into production and consumption, because their throughput determines the magnitude of final waste and emissions released to the environment.

2. Decoupling economic activity and human well-being from resource use – in the form of enhanced resource efficiency – is necessary to achieve the Sustainable Development Goals for all.

Traditional pollution control often uses end-of-pipe technologies such as filters and catalysts to keep the release of hazardous substances below critical thresholds. Such an approach may help to reduce SO_2 and NO_x emissions from power plants/car exhaust pipes and improve air quality in cities, for instance. However, the equipment also requires materials and energy upfront (such as mining and refining of platinum group metals for catalysts) (figure 3.1a). Moreover, the upstream processes (including coal and fuel for power stations and cars) and their environmental impacts are not reduced, but may even be increased by reductions in process efficiency. As a consequence, over the whole production-consumption system, those end-of-pipe technologies lead to increased resource requirements

15 This section largely draws from the International Resource Panel report (UNEP, 2015b) on the policy coherence of the Sustainable Development Goals.

16 People are forced to leave their homes due to phenomena including land grabbing and climate-change-induced conflicts (see Institute for Climate Change and Adaptation, University of Nairobi (ICCA, 2016), on experiences from Kenya).

and environmental impacts (albeit in other places) (see Saurat and Bringezu, 2008).[17]

In contrast, resource efficiency gains (in power supply or mobility provision) may still generate the same output in terms of products and their functionality (electricity/transport) while reducing not only the critical emissions of the original target process, but also the resource requirements and environmental impacts in the upstream processes (figure 3.1b). Such innovations in resource efficiency may range from resource savings (as depicted in figure 3.1b) to out-of-the-box solutions for providing the same service in new ways (including through user-led, social and business model innovation) (O'Brien et al., 2014).

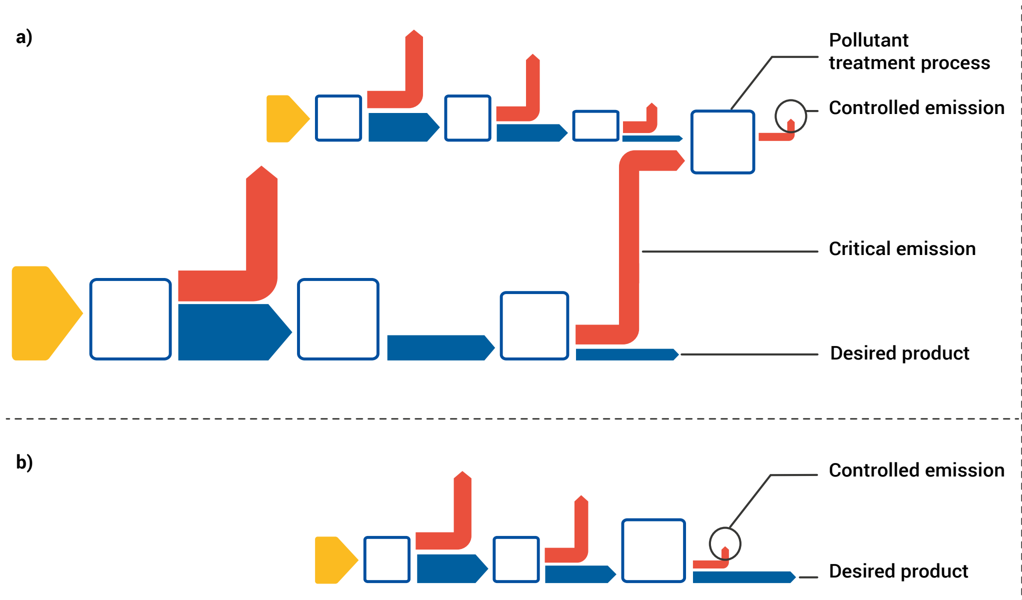
While end-of-pipe technologies can lead to reductions of proximate environmental impacts, systems-wide reductions of environmental burdens can only be reduced by life-cycle oriented increases in resource efficiency**.** This is integral to SDG 12, which aims to reshape consumption and production patterns by transforming resource use in a way that reduces pressures on the environment and climate while promoting human and economic development. Figure 3.2 depicts the targets and indicators of SDG 12 in more detail, as well as where further information on each topic can be found in this chapter. The decoupling of economic growth from environmental degradation is also explicitly stipulated in target 8.4 of the SDGs.

BOX 3.1 Towards Sustainable Consumption and Production in Asia and the Pacific

Issues, priorities and progress in implementing sustainable consumption and production (SCP) have been varied in the Asia-Pacific region, with Northeast Asian countries leading its promotion and practice. Several priorities have been determined, usually as a result of the Marrakech Process, including energy, mobility, water and waste. Poverty and unemployment rates are given due consideration in the implementation of SCP programmes alongside resource conservation. The demand for green consumerism, technical knowledge on life cycle analysis, development of national policies on SCP for business and the emphasis on products and companies over services are some of the key concerns raised in roundtables in the region. Following years of work by United Nations agencies in the region, several SCP programmes and actions have been built from bottom-up consultations and roundtables to the establishment of national plans and strategies. The regional accomplishments in the implementation of SCP include the following:

- SCP tools and initiatives have progressed, particularly in terms of sustainable production as energy efficiency legislations (Copenhagen Centre on Energy Efficiency (C2E2), 2015), national cleaner production centres (United Nations Industrial Development Organization (UNIDO) and UNEP, 2015) and national SCP policies (Akenji, 2012) have been established in many countries.
- The Asia-Pacific region is also part of the Sustainable Public Procurement and Ecolabelling Project (2013–2017), which aims to promote a shift in consumption and production patterns.
- The Seoul Initiative Network on Green Growth has been established with Asia-Pacific member countries to support the Seoul Initiative (2005), which provides a framework for green growth in the region.

FIGURE 3.1 Scheme of pollution reduction by (a) end-of-pipe technologies, and (b) efficiency increase of processes



Note: The same volume flow of product and the controlled emission result in (a) and (b) while resource extraction and other emission flows are higher in (a) than in (b). The boxes represent production or consumption processes, the width of the arrows indicate turnover volume of material flows, inputs match output of each process. Blue arrows: product flows; red arrows: uncontrolled emissions to air, water or waste disposal; yellow flows: resource extraction (input side) or non-critical release to the environment (output side)

17 The study shows the additional resource requirements for platinum-group metals used for car catalysts (end-of-pipe technology) and finds that emissions are shifted from cities to point sources at the refining sites. Taking the higher fuel consumption into account, the overall waste and emission flows increased (with various specific environmental impacts as a result).

1 2 3 4 5

FIGURE 3.2 Targets and indicators toward Sustainable Development Goal 12

SUSTAINABLE DEVELOPMENT GOAL 12		
TARGETS	**INDICATORS**	**LINK**
12.1 Implement the 10-year framework of programmes on sustainable consumption and production, all countries taking action, with developed countries taking the lead, taking into account the development and capabilities of developing countries	**12.1.1** Number of countries with sustainable consumption and production (SCP) national action plans or SCP mainstreamed as a priority or a target into national policies	See this section and Box 3.1
12.2 By 2030, achieve the sustainable management and efficient use of natural resources	**12.2.1** Material footprint, material footprint per capita, and material footprint per GDP **12.2.2** Domestic material consumption, domestic material consumption per capita, and domestic material consumption per GDP	See Section 3.2.1
12.3 By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses	**12.3.1** Global food loss index	See Section 3.3.1
12.4 By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment	**12.4.1** Number of parties to international multilateral environmental agreements on hazardous waste, and other chemicals that meet their commitments and obligations in transmitting information as required by each relevant agreement **12.4.2** Hazardous waste generated per capita and proportion of hazardous waste treated, by type of treatment	See this section
12.5 By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse	**12.5.1** National recycling rate, tons of material recycled	See Section 3.2.5
12.6 Encourage companies, especially large and transnational companies, to adopt sustainable practices and to integrate sustainability information into their reporting cycle	**12.6.1** Number of companies publishing sustainability reports	See Section 3.2.6
12.7 Promote public procurement practices that are sustainable, in accordance with national policies and priorities	**12.7.1** Number of countries implementing sustainable public procurement policies and action plans	See Section 3.3
12.8 By 2030, ensure that people everywhere have the relevant information and awareness for sustainable development and lifestyles in harmony with nature	**12.8.1** Extent to which (i) global citizenship education and (ii) education for sustainable development (including climate change education) are mainstreamed in (a) national education policies; (b) curricula; (c) teacher education; and (d) student assessment	See Section 3.2.6

Source: The Sustainable Development Goals, targets and indicators. Available online: https://sustainabledevelopment.un.org/sdg12.

The concept of 'sustainable consumption and production' joins up economic and environmental processes to provide policy instruments and tools that can contribute to cleaner production and responsible consumption (UNEP, 2012b). Sustainable consumption and production strategies are designed to ensure that (a) multiple SDGs are attainable simultaneously, (b) policy measures are implemented effectively in a multi-objective environment and (c) problem shifting is minimized. However, despite being an explicit global objective since at least the Earth Summit in 1992, sustainable production and consumption has so far proved an elusive goal - probably because the need for increased resource efficiency has been underestimated so far. As an example, box 3.1 provides an overview of sustainable consumption and production activities in the Asia-Pacific region.

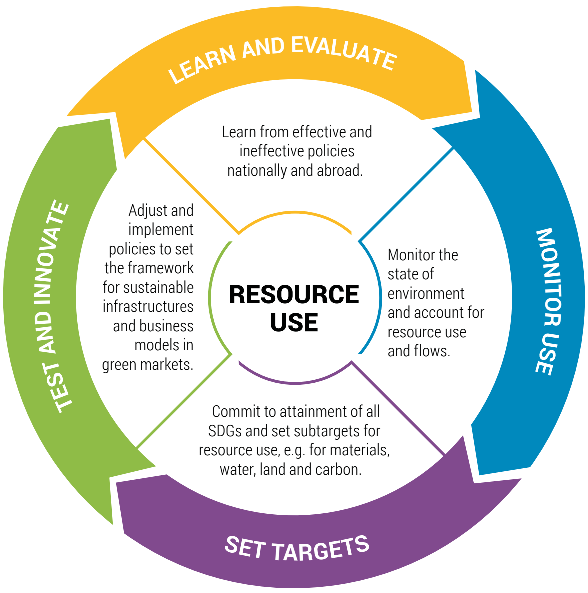
Overall, the SDG framework provides an opportunity to transform the international debate about sustainable development and take it beyond the usual question of trade offs between environment and development (UNEP, 2014c; 2015b). The need to make progress on all the goals together offers an opportunity to avoid the all-too-common experience of "sacrificing" one desirable outcome to reach another. A systems approach is needed to understand the complexities and support the development of coherent policy mixes (see the case studies in chapter 4).

3.1.2 Driving a profound resource efficiency transition

Resource efficiency is vital for transforming unsustainable production and consumption practices into sustainable ones. Resource efficiency can be achieved through the following parallel actions: (a) technological, organizational and social innovations that foster savings (such as reducing resource use - including changing citizen behaviour - in high-consumption countries); (b) reuse and recycling of products and materials (such as keeping resources within the economic system for longer); and (c) an orientation towards service provision (including focusing on providing functions instead of physical products). Over the long run, the physical economy needs to be supplied mainly by recycled material flows driven by renewable energies, while maintaining the extraction of primary resources and final releases within "safe" thresholds (see section 3.2.1 below).

In the process of a transition (Geels and Schot, 2007; Kemp et al., 2007), countries with a long-term vision (underpinned by targets and incremental policy signals that make smart and efficient use of natural resources more profitable than inefficient use) are more likely to succeed (UNEP, 2014b). A coordinated and coherent approach to policymaking across ministries, underpinned by scientific evidence, is crucial (as shown in chapter 2). It will require the participation of stakeholders able to turn shared visions into reality and manage any resistance to change by clarifying multiple benefits for the actors.

FIGURE 3.3 Transition cycle toward sustainable resource use



Steering long-term and profound changes in the way resources are extracted from the environment, processed in production and used in society requires four iterative steps across all levels of governance (figure 3.3):

1. Monitor current performance and use (including by improving knowledge of the state of natural resources like soil, air, biodiversity and water and increasing understanding of earth operating systems and planetary boundaries); monitor the flows and stocks of resources used in the economy; and, in particular, improve footprint accounting for different types of resource use;

2. Set targets and define future objectives in the light of the SDGs (such as setting targets for resource consumption until 2030 and 2050, based on the principles of a safe operating space);

3. Test innovations to change infrastructure, business models and markets as well as lifestyles (including by adjusting targets, subsidies and taxes and

establish a framework for resource efficiency within the economy; and establishing a framework for integrated resource management across scales: national-community-company-product);

4. Learn from effectiveness and evaluation (for instance, through impact assessments of policies to determine which strategies were particularly effective or ineffective for next time; promote cross-country learning).

3.2 Key strategies towards sustainable consumption and production

Change across all levels of society is needed to achieve the SDGs. This implies both "bottom-up" changes in the way businesses create value and citizens access, use and dispose of resources, as well as "top-down" changes in the way that policies steer the markets where businesses operate and build the social infrastructure in which citizens live. This section identifies seven strategies for fostering consumption patterns and production systems that contribute to human well-being without putting unsustainable pressures on the environment. The first sub-section covers the first and second steps of the transition cycle, while the bulk of strategies presented focus on the third step: namely, policy options to steer development and promote innovations toward an inclusive and resource-efficient global economy. Many of the examples focus on the national level, with the potential to manage and steer global natural resource use. If the SDGs are to be achieved, global initiatives[18] and governance will need to play a strengthened role (particularly in terms of responsible mining) (Ali et al., 2017).

3.2.1 Set targets and use footprint, waste and pollution indicators to measure progress

The foundation for change is accurate information and a common understanding of challenges. The transition must be underpinned by greatly increased knowledge and data about the current state of natural resources in the environment, related trends and their use at different levels of society. A thorough analysis can assist policymakers in identifying the most important challenges, such as the prevention of problem shifting, as well as opportunities for effective regulatory, fiscal, social and/or technical policy interventions. In particular, indicators reporting and evaluating the use of materials, energy, land and water (as well as the disposal of waste and greenhouse gas emissions) should play a central role as they capture major environmental pressures and can be applied across sectors and for all geographical scales (Bringezu et al., 2016). **This implies the need for a systemic monitoring system that includes targets and indicators, in particular on footprints.**

International and national targets play a vital role in providing incentives for business to prioritize resource efficiency, as well as in encouraging policy development and guiding policy implementation. A resource-efficiency target, underpinned by targets for the use of key resources (materials, land and water) as well as) GHG emissions could become a fundamental aspect of a regular monitoring framework. Nine countries in the European Union currently have resource efficiency targets.[19] Japan developed an indicator framework and set targets for 2020 related to three aspects of material flow (entrance, circulation and exit) in the context of its Sound Material-Cycle Policy. Monitoring of progress reveals that these targets are on track to being met (Japan's Ministry of the Environment, 2014), and it therefore provides a good example of target setting and progress to reach targets (see box 3.2). **While resource efficiency targets are the first step forward, targets for sustainable levels of global resource consumption[20] are still in an early stage of development.**[21]

18 For example, the Global Reporting Initiative is an independent international organization that helps businesses, governments and other organizations to understand and communicate how business activities cause impacts on issues like climate change, human rights, corruption and many others. More information is available online: https://www.globalreporting.org.

19 Austria, Estonia, France, Germany, Hungary, Latvia, Poland, Portugal and Slovenia

20 At the global level, resource consumption equals extraction. National targets should be based on the final consumption of products and services and set budgets for the resources used to supply that consumption (so that not final consumption is limited but the use of resources for that purpose)

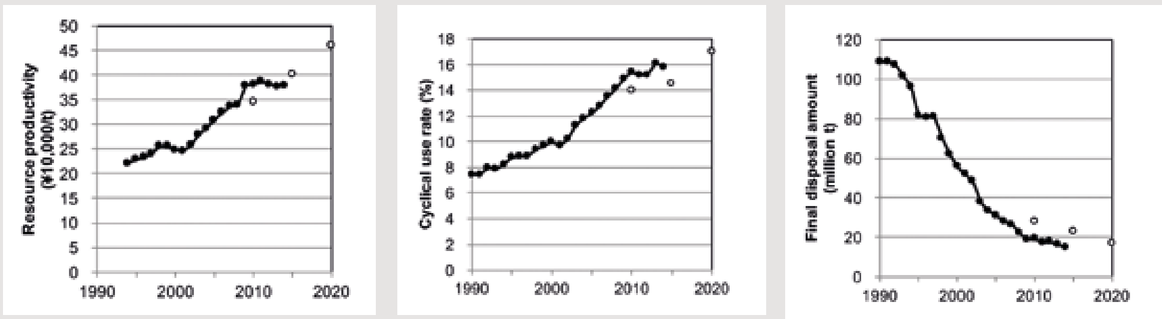
21 For example, the German Federal Environment Agency recognizes an order of magnitude of 5 to 8 tonnes per person annually as a target corridor for 2050, based on current thinking (see Bringezu, 2015), and supporting the precautionary principle and a limit to the amount of resources that may be extracted in the light of intra and intergenerational equity (German Federal Environmental Agency (UBA), 2015).

BOX 3.2 Indicators and targets in Japan's Sound Material Cycle Policy

Japan's first Fundamental Plan for Establishing a Sound Material Cycle Society (SMCS) was developed in 2003, together with quantitative targets for resource productivity, cyclical use rate and final disposal amount (Takiguchi and Takemoto, 2008). These three headline material flow indicators monitor the overall performance of the country. So-called 'effort indicators' are also used for promoting concrete measures and evaluating the progress toward a Sound Material Cycle Society, some of which also have quantitative targets (See tables A2 and A3 in the Annex). The plan has been revised every five years and the current – third – plan consists of 13 material flow indicators and 41 effort indicators. Resource productivity of fossil fuels has been included since the second plan, to enhance synergies between material and climate policies. Indicators such as the 'ratio of municipalities that adopted unit pricing for household waste' and 'power generation capacity of incineration facilities' have been included to promote concrete actions at the municipal level. A variety of indicators are used to monitor the progress toward a Sound Material Cycle Society from multiple viewpoints and levels (See Japan's Ministry of the Environment, 2013). The Central Environment Council of Japan discusses the level of targets and annually reviews progress by monitoring these indicators. As shown in figure 3.4, the targets of the three headline material flow indicators have been met. The review results are used to improve the programmes for establishing a Sound Material Cycle Society. Indicators and targets are also set under the Waste Management and Public Cleansing Act, as well as individual recycling laws for home appliances, construction materials and food waste.

FIGURE 3.4 Trends (●) and targets (○) of three headline material flow indicators in Japan's Fundamental Plan for Establishing a Sound Material Cycle Society

(a) Resource productivity (GDP/DMI) (b) Cyclical use rate (c) Final disposal amount



Source: Japan's Ministry of the Environment 2013.

The use of natural resources must be kept within a safe operating space. This means developing, respecting and governing low-risk thresholds for ecosystem services. While it may not be possible to increase the Earth's absolute carrying capacity, nature's ability for the provision of **ecosystem services can be supported** so that the quality of everyday living can improve, resilience can be enhanced and future options expanded and reinforced (Birkeland, 2008). It also means **reducing environmental impacts of resource extraction, use, recycling and final disposal towards acceptable levels across all scales**. Scientific evidence on where these levels are, such as the planetary boundaries determined by Rockström et al. (2009) and Steffen et al. (2015), how they relate to production and consumption processes[22] at different scales (Häyhä et al., 2016) and how societies interpret and judge risk associated with resource overuse and pollution, is needed to provide the basis for developing targets for benchmarking the sustainable use of natural resources (see, inter alia, O'Brien and Bringezu, 2017). Ultimately, such targets will require normative reflections of social acceptability of environmental change and may not be based on pure scientific deduction. This means that a discourse on potential targets, such as in of the context of SDGs, should be ongoing and part of a longer policy learning process.

To improve the knowledge base, **sustainability criteria will have to be considered in a consistent and synergistic way across different assessment levels**. Consistency across scales is necessary to capture total natural resource use of lower scale actors and processes and to minimize problem shifting across sectors and regions. For instance, indicators of global resource use of cities or companies - such as their material footprint - need to be comparable with the same indicators applied at the national level (and vice versa) in order to facilitate the implementation of national targets. Data on economic sectors can also be used to inform decision-making

22 For example, the UNEP-GRID (Global Resource Information Database) has been working towards applying the planetary boundary framework to the regional and national levels using footprints to describe production and consumption perspectives. More information is available at: http://bluedot.world/.

and guide sectoral policies in the domains of primary industries, cities and trade. It would also strengthen the value of the information beyond the policy community by increasing its usefulness for business. Consistency across the supply chain is needed to capture indirect material flows associated with trade and to prevent problem shifting across countries. In other words, **a whole-product life cycle perspective is also needed at the national level** (Bringezu et al., 2016). Research to report outflows to air, soil and water (UNEP, 2016c), as well as on material in-use in stocks (existing building stock of infrastructure) (Krausmann et al., 2017; Zhang et al., 2017) should be strengthened. This would also allow the material balance at different scales to be closed and enable better understanding of the material stock that services the global economy, the relationship between existing assets and flows and the long-term waste and emission potential of the global economy (UNEP, 2017a).

At the international and national levels, **a monitoring process to assess and benchmark the resource use and resource efficiency of countries, with harmonized metrics and results published at regular intervals, could also give resource efficiency a higher profile** and lead to greater ambition to increase such efficiency (in the same way as currently occurs for GDP growth) (UNEP, 2017a). For example, the European Resource Efficiency Scoreboard[23] benchmarks and compares country performance with regard to resource productivity, similarly to a competitiveness index or innovation scoreboard. Also, the European Raw Materials Scoreboard[24] - which monitors progression of the circular economy in the European Union (EU) - raises the visibility of challenges related to raw materials across the life-cycle of resource use, and also includes social, economic and environmental aspects. The International Resource Panel aims to provide a systemic understanding of linkages between the economy, population and material use (based on a new and authoritative database of global material extraction and a revised database for materials trade). **This report could be taken as a pilot for providing key elements for regular reporting.** One option would be to establish a regular reporting mechanism on the global resource use of countries, including their resource productivity (to monitor progress of decoupling) and natural resource footprints (to monitor progress towards sustainable resource consumption), within the United Nations system. The International Resource Panel could potentially supervise the reporting and support with assessment. Further outlets of strategic indicators could include the Green Growth Knowledge Platform. In the future, research and analysis from the International Resource Panel shall strengthen the links to the resource nexus, including materials, water, land and greenhouse gas emissions.

National accounting capacities need to be supported, particularly in countries facing stringent limitations on the gathering of information about their resources and environments due to the absence or weakness of institutions responsible for collecting statistical data. International or regional intergovernmental organizations could lead the way in developing statistical capacities, including at the national level (Bringezu et al., 2016). Improving the quality of data collection and the creation of decision support tools suited to all country contexts, potentially as part of the SDG process, will help **build more reliable information for national and international policy planning** (UNEP, 2015b).

Data and indicators, in particular on the four footprints measurable across scales (land, water, GHG emissions and materials), would combine to provide the knowledge base for facilitating a transition and the tools to monitor its progress at the global, country, community, company and household levels.

3.2.2 Target key leverage points across all levels of governance

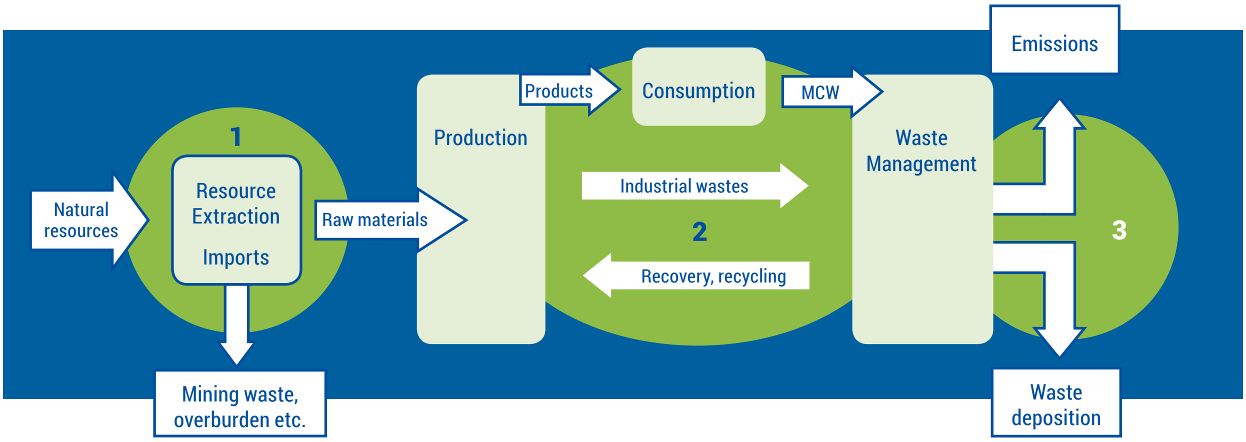
Policies address material flows at three general phases across the life cycle (figure 3.5): (1) controlling impacts of mining, agriculture, forestry and fisheries; (2) improving efficient use in manufacturing and final consumption, including recycling; and (3) safe disposal of waste (and emissions control). The reader will note that, the higher the recycling in phase (2), the lower the material flows and impacts on (1) and (3).[25]

23 Available at: http://ec.europa.eu/eurostat/web/europe-2020-indicators/resource-efficient-europe.

24 The 2016 version is available at: https://bookshop.europa.eu/en/raw-materials-scoreboard-pbET0416759/.

25 Problem shifting by end-of-pipe technologies can also be reduced by recycling, as shown for platinum group metals in car catalysts (Saurat and Bringezu, 2009).

FIGURE 3.5 **Main target areas for economy-wide material flow management including pollution control**



Note: MCW stands for municipal waste.
Source: Bringezu, 2002.

BOX 3.3 **National programmes for material resource efficiency in Germany, Austria and Finland**

The number of national programmes and policy initiatives for improving material resource efficiency has recently increased across Europe. This goes hand in hand with the European Union Flagship initiative for a Resource Efficient Europe and the Roadmap to a Resource Efficient Europe. Meanwhile, three countries have dedicated national strategies for resource efficiency, in addition to two regions (Flanders, Belgium, and Scotland, United Kingdom). **The German Resource Efficiency Programme (ProgRess)** was adopted in 2012 with the aims of securing a sustainable supply of raw materials, raising resource efficiency in production, making consumption more resource efficient, enhancing resource-efficient closed-cycle management and using overarching instruments. It promotes twenty strategic approaches and highlights the particular importance of market incentives, information, expert advice, education, research/innovation and voluntary measures and initiatives. In addition, it adopts an indicator and target framework for promoting resource efficiency. **The Austrian Resource Efficiency Action Plan** was published in 2012 with the overarching aim of increasing resource efficiency by at least 50 per cent by 2020 relative to 2008, and fourfold to tenfold by 2050. It outlines measures such as resource-efficient production, public procurement, the circular economy and awareness-raising. In 2015, the Resources. Efficiency.Technologies initiative was developed to implement resource efficiency in the areas of environmental technology, sustainable production and sustainable consumption. **Finland's 2014 National Material Efficiency Programme** promotes sustainable growth through material efficiency, aiming to achieve economic growth, the sensible use of natural resources and disengagement from harmful environmental effects at the same time. It proposes eight measures for material efficiency and focuses in particular on creating the preconditions for ecologically sustainable growth and employment; promoting competitiveness and balanced operational preconditions for business; utilizing non-renewable natural resources in a sustainable manner; and promoting the production of high added-value products based on strong knowledge and skills.

Source: EEA, 2016.

To promote resource efficiency in a targeted way, leverage points for specific resource streams must be identified. **These leverage points refer to particularly resource intensive processes, products or infrastructure, as well as inefficient practices (where change could have a high impact on overall resource efficiency)**. For example, footprint analysis shows that food consumption is the most important driver of biodiversity loss for most countries, as well as across borders (Wilting et al., 2017). Around one third of global food produced for human consumption is estimated to be lost or wasted (Gustavsson et al., 2011). In high-income economies, food waste is more prevalent at the end of the supply chain. For example, it was recently estimated that around 53 per cent of food wasted in the European Union is from households, and that around 60 per cent of the food thrown out is edible (Stenmarck et al., 2016). In the United Kingdom, the voluntary 'Love Food Hate Waste' campaign promotes behavioural change across five hot spot areas that typically lead to food waste: planning, portions, date labels, leftovers/forgotten foods and storage. It contributed to a 21 per cent reduction in the amount of food being wasted between 2007 and 2012 (Waste and Resources Action Programme, United Kingdom (WRAP), 2013).

To identify "hot spots" for policy action, **national and international resource efficiency programmes could play a strategic role.** Such agencies could coordinate monitoring (see section 3.2.1 above), as well as streamlining institutional arrangements to promote synergies in national – and cross-sectoral – policy interventions. This is particularly important as policy coherence and coordination is a struggle in many countries. For example, in the European

Union: "Many and varied institutional arrangements are in place to develop and implement policies for material resource efficiency, reflecting national conditions and requirements. In most cases, however, several ministries are involved, with overlapping responsibilities and competencies" (European Environment Agency (EEA), 2016). As a first step, three European countries currently have national strategies focused on material resource efficiency (See box 3.3). In at least 56 developing economies, 'National Cleaner Production Centres' (NCPC) have increased their focus on preventative measures for pollution control, including resource efficiency in particular (see box 3.4).[26] In the United States, the Sustainable Materials Management Programme helps to promote capacity and consistency at state and local levels, as well as to facilitate dialogue and collaboration for meeting challenges in a cross-cutting way (US EPA, 2015).

3.2.3 Take advantage of leapfrogging opportunities to achieve relative decoupling in developing economies and promote absolute decoupling in developed economies

There are huge global inequalities in terms of access to natural resources and their economic benefits, both among and within countries (see section 2.4.2).[27] The twin issues of reducing overconsumption and waste of natural resources on the one hand, and providing secure access to natural resources and food on the other, must be addressed simultaneously to ensure that neither resource extraction/equitable use nor waste disposal/emissions surpass the thresholds of a global "safe operating space". **Strategies and solutions should therefore be designed according to national circumstances, but in a globally consistent manner** by approaching the SDGs without compromising other regions' progress towards this end.

While the challenge of decoupling is the same across the world, it manifests differently in terms of strategies and possible pathways in countries at varying stages of "development". **Absolute decoupling is the aim of high-income nations**, with strategies needed to lower average resource consumption levels, distribute prosperity equally and maintain a high quality of life (UNEP, 2014b). To achieve an *inclusive*, green economy – and meet the SDGs *for all* – overconsumption must be reduced. Strategies for waste prevention, resource recovery, new business models and changed consumption patterns are further discussed in this chapter. The magnitude and speed of the decoupling challenge must be established by targets for "sustainable" levels of total resource consumption (see section 3.2.2 above).

Relative decoupling is a key strategy for developing economies and economies in transition to raise average income levels and eliminate poverty. These countries must strive to improve resource efficiencies and achieve cleaner production processes, even as their net consumption of natural resources increases for a period (in other words, until a socially acceptable quality of life is achieved). This could be seen as an opportunity to fast track development goals by learning from and avoiding the unsustainable economic development pathways previously adopted by more developed economies. Some even view this as a relative advantage for decoupling as there are **weaker biases**[28] **against resource efficient investments** (UNEP, 2014b). Moreover, where much of the population is poorly serviced by infrastructure networks, as in many fast-growing cities in lower-income countries, there are **opportunities to design and build new infrastructure that avoids the resource- and energy-intensive approaches typical of many cities in high-income countries** (UNEP, 2013a).

Opportunities to leapfrog infrastructure and technology development require access to sustained finance and international cooperation on capacity-building, technology advancement and investment. In low-income countries in particular, support from development aid cooperation agencies is needed to build the necessary capacity for fiscal reforms, strengthen weak institutions and develop coordination mechanisms that involve key stakeholders.

BOX 3.4 The National Cleaner Production Centre (NCPC) of South Africa

The vision of the NCPC of South Africa is: "To be South Africa's leading catalyst for industrial resource efficiency and cleaner production that contributes to economic growth, sustainable industry practices and human development". It offers a range of subsidized services, such as resource efficiency assessments of companies to help identify areas and strategies for improvement; a training programme for creating skills to maximize resource efficiency; an internship programme; as well as advocacy and awareness raising.

Source and more information available online: http://ncpc.co.za.

26 Also as indicated by the change in the programme name to UNIDO-UNEP Joint Global Resource Efficient and Cleaner Production (RECP) Programme for developing and transition countries in 2009 and the launch of the RECP network. See the UNIDO website: http://www.unido.org/ncpc.html.

27 There is no longer a geographical divide in terms of poverty: countries in which citizens on average enjoy high levels of material comforts co-exist with poverty stricken communities, and vice versa, throughout the world.

28 This relates to the fact that vested interests may not be as set on defending the status quo and consumption habits may not yet be as tied to mass consumption with rapid obsolescence, thereby providing greater scope for new forms of consumption and leasing (Swilling and Annecke, 2012; Boston Consulting Group, 2010).

3.2.4 Align price signals with the strategic goals of society: Implement a policy mix that builds incentives and corrects market failures for resource efficiency

Aligning price signals with the strategic goals of society has the potential to adjust the goals and operation modes of firms and individuals, so that their investment and purchase decisions reflect those of society as a whole (UNEP, 2014b). Currently, the vast majority of taxes on emissions, energy or – rarely – on raw materials (Commonwealth Secretariat and International Council on Minerals and Metals (ICMM), 2009) are designed primarily to raise revenues and tend to be set at modest levels, partly to avoid migration of polluters to tax havens.[29] Subsidies of up to 1.1 trillion USD each year for the productive use of energy, land and water resources (McKinsey Global Institute, 2011) block incentives to invest in resource efficiency in order to save resources and lower costs. The same can be said of tax systems that place the burden of taxes on labour instead of resources, as in most European countries (which derive more than 50 per cent of tax revenue from labour) (EEA, 2017). Moreover, the regulatory frameworks for markets have often been developed in ways that discourage long-term management of resources, and instead incentivize their wasteful early use. **Adjusting such frameworks will require strong leadership at the level of prime ministers, as well as policies that cut across economic sectors to address economy-wide resource use** (UNEP, 2014b).

BOX 3.5 Reformed water pricing leads to significant decoupling in Singapore

Singapore is heavily dependent on imported water and faces chronic water shortages. In 1997, water-pricing reform was undertaken to reflect the ecological costs of water use and to streamline the tax rate based on the amount of water used. It raised average monthly domestic bills for water from S$ 13 in 1996 to S$ 30 in 2000, and provided a rebate scheme for lower-income households tied to incentives to conserve water, energy and gas. As a result, domestic per capita water consumption decreased from 176 to 160 litres daily between 1994 and 2005, while water imports decreased from more than 50 per cent in 1994 to 33 per cent in 2008. The average home in Singapore now uses four times less water than a United States home of comparable income.

Source: UNEP, 2014b; United Nations Economic and Social Commission for Asia and the Pacific (ESCAP), 2012.

Implementing a price signal that steadily increases at the pace of decoupling successes is one key strategy (UNEP, 2014b)**.** Economic instruments face a characteristic challenge: if price signals are strong, citizens may contest and industries may just give up or emigrate. If price signals are weak, however, the effects for resource efficiency may be insignificant: the efficiency gains risk being eaten up by the combination of rebound effects and economic growth. By explicitly linking price rises to efficiency gains, the political discourse around the effects of the proposal broadens. **It moves the discussion to net costs, innovation and investment, rather than just price and fear of losses.** Moreover, gradual introduction of measures such as tax reform may have a strong steering effect and help to avoid rebounds. In many cases, the announcement of future changes in taxes alone induces more resource-efficient behaviours, as firms and people adjust in anticipation (the signalling effect). Addressing flawed price signals could also provide multiple benefits. The removal of fossil fuel subsidies would not only have direct consequences on air pollution and greenhouse gas emissions, but would also free up resources that can be allocated to the general budget and/or invested in the wider economy (ibid). **In any case, whenever prices are changed, special attention must be focused on the impacts on the very poor**. A growing number of lower-income countries have embarked on tax and subsidy reform as part of their poverty reduction strategies, combining those with water and energy block tariffs for meeting the needs of the poorest (see box 3.11 in section 3.2.7). **How a particular policy addresses job creation, raises revenues and its associated costs and benefits are considerations that would be important to policymakers.**

Table 3.1 provides a summary of different financial instruments for a selected number of sectors related to resource efficiency. The list is not exhaustive, but identifies examples of specific policy instruments related mainly to taxation and expenditure, as well as stating where such policies have been implemented (with effectiveness or sustainability not necessarily assessed in each context). **It outlines the wide range of financial instruments that can be used as part of a policy mix to promote resource efficiency** (see also Bontoux and Bengtsson, 2016). For example, many industrialized countries (including Australia, Sweden and Canada) are using carbon taxes to encourage companies and households to invest in cleaner technologies and adopt green practices. The Danish pesticide tax was meant to improve environmental performance, and has the spillover effect of improving material efficiency (Directorate General (DG) Environment, 2011). In Burkina Faso, a progressive tariff grid for drinking water has reduced per capita water use and improved efficiency. Ecological fiscal transfers aim to provide financial resources to local governments for their conservation activities, and have experienced some success in Brazil. Trading emission permits was successful in reducing SO_2

29 South Korea is now the country with one of the highest levels of resource and environmental taxation: roughly 10 per cent of fiscal revenues (compared with about 6 per cent in typical European Union countries and 3 per cent in the United States).

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emissions in some states of the United States, while the European Emission Trading System for greenhouse gas emissions has so far proven rather ineffective due to low prices (with the EU now striving to cap the number of available certificates). **These examples show the variety of tools available and appropriate for different national, sectoral and resource contexts.** All in all, identifying good practices that have been employed elsewhere may support policy development and implementation in a cross-country capacity-building and learning exchange.

TABLE 3.1 Examples of fiscal policy instruments by sector/policy area used to promote resource efficiency across the globe

SECTOR/POLICY AREA	POLICY INSTRUMENT	SELECTED COUNTRY EXAMPLES
MATERIAL USE	Raw material levy Aggregates and gravel taxes	Denmark United Kingdom, Italy, Sweden
ENERGY AND CLIMATE	Clean vehicle/energy tax Carbon tax Clean technology subsidies	Germany, Netherlands Denmark, Slovenia, Norway, Netherlands and several European countries. Netherlands, Denmark
WATER	Block/grid tariffs Plastic bag charges/taxes Water supply and sanitation tariffs	Burkina Faso United Kingdom, Denmark South Africa, Malaysia
LAND	Landfill tax Pesticide tax	United Kingdom Denmark
BIODIVERSITY AND CHANGES TO ECOSYSTEM	Ecological fiscal transfers	Brazil
WASTE	Waste tax	Denmark
EMISSIONS	Pollution charge Nitrogen Oxide tax Emission trading (SO_2, GHG)	China, Colombia, Mexico Sweden United States, European Union
MINERALS AND OIL	Mineral (extraction) tax Mineral oil tax	Bulgaria, Estonia Germany

Source: Compiled by the authors from various sources: DG Environment, 2011; EEA, 2011.

3.2.5 Promote innovation for a circular economy to reduce resource demands and increase resource security

A switch from consumption of finite resources to recycled materials and renewable resources (such as sunlight, wind and sustainably managed biomass) opens up the possibility of meeting the needs of more people over the long term. This shifts the focus from reducing damage to generating new alternatives, and broadens the scope of innovation for sustainable solutions beyond the status quo. Increased use of recycled resources also promotes security and decreases dependence on trade.

There are emerging national specializations in terms of natural resource extraction for trade, and this has led to different environmental and social issues in countries that are net exporters versus net importers, **thereby creating different policy contexts for decoupling** (UNEP, 2016c). Both types of countries are affected by global resource price changes but in very different ways. Countries relying on material imports profit from low world market prices, and their economic performance is harmed by high prices. Material exporters make windfall gains when natural resource prices are high but experience a drop in their trade balance when prices fall. Commodity-exporting region, including Latin America, Africa and Australia, have experienced such effects in recent years (UNEP, 2017a). There are two complementary interests and strategies that are relevant here:

- Net importers may strive to become more independent from external supply and develop resource saving technologies and reliable domestic supply routes, depending also on cost considerations; they will also have strong incentives to invest in material efficiency strategies and policies – achieving more with less.
- Net exporters may strive to become more independent from fluctuating and diminishing returns of their

resource exports and develop domestic markets in a more resilient manner.

Both strategies will mutually enhance one another. Even more importantly, **net importers and exporters will need to innovate to shift their economies towards greater and sustainable shares of renewable and recycled resource use to relieve environmental burdens locally and globally**.

As regards the reuse and recycling of resources, high-level policy agendas have been implemented in Japan (the Sound Material-Cycle Society), the European Union (the Circular Economy policy package) and China (the Circular Economy Promotion Law). Table 3.2 outlines a range of initiatives and strategies employed by European countries across the supply chain in the context of circular economy. It demonstrates the wide range of activities to this end, but is not exhaustive. **In general, policies have tended to focus more on regulating or taxing waste to landfill, or on recycling targets, rather than on life-cycle based interventions** (EEA, 2016). For example, targets are increasingly used to promote the recovery of critical, valuable materials from end-of-life products. Both Japan's Home Appliance Recycling Act and the EU's Waste Electrical and Electronic Directive set mandatory targets, based on the weight of recovered materials. While such targets are a crucial first step in reducing the amount of waste sent to landfills, targets based on physical weight of product composition may miss the aim of recovering the most resource-intensive raw materials along the whole production chain (Bahn-Walkowiak et al., 2014). For instance, palladium comprises only about 0.005 per cent of the weight of a mobile phone, but accounts for 5 per cent of the total material requirements (Chancerel and Rotter, 2009).

BOX 3.6 The Circular Economy Promotion Law in China

In 2009, the Chinese government made circular economy one of China's major socio-economic development strategies by enacting the Circular Economy Promotion Law. It required the central government and local authorities to compile dedicated circular economy content in their socio-economic development plans. For example, The 12th Five-Year Plan for National Economic and Social Development included a target to raise the country's resource productivity by 15 per cent between 2011 and 2015, and focused in particular on reducing waste. More than 200 national standards were proposed, as well as concrete actions including the "Ten-Hundred-Thousand Demonstration Programme on Circular Economy", with a plan to implement 10 major pilot projects, establish 100 demonstration cities and foster 1000 demonstration enterprises and industrial parks by the end of 2015.

The National Urban Mine Demonstration Base project, which focused on the scale development and industrialization of urban mine utilization (waste iron and steel, non-ferrous metals, plastics and rubber) was one such example. The aim was not to construct new recycling centres for resources, but to upgrade the existing system with the help of fiscal subsidies and policy supports for scaling up, advancing innovation and reducing pollution. To date, 49 Urban Mine Demonstration Bases have been established to collect and treat recycling resources such as waste iron and steel, non-ferrous metals, plastics and rubber. The newly increased capacity for the collection and treatment of recycling resources in these 49 bases is planned to reach more than 40 million tonnes per year.

To evaluate the effectiveness of policy measures and strengthen policy enforcement in early 2017, relevant Government departments in China jointly issued the Evaluation Indicator System of Circular Economy Development. The indicator system is built upon the Material Flows Analysis framework and consists of 17 indicators (four focused on inputs, nine on recycling and four on waste output). Resource productivity (based on major constituents of domestic material consumption) and the recycling rate for main waste were selected as the two headline indicators. Evaluation has shown that resource productivity increased by more than 20 percent in 2011–2015, the use of recycling resources reached 246 million tonnes in 2015 and 10 major pilot projects were completed successfully. In particular, the circular transformation of industrial parks, commercialization of remanufacturing, resource regeneration and decontamination processing of kitchen waste were broadened and generalized throughout the period. In May 2017, the Chinese government issued "The Guiding Action Plan for Circular Economy for 2016–2020", which includes new actions to promote circular development.

Source: National Development and Reform Commission of the People's Republic of China (2016). B. Zhu, Tsinghua University.

BOX 3.7 Extended producer responsibility has increased recovery in Sofia, Bulgaria, and Ilfov, Romania.

Extended producer responsibility (EPR) means that producers must take responsibility for the "post-consumer stage of a product's life cycle" (OECD, 2011). This is a strategy in Europe where proposals in the Action Plan of the European Commission's Circular Economy Strategy (European Commission (EC), 2015) seek to make EPR schemes more transparent and cost effective (UNEP, 2017a). In practice, the Municipality of Sofia, Bulgaria, introduced a requirement for producers of electrical equipment to finance separate collection of waste electrical and electronic equipment (WEEE) from households. It set up two organizations responsible for implementation and partly due to a vigorous information campaign, the amount of WEEE recovered increased from 722 tonnes to 1,831 tonnes between 2009 and 2013. The Municipality of Ilfov, Romania, requires all consumers to pay a "green stamp" when they purchase electrical and electronic equipment. This is put towards financing two producer responsibility organizations that "buy back" or collect WEEE. Buy-back campaigns now represent about 30 per cent of total WEEE sales in Romania, and the total percentage of raw material recovery is 80–90 per cent (partly thanks to such instruments).

Source: Regions 4 Recycling; www.regions4recycling.eu/R4R_toolkit/R4R_good_practices.

TABLE 3.2 Examples of circular economy strategies and initiatives reported by countries in Europe

STAGE OF MATERIAL LIFE CYCLE	STRATEGIES AND INITIATIVE REPORTED BY DIFFERENT COUNTRIES
Extraction of raw materials	▪ Reduce the use of primary raw materials (Iceland) ▪ Reduce the impact of material extraction (United Kingdom)
Design of products	▪ Integrate environmental aspects into product design (France) ▪ Extend the lifespan of products (Ireland)
Production and distribution	▪ Extended producer responsibility, for example for waste electrical and electronic equipment, packaging and end-of-life vehicles (Portugal) ▪ Industrial symbiosis and new business models (Sweden)
Consumption and use	▪ Pay-as-you-throw schemes (Belgium) ▪ Changing consumption patterns (Italy)
Reuse, repair, redistribute, refurbish and remanufacture	▪ REPANET and REVITAL initiatives (Austria) ▪ The Scottish Institute for Remanufacture (Scotland, the United Kingdom)
Waste prevention	▪ Secondary Raw Materials Policy (Czech Republic) ▪ Strategies for prevention of waste (Denmark)
Waste management (including recycling)	▪ Separate collection of metal and biowaste to improve recycling rates (Croatia) ▪ Seven goals for the National Waste Management Plan and Waste Prevention Programme (Finland) ▪ Tailor norms or certifications to the circular economy (Netherlands) ▪ Transform waste into resources (Poland)

Source: EEA, 2016.
Note: This list is not exhaustive, but rather outlines the range of activities across the economy and throughout Europe.

One tool for policymakers is supporting “design for recycling”, whereby product designers must make design choices that help rather than hinder recycling processes (for instance by avoiding incompatible metal mixtures or joints that hinder recycling) (UNEP, 2013c). **A product-centric approach[30] supports high material recovery rates as it considers all elements within a product at the same time, sees the value in each and optimizes various recycling options and processes accordingly** (UNEP, 2013c). To this end, design requirements and standards for high quality re-applications are crucial to developing a well-functioning secondary materials market geared not only toward downcycling, but also promoting upcycling of valuable material resources. A shift toward product-service-systems may also be used to extend the lifetime of products. This is because, if producers retain ownership, incentives to develop high-quality, robust products and to maintain them may be increased (see Tukker and Tischner, 2006; Fischer et al., 2015).

Before recycling, extending the lifetime of material resources through direct reuse, repair, refurbishing or remanufacture is crucial to achieving policy aims for waste reduction. In this case, **overcoming infrastructural lock-in is a key policy challenge, in particular as the demand for waste streams for energy generation and recycling may run counter to prioritizing reuse and waste avoidance.** Wilts et al. (2014) found that, in rich Western societies, repair and second hand have become more of a niche phenomenon primarily targeting low-income populations. This is mainly attributed to increasing product complexity, shorter innovation cycles and sometimes deliberate degradation of product quality (built-in obsolescence), which rapidly lowers the value of products and has resulted in a subtle throw-away mentality. Overcoming this stigma, as well as the vested interests in generating waste due to large investments in waste incineration, will require systemic and innovative policy tools. In Sweden, for example, reuse is promoted through tax breaks (see box 3.8).

BOX 3.8 Reduced taxes for repair of household commodities in Sweden

A new tax law was implemented in Sweden at the beginning of 2017 to reduce value added tax (VAT) rates on repairs to bicycles, clothes and shoes from 25 per cent to 12 per cent. It also allows for half of the labour costs to repairs on appliances like fridges, ovens, dishwashers and washing machines to be claimed back from income taxes. In this way, Sweden aims to promote repair to reduce waste and lower emissions.

Source: Government Offices of Sweden 2016, www.recyclingpoint.info/sweden-repair-your-goods-to-pay-less-taxes/?lang=en.

30 As opposed to a “material-centric” approach, which sees recycling as a process to extract one (usually bulk) metal and views other materials as a hindrance.

3.2.6 Build capacity to support change in the way businesses create value and citizens access, use and dispose of resources

"There is a growing awareness that regulatory/top-down measures are not the only ones needed for economies to become more resource efficient; bottom-up and collaborative approaches can be equally effective" (EEA, 2016, p. 114). In this sense, **the role of government is to provide the training, knowledge and socio-economic conditions that enable business and consumers to embark on and scale up eco-innovations**.

One of the primary challenges is overcoming systemic lock-ins. Behaviours are generally tied to the use of existing products and technologies, creating a barrier to the uptake of eco-innovations requiring a change in habits. Individual behavioural patterns are strongly influenced by peer groups and their social norms (Thomas and Sharp, 2013). In instances of excessive consumption, this can cause particular challenges for efforts to initiate a wide-scale shift from personal ownership, also associated with social status, to a service-based approach for using appliances, vehicles and other consumer goods in a more resource-efficient way (Healy et al., 2011; Duhigg, 2012). **Social norms do change and can be influenced by leadership, education and marketing, all of which can either work to perpetuate current patterns of (excessive) consumption engrained in certain lifestyles or move to change them**. One particular norm that works against investments in innovation and resource efficiency is the preference of short-term financial gain. Long-term economic success and stability require a longer-term framework (UNEP, 2014b). Moreover, environmental education and pricing mechanisms aimed at changing consumer behaviour are helpful, but when people are "locked-in" to infrastructure that influences certain behaviours (such as the absence of a separated waste recycling system or alternatives to commuting via private vehicle), significant change is unlikely (UNEP, 2013a).

New types of alliances to collaborate, experiment and learn are critical to a successful transition. Associations, networks and partnerships that pool knowledge, share risk, mobilize support and instigate innovation are needed (UNEP, 2016b). To this end, identifying the dominant agents of change for reaching specific visions is essential (UNEP, 2014b). Possible examples of change agents include businesses, political elites or groups dominated by community interests and local forms of expertise. Shared-vision development provides an avenue for building networks, gaining commitments, orienting actions and forming alliances (UNEP, 2013a).

One strategy for both national and global governance could be to **establish an information centre on technologies and institutional options to enhance resource efficiency and sustainable use of resources,** as also requested by the 10-Year Framework of Programmes on Sustainable Consumption and Production on the Global Sustainable Consumption and Production Clearing House. For instance, the German Centre for Resource Efficiency[31], which is run by the Association of German Engineers and supported by the Environmental Ministry, provides practical guidance for small and medium-sized enterprise (SMEs) and industries. Also at a regional level in Germany, the Efficiency Agency of North Rhine Westphalia plays an important role in promoting resource efficiency, in particular by offering consulting services, financing activities, events and training courses for companies. National Cleaner Production Centres can play a similar role (see box 3.4 above).

Governments may lag behind businesses and civil society in terms of eco-innovations. **Cooperating with private actors can be a way of promoting innovation, and requires governments to adopt institutional frameworks that are flexible and participative in order to broker new and broader coalitions for change**. This requires procurement criteria that favour sustainable innovation (see box 3.9), regulatory reforms that open up markets monopolized by existing infrastructure providers, social processes that encourage and stimulate a culture of innovation, research funding that supports networks of innovators and protective measures that create space for innovations to mature to a point where they can compete in the open market (UNEP, 2013a; 2016a). To create an enabling environment for scaling up eco-innovations, policymakers may aim to:

- **Initiate multi-stakeholder platforms on resource efficiency and sustainable resource use to facilitate and mediate cooperation, for instance** by acting as a "third party" to counter distrust among business accustomed to high levels of competition and to promote the sharing of good practices. For example, the United Nations Global Compact supports companies to act in a way that advances the SDGs. See also box 3.10.

- **Address institutional constraints on cooperation**, in particular where cooperation is feared to clash with existing competition law and anti-trust agreements. A cross-ministerial dialogue for institutional adaptation would help governments to identify key barriers to scaling up (UNEP, 2016b).

31 www.resource-germany.com.

BOX 3.9 Leading by example: creating markets for sustainable innovations through sustainable procurement

Public procurement generally accounts for around 8–30 per cent of a country's GDP (The Australasian Procurement and Construction Council Inc (APCC), 2007; UNEP, 2009a). It therefore (a) provides the opportunity for governments to set an example for private and corporate consumers and (b) enables governments to use their purchasing power to create a market for "sustainable" products and services. For example, **public buildings may be used to illustrate how solarization, energy and material efficiency can be combined, and to show how electric cooling in tropical countries can be minimized.** Governments may lead by example, for instance in terms of sustainable food choices in public canteens. Use of eco-labels, such as fair-trade coffee in government offices, may also help to create a market for such products. For example in Korea, the Act on Encouragement of Purchase of Green Products in 2004 stimulated the market for eco-labelled products in public procurement, leading to an increase in certified products (with the Korean Eco-label) by a factor of 3.8 from 2004 to 2012 (OECD, 2014). Products and services in the IT, energy, transport and building sectors are key candidates for sustainable procurement. To this end, labelling must be further developed and mainstreamed to provide information on the material and energy efficiency of products, in order to promote purchasing decisions that reflect the transition toward resource efficiency.

Source: Based on UNEP, 2017a.

BOX 3.10 Multi-stakeholder initiatives promote collaboration in Sweden, Switzerland and France

Sweden's Centre for Resource Efficiency brings together companies, authorities and research institutes from various industries (energy, pulp and paper, manufacturing, chemicals, waste and recycling) to support competitiveness and resource efficiency, in particular through network seminars and participation in joint research projects. Switzerland's Green Economy Dialogue brings together stakeholders from the private sector, non-governmental organizations, science and academia to work on voluntary measures that promote resource conservation and efficiency. In line with the SDGs, it specifically targets participants who are responsible for the sustainability and business performance of their organizations and who demonstrate willingness to approach the green economy agenda in a systemic way. France's National Council for Ecological Transition is chaired by the Minister for the Environment, and membership is made up of representatives of all social stakeholders (communities, management institutions, environmental protection associations, civil society representatives of and parliamentarians). The Council (1) supports the preparation of international negotiations on environment and sustainable development; (2) prepares national environmental conferences (annual stakeholder meetings to define and debate various actions to be pursued during the year to come); (3) monitors implementation of roadmaps; and (4) is consulted on any proposed environmental legislation.

Sources: cerise.ivl.se; www.gruenewirtschaft.admin.ch; www.developpementdurable.gouv.fr.

- **Provide financial support for innovation and scaling up**, in particular to manage and spread risks associated with new technologies and potential breakthrough innovations that may not receive enough private-sector investment, in addition to creating a level playing field through regulatory frameworks and fiscal incentives that set the price of resources at the right level. For example, Climate-KIC[32] is the largest public-private innovation partnership in the EU for developing and scaling-up low carbon solutions.

- **Build knowledge and capacity** to provide companies and stakeholders with the tools needed to improve resource efficiency in their current operations (including international standards for measuring systems-wide resource efficiency) and to scale up their new and innovative solutions. For example, the 10-Year Framework of Programmes on Sustainable Consumption and Production supports capacity-building partnerships, in particular for smallholder farmers in low- and middle-income countries by helping to provide them with the tools to coordinate, collaborate and compete in markets. Strengthening knowledge and capacity already in schools promotes an educated population from the ground up. For example, the German network "Education for resource conservation and resource efficiency" aims to anchor learning about sustainable resource use across different levels and areas of education.[33]

3.2.7 Unlock resistance to change by addressing barriers and creating opportunities for "losers" from the transition

The transition to a resource-efficient and sustainable global economy may make some industries, business models and extractive/harvest practices outdated or obsolete. **Reduced revenues and job losses must be addressed by policies to (1) overcome resistance to change that may be stepped up by those affected (systemic lock-ins) and (2) provide options on how losses may be reduced, cushioned or turned into new opportunities for workers and businesses**. The particular challenge for policy is that such new opportunities may require skills training, education and investment (which all depends on financing). The very poor and vulnerable may need extra protection, particularly if getting the prices of resources "right" implies raising prices for essential resources and goods (see box 3.11). This emphasizes the need for a coherent policy package addressing different aims and impacts of the transition (UNEP, 2014b; 2017a).

32 KIC stands for knowledge and innovation community. For more information, see: http://www.climate-kic.org/.

33 See also http://www.bilress.de.

One policy solution could be the "recycling" of revenues from a tax or charge. The goal here is to align implementation of change with existing investment cycles in order to reduce capital loss. For example, countries applying a virgin resource tax might find that their net tax revenues increased, even if the export or domestic use of their virgin resources slowed. These countries could use their increased revenue to support sectors affected by the rising tax. An example of a pollution tax being recycled back to industry can be seen in Sweden (box 3.12).

Resource efficiency has the potential to create jobs, which could compensate job losses in other industries. This would require programmes to transfer and retrain workers for employment in resource-efficient sectors and activities. The scale of available job creation through resource efficiency has been estimated by a number of studies. For example, employment in the EU was estimated to increase by around 1 per cent per year (around 2 million net extra jobs) by 2030 (BioIS et al., 2014). A report by the Club of Rome found that measures to increase energy and resource efficiency, and the deployment of renewables, may reduce unemployment by around a third in Sweden, the Netherlands, Finland and France (Wijkman and Skånberg, 2015). It should be noted that, even in countries where change is not immediately visible, economies experience day-to-day changes as firms succeed and fail and employees change jobs. For example, in the United Kingdom 28 per cent of private-sector jobs are estimated to be lost every year, and around the same number created (Anyadike-Danes et al., 2011; UNEP, 2017a).

There is a bundle of strategies and tools available to public authorities to promote a systems-wide transition to resource efficiency in a way that meets the objectives of all SDGs for sustainable and inclusive economic development.

BOX 3.11 Protecting the very poor and vulnerable: an integrated water plan in South Africa

Countries have found ways to protect vulnerable, low-income people from policy-induced price rises. Moves away from generally low and subsidized energy and water prices towards realistic market prices have often been accompanied by policies that provide for preferential low prices for poor families. South Africa has set a good example with its Integrated Water Plan. The Plan involves realistic water prices to encourage private and public investments in water conservation and water supply, while also ensuring that a "lifeline" amount of water is affordable for the poor.

Source: UNEP, 2017a; Republic of South Africa, 2009.

BOX 3.12 Nitrous oxide tax revenues returned to plant operators in Sweden

Nitrous oxides were seen as one of the main causes of acid rain, which plagued Sweden in the early 1990s. A nitrous oxide tax was announced, which large power plants were liable to pay. Small plants had no obligation because of prohibitive cost – but that would have been unfair to the big operators. Sweden therefore applied the tax with a mechanism that returned tax revenues to the operators of power plants in relation to how many kilowatt hours of power they produced. The industry as a whole did therefore not lose any money, but each operator had a strong incentive to reduce nitrous oxides. This model can and has been adjusted to energy and resource taxes for industry. For example, the refund of revenue raised could be made based on workers employed.

Source: UNEP, 2017a.

3.3 Key solutions in specific policy areas

Although the sector-specific challenges faced by countries do differ based on their socio-economic contexts, sustainable resource management can be promoted effectively by adopting a systems perspective and focusing on key lever points. In particular, sharing experiences and learning from what has succeeded ***and*** failed in other contexts will support learning-by-doing and adaptive approaches (Allen et al., 2011; Ludwig, 2001). Examples provided in the following sections address different aspects of the decoupling challenge related to how food and shelter are provided, as well as how infrastructure is organized. Enhancing resource efficiency in these areas has great potential for reducing resource demands overall (see, inter alia, the material footprint assessment identifying priority areas for resource policies with benefits for reducing pollution and increasing well-being within the EU by Giljum et al., 2016).

3.3.1 Food systems[34]

Ensuring access to nutritious food for all is at the core of the SDGs. Over 800 million people are hungry, over 2 billion suffer from micronutrient deficiencies and over 2 billion are overweight or obese (Ng et al., 2014). Changes are needed across food systems to (a) change the way markets perform at the local, national, regional and global levels, (b) ensure that the social safety nets created for vulnerable groups function, and secure their access to infrastructure, finance, knowledge and technology, and (c) support a shift

34 This section largely draws on two International Resource Panel reports: UNEP, 2016b, Food Systems and Natural Resources; and UNEP, 2014a, Assessing Global Land Use: Balancing Consumption with Sustainable Supply.

in the lifestyles and wasteful behaviours of overconsumers, as well as their access to information regarding the impacts of their choices.

Trends towards increased liberalization from regulations, privatization of State-owned agribusiness enterprises, consolidation across food sectors and supply chains and increasing supermarketization[35] have shifted power to large private actors. This speaks to the growing responsibility of business, as well as unique policy challenges. **Food production and food consumption no longer take place within clear boundaries, making it more difficult for governments to regulate and control and for business to get a full overview**. This highlights the need for policymakers to cooperate with other governments, private actors and civil society to exercise oversight in the food sector. Interventions can occur across all levels of governance: examples span from international (e.g. trade regulations), national (e.g. standards, regulations and pricing) to local (e.g. local farming extension services, location of restaurants and urban waste management) level.

National governments can support the development of more sustainable food systems with measures aimed at all stages of the production-consumption chain. **At the beginning of the food chain, enhanced measures promoting and regulating sustainable cultivation and best practice management of farms and fisheries - to improve and maintain land, soil and water quality - are needed**. Good agricultural and fisheries practices are increasingly being certified by expert institutions, which leads to more reliable consumer information and choice. Policy support to assist smallholders in complying with health, safety and environmental criteria would help them to compete in their region with global markets. Governments could facilitate collaborative schemes, such as cooperation agreements among producers, to help increase their market power. Consolidating the legal framework for farmers in clear property and tenure right regimes is a critical precondition. At the international level, global guidance[36] is useful for national governments in setting up land-use and land-tenure laws and ensuring their local implementation and enforcement. Another priority issue for government reform, especially in low-income countries, is the need for investments in rural infrastructure including irrigation, water supply, roads and services that enable local production and "value-addition" activities such as processing and packaging (The High Level Panel of Experts on Food Security and Nutrition (HLPE), 2013; UNEP, 2017a). Financial support for the use of fertilizers by cooperatives could be also helpful, potentially in "subsidy to sustainability" schemes.[37] In rich countries, oversupply of fertilizers and manure leads to eutrophication of water bodies, which can be reduced by more stringent regulations and compliance control, taxation of fertilizers and cooperation agreements between farmers and water suppliers. In Finland, for example, a key Government project is promoting nutrient recycling - as part of a circular economy - to improve the health of water systems and create new business opportunities.[38] **It is crucially important to remove harmful subsidies (such as those on fossil fuels) that stimulate over-extraction of water for irrigation or unsustainable fishery practices**. Price subsidies for agricultural commodities (such as rice and sugar), which are generally distorting and lead to overproduction and inefficient practices, should also be re-evaluated.

The SDGs include a 50 per cent reduction target for global food waste by 2030. The Zero Hunger Challenge was launched by the United Nations in 2012 with the goal of eliminating hunger, malnutrition and rural poverty by 2030. **Minimizing food loss and waste are integral to these efforts**. For example, UNEP launched the "Think Eat Save" initiative in 2013 as a public awareness-raising and engagement activity to catalyse global action toward this vision. Increased reliability, consistency and depth of data on food waste and loss, in particular across borders, is urgently needed to inform policy and aid efforts towards food waste and loss reduction (Xue et al., 2017).

The current business logic of many food systems does not always give actors the right incentives to promote more sustainable practices. Consumer preferences, which are heavily influenced by food marketing and media, have become a driving force for what are often processed, fast and convenient foods. On the other hand, trends for organic, seasonal and locally produced food are increasing in many countries, and may be supported by government. Through its procurement policies, the city of Copenhagen for instance, serves around 20,000 meals per day (in nursing homes, schools, day care centres and so on) and aims to

35 This refers to the increasing share (in most cases) of internationally operated supermarkets in the total share of consumer food purchases. This is particularly prevalent in Asia and South America (with supermarket dominance in Brazil rising from around 15 per cent in the 1990s to a more than 60 per cent current share in overall food retail). This not only affects power relations across the food supply chain, but also eating habits and product sourcing.

36 As is done in the FAO Voluntary Guidelines on Responsible Governance of Tenure of Land and other natural resources by the Committee on World Food Security.

37 In contrast to pure fertilizer subsidy schemes, such an approach links directly to investments on the farm to provide long-term nutrient supply, enhance soil health for sustained yields and improve efficiency in fertilizer use (Garrity et al., 2010).

38 For more information, see the Finnish Ministry of Agriculture and Forestry website on "Making use of agricultural nutrients": http://mmm.fi/en/recyclenutrients.

serve 100 per cent organic, seasonal fruit and vegetables. Because organic food tends to be more expensive than non-organic food, the municipality kept costs the same by making simultaneous changes in kitchens and meal plans (particularly by reducing meat and replacing it with more vegetables, with synergistic benefits for greenhouse gas emission reductions). **Further consumption-oriented policies may be used to promote behaviour research and stricter marketing rules for unhealthy food, as well as creating a food environment that stimulates healthy and sustainable diets.** In this regard, education is crucial for food producers and consumers (especially children). In general, special attention is needed for the role of women, as they are usually critical participants in food production and the main managers of food consumption in their households. Lastly, countries can monitor the overall consumption of agrarian and fisheries products against domestic production capacities in terms of global footprints in order to determine their fair share and adjust the incentive framework towards a more efficient use of biotic resources if necessary.

BOX 3.13 Improving material efficiency in Rathkerewwa desiccated coconut mill in Sri Lanka reduces food waste

Measures such as laying rubber carpets on the floor of loading bays, raising employee awareness, reduction of wash water and energetic reuse of coconut shells reduced waste and saved energy. Combined measures provided savings of around USD $200,000 for an investment of less than usd $5,000.

Source: UNIDO, 2013.

BOX 3.14 Relaxing cosmetic standards for French beans in supermarkets leads to lower food loss in Kenya

In general, supermarket retailers of French beans order beans of a specific length to fit their packaging requirements, meaning that farmers must cut them to the required length, wasting 30–40 per cent of the bean. One major customer was persuaded to change its buying policy, allowing Kenyan exporters to reduce waste by one third.

Source: Feedback, 2015.

BOX 3.15 The School Lunch Programme in Brazil: The case of Paragominas boosting the local economy and shortening the supply chain

At least 30 per cent of the total funds allocated in the Brazilian National School Feeding Programme must be used to purchase food directly from family farms. The city of Paragominas (with around 100,000 inhabitants) has been purchasing food from family farms since 2005, mostly for school lunches. In doing so, it has stimulated and diversified production, boosted the organization of associations of farmers and the value of household production.

Source: UNEP, 2016b.

3.3.2 Buildings and construction

On a global scale, buildings use around 40 per cent of resources, 25 per cent of water and 40 per cent of energy, and they account for around one third of greenhouse gas emissions.[39] Changes in the planning, design, commissioning, construction, maintenance, refurbishment and end-of-life stage of buildings provide significant opportunities to reduce environmental impacts while providing healthy and safe living and working spaces. Meeting the needs for housing, employment and public infrastructure in a sustainable way is particularly crucial for those countries facing rapid urbanization and urban population growth. **Investing in green sustainable buildings has the co-benefit of creating jobs, especially at the local level**. It has been estimated that, for every USD $1 million invested in building energy efficiency retrofits, 10–14 direct jobs and 3–4 indirect jobs would be created (UNEP, 2011c; 2012a).

Harnessing the potential for resource efficiency in construction requires a collaboration of home and building owners and users, businesses and governments. Innovation in the construction industry is traditionally slow moving, with various actors and experts addressing different aspects, often in isolation (building core, energy provision, functional use of the developed space for living, working and so forth). There is little communication across supply chains in the construction sector, and a lack of integration of technical and social challenges and solutions (Eco Innovation Observatory (EIO), 2011). Integrated planning from a systems perspective may make progress towards innovative and case-specific solutions for various types of buildings in different world cities.

A systems perspective is essential for retrofitting existing building stock to ensure that the energy efficiency of operating a building is not improved at the cost of resource efficiency in the life-cycle-wide impacts of the materials used. A systems approach must play a role in evaluating the demolition and construction of buildings compared to the renovation of existing building stock, in particular in terms of operational versus "embodied" carbon dioxide emissions (Ibn-Mohammed et al., 2013). Beyond a systemic vision for individual buildings, greater resource, energy and water savings can be made at the settlement level in relation to many different types of buildings. For energy efficiency and local nutrient management, this is demonstrated in numerous examples of eco-villages, transition towns and one-planet communities. For example, the Beddington Zero Energy Development community (BedZED) in the United Kingdom has enabled residents to significantly reduce their ecological footprint due to its innovative approach to design, energy provision, service

39 Based on data from the website of the UNEP Sustainable buildings and climate initiative: www.unep.org/sbci/,.

organization and lifestyles.[40] Building standards to also include material footprints are still under development.

As owners and operators of buildings, governments have the opportunity to promote sustainable construction of new buildings and environmentally conscious use of the built environment through their procurement strategies (through reuse of construction materials and renewable power sources, for instance) and behaviours (lighting, cooling and heating practices and so forth). Multiple standards and certification systems showcase sustainable practices and support the creation of a green building sector. Prominent examples of green building rating systems developed in different parts of the world include BREEAM (United Kingdom), the LEED programme (United States), Green Star (Australia), CASBEE (Japan), and HK-BEAM (Hong Kong).[41] Environmental product declarations (EPDs) are another tool that are increasingly used as a basis for the certification of green or sustainable buildings and the materials used for construction. However, the standard indicators remain focused on climate and pollution pressures, and indicators of material resource requirements still need to be incorporated in order to support the design of new buildings and the retrofitting of old buildings in anenergy- ***and*** material-efficient manner.

Financial support is vital to develop new technologies and methods and to facilitate their uptake**. In the building sector, this may take the form of government-sponsored cost-efficient loans for homeowners to renovate or retrofit their homes.** It is possible to ensure that such loans are affordable and accessible for all through programmes specifically targeting low-income households. Accompanying measures are also needed in the form of awareness raising and information campaigns to promote adoption of such loans. These campaigns may focus on the cost-saving potential, with environmental and health benefits presented as a bonus (UNEP, 2017a).

The construction, renovation and demolition of buildings account for about 40 per cent of solid waste streams in "developed" countries (UNEP, 2012a), and there is substantial potential to reuse the non-hazardous portions of this waste. **Governments have had success encouraging innovation in waste prevention and recovery through the implementation of landfill bans and taxes.** For example, the Landfill Tax implemented in the United Kingdom in 1996 (and steadily increasing since then) has been a key factor in changing attitudes and diverting waste from landfill, so much so that recycling and recovery are in many cases cheaper than sending construction and demolition waste to landfill (Deloitte, 2016). The introduction of an aggregate tax for mineral extraction in 2002 most probably enhanced the effect (EEA, 2008).

BOX 3.16 A housing finance scheme encourages energy-efficient systems and technologies for low-income households in Mexico

More than 900,000 "Green Mortgage" credits were granted between 2007 and 2012 in Mexico, mostly targeting low-income households. This includes an additional credit of up to USD $1,250 to cover the cost of additional eco-technologies such as energy-saving lamps, ecological level toilets, purified water filters and gas water heaters, among others. These technologies have led to resource savings and lower utility bills for households.

Source: www.bshf.org/world-habitat-awards/winners-and-finalists/green-mortgage/

BOX 3.17 Decentralized production and recycling help create eco-materials for boosting construction in Cuba

In Cuba, local production and distribution of environmentally and economically sustainable building materials are needed for low-cost repairs and new constructions, especially in disaster-prone areas and for social housing (relying on centralized and remote production of building materials was no longer viable for large parts of the population due to rising fossil fuel costs). A project helped to develop the local manufacture of eco-building materials, in particular by recycling waste such as roofing tiles, concrete blocks and clay bricks; by supporting eco-material workshops; and backing a decentralized management model for housing renovation including a micro-credit facility. The project contributed to job creation and won the World Habitat Award in 2007.

Source: www.bshf.org/world-habitat-awards/winners-and-finalists/ecomaterials-in-social-housing-projects/

BOX 3.18 Improved resource efficiency of brick production in Bangladesh also reduces local air pollution and CO_2 emissions

Green Bricks Bangladesh, which promotes smokeless brick production while also increasing resource productivity, has shown how a change in the manufacture of construction materials can have significant impacts on reducing energy use and air pollution. In comparison to traditional brick fabrication, Green Bricks require only about one third of the amount of coal and a single improved kiln, which can produce up to 15 million bricks, can cut CO_2 emissions by 5000 tons every year (Hossain and Abdullah, 2012). It is estimated that the 15 demonstration kilns built in the Green Brick project in Bangladesh will save 314,000 tonnes CO_2 equivalent by the end of the project in 2015, while also improving workers' health and incomes.

Source: United Nations Development Programme (UNDP) Bangladesh 2010; UNEP 2017a.

40 Sustainable lifestyles accounted for around half of the eco-savings achieved, highlighting the importance of considering how residents can conveniently access services in future projects (BioRegional and Peabody, 2009).

41 BREEAM: Building Research Establishment Environmental Assessment; LEED: Leadership in Energy and Environmental Design; CASBEE: Comprehensive Assessment System for Building Environmental Efficiency; and HK-BEAM: Hong Kong Building Environmental Assessment Method.

3.3.3 Cities and urban infrastructure[42]

Cities are the building blocks of a socially inclusive global green economy. They are the spatial nodes where the major global and national resource flows connect, as well as being centres of innovation, diversity and culture. They also account for the bulk of resource consumption: approximately 75 per cent of global energy and material flows were consumed in cities in 2005, despite the latter covering just 2 per cent of the land. However, **the metabolism of cities is often not well understood, and there is limited research into the links between social organization and the policy dynamics of resource flows at an urban scale.** Nevertheless, understanding those flows is the first step to being able to address the environmental externalities of urban activities (UNEP, 2013a). A systems approach to sustainable cities can help promote long-lasting solutions toward achieving the interlinked goals of the SDGs (Bai et al., 2016; see also the city case studies in chapter 4).

Each region has distinct patterns and processes that reveal the emergence of a lumpy "rural-urban continuum", in which rural-urban links are highly heterogeneous between and within countries and change slowly over time. **Challenges, such as the growing number of urban poor, resource security and infrastructure development, must be approached together on a case-by-case basis and oriented by vision building.** For example, urban planning in low-income countries with rapid population growth has been highly challenging in cities all over the world. Master plans have to be made and, within the master plans, micro planning is needed to develop appropriate transit infrastructure (including bus and road).

The design, construction and operation of energy, waste, water, sanitation and transport infrastructure creates a socio-technical environment that shapes the "way of life" for city residents and determines how they obtain, use and dispose of the resources they require. How resources flow within cities, as well as how cities are linked to their hinterlands and to more long-distance resource wells and final sinks, are important considerations for assessing infrastructure networks. **There is evidence to suggest that it can often be more resource efficient to achieve the well-being of people with respect to services, health, education and income if they are concentrated in cities, rather than spread out across rural areas** (UNEP, 2017a).

Infrastructure is key to urban resource efficiency. Infrastructure built today lasts 25 to 75 years. This not only requires materials and energy to build (contributing to the physical "stock" of resources within national economies), but also determines how energy, water, materials and waste are managed at a city scale. The design of urban infrastructure is thus critical to environmental aims, as well as being costly to build, maintain and refurbish (especially if it is redundant).[43] It is estimated that a total of USD $41 trillion is required to refurbish the urban infrastructure old (mainly in "developed" country cities) and build the new (mainly in the "developing" country cities) between 2005 and 2030. Over 50 per cent (USD $22.6 trillion) would be required for water systems, USD $9 trillion for energy, USD $7.8 trillion for road and rail infrastructure and USD $1.6 trillion for air and sea ports (Doshi et al., 2007).

A combination of resource productivity improvements, increased use of local renewable resources and reuse of waste products can allow cities to better manage the flows passing through them in pursuit of decoupling. "Green cities" show signs of a trend towards re-localization and attempts to create more autonomous circular or "closed-loop" metabolisms. Four types of interventions are particularly important for promoting resource efficiency in cities (Salat, 2011; Salat and Bourdic, 2011; UNEP, 2017a):

- spatial restructuring of urban morphology to reverse the century-long trend towards de-densification and to instead achieve much greater densities – and a richer mix – of housing, jobs and amenities at the neighbourhood level;
- human-scale sustainable design to create the conditions for "soft" mobility (pedestrianization and cycling) at the city and neighbourhood scales and "passive" heating, cooling and lighting at building level;
- sustainable energy (radical resource efficiency of all components such as vehicles, infrastructure, buildings and factories, plus maximum use of renewable energy) at all scales (city-wide, neighbourhood and building); and
- the promotion of sustainable behaviours (such as the wish to recycle waste, use public transport, walk, cycle, use parks and so on).

42 This section is largely based on the IRP report: UNEP (2013a). City-Level Decoupling: Urban resource flows and the governance of infrastructure transitions.

43 Maintaining redundant water infrastructure, for example, creates "artificial demand" that may use clean water resources for purposes that would otherwise use grey water. Such challenges are prevalent in "shrinking" cities, found mainly in Europe, North America and Japan, thereby slowing the potential rate of both resource and impact decoupling (UNEP, 2017a).

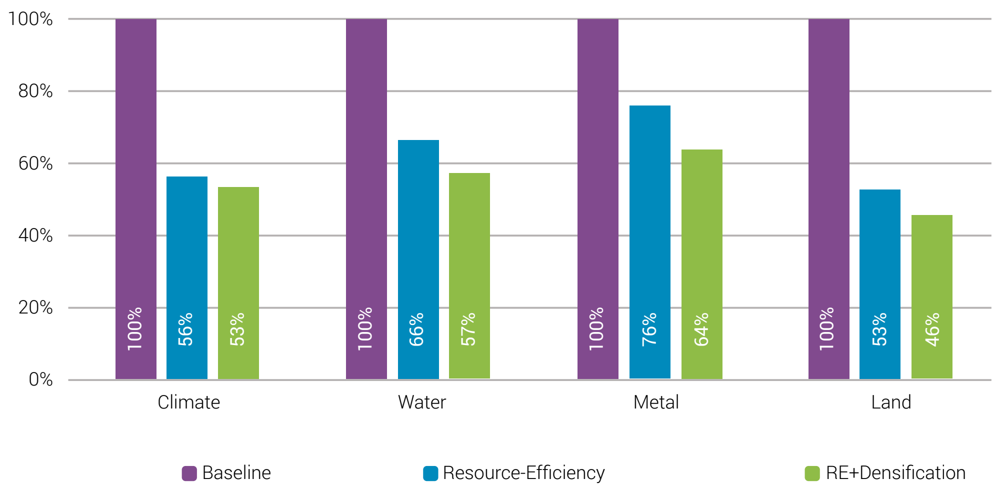
One strategy for national governments is the adoption of National Sustainable Urban Development Policy Frameworks that support the role of cities in national sustainable development strategies. They should align spatial planning guidelines, infrastructure investment strategies and financial and long-term sustainability goals. City planners must be able to take the rural-urban continuum into account, highlighting the importance of multi-disciplinary spatial planning mechanisms and tools to support the long-term transition process from rural to urban areas in a resource-efficient way. In South Africa, for example, national legislation stipulates that every town and city must set a vision and draft an "Integrated Development Plan" on an annual basis.

UNEP (2017b) identified broad sets of strategies that focus on systems level transformation as a pathway to achieving resource-efficient urbanization. The broad strategies include:

- Avoid urban area expansion to agricultural areas and lands that provide high value ecosystem services, such as flood protection.
- Plan for strategic intensification and limit urban sprawl with higher density and mixed use around transit, developing human-scaled urban forms and encouraging non-motorized travel and social interactions.
- Promote energy-efficiency strategies in single sectors, including high-efficiency buildings, district energy systems and transit.
- Support cross-sectoral efficiency by promoting strategies that include reusing waste heat in district energy systems (see case study 2 in section 4.5).

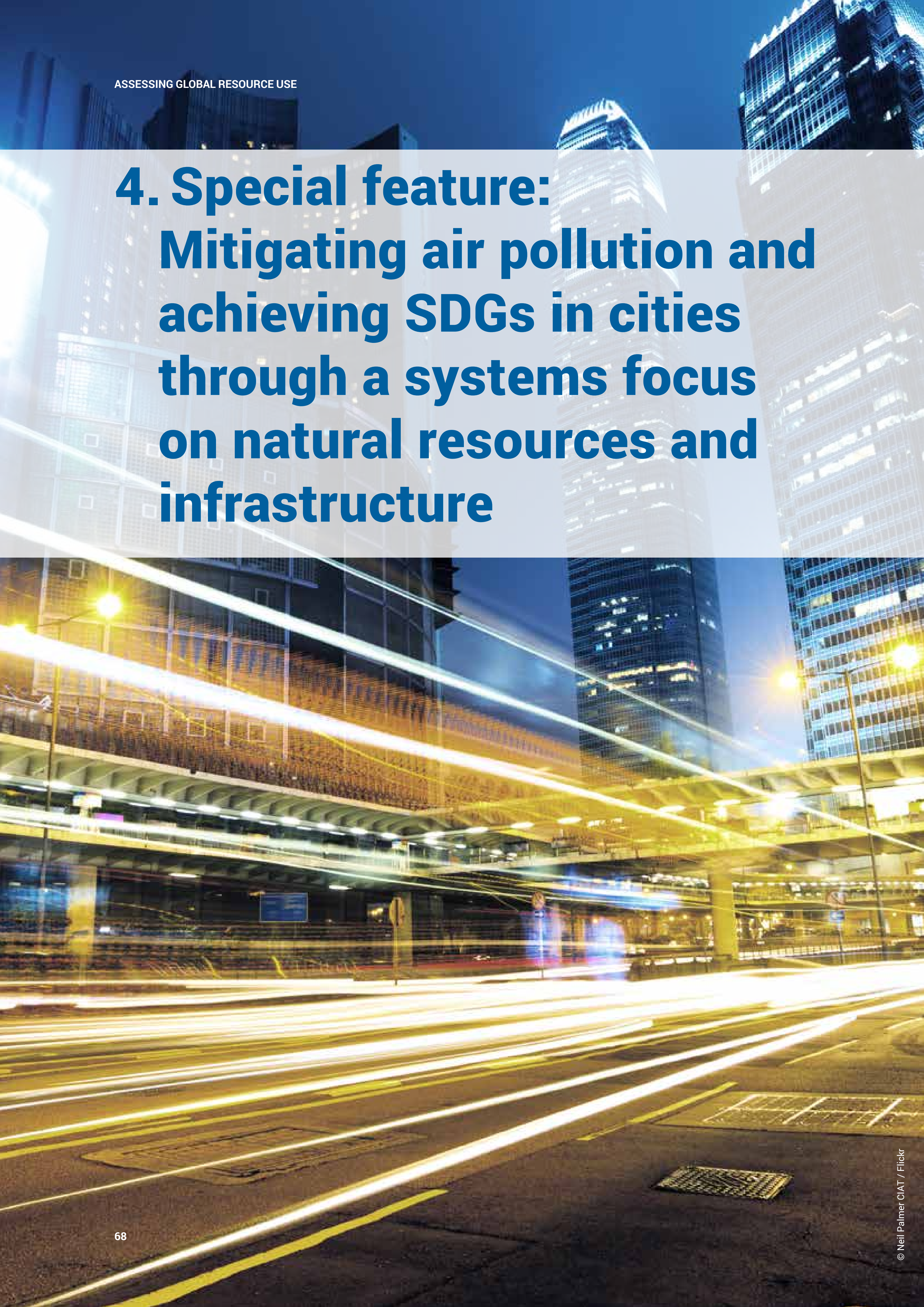
Scenario analyses indicate that these strategies have the potential to achieve a 30 per cent to 60 per cent reduction in resource use in buildings and transportation sectors in diverse world cities (see figure 3.6; UNEP, 2017b). In order to proceed towards more sustainable paths, one might expect system-level transformations at the city level to reflect, incorporate and drive socioeconomic transitions at the national and global levels. The next chapter builds upon the basic strategies for building resource-efficient cities outlined here, expanding the strategies to address the challenge of air pollution in cities.

FIGURE 3.6 Reduction potential of system-level transformation strategies in buildings and transportation sectors



Source: UNEP, 2017b.
Note: Depicts aggregate change in resource consumption for each socio-technical system in 84 cities combined under resource-efficient scenarios in 2050 (compared to forecasted baseline in 2050).

4. Special feature: Mitigating air pollution and achieving SDGs in cities through a systems focus on natural resources and infrastructure



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BOX 4.1 Highlights of the special feature

- Air pollution has emerged as one of the primary risk factors for premature mortality in the 21st century, linked with 6.5 million premature deaths annually due to cardiovascular disease, respiratory disease, lung cancer and diabetes, (with the majority occurring in global cities). Indoor and ambient air pollution by fine particulate matter (PM2.5) is the dominant risk factor, accounting for 96 per cent of these health effects.
- Addressing PM2.5 air pollution has been challenging because it arises from multiple infrastructure sectors within the city boundary (industry, transportation, household cook stoves, waste burning, construction and road dust) and outside city boundaries (agricultural burning, industrial emissions and natural sources). Furthermore, PM2.5 concentrations in the air are influenced in complex ways by local weather patterns and exacerbated by climate change, particularly extreme heat and drought events.
- Lessons learned from air-quality management experiences in the United States and other countries indicate that systems-based approaches complemented by end-of-pipe control strategies are important for addressing the multi-faceted sources of PM2.5 (such as waste burning, biomass burning stoves and agricultural burning).
- This chapter presents a systems approach anchored in the use of natural resources, with a focus on essential infrastructures and food supply in cities, which delineates pathways to reduce pollution while also providing multiple co-benefits that advance SDGs locally.
- Applying this systems approach to developing economies, strategic pathways are identified for transforming cities with underserved populations, high inequality and high pollution levels into more inclusive, resource-efficient and cleaner places that advance the well-being of large urban populations.
- Pathway analysis based on a systems approach to emerging economies undergoing rapid urbanization and industrialization finds that circular economy policies, along with urban planning that enables beneficial exchange of materials and energy across different industry and infrastructure sectors, can yield economic gains, natural resource conservation, greenhouse gas mitigation and air pollution reductions.
- Overall, a “bundle of strategies”, when implemented together, can simultaneously reduce air pollution and advance human well-being, achieving multiple SDGs in diverse world cities. The key strategies include:
  - Avoid urban area expansion to agricultural areas and land that provide high value ecosystem services, developing urban-rural market mechanisms that ensure preservation of lands and reduction of dust/air pollution emissions;
  - Strategic urban land-use and infrastructure planning within cities and urban areas to reduce travel demand;
  - Investments in efficient transit systems to reduce vehicular emissions and congestion;
  - Inclusive development and in situ slum rehabilitation in multi-storey buildings within denser city cores that provide essential services and access to livelihoods with reduced travel burden on the poor;
  - Promoting multi-storey resource-efficient building construction and energy efficiency for all buildings;
  - Promoting culturally sensitive behavioural strategies to reduce resource use;
  - Focusing on key resource substitutions for dirty cooking fuels and construction materials with high embodied fuel and PM2.5 emissions;
  - Electricity grid transformations with high levels of renewable energy;
  - Creating business innovations to reduce agricultural and solid-waste burning.

4.1 Objectives of the special feature

Consistent with the third United Nations Environmental Assembly's focus on pollution, chapter 4 specifically addresses the topic of air pollution in cities from a resource-based systems perspective. The specific objectives of this special feature are:

- To demonstrate application of a systems approach to world cities that links resource use in essential infrastructure and food supply sectors with more than 9 SDGs, with special emphasis on inclusive development, resource efficiency and the resource-infrastructure-air pollution-health nexus.
- To illustrate the air pollution and health co-benefits of resource-efficient urbanization, specifically focusing on co-beneficially achieving multiple SDGs in case studies from India and China where the bulk of future urbanization will occur and where cities are facing substantial air pollution challenges.
- To highlight a general "policy/strategy bundle" focused on resource transitions and infrastructure transformations that combine to conserve natural resources, mitigate air pollution and advance multiple SDGs in diverse world cities.
- To outline quantitative metrics for individual cities to track progress toward multiple SDGs, with a focus on natural resource use in urban infrastructures.

Overall, this chapter presents a city-level approach to monitoring resource use, infrastructure provisioning and associated PM2.5 air pollution and greenhouse gas impacts, as well as assessing progress toward SDGs in keeping with the DPSIR framework illustrated in figure 1.4. The chapter begins with an overview of the global urbanization challenge. It describes resource use for basic infrastructure and food provisioning in cities, and the resulting impacts on multiple SDGs (including human health impacts of PM2.5 pollution in world cities). Historical trends in air-quality management in the United States (including the significant progress made) are briefly reviewed, as are challenges that require a whole systems approach to achieve healthy and clean air in all cities. Lastly, a systems approach to assess the air pollution, health, and multiple SDG co-benefits of resource-efficient urbanization is presented through pathway analysis in cities of India and China. The case studies represent two broad situations, and serve to illustrate different insights:

1. Cities in growing economies that are dealing with basic infrastructure challenges, air pollution and resource scarcity. The case study of Delhi, India, represents rapidly growing cities in the developing world where infrastructure is inadequate and unable to keep up with growth, resulting in informal settlements that lack basic infrastructure provisioning (which in turn leads to deprivation and inequality). The case study demonstrates the potential benefits of a bundle of strategies that can promote more inclusive development, while reducing net air pollution emissions, greenhouse gas mitigation and human health risks. This case study also illustrates metrics to track progress toward SDGs in individual cities, applying the DPSIR framework to Delhi, India.

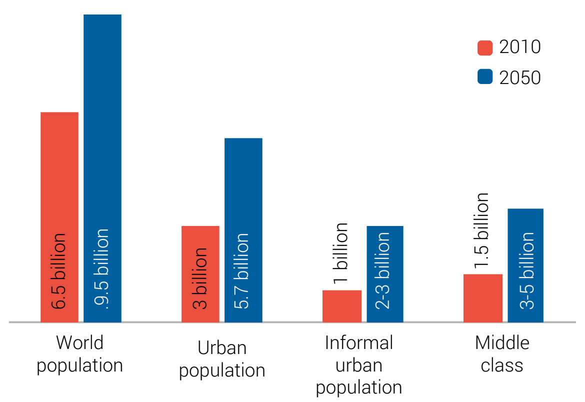
2. Middle-income countries undergoing rapid urban infrastructure development and industrialization that are experiencing the challenges of high resource use and air pollution. This case study provides baseline energy use and air pollution emissions data for of all 637 cities in China (Ramaswami et al., 2017c), and illustrates potential multiple co-benefits achievable by implementing urban-industrial circular economy strategies in cities. This case study seeks to demonstrate the collective role that cities can play in achieving national greenhouse gas mitigation targets through urban-industrial symbiosis strategies, while also providing local air pollution and health benefits, along with significant natural resource and monetary savings. The urban-industrial resource efficiency strategies are broadly relevant to China and other nations in Asia and Africa where future urbanization and industrialization are expected to occur together. This illustrates that the adoption of resource-efficient infrastructure planning is a key pathway to prevent air pollution.

Both studies demonstrate the value in applying a systems approach that quantifies linkages between natural resources, infrastructure and multiple SDG co-benefits.

4.2 Challenges of urbanization

By the year 2050, about 6 billion people (nearly 70 per cent of the global population) are expected to be living in cities, almost doubling our current urban population of 3 billion in a short span of only 40 years (UNEP, 2013a). Such rates of urban growth are faster than any previously experienced in human history, and are placing enormous pressures on the local environment within cities, as well as impacting the global resource base and regional and global environmental quality. While the urban middle class is projected to expand, inequalities are also expected to become worse. Between 30 and 40 per cent of the population in many world cities are already living in slums and informal settlements (UN-Habitat, 2016), and this proportion is projected to grow (particularly in Asia and Africa where the bulk of future urbanization will occur). **Increasing urban populations, rising affluence, growing inequalities, rapid rates of migration and inequalities in basic infrastructure are major drivers that shape resource use, environmental quality and associated human well-being**.

FIGURE 4.1 World urbanization trends



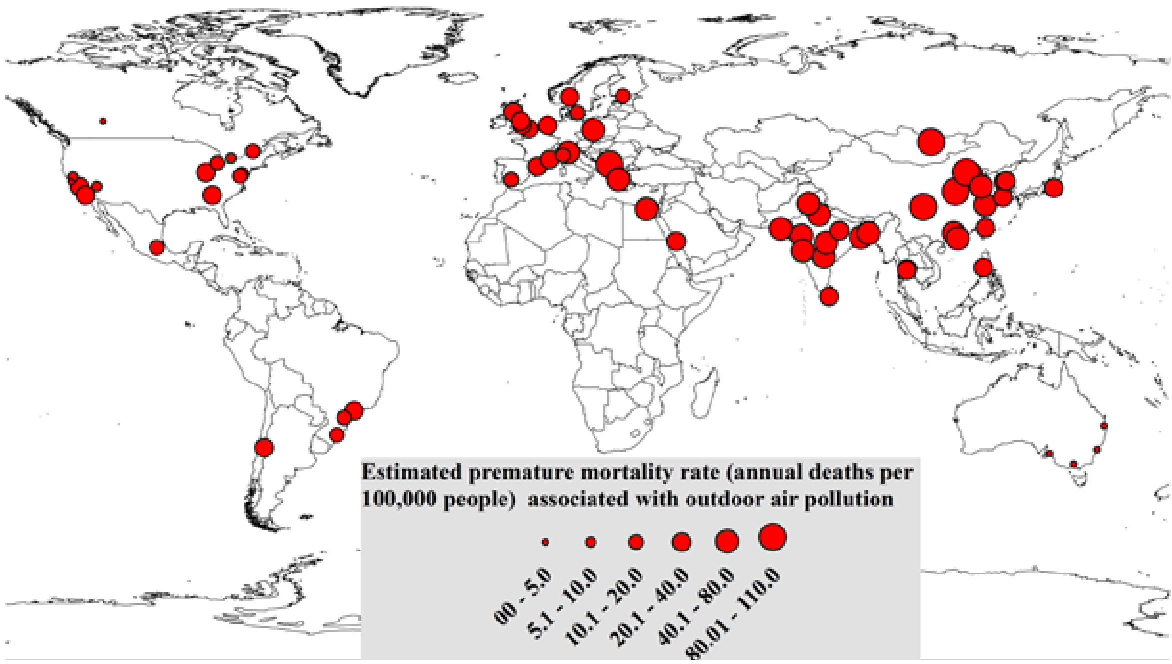
Source: UN-Habitat, 2016.

Cities are engines of global innovation and economic activity. While the high concentration of people, in proximity to industrial and commercial activities in cities, helps enable innovation (Bettencourt, 2013), it has also historically impacted the environment negatively through soil, water and air pollution. Sanitation, sewerage and waste management infrastructures have evolved and become effective in addressing pollution in many world cities. For example, the cholera outbreak in London led to the first water supply and sewage treatment systems (Angelakis, 2015), yielding vast improvements in human and environmental health in many world cities. **However, the global challenge of air pollution in cities remains, and suggests that end-of-pipe pollution control alone is not sufficient to comprehensively address complex environmental pollution challenges.**

Air pollution by particulate matter (PM) has emerged as one of the primary risk factors affecting human health in the 21st century (Institute for Health Metrics and Evaluation (IHME), 2016). The global burden of disease study identifies air pollution to be among the top ten risk factors for premature death in several nations of the world (IHME, 2016). In fact, indoor and outdoor air pollution in 2015 was associated with about 6.5 million premature deaths worldwide, with a vast majority occurring in cities. Annual premature deaths from air pollution are estimated at 99,000 in the United States, more than 283,000 in the European Union and over 4.6 million in Asia (IHME, 2016). Particulate matter of less than 2.5 micrometers is the dominant air pollutant linked to adverse health effects such as cardiovascular disease, respiratory diseases, diabetes and lung cancer (Lin et al., 2002). Among 74 world cities with reliable air quality data collated by the World Health Organization and with populations of over 400,000, only 9 cities report annual average PM concentrations of less than the 10 μg/m^3 World Health Organization (WHO) guideline. Average estimates of premature mortality rates from air pollution in these cities, assessed using the global burden of disease methodology (Burnett et al., 2014) in conjunction with air quality data, are staggering (see figure 4.2).

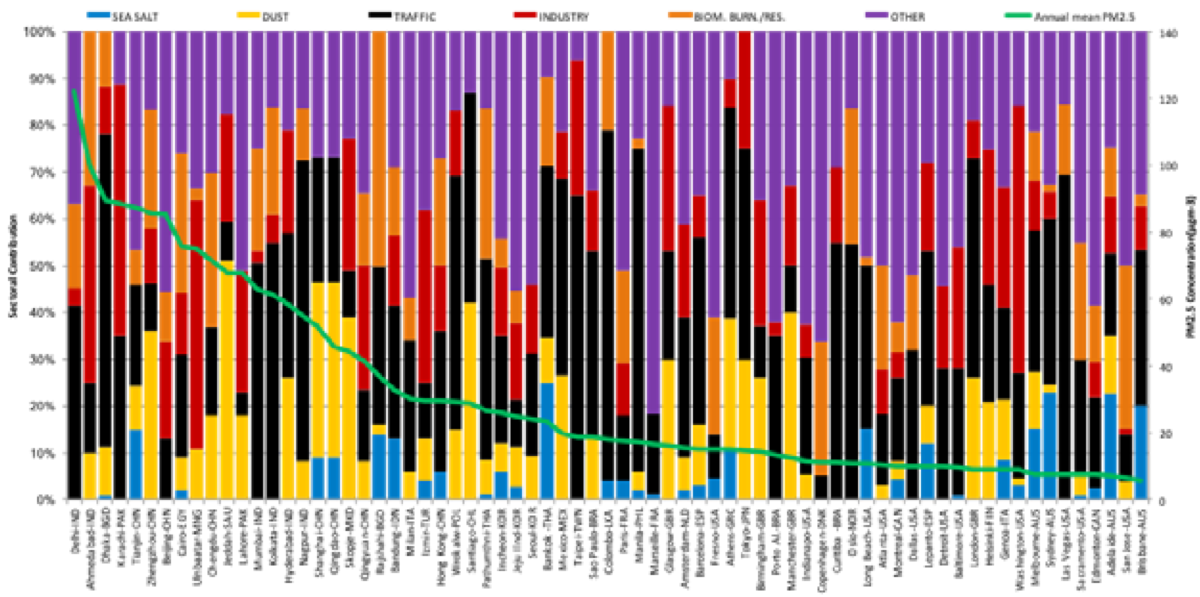
Despite the severity of health effects, controlling air pollution has proved to be challenging because it arises from multiple infrastructure sectors within the city boundary (transportation, industrial combustion, household cooking stoves, waste burning, construction and road dust) and outside city boundaries (agricultural burning, industrial emissions and natural sources) (see figure 4.3). Furthermore, PM2.5 concentrations in air are influenced in complex ways by local weather patterns and exacerbated by climate change, particularly extreme heat and drought events. The history of air pollution regulations in the United States over the past several decades (see box 4.2) illustrates that controlling large sources of pollution by end-of-pipe control has proven to be easier than controlling smaller ubiquitous sources such as household cook stoves, waste burning in streets and land management (dust, agriculture, forest and fires). Increasingly, fuel switching, waste management and land management are becoming important aspects for managing air pollution that complement pollution control, based on a combination of regulations, incentives, technology and business innovations (Sharma et al., 2016). **Therefore, a systems approach focused on resource use in seven key essential infrastructure and food supply sectors (see figure 4.4) can provide a strategic pathway to reduce air pollution while achieving broader SDG co-benefits.**

Figure 4.2 Average estimates of premature mortality rates from air pollution in world cities (premature deaths per 10,000 population): assessed by applying the global burden of disease methodology (Burnett et al., 2014) to city air quality data reported by the World Health Organization (WHO, 2016b)



Based on WHO Global Urban Ambient Air Pollution Database
http://www.who.int/phe/health_topics/outdoorair/databases/cities/en/

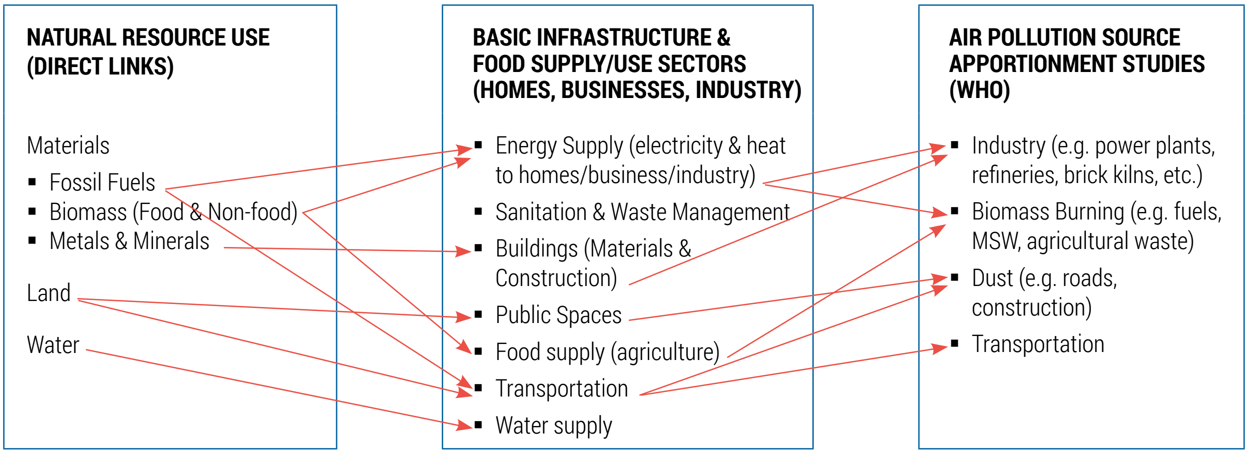
FIGURE 4.3 PM2.5 concentrations and sources as reported by the World Health Organization in world cities with population >400,000 people (WHO, 2016b)



Note: Concentrations greater than the WHO guideline of 10 µg/m3 (annual average) are seen in a majority of cities, across all development levels. Sources of pollution are also diverse in different cities, encompassing many infrastructure sectors.

1 2 3 4 5

FIGURE 4.4. Linking natural resource use with infrastructure and food supply/use sectors, and associated sources of air pollution emissions



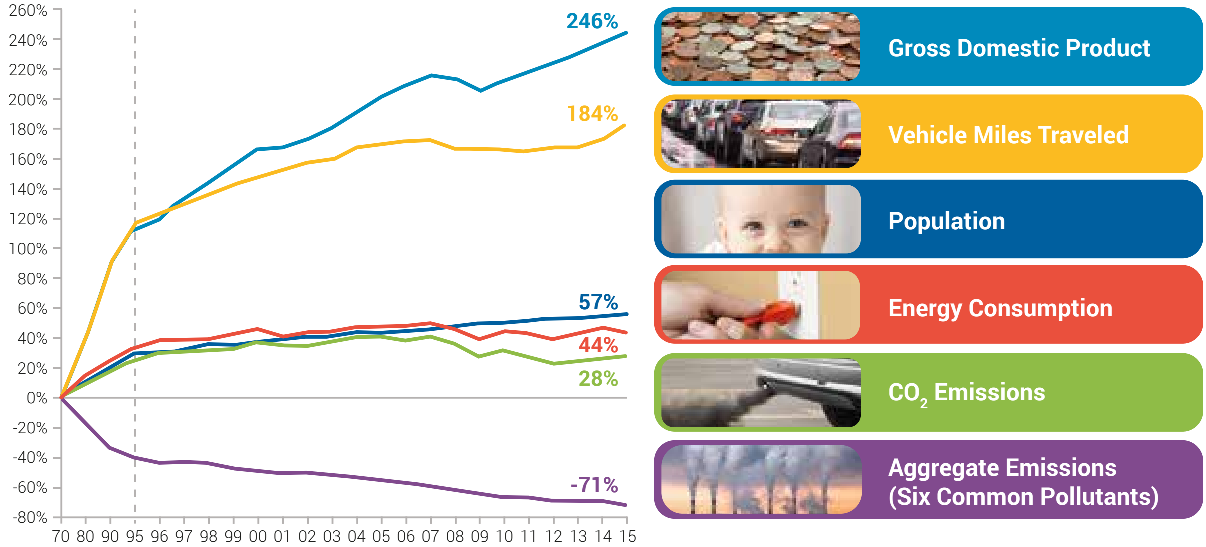
BOX 4.2. Emerging insights from air quality management in the United States: 1970-2016 – A need for a systems approach

The United States has seen significant improvements in air quality over the past 46 years. In particular, the Clean Air Act (1970, with significant amendments in 1977 and 1990) established National Ambient Air Quality Standards (NAAQS) and increased enforcement authority for controlling industrial point sources and motor vehicle emissions. While the Act provides flexibility in how to achieve lower emissions, much of the improvement has come through end-of-pipe pollution controls. These efforts resulted in substantial decoupling of emissions from continued growth in population and GDP (see figure 4.5), and substantial reductions in the absolute level of pollutant concentrations in ambient air. Most of the country's cities now meet annual air quality standards representing clean air overall, yet, some cities are still exceeding the national standards and the World Health Organization (WHO) guidelines, notably for PM2.5 and ozone (American Lung Association (ALA), 2017). For example, in the city of Los Angeles, the number of days of daily PM pollution exceedance has reduced ten fold from 120 days in 2001, to about 13 days in 2011 (Hayward, 2013), but achieving further reductions has proved to be challenging. Cities and states that are facing such pollution challenges are increasingly integrating end-of-pipe pollution control strategies with broader systems approaches (US EPA, 2017; National Research Council (NRC), 2004). For example, in Los Angeles, such systems efforts to achieve clean air now include managing and reducing travel demand, promoting electric vehicles and energy efficiency, along with land-use management plans (Barboza, 2016; Air Quality management District (AQMD), 2014; Clean Air Action Plan (CAAP), 2016; Metro, 2017). These experiences in the United States over the past 46 years yield several insights that can inform future air pollution mitigation efforts in developed and developing economies. Key insights are noted below:

- Controlling air pollution is challenging because multiple interacting resource sectors and infrastructure sectors shape pollution in cities, including land use (which shapes transportation networks, building intensity and green spaces); fuel types (such as biomass-based fuels, diesel and natural gas); and construction material choices (some more polluting than others).
- PM2.5 concentrations are influenced in complex ways by local conditions (meteorology and topography) and exacerbated by climate change, particularly extreme heat and drought events. Emission reductions do not result in proportional reductions in concentrations in all cities, and controls have varying effectiveness across space and time.
- While controlling pollution emissions from large industrial sources, power plants and vehicles can be accomplished more readily via end-of-pipe regulations, controlling ubiquitous smaller sources is a challenge. Approaches such as increased efficiency, fuel switching (to renewables or electric vehicles) and land-use and transit strategies to reduce motorized travel demand are being recognized as important, as they complement end-of-pipe control by addressing different aspects of the system. Future improvements will benefit from systems transformations to further address and improve air quality and human health conditions.
- Effective pollution control is dynamic, requiring continuous monitoring of air quality and a systems-based response strategy that integrates end-of-pipe control with systemic resource management strategies that address population, economy, lifestyles, wealth, industry, resource use, infrastructure and technology trends unique to each city. Such a systems approach can provide multiple SDG co-benefits.

Based on these insights, this chapter illustrates a systems approach that explores the linkage of multiple resources (land, fuels and biomass) and their interaction with multiple infrastructure and food supply sectors to provide air quality, climate (mitigation and adaptation) and other SDG co-benefits.

FIGURE 4.5 Decoupling of air pollution emissions in the United States, showing steady decreases in emissions since 1970 when the Clean Air Act was implemented, even as economy and populations continue to grow. Reductions in pollution concentrations in air are more variable



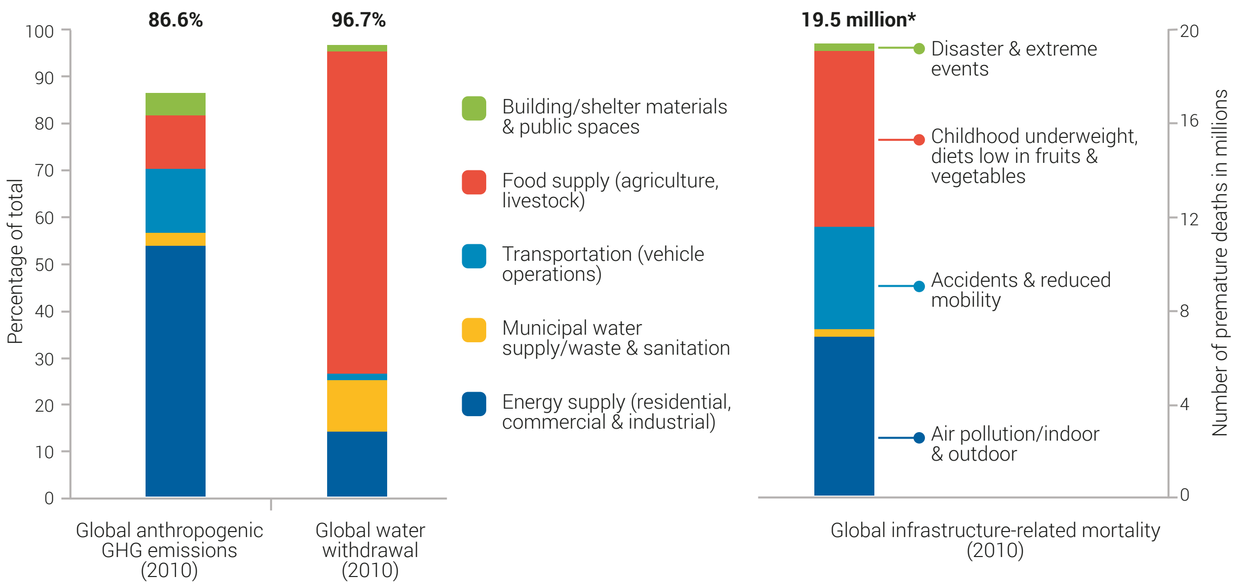
Source: ALA, 2017.

4.3 The importance of infrastructure and food supply systems to SDGs

The provisioning of infrastructure and food supply profoundly shape human health and well-being, as they are associated with about 19.5 million premature deaths annually worldwide, including air pollution-related health effects accounting for about 6.5 million deaths in 2010 (Ramaswami et al., 2016; see figure 4.6). Globally, traffic accidents related to transportation infrastructure and sedentary lifestyles contributed to about 4.4 million deaths worldwide, while a combination of undernourishment, and poor diets contribute to 7.6 million lives lost prematurely each year (WHO, 2013; Lim et al., 2012; Institute for Health Metrics and Evaluation (IHME) 2016). Poor water and sanitation infrastructures accounted for approximately 337,00 premature deaths annually (Lim et al., 2012). Those numbers are for 2010, while updated figures are provided by IHME (2016).

These global health risk factors are often exacerbated and/or concentrated in cities. For example, the majority of ambient air-pollution related mortality occurs in cities (WHO, 2016a). Furthermore, inadequate infrastructure in informal settlements in many world cities results in about 1 billion people today (and 2 to 3 billion projected in 2050) not having basic access to water, energy, food, sanitation and adequate housing (affecting SDGs 6, 7, and 11). This places them at risk for hunger and poverty (SDGs 1 and 2). Lack of access to convenient and affordable transportation impacts urban livelihoods, and is an integral part of SDG 11. Exposure to water- and climate-related risk factors can also take a toll on people and the economy of cities, as seen during recent storms and flooding events in New York City, Mumbai and Bangkok. Lastly, the distribution, provision and consumption of infrastructure in cities, and exposure to infrastructure- and pollution-related risks, are unequal within (and between) cities, thereby impacting equitable and inclusive development (SDG 10). The gender dimensions of these inequalities are particularly striking (UN, 2010) – including exacerbated loss of economic opportunity for women without access to basic services, and proportionately higher exposure of women and children to health risks from poor sanitation and waste management, and increased exposure to indoor air pollution from cook stoves (National Institute of Health, united States (NIH), 2017; Smith, 2000). **Essential infrastructure and food supply sectors are therefore intricately connected to diverse human health impacts, including access to clean water and energy (SDGs 6 and 7) and pollution-related health impacts on well-being (SDG3). They also contribute to multiple dimensions of inequality in cities (SDG 10 and 3), and this is relevant to the goal of inclusive urban development (SDG 11).**

FIGURE 4.6 Impacts of key urban infrastructure sectors and food supply on global anthropogenic greenhouse gas emissions, global water withdrawals and the global disease burden



Source: Ramaswami et al., 2016.

Infrastructure and food supply sectors are also impacting global material, energy, carbon and nutrient cycles to an unprecedented degree. Figure 4.6 shows that these sectors are responsible for almost all the world's water extraction, material extractions, global energy use and greenhouse gas emissions. For example, when imports of electricity and other fuels are included, urban areas are estimated to account for over 70 per cent of global energy use and greenhouse gas emissions (Seto et al., 2012). In terms of direct land impacts, although urban areas presently occupy only around 3 per cent of land, urban land expansion in most world regions is growing dramatically at rates that exceed urban population growth (Seto et al., 2011). Such expansion is displacing agricultural lands, which in turn displaces forested land (UNEP, 2014a). This results in significant loss of biodiversity worldwide (Seto et al., 2012; D'Amour et al, 2016).

Furthermore, the supply chains that provide cities with essential infrastructural services – water, energy, buildings, transportation, sanitation-waste management and food supply – extend well beyond the city boundary (drawing resources, generating associated pollution and impacting biodiversity in the regions of supply). For example, as seen in the case study of Delhi, industries that support demand for Delhi's construction materials are large sources of regional air pollution. Likewise, water drawn to support Delhi's municipal water and food needs is a heavy drain on the already water-stressed Northern Gangetic Plain. In fact, the indirect (transboundary) impact of urban areas on natural resources (like land and water) is often much larger than the direct use of resources within cities – often by a factor of 2 to 3 (Ramaswami et al., 2008; Kennedy et al., 2009; Chavez and Ramaswami, 2013). **Urban resource demand therefore essentially shapes global resource demand, and it is essential to examine the transboundary impact of cities on natural resources and environmental pollution through footprint approaches if we are to address the global sustainable development goals and promote sustainable consumption-production (SDG 12).**

4.4 The opportunity of urban transformations

Given that infrastructure and food supply systems, collectively, place tremendous pressure on the global natural resource base, pollution and human well-being (figure 4.6), transforming these systems offers an opportunity to achieve multiple SDG co-benefits. Urban areas today are on the cusp of catalysing such future transformations.

Around 60 per cent of the urban area required to accommodate the urban population by 2050 is yet to be built and, once built, it will last for the next 40 years. This provides a historic opportunity and an imperative to build 'better' infrastructure from the outset (UNEP, 2013a). At the same time, existing cities in advanced economies are repairing or replacing aging infrastructures. Several infrastructure innovations are on the horizon in developed and developing cities, including new strategies for shared mobility, in-situ slum rehabilitation, a One-Water approach[44] to urban water management, urban-industrial symbiosis, electric and autonomous vehicles and distributed solar energy to achieve a decarbonized grid. Cities around the world are engaging in experimentation around infrastructure – involving technology, human behaviours, financing and novel governance arrangements.

The interactions among the infrastructure sectors, and between infrastructures, natural systems and social systems impact almost all 17 SDGs. However, the relationship between resource use in the multiple sectors and the various well-being outcomes is complicated by nexus challenges. **This chapter highlights the resource-infrastructure-health nexus, representing the linkages between resource use, infrastructure provisioning, environmental pollution and human well-being impacts. Quantifying such linkages through systems-based methods is essential for systematically assessing co-benefits and trade offs among multiple SDGs, as well as to evaluate pathways and scenarios toward a more sustainable future.** The systems approach utilizes trans-boundary, life cycle-based footprint analysis to quantify the multiple natural resources used in basic infrastructure and food supply to cities, and connects these to inequality measures and pollution/health impacts that are at the heart of the SDGs. The impacts of potential future infrastructure transformation pathways are then evaluated in terms of their effects on multiple natural resources, pollution and measures for human well-being (including health and inequalities). The case studies in this chapter apply this systems approach to highlight resource-efficient urban infrastructure transformations that can co-beneficially address the air pollution challenge and achieve multiple SDGs in cities.

City case studies: The first case study presents the linkage between multiple natural resources, infrastructure, inclusive development, air pollution and health - focusing on these processes and associated metrics in a single city: Delhi, India, which is a fast-growing city in the developing world facing infrastructure challenges. The second case study demonstrates the collective role that all 637 cities in China can play, through urban-industrial symbiosis and resource efficiency strategies, in achieving national greenhouse gas emission mitigation targets while also providing local air pollution and health benefits (along with significant natural resource and monetary savings).

44 A One Water approach is an integrated planning and implementation approach for water resource management considering water treatment and supply, wastewater treatment and stormwater management holistically to meet community and ecosystem needs (Water Research Foundation (WRF), 2017).

4.5 Case Study: Air pollution and SDG co-benefits of developing resource-efficient and inclusive cities (Delhi, India)

Purpose of the case study

Delhi is typical of many megacities in Asia and Africa with large populations, rapid economic growth that spurs in-migration and significant underserved populations lacking access to basic services. The combination of rapid development and inadequate infrastructure to keep up with such growth places pressures on the built environment and the natural environment in terms of air pollution, water quality degradation, ground water depletion and human well-being (thereby impacting almost all the SDGs). In response, new urban design strategies, infrastructure transformations and policy innovations focused on social inclusivity and the environment that have potential to advance multiple SDGs are emerging in many Indian cities.

The DISPR framework can be used to evaluate the impact of inclusive and resource-efficient development in cities such as Delhi, including on air pollution and Delhi multiple SDGs (figure 1.4).

FIGURE 4.7 The developing city of Delhi - drivers of future resource use and related SDGs

10% in poverty

25% & 43% lack access to tap water and sewerage

4%, 1% & 10% lack access to permanent housing, electricity and clean cooking fuels

6% of surveyed homes report diarrheal disease (Desai and Vanneman 2015), 2500 premature deaths are estimated from dirty cooking fuels (Ramaswami et al 2017)

1. DRIVERS

Census data showed Delhi's population (in 2011) to be 17 million people - growing at 2.4 per cent annually in the past decade, and a largely service-dominated economy growing at ~12 per cent per year. Similar to many world cities, infrastructure development does not occur fast enough to cope with the pace of growth, resulting in significant inequality in access to basic infrastructure. In Delhi, 4 per cent of the population does not have permanent housing, while 25 per cent lack access to treated tap water, 43 per cent have no access to sewerage and 10 per cent lack access to clean cooking fuels. These figures are highly relevant to several SDGs (1, 3, 6, 7, and 10).

To provide perspective, 30 per cent of the urban population in Asian cities live in slums, while this number is estimated at 60 per cent in African cities (UN-Habitat, 2016). Therefore, the situation in Delhi is commonplace for a developing city where infrastructure is inadequate, creating a demand for more and better infrastructure and with it, increasing demand for resources).

2. PRESSURES, STATE AND IMPACTS

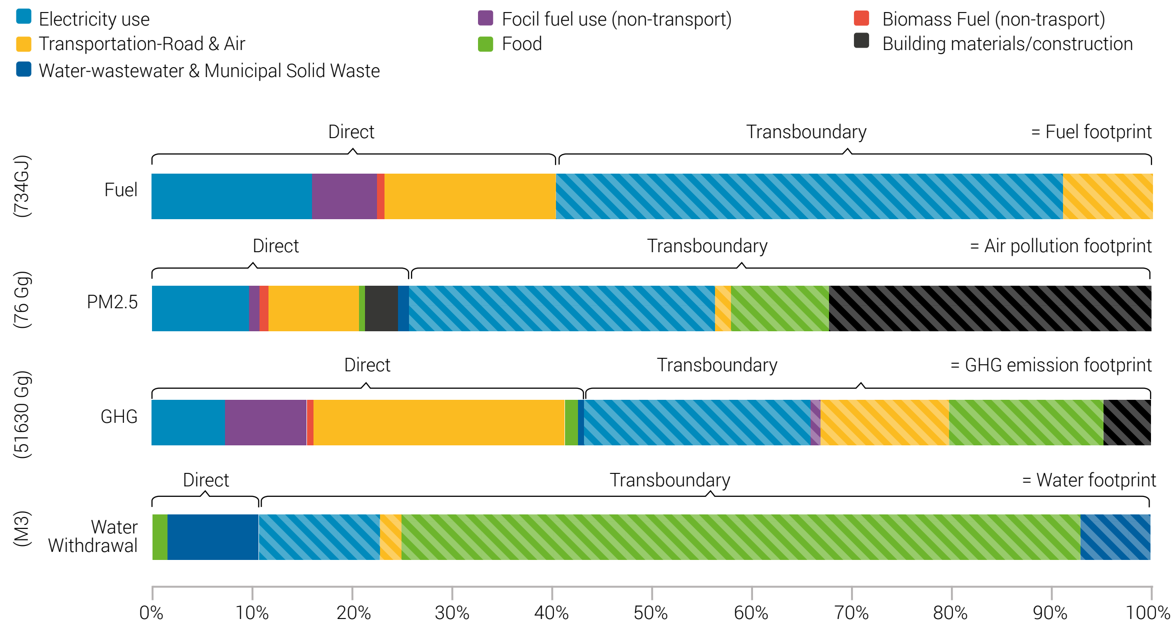
The above drivers place large pressures on the natural resource base, the environment and on human life experience.

Footprints

The natural resource use and the environmental pollution impacts of infrastructure and food provisioning to Delhi are quantified by trans-boundary footprints that represent both direct resource-use (fuel and water), greenhouse gas emissions and air pollution emissions within the city boundary, as well as transboundary impacts from supply chains serving cities. For example, the energy use and greenhouse gas emission footprints of community-wide infrastructure and food provisioning to homes, businesses and industry results in 51,000 Gg of CO_2e, of which only half is emitted within the city boundary. **Given the global reach of greenhouse gas emissions and the transboundary nature of supply chains, the in-boundary plus transboundary footprint approach better captures the larger impact of cities on the planet (beyond their local impact).** The overall greenhouse gas emissions footprint of community-wide infrastructure and food provisioning in Delhi is dominated by transportation (38 per cent), electricity supply (30 per cent), food supply (16 per cent) and cooking and other fuels (diesel, kerosene, diesel used in power generation ~9 per cent), followed by emissions from producing infrastructure construction materials (cement, bricks and steel) of 5 per cent.

Special feature

FIGURE 4.8 Resource use (water and fossil fuels) footprints and air pollution and greenhouse gas emission footprints of infrastructure provision and food supply in Delhi, India



Data from Ramaswami et al., 2017a; Nagpure et al., 2017a.

BOX 4.3 Assessing infrastructure linkages with air pollution — greenhouse gas emissions and health co-benefits

Waste burning

Source: Ajay Nagpure (personal photo)

Focusing on direct PM2.5 emissions sectors within the city boundary, transportation, industrial powerplant energy use, construction dust, residential energy use (dirty cooking fuels) and garbage burning are main contributors to PM2.5 emissions (Amman et al., 2017). In recent years, garbage burning in cities has been identified as a major source of PM2.5 emissions globally (Wiedinmyer et al., 2014); studies in Indian cities show 5 per cent and up to 25 per cent of garbage being burned in different Indian cities (Nagpure et al., 2015).

Transboundary PM2.5 emissions: In addition to the in-boundary sources, many of the supply chains that serve Delhi are in close proximity to the city. Examples include brick kilns and agricultural burning in near proximity to Delhi, which are both found to contribute to pollution in Delhi. Consequently, brick manufacturing (construction materials) and agricultural crop-residue burning outside the city have also now become the focus of transboundary air quality management efforts in the region (Guttikunda and Calori, 2013; Bhattacharya, 2016; Amman et al., 2017). These same sectors contribute to significant energy use and GHG pollution emissions as seen in the GHG emissions footprint, thus enabling assessment of co-beneficial reduction in emission of both pollutants from specific infrastructure changes.

Connecting PM2.5 emissions with airborne pollutant concentrations and human health risk assessment: The air pollution emission footprint can then be mapped out by specific area and linked with environmental transport and fate/exposure models to reveal health impacts at various locations in cities, computed using methods consistent with the WHO'S global burden of disease study. This provides a systematic approach to assess the linkages between infrastructure changes and their carbon-PM2.5 pollution and health co-benefits, recently demonstrated in Chinese cities (Ramaswami et al., 2017b). Such a modelling approach advances the emerging co-benefits methods that are typically implemented at larger national or regional scales to uniquely capture the co-benefits and cross-sector interactions at the city scale. Such methods provide location-specific information needed by cities about the trade offs, co-benefits and SDG linkages that may arise from different infrastructure designs and policies.

Using multiple footprints of infrastructure provision to assess SDG linkages

Figure 4.8 illustrates the footprints for natural resources-use (water and fossil fuels) and for air pollution and greenhouse gas emission, which are closely related to infrastructure provision and food supply in Delhi, India, distinguishing in-boundary from transboundary contributions). Nexus issues, such as the greenhouse gas-air pollution nexus, food-water-energy nexus and multiple SDG linkages, can be quantitatively addressed through these footprints. For example, policies that reduce vehicle miles driven will reduce greenhouse gas emissions and PM2.5 emissions as a result of lower fuel use, as well as reducing PM2.5 from road dust. All three are calculated from the linked greenhouse gas emissions and PM2.5 footprints shown (showing that they are connected through their association with all the seven infrastructure and food supply sectors). The application of footprints to address the greenhouse gas-air pollution-health nexus is highlighted in box 4.3. Figure 4.7 and box 4.3 assess potential SDG linkages to be considered by implementing policy responses to achieve SDGs.

3. RESPONSES

Sustainable Development Goals 11 (Developing Sustainable Cities) highlights the importance of inclusive and resource-efficient cities. Cities in India and worldwide have responded to their sustainability and air pollution challenges by experimenting and innovating with diverse policies. This report applies a coherent bundle of strategies drawn from case studies and policies already emerging in Indian cities, building upon the base set of resource efficiency strategies highlighted in UNEP, 2017b. The policy bundle (see table 4.1) identifies a set of strategies to achieve inclusive and resource efficient urbanization that can bring benefits in terms of greenhouse gas and air pollution mitigation in exchange for modest additional resource requirements. Table 4.1 highlights the basic natural resource focus of these strategies, and their linkages to different infrastructure sectors.

TABLE 4.1 Policy strategies toward inclusive and resource-efficient cities

RESOURCE FOCUS	STRATEGY
LAND USE INTENSIFICATION	Strategic urban land use and infrastructure planning to reduce travel demand. Focuses on the 5Ds of: **d**ensity, **d**iversity (mixed land uses), **d**istance to transit, multimodal street **d**esign and **d**estination access (to jobs)
	Investments in efficient transit systems to reduce vehicular emissions and congestion
RESOURCES FOR THE UNDER-SERVED	Inclusive development and in situ slum rehabilitation in multi-storey buildings within denser city cores that provide essential services and access to livelihoods with reduced travel burden on the poor
RESOURCE EFFICIENCY FOR ALL	Promoting multi-storey resource-efficient building construction and energy-efficient buildings for all
	Using culturally sensitive behavioural nudges to reduce resource use
RESOURCE SUBSTITUTION	Phasing out dirty cooking fuels and construction materials with high embodied fuel and PM2.5 emissions
RENEWABLE ENERGY	Electricity grid transformations with higher levels of renewable energy
WASTE MANAGEMENT	Creating business innovations to reduce agricultural burning outside cities and waste burning within cities, both of which significantly contribute to PM2.5 emissions that cause air pollution and to GHG emissions.

Assessing SDG linkages and co-benefits

A systems approach is applied to assess the multiple SDG co-benefits arising from each of the strategies, using the following mechanisms.

A compact urban form can reduce motorized travel distances by as much as 40 per cent, as suggested from case studies comparing a compact city (Ahmedabad) with other similarly wealthy but more sprawling Indian cities (Hyderabad & Bangalore) (Munshi, 2012). Provision of transit (such as the metro rail in Delhi) can further create a mode shift, displacing about 10 per cent of Delhi's private motorized trips in the first year of operation. About 30 per cent personal motorized trips are expected to be displaced at the build-out stage.

Against the backdrop of a compact urban form, in situ slum rehabilitation in multi-storey buildings (>5 storeys)

provides good housing and basic services (water, sewerage and electricity) for underserved populations within the city core, thereby enhancing well-being and providing access to livelihoods without an added burden of transportation (UNEP, 2017b). Indeed, almost 40 per cent of trips to work in Indian cities are by walking or cycling (DowntoEarth, 2011), which could be preserved with a successful integration of economically weaker sections in the city core.

There is considerable inequality in infrastructure provisioning in cities. Because the underserved consume so little compared to the wealthiest high-consuming groups, industry and businesses, providing basic services for the underserved results in very small (<10 per cent) increases in citywide resource flows in Delhi (Nagpure et al, 2017b).

The added resource needs of providing basic services to the underserved can readily be countered by modest behavioural nudges and energy-efficiency strategies aimed at high consumers, such as those already being evaluated in Delhi's Solar City Plan (Ministry of New and Renewable Energy, India (MNRE), 2016).

Material and resource efficient designs for multi-storey buildings in India's hotter climate have been field tested and show that basic energy services can be provided with a comfortable living environment, consuming less than 25 kWh/person/month. Locally produced, low-polluting construction materials that use waste materials and generate lower PM2.5 emissions have also been field tested (World Bank, 2011).

Resource switching, particularly from current use of dirty cooking fuels to clean burning gas is estimated to reduce 2,500 premature deaths annually (Nagpure and Ramaswami, 2017c). A majority of these avoided deaths are likely to be women and children, who are disproportionately exposed to indoor air pollution from cooking fuels (Smith, 2000).

When applied together, these strategies are estimated to improve well-being for about 7 million underserved homes in Delhi, with only a modest increase (<10 per cent) in Delhi's current communitywide material-energy demand, along with a 22 to 25 per cent reduction in communitywide GHG and PM2.5 emissions (Nagpure et al., 2017b; Ramaswami et al., 2017a). The reduced PM2.5 emissions result in significant health benefits, estimated to prevent 2,500 premature deaths annually. **This case study indicates a significant improvement in human well-being, with a relatively small investment in resources (thereby exemplifying the concept of decoupling).**

Delhi's Metro Rail

Source: PTI 2015

Slum-rehabilitation in Delhi

Source: Haidar, 2017

Delhi's solar plan to provide energy access

Source: PTI 2016

Compressed stabilized earth blocks

Source: World Bank 2011

Policy learnings for inclusive infrastructure in cities

India has recently initiated several successful pilots projects to upgrade basic services in cities, particularly in situ slum rehabilitation programmes in many cities, such as Ahmedabad, where slum dwellers are rehabilitated in new multi-storey constructions within the city core, thereby reducing the travel burden for improved access to jobs/livelihoods within the city (UNEP, 2017; Society for Excellence in Habitat Development, Environment Protection and Employment Generation (India) (SHEE), n.d.).

BOX 4.4 Towards in situ slum rehabilitation and resource-efficient construction with low-polluting materials

Key enabling factors:

- Partnerships between government, builders and slum dwellers
- Incentives for builders to finance slum upgrades, along with active participation of slum dwellers. Rehabilitation plans require consent of >70 per cent of slum dwellers
- Multi-storey construction enables rehabilitation in the city core and reduces material use by 36 per cent (UNEP, 2017b)
- Construction with alternative building materials and technologies such as 'green bricks' reduces air pollution emissions from manufacturing bricks (World Bank, 2011)
- Fly ash and steel slag cements reuse industrial waste, thereby saving energy and virgin materials
- Consider manufactured sand, lightweight concrete and other materials to combat sand scarcity.

Source: UNEP, 2017b; SHEE n.d.

Policy learning on air pollution

Delhi and other cities in Asia have explored numerous strategies to reduce air pollution, as shown in the inset for the transportation sector. The main lesson is that, while fuel switching and end-of-pipe control solutions are important and have temporarily reduced air pollution in the past, these strategies alone cannot address the overwhelming pace of urbanization. Eventually, a transformation of urban form for reduced travel demand, transit investment, co-location/mixed use development and efforts to retain the walkability and bike-ability of cities will be essential if we are to combat air pollution. Better waste management, provision of clean cooking fuels and industrial emission controls will also prove vital. Such strategic land use and transit polices have the potential to reduce energy use, GHG emissions and PM2.5emissions (UNEP, 2017b), as illustrated in Delhi and other Indian cities.

A second important lesson is that policies in individual cities are insufficient to address the challenge of air pollution – given the wind-blown transport of pollution into and out of cities, as well as the transboundary pollution stimulated by urban demand for infrastructure and other goods and services (see figure 4.3). A recent high-level commission on air pollution in India (Sharma et al., 2016) stressed the role of cross-sector and multi-level governance to address this challenge, including actions that address agricultural crop burning and brick kilns.

BOX 4.5 Strategies to reduce air pollution in Delhi

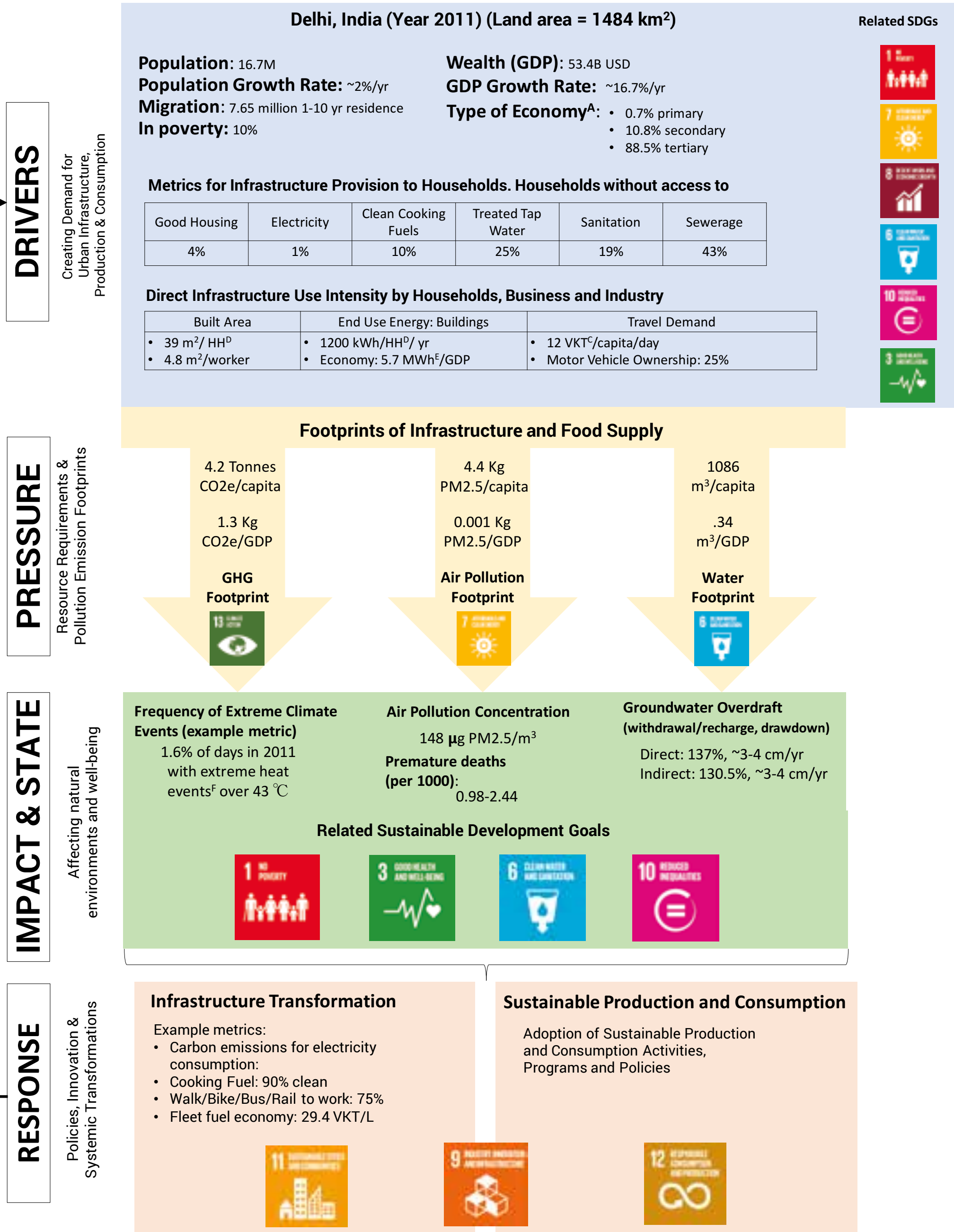
- Fuel switching: In 1985, Delhi issued a Supreme Court order for all diesel buses and commercial vehicles to switch to cleaner-burning natural gas fuels.
- In 2017, all vehicles are required to adhere to EU's Euro 4 emissions standards; diesel-burning trucks are not allowed in the city boundary in the day.
- India's Green Tribunal banned waste burning in 2015, recognizing that it contributes to air pollution.
- During extreme air pollution episodes, odd-even day license plate policies were introduced in 2016 to reduce travel congestion.
- Increasingly, urban land use and transit planning is recognized as the main solution to address the root cause of air pollution: excessive automobile dependence. The key strategies include: (a) higher density development around transit nodes, diversity of travel modes, street designs for mixed use and walkability and (b) a more compact urban form promotes transit, while well-designed transit promotes more compact development (thereby initiating a virtuous cycle).
- Such strategies can reduce not only transportation demand, but also a building's energy use by a factor of 2 to 4 (UNEP, 2017b), thereby contributing to resource efficiency, air pollution reductions and GHG mitigation.
- In 2010, Delhi invested in developing the Metro rail and experimented with Bus Rapid Transit Systems to reduce energy use and air pollution. It is expected to offer longer term land-use intensification benefits in addition to trip reductions in the short term.
- Delhi's experience offers insights to other cities – that a comprehensive resource-focused approach to address land, biomass and fuel in multiple infrastructure sectors is essential for tackling the air pollution challenge.

Metrics to track progress

As cities embark on infrastructure transitions to achieve multiple SDGs, tracking progress through the metrics illustrated in the DPSIR framework becomes important to ensure that progress is being made. Figure 4.9 provides a set of metrics that cities can track to indicate their relationship with each of the SDGs. The examples of metrics shown here for Delhi can be replicated for various world cities, on the basis of individualized information to assess SDG co-benefits and trade offs using location-specific information. Metrics such as those shown in figure 4.9 will be an important part of multi-level and cross-sector policymaking.

Special feature

FIGURE 4.9 Drivers, pressures, impact, state and response framework related to the SDGs for Delhi



^A Primary is primary extraction, Secondary is industrial manufacturing, and Tertiary is commercial services
^B TBD: To be determined upon data availability
^C VKT: Vehicle Kilometers Traveled
^D HH: Households
^E MWH: Megawatt hours
^F Extreme heat events over 43 C° are based on temperature thresholds for Ahmedabad due to limited data availability for Delhi.

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Note that the examples are not exhaustive, and other drivers, pressures, states, impacts, and responses could be included in future assessments

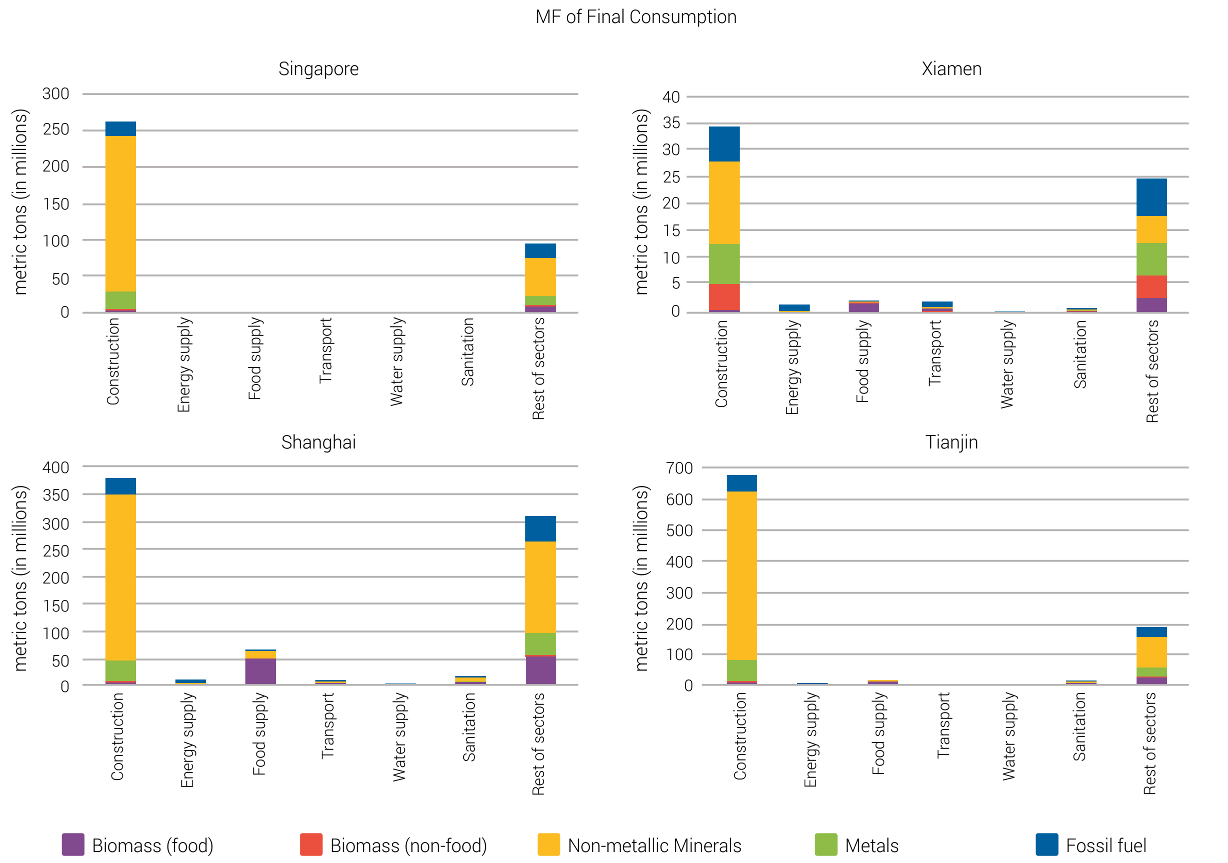
4.6 Case Study: Greenhouse gas, air pollution and health co-benefits of circular economy and urban-industrial symbiosis in Chinese cities

Purpose of case study

This case study applies a resource-based systems approach to demonstrate the potential economic savings, energy savings, resource-savings, GHG and PM emission reductions and air quality improvements and associated health co-benefits that may be achieved by implementing circular economy strategies in all 637 cities in China (Ramaswami et al., 2017c). The goal is to quantify the potential co-benefits of implementing resource-efficient urban planning (including urban-industrial symbiosis strategies) in all 637 Chinese cities, with a view to achieving national GHG mitigation targets while providing local air pollution and health benefits. A database with baseline energy use and air pollution emissions data for of all 637 cities in China consistent with national energy use is developed to achieve local-national scale energy supply-demand linkages (Ramaswami et al., 2017c).

The urban-industrial symbiosis strategies include: 1) the reutilization of industrial waste heat in urban district energy systems, and 2) beneficial reuse of waste materials, such as steel slag and fly ash in lieu of cement in the construction sector (which is a heavy user of materials in urban areas). Indeed, the material footprint of Asian cities (Singapore, Tianjin, Xiamen and Shanghai) shows the construction sector contributes more than 40 per cent of all material usage on a life cycle basis due to final consumption in cities (Hu and Ramaswami, 2017). Thus, reducing demand for construction materials can reduce the material footprint and reduce pollution associated with producing these materials.

FIGURE 4.10 Material footprint of final consumption for Shanghai, Singapore, Xiamen and Tianjin, illustrating the dominant role of the construction sector) in material use (out of the 7 key infrastructure and food provisioning sectors)



Source: Hu and Ramaswami, 2017 (in prep.).

Chinese cities are the focus of this case study because China is now the world's largest user of fossil fuels globally, and about 80 per cent of fossil fuel use in China occurs in the industry sector, creating a source of unused waste heat that can displace fossil fuel use in individual stoves and boilers in homes/businesses (which are difficult to regulate and are large contributors of PM pollution) (Liu et al., 2016). Furthermore, low-grade waste heat is not readily reused in industries, but can be cost effectively used to heat/cool buildings using new technologies (known as 4th generation district energy systems) (Lund et al., 2014). Thus, district energy systems – which are cost-effective in higher density areas in cities - provide an ideal sink for using ubiquitous waste heat generated in industries, while offering a cost-positive strategy to achieve monetary savings and environmental/health co-benefits. Indeed, the United Nations has identified district energy as one key strategy to significantly and cost effectively reduce energy use in cities; district energy systems that reuse industrial waste heat are almost zero-energy systems. Lastly, material substitutions – particularly in the infrastructure construction sector – are also significant opportunities to reduce mineral and metal resource use because cities have high levels of construction activity and large material footprints. The case study therefore illustrates how multiple strategies (such as denser high-rise building construction requiring fewer land resources) supported by district energy systems capable of reusing waste heat and construction sectors that reuse materials can combine to provide multiple economic, natural resource, environmental, and human health co-benefits.

Relevance

The cross-sectoral urban-industrial symbiosis and circular economy strategies explored in this case study are relevant to Chinese cities, and to future urbanization in Asia and Africa where industrialization and urbanization are expected to co-occur. As new cities are developed and planned, infrastructure design for high-rise buildings with shared heating-cooling systems that utilize waste heat, and circular economy polices that promote beneficial exchange and reuse of materials, can be powerful tools that provide multiple co-benefits. Given that multiple sectors contribute to air pollution and that pollution prevention is better than control, such **circular economy strategies that reduce resource use in the first place can be an important part of arsenal in the mix of strategies needed to improve air quality in global cities**.

Study details

The study was conducted as a collaboration among United States and Chinese scholars (details are in Ramaswami et al., 2017c). The study modelled energy use in different sectors (residential, commercial, and industrial) in more than 630 Chinese cities in the 2010 baseline year, using a mix of bottom-up and top-down data consistent with China's national and provincial energy use information, and drawing upon an air pollution emission database provided by Tsinghua University. A 'What-If' scenario model compared the impact of single sector efficiencies (such as improvements in buildings, industries and power plants) as noted in China's five-year plan, with the novel cross-sectoral urban-industrial symbiosis strategies described above. Co-benefits assessed included: energy savings, materials savings, reduction in GHG and PM emissions, reduction in PM concentrations in air and the resulting health co-benefits in the 637 cities. Several circular economy strategies were evaluated involving the utilization of industrial waste heat of different grades (high-grade, medium-grade, and low-grade) in various reuse applications including electricity generation (of high-grade heat), reusing medium-grade heat in conventional district energy systems using steam and hot water and using low-grade heat in advanced 4th generation district energy systems that circulate lower temperature water. Key strategic material exchanges were modelled, such as the reutilization of fly ash and steel slag to displace cement (beyond current reuse levels). Air pollution models evaluated PM2.5 pollution concentrations in air considering the meteorological conditions. Health risk assessments were conducted using methods consistent with those used in the global burden of disease study (Burnett et al., 2014).

Key results and insights

- **GHG mitigation potential**: Models indicate that the cross-sectoral urban industrial symbiosis strategies - enabled by compact urban design and circular economy policies -contributed between 15 per cent and 36 per cent to additional national CO_2 mitigation (compared with conventional single-sector strategies), thereby pointing to a new pathway toward de-carbonization in China and globally.

- **Air pollution and health co-benefits**: Co-beneficially across all cities, about 47,000 premature deaths (range 25,500-57,500) are estimated to be avoided annually through air pollution reductions from these strategies.

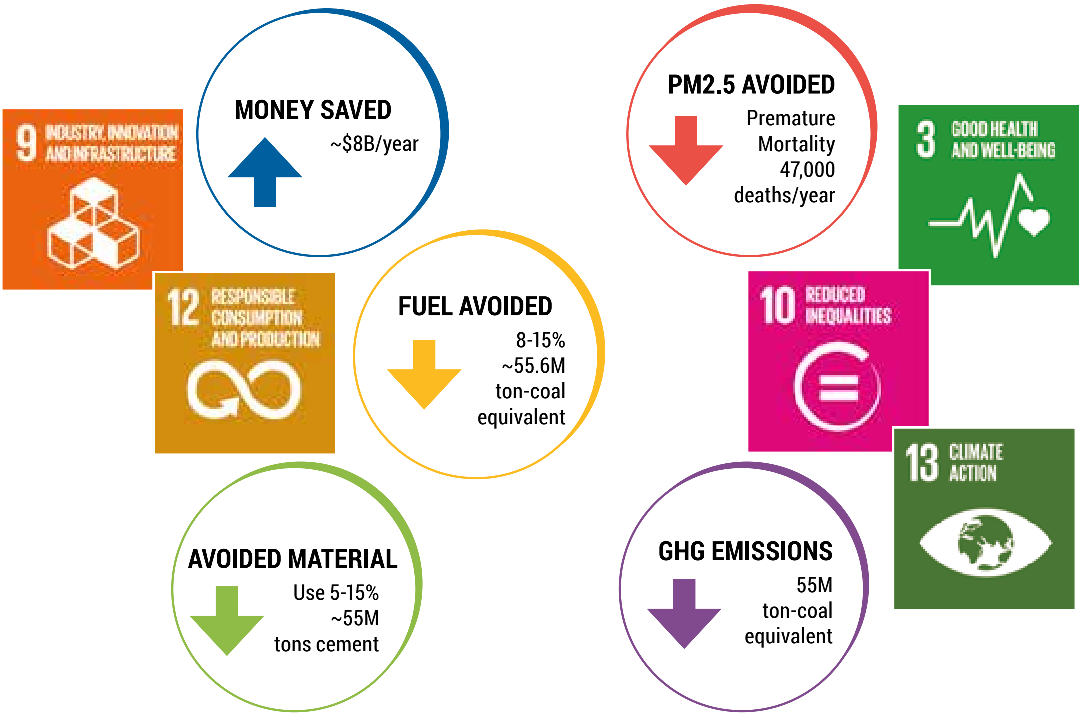
- **Individuality of each city**: GHG and health risk-reductions vary from (<1 per cent-37 per cent) and (<1 per cent-47 per cent), respectively, across individual cities. This shows the importance of detailed systems modeling incorporating the specific economic structure, industrial structure, household/buildings

characteristics, air pollution dispersion and population structure in individual cities.

- **Economic payback**: The circular economy strategies are cost effective, with payback periods estimated between 1 and 4 years for district heating systems that reuse waste heat in China. (Tong et al., 2017).

A whole systems approach that connects resources with infrastructure, new technologies and circular economy policies, can clearly play a significant role in providing cost-effective solutions to the air pollution challenge. In particular, this case study demonstrates modelling of the collective impact of applying circular economy strategies in cities on national sustainability GHG targets, while also demonstrating local health co-benefits customized to each city's situation. The distribution of carbon mitigation and health risk benefits across the modelled cities is shown in figure 4.12. It presents methodological advances in health co-benefits assessment, as well as a multi-scale trans-boundary modelling approach with city data in accordance with national energy use statistics.

FIGURE 4.11 Environment, human well-being and economic co-benefits estimated across all 637 Chinese cities in a resource efficiency and symbiosis scenario compared to the year 2010 baseline



Source: Ramaswami et al., 2017c.

FIGURE 4.12 Potential reutilization of industrial waste heat in urban district energy systems and reuse of waste materials in mainland China results in co-benefit reductions in air-pollution related premature mortality and GHG emissions (data and figure from models in Ramaswami et al., 2017c)

a. Direct CO_2 reduction (million metric tonne) across 637 cities in mainland China grouped in What-If FYP-Efficiency-plus-Symbiosis scenario vs Base-Case (urban total=741 million metric tonnes)

b. Premature death avoided (person) across 637 cities in mainland China grouped in What-If FYP-Efficiency-plus-Symbiosis scenario vs Base-Case (urban total=47,230 persons)

Source: Ramaswami et al., 2017c.

Policy enablers

Circular economy policies in China have enacted urban planning guidelines to promote energy and material use efficiency in cities by encouraging increased reuse of materials and energy in pilot cities (State Council of the People's Republic of China (PRC), 2013). Using industrial waste heat in the residential sector has also been highlighted by the Chinese Government in its 13th five-year plan period (2016-2020) to further reduce energy use in cities and improve air quality (People's Republic of China (PRC), 2013; IEA, 2016). Moreover, national policies have set industrial waste heat utilization targets in district heating systems, including replacing 50 million tons of raw coal through utilization of low-grade waste heat for supporting a 2 billion m^2 heating area (National Development and Reform Commission, China (NDRC) and Ministry of Housing and Urban-Rural Development, China (MOHURD), 2015). Financing strategies also support the implementation of district energy systems in China. Currently, the capital cost of district energy systems as public infrastructure in China is mainly funded through governmental fiscal revenue, investment from state-owned companies and bonds (Wang et al., 2011). The State Government also encourages public-private partnership in the district energy sector, which can relieve the fiscal burden on local government. These policies have resulted in district heating systems, including advanced 4th generation district energy systems, becoming relatively prevalent in China and in many European cities (particularly in denser high-rise urban centres) (Werner, 2017).

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5. Conclusions and opportunities

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This report has shown that sustaining and managing resource use is a cornerstone of sustainable development, particularly in order to achieve both environmental and socio-economic SDGs. A systems approach considering material flows from raw material extraction through to production, consumption, recycling and final disposal is needed to (a) understand the physical basis of societies and (b) to design effective measures across all sectors and levels of the economy to promote resource efficiency and reduce pollution.

This report has shown that 'business as usual' will further increase global use of natural resources and environmental impacts associated with extraction, production, consumption and disposal. All countries and world regions will face increased consequences, although the environmental burdens and economic benefits will continue to be disproportionally distributed. Currently, rich countries consume ten times more per person than low-income countries. These differences are measured by indicators such as the material footprint.

The material footprint measures the physical amount of natural resources extracted for further use. It determines the magnitude of material throughput of the economy (in different countries) and the resulting emissions (including pollutants) and final waste disposal associated with final consumption of products and services.

Conventional pollution control by add-on technologies is bound to shift environmental problems and increase resource consumption. Effective measures are needed to keep natural resource use and associated impacts within safe limits. This can only be achieved through significant increases in resource efficiency within production and consumption systems, including a shift towards reuse and recycling. Transformations toward resource-efficient urban infrastructures also have the co-benefit of increasing progress toward multiple SDGs, especially those related to human health and well-being.

This report has pinpointed key strategies and instruments for making resource use more efficient and inclusive for all. It has shown that some countries and cities have already undertaken first steps, for example developing national programmes for the efficient and sustainable use of natural resources. These seem to be particularly effective when they include the following elements:

- Monitoring resource use, in particular by footprint indicators (such as material footprint, to be complemented with land, water and GHG emission footprints)
- Providing orientation by target setting (such as increasing resource productivity and reaching more sustainable levels of resource consumption)
- Communicating with stakeholders on how to improve performance (including through networks, information campaigns and leading by example through procurement practices)
- Enabling actors across sectors and levels to develop resource efficient solutions (such as through skills training, improved education programmes and consulting services by resource efficiency agencies)
- Incentivizing actions for change (such as through price signals like a tax shift from labour to materials, through regulatory frameworks, including extended producer responsibility and by raising awareness).

Altogether, transformational policies are needed to enhance resource efficiency and sustainable resource use throughout the economy. An improved information base on resource use – which is reported regularly – would support policy design and evaluation. Scenario analysis should be further pursued to look at the big levers of change for transforming production and consumption systems. Initial progress to establish instruments fostering a more sustainable use of natural resources in production and consumption systems, including infrastructure management, has been made. Nevertheless, the opportunities for the future are still enormous.

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ASSESSING GLOBAL RESOURCE USE

A systems approach to resource efficiency and pollution reduction

The way in which societies use and care for natural resources fundamentally shapes the well-being of humanity, the environment and the economy. Better and more efficient use of natural resources can be one of the most cost-efficient and effective ways to reduce impacts on the environment, while also achieving the socio-economic objectives of international sustainable development and climate goals. Viable pathways exist for society to undertake such decoupling of economic growth from natural resource use and environmental impacts. But how can we get there?

Environmental and sustainability policies require a new evidence base that makes it possible to monitor the scale of the physical economy, that is - the amount of material, energy, water and land used and emissions generated in making, using and providing goods, services and infrastructure systems. This publication provides an assessment of the state, trends and outlook of global natural resource use, with a focus on material resources as part of the evidence base for policymaking for sustainable consumption and production. The report pinpoints seven strategies for system-wide pollution reduction and more sustainable resource use throughout the economy, including consideration of appropriate policy instruments and good practice examples from cities and countries around the world. A special feature on the link between resource use, infrastructure, air pollution and human health in cities is included.

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ISBN: 978-92-807-3677-9

DTI/2141/PA