Resource Efficiency: Potential and Economic Implications

Summary for Policy-Makers

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Summary for Policy-Makers




Resource Efficiency: Potential and Economic Implications

Produced by the **International Resource Panel**.

This document highlights key findings from the report and should be read in conjunction with the full report.

The report can be downloaded from www.unep.org/resourcepanel.
Additional copies can be ordered via email: resourcepanel@unep.org

Preface

Since its inception in 2007, the International Resource Panel has been committed to providing independent, authoritative and policy relevant scientific assessments on the future state, management and use of natural resources. With the publication of 15 assessment reports and continuous dialogues with policy-makers, industry leaders and civil society, the Panel has stood out as a credible voice in the international community that underlines imperatives and the urgency for the sustainable management of natural resources and that articulates the technological and economic potential of resource efficiency and ways forward for the related public policies.

Two historic events in 2015 figure prominently on resources issues: the 2030 Agenda on Sustainable Development highlights that sustainable resource management is critical to poverty eradication and to the sustainable future we want; and the Paris Agreement on Climate Change confirms that decarbonisation must go hand in hand with decoupling economic growth from the escalating use of natural resources and environmental degradation as one of the key components for achieving the transformation towards a better tomorrow for current and future generations.

It is exactly for these reasons that the G7 at their Summit in Germany in June 2015, as part of their increased commitment to improving their efforts in resource efficiency, asked the International Resource Panel to produce a report on the most promising potentials and solutions for resource efficiency for all countries - developed, newly industrialized and developing. This rapid assessment report is the result of a truly collective effort by scientists and experts of the International Resource Panel who thoroughly reviewed the best science available. The findings of the report point out the importance of joining forces for acting now as well as the huge potential that resource efficiency can have, if it is implemented carefully and supported across different sectors and at multiple levels. The pressing need to invest in resource efficiency could actually lead to a positive economic outcome. The report shows how resource efficiency can lead to higher economic growth and employment, if supported by well-designed policies.

The assessment demonstrates that because many areas of resource use are relatively inefficient, the potential for resource efficiency is tremendous. This is supported by the results of the modelling undertaken for this study, which shows that resource efficiency combined with climate policy could at the same time

stabilise global resource use by 2050 and boost incomes and economic growth.

Looking forward, the report demonstrates numerous examples from different countries around the world of increasing resource efficiency in different sectors. It thereby puts the different challenges ahead into perspective and illustrates how to learn from each other and how to scale up what is working.

We are very grateful to Paul Ekins and Nicholas Hughes for their tremendous effort in presenting a comprehensive up-to-date perspective for understanding the potentials and economic implications of resource efficiency. Their remarkable work gives us hope that with engaged actors, it will be possible for us to improve wellbeing for everyone and protect the planet today and tomorrow.

Co-Chairs,
International Resource Panel (IRP)

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Foreword

Over the past decade, the importance of resource efficiency and sustainable management of natural resources has increased considerably, culminating last year in the historic adoption of the 17 Sustainable Development Goals and in the decision by the leaders of the Group of Seven (G7) nations to promote ambitious actions to improve resource efficiency as a core element of sustainable development.

As part of that commitment, the G7 asked the International Resource Panel to prepare a synthesis report that highlights the potential and most promising solutions for resource efficiency. This rapid assessment report - *Resource Efficiency: Potential and Economic Implications* - provides an analysis of the status and trends of resource efficiency and presents best-practices and possible solutions for developed countries, emerging economies and developing countries.

While it is essential and significant for the G7 to champion resource-efficiency, that alone will not be sufficient. Achieving an increase in resource efficiency will require a concerted action by all countries to change the way that resources are produced and consumed across the economic and development spectrum. Genuine and effective international cooperation will make transformation to a resource efficient future a reality.

Such a transformation presents all countries with not only a major challenge, but also an historic opportunity to build dynamic, sustainable, innovative and people-centred economies while preserving the natural resource base and environment for future generations. In short, the global improvement of resource efficiency represents a major instrument to achieve the goals we have set in the 2030 Agenda.

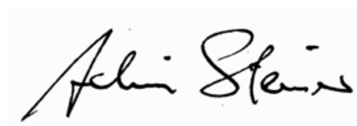
Achieving this will only be possible with focused political will, action and determination at all levels, along with the acknowledgement that there are differences in resource challenges determined by local contexts that make a 'one size fits all' solution impossible.

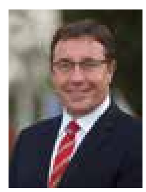
The examples in this report illustrate what is working and why. The report shows that a landfill tax in the United Kingdom contributed significantly to increased recycling rates, reaching nearly 45 per cent for household waste in 2014, up from 26 per cent for overall waste in 2012. It also shows that Japan's 'Top Runner' scheme, which uses as a benchmark the highest performing energy-efficient appliances for setting the required average standard in a future year, led to efficiency

improvements in different product groups of 16-80 per cent in the last 12 years. It further demonstrates that planting trees alongside crops can improve soil fertility, such as in Zambia, where 160,000 farmers have planted nitrogen-fixing acacia trees among their crops, leading to average maize yields of 4.1 t/ha from fields planted with acacias, compared to 1.3 t/ha outside of the tree canopy.

These examples show what is possible if we work ambitiously and jointly and should fill us with hope and motivation for the way forward. It is my strong desire that the findings of this important report will inspire determined action in increasing resource efficiency.

I would like to express my gratitude to the International Resource Panel, under the leadership of Janez Potočnik and Alicia Bárcena, for developing this important report.





Achim Steiner
UN Under-Secretary General and Executive Director,
UNEP Nairobi, Kenya, March 2016

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Key Messages

With concerted action, there is significant potential for increasing resource efficiency, which will have numerous benefits for the economy and the environment

1. Substantial increases in resource efficiency are essential to meet the Sustainable Development Goals (SDGs) – enabling development while protecting the environment

Resource use is central to human prosperity. Of the 17 Sustainable Development Goals (SDGs), 12 directly depend on the sustainable economy-wide management of a whole range of natural resources. Current patterns of resource consumption have many negative effects on human well-being. Resource efficiency yields both short- and long-term benefits, and improves overall economic and environmental resilience. Increases in resource efficiency are critical to providing the resource security that is vital for human development, and for balancing such development with environmental protection to deliver "the future we want", as envisaged by the SDGs.

2. Improving resource efficiency is indispensable for meeting climate change targets cost effectively

The extraction, processing and use of resources require much energy, at present mainly sourced from fossil fuels with resulting carbon dioxide (CO_2) and other emissions. Much land use and land use change entails emissions of both CO_2 and non-CO_2 greenhouse gases (GHGs). Resource efficiency can reduce these emissions substantially, as well as the adverse impacts from the increased material use that is required for many low-carbon technologies. Without significant improvements in resource efficiency, it will be difficult and substantially more costly to keep average global warming well below 2 degrees Celsius (^{o}C).

3. Resource efficiency can contribute to economic growth and job creation

There is strong evidence that increasing resource efficiency can yield higher economic growth and employment. However, achieving this will require barriers to resource efficiency to be overcome through changes to the rate and direction of innovation and technical change, and some combination of intelligent and targeted regulation, appropriate investment in enabling infrastructure, environmental tax reform and strategic use of fiscal policy

and sustainable public procurement in support of resource efficiency and innovation. Targets for resource efficiency increases need to be set and progress towards them monitored.

4. There are substantial areas of opportunity for greater resource efficiency

Many areas of resource use are relatively inefficient, presenting significant opportunity for improvement in many areas of the economy. Developing countries have further opportunities to design their infrastructure and development paths in a resource-efficient way from the outset. New modelling undertaken for this report finds that resource efficiency combined with climate policy could reduce global resource use in 2050 by 28 per cent relative to existing trends, while reducing greenhouse emissions and boosting income and economic growth.

5. Increased resource efficiency is practically attainable

There are numerous examples from countries around the world at very different stages of development of increasing the resource efficiency of different sectors and economic activities, thereby gaining social, environmental and economic benefits and helping to realize a world worth living in. The challenge for policy-makers is to learn from and scale up these good practices, and to conceive and implement a set of transformative policies suitable to countries' specific circumstances.

Introduction

Note: This report on resource efficiency has been produced by the United Nations Environment Programme's (UNEP) International Resource Panel (IRP) in response to a request by G7[1] Leaders at the Summit held in June 2015 in Schloss Elmau, under the German Presidency. It is a Summary for Policy Makers of a much longer forthcoming Assessment Report by the IRP, which synthesizes the main work of the IRP and other international organizations and researchers in this area (UNEP, 2017).

This is a report about prospects for resource efficiency. It considers how resource efficiency can contribute to economic growth and development, at the same time as reducing the world's use of materials, energy, biomass and water, and the resulting environmental impacts.

2015 was a landmark year, due to the establishment of two historic global agreements which confirm the international community's shared commitment to achieving equitable and sustainable development. The 2030 Agenda for Sustainable Development, with its 17

[1] The Group of Seven (G7) nations is made up of Canada, France, Germany, Italy, Japan, the United Kingdom and the United States. The European Union (EU) is also represented.

Sustainable Development Goals (SDGs), is now the most complete expression of the positive aspirations of human societies worldwide through to 2030. Further, the agreement in Paris at the 21st Conference of Parties (COP 21) to the United Nations Framework Convention on Climate Change (UNFCCC) saw 195 countries pledging to keep global temperature rise to well below 2°C above pre-industrial levels.

Both the 2030 Agenda and the Paris Agreement are highly significant in that they commit industrialized and emerging economies and other developing countries to join forces to eradicate poverty, and protect Earth's resources and ecosystems for the benefit of present and future generations.

Resources, including renewable and non-renewable energy, materials, water, air, biomass and land, are fundamental to human well-being. Box 1 sets out the definition and terminology of resources that are used in this report, and how resource use is measured.

Box 1: Resources and their measurement

In this report the term "resources" is used to describe elements of the physical world that have the capacity to provide goods and services for humans. Resources therefore include air (the atmosphere), water (marine and fresh) and land. Land consists of terrestrial space (for human habitation or the habitats of other species), which in conjunction with soil produces biomass and biodiversity. Sub-soil resources comprise metal ores, non-metallic minerals, and fossil fuels, the combustion of the latter being the major source of increases in atmospheric carbon dioxide, which is the principal greenhouse gas (GHG). Ambient energy (for example, solar or wind energy) is also an important resource. "Natural resources" are those provided by nature before their extraction or processing by humans (for example, metal ores, rather than metals).

Material resources are often divided into four major categories: fossil fuels, biomass, metals, and non-metallic minerals, the quantities of which are often measured in tonnes. Land is usually measured by its area (for instance, in square metres) and water by its volume (for instance, in cubic metres).

Measures may distinguish between resources produced or environmental impacts occurring in a territory, and those associated with or arising from the whole supply chain of a product or service or a country's final demand. The latter are called "consumption-based" indicators or "footprints". The four main calculated footprints are those for land (which includes the land required for the production of biomass), water, materials (metals and minerals) and carbon dioxide.

The term "resource efficiency" is here used to encompass a number of ideas: the technical efficiency of resource use (measured by the useful energy or material output per unit of energy or material input); the resource productivity, or extent to which economic value is added to a given quantity of resources (measured by useful output or value added per unit of resource input); and the extent to which resource extraction or use has negative impacts on the environment (increased resource efficiency implies reducing the environmental pressures that cause such impacts). Resource intensity is the inverse of resource productivity, and is therefore measured by resource use per unit of value added. Environmental intensity is similarly the environmental pressure per unit of value added.

Earth provides natural resources in abundance, and human populations use them abundantly. In 2015, 84 billion tonnes of materials were extracted and used by the human economy (UNEP, 2016c). A third of land on Earth is now cultivated to meet human needs and wants (FAO, 2016; UNEP, 2014a). Globally in 2005 humans consumed 25 per cent of the biomass produced on land in that year (Haberl et al., 2014; Krausmann et al., 2013). An estimated 61 per cent of commercial fish populations are fully fished, and 29 per cent are overfished (FAO, 2014).

In many parts of the world, supplies of freshwater are stressed or scarce (WWAP, 2015).

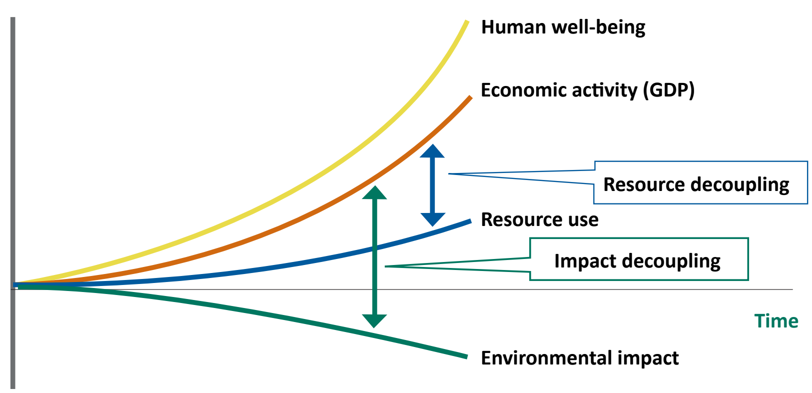
Human activity is changing ecosystems rapidly and extensively, largely in response to increasing demands for food, fresh water, timber, fibre, minerals and fuel (MEA, 2005; UNEP, 2012a). These changes have depleted and degraded many ecosystem services, increased risks of sudden and disruptive environmental change, and exacerbated poverty for some groups of people (MEA, 2005).

The world population is projected to reach 9.7 billion in 2050, an increase of 33 per cent from 2015. Much of the population growth is likely to be concentrated in urban regions of Africa and Asia (UN, 2015). This increase, coupled with continued economic growth in a business-as-usual mode, is likely to dramatically increase pressures on the environment and demand for resources (Krausmann et al., 2009; UNEP, 2012a). For example, under 'business as usual', annual global material extraction has been projected to reach 183 billion tonnes by 2050 (Schandl et al., 2015), more than double the amount in 2015. Demand for food and fibre could increase by 60 per cent and 80–95 per cent, respectively, by 2050 (FAO, 2012). Demand for water could increase by 55 per cent over the same period (OECD, 2012).

This report draws on many sources to show that there are major constraints on the supplies of some of Earth's resources, and real limits to the environmental impacts that can be safely absorbed by Earth's ecosystems. What is required is a *decoupling* of resource use and associated environmental impacts from the growth of economic output.

The concept of decoupling is represented in Figure 1, which shows increasing trajectories for economic performance (measured by gross domestic product – GDP) and human well-being such as might be implied by the achievement of the SDGs. However, Figure 1 also shows resource use increasing at a much slower rate than GDP (relative resource decoupling) and environmental impacts actually declining

Figure 1: Decoupling of resource use and environmental impacts from GDP growth.



Source: UNEP (2011a), Figure 1, p. xiii

(absolute environmental decoupling). This conceptual figure therefore indicates the ideal goal of resource efficiency through the notion of decoupling – that economic output and human well-being shall continue to increase, at the same time as rates of increasing resource use and environmental impact are slowed, and in time brought into decline, thereby sustaining resource use and the delivery of ecosystem goods and services for current and future generations.

The capacity of Earth to continue to provide resources for human populations in the immediate and more distant future is a matter of critical importance. In order to avoid dangerously depleting that capacity, it is vital that humans use Earth's resources more efficiently.

This report first makes the case that increased resource efficiency is essential to reducing the environmental impacts associated with resource use to within a scientifically delineated "safe operating space" (Steffen et al., 2015). Remaining within such ecological limits, as is pledged in the case of climate change by the COP21 agreement, is an imperative if the increased human well-being envisaged by the SDGs is to be realized and sustained, and if economies are to be resilient to resource supply disruptions and associated resource price volatilities. It is then shown that with the imperative of increased resource efficiency come opportunities for increased economic growth and employment. The report then documents some best practices in resource efficiency in the use of materials, food, land, water and energy, and how they have been implemented. The study concludes that the opportunities for resource efficiency are numerous and beneficial for both the economy and the environment, and could facilitate social development. They are also attainable with public policy interventions.

There are therefore strong reasons for seriously addressing resource efficiency and exploring more deeply the opportunities for it. These reasons explain the increasing interest from governments and other policy-makers in resource efficiency, and the large volume of literature on this subject, on which this report seeks to build. Indeed, they explain why the G7 governments have requested this report.

2. The imperative and opportunity of increased resource efficiency

2.1 The imperative of increased resource efficiency

2.1.1 Substantial increases in resource efficiency are essential for meeting the SDGs

While attainment of all the SDGs requires to a large extent the sustainable management and use of Earth's natural resource base, no fewer than 12 of the Goals refer directly to resources and the environment as fundamental to their achievement (Figure 2).

Figure 2: Number of Sustainable Development Goals that directly depend on the sustainable use of natural resources.

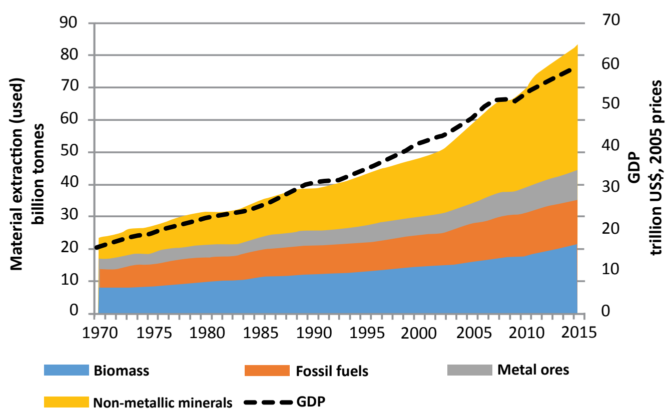
Source: UNEP (2017)

Resource efficiency contributes to GDP growth and human well-being in an environmentally sustainable manner from four key perspectives, which are at the heart of achieving the SDGs presented above[2] : future resource availability, increasing and volatile resource prices, the present unsustainable use of renewable resources, and the environmental impacts of resource extraction and use.

2.1.1.1 Future availability of material resources

Past trends show consistently increasing global resource use. UNEP (2011a) estimates that the amount of materials extracted and used globally – including ores, minerals, fossil fuels and biomass – increased eightfold between 1900 and 2005. This was twice the rate of population growth, but somewhat less than the rate of GDP growth, which increased by an estimated factor of 19, at constant prices, over the twentieth century (De Long, 1998). These statistics therefore present long-run evidence of "relative decoupling" of material extraction from GDP. However, such relative resource decoupling does not entail an absolute reduction in resources used. Figure 3 shows trends in material extraction and GDP from 1970 to 2015, which illustrates that material extraction has continued to increase strongly. Indeed, according to this more recent data, since 2000 material extraction appears to have grown at a faster rate than GDP – suggesting the possibility of "recoupling" if this trend persists.

Figure 3: Global material extraction in billion tons, and global GDP in trillion US $ (2005 prices), 1970-2015.

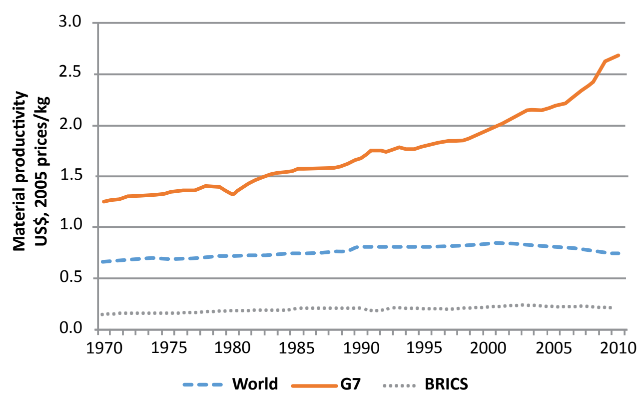


Source: Material extraction data from UNEP (2016c), GDP data from UNSD (2015).

[2] Of course, the SDGs have other objectives, such as poverty eradication, gender equality and more equitable development outcomes. The extent to which increased resource efficiency contributes to the achievement of these other objectives will depend on the detail of the policies through which resource efficiency itself is achieved. Such policy detail is outside the scope of this report.

Figure 4 shows that over the period 1970-2010, material productivity (MP) – measured as the amount of economic output per weight of domestic material consumption (DMC)[3] – in G7 countries increased steadily at an average rate of 1.9 per cent per year. Material productivity in the BRICS[4] group of countries is substantially lower throughout the period, though it also increases slightly, at a rate of 1.2 per cent per year on average. However, Figure 4 also shows that at the global scale material productivity has remained practically constant, and even declined slightly since 2000, which reflects the fact that material extraction increased at a faster rate than GDP during this recent period (Figure 3). The recent fall in overall global material productivity occurred because of a global shift of production from countries with high material productivity to countries with much lower material productivity. This is the result of rapid industrial transformation in many parts of the developing world. Thus, while the higher and increasing MP of G7 countries may be partly due to a more economically efficient use of materials in these countries, it may also be caused by structural shifts away from heavy industry and manufacturing, and towards service-based activities. Economies with an increasing share of services and imported manufactured goods can therefore increase their material productivity, on a DMC basis, as a result of their changing economic structure. However, this does not necessarily increase material productivity on a global level, and indeed may rather involve service-based economies "exporting" the material and environmental burden of their consumption (UNEP, 2015b).

Figure 4: Material productivity of the world, BRICS and G7 countries, in constant US $ 2005 per kg of domestic material consumption (DMC) in the economy, 1970-2010.



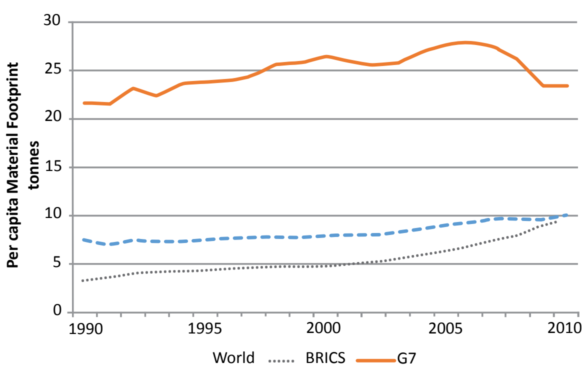
Source: Data from UNEP (2016c)

[3] DMC measures the total amount of materials directly used by an economy, and is calculated as domestic extraction, plus all physical imports, minus all physical exports. See: http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Domestic_material_consumption_(DMC)

[4] Brazil, Russian Federation, India, China, South Africa

This effect can be seen in Figure 5, which shows the total per capita material footprint (MF) of the G7, the BRICS countries and the world as a whole. The MF measure allocates all upstream material extraction related to traded goods and services to the country of final consumption, rather than the country or countries of production. The figure shows that the MF of BRICS countries has been rising steadily and is now approaching the global average, representing rising consumption in these countries. However, the BRICS MF remains less than half that of the G7 countries, even after the latter suffered a substantial drop following the 2008 global financial crisis. This shows that G7 countries are responsible for a much higher level of per capita material consumption than BRICS countries or the world average, even if the material extraction and resulting environmental impacts do not all take place within G7 countries.

Figure 5: Per capita material footprint of domestic final demand in the G7, the BRICS and the global economy, 1990-2010, in tonnes.



Source: Data from UNEP (2016c)

Overall, these data suggest that while long-run relative decoupling of material extraction from GDP can be observed at a global level, this relative decoupling is not sufficient to prevent a persistent increasing trend in absolute resource extraction. Indeed, in contrast to the long-run relative decoupling trend over the 20th century, recent years' data suggest that resource extraction has begun to increase at a faster rate than GDP, suggestive of "recoupling".

Human populations are still growing, as are their economies. Current trends suggest that a growing global population with rising average wealth will continue to drive up the consumption and use of materials. These drivers have been projected to push material extraction towards 183 billion tonnes per year by 2050 as previously mentioned. The mobilization of such quantities of materials

within the global economy, in a smooth and timely manner year after year, will be increasingly challenging. Ores and minerals are finite, and many are geographically concentrated (UNEP, 2015b). Biomass, while renewable, has a limited rate of renewal, which places bounds on what can be sustainably consumed. Bulk metals such as iron, copper and aluminium play critical roles in providing large-scale infrastructure, and elements such as indium, platinum, rhodium and neodymium, though mobilized in smaller quantities, will be increasingly critical to efforts to reduce carbon emissions due to their roles in low-carbon technologies such as solar photovoltaic cells, batteries, catalysts and wind turbines (BMUB, 2012; UNEP, 2010, 2013b, 2013c). Nitrogen and phosphorus are crucial inputs to land for the production of biomass (BMUB, 2012; UNEP, 2014a). The efficient use and recycling of such materials can reduce the risks and threats of serious disruption to their future availability.

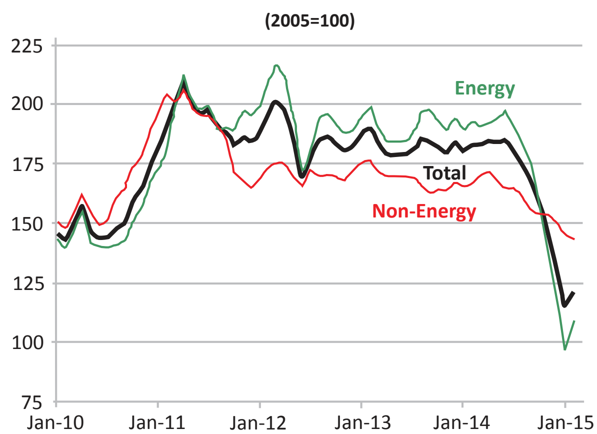
2.1.1.2 Volatility and long-term increases in resource prices

The second issue relates to the market dynamics of resource supply, which have produced highly volatile resource and commodity prices over time (UNEP, 2015b; and see Figure 6 for commodity price movements over 2010-2015). In addition, there is evidence that the long, slow decline in resource and commodity prices that characterized the twentieth century came to an end at the start of the twenty-first, with commodity prices increasing steadily over 2000 to 2012 (Dobbs et al. 2013, Exhibit 1, p.6). Despite the dramatic fall in prices in 2014 (see Figure 6), and with the exception of fossil fuels, demand for which may be constrained by climate policy, it is likely that in due course demand growth in emerging countries will set the prices of commodities, including food, on an upward course again.

High and volatile resource prices can present serious economic and social challenges by restricting market access, particularly among the poorest and most vulnerable groups; hampering investment, owing to increased uncertainty; and even undermining peace and security, as attested by the riots that broke out in numerous countries in 2007-2008 partly in response to high food prices.

If resource efficiency can reduce the demand for resources, then it may be able to dampen the negative economic impacts of price volatility, improve equitable and affordable access to resources, and increase resource security, especially in resource-importing regions.

Figure 6: IMF commodity price indices, 2010-2015.



Source: IMF (2016) https://www.imf.org/external/np/res/commod/index.aspx

2.1.1.3 Sustainable use of renewable resources

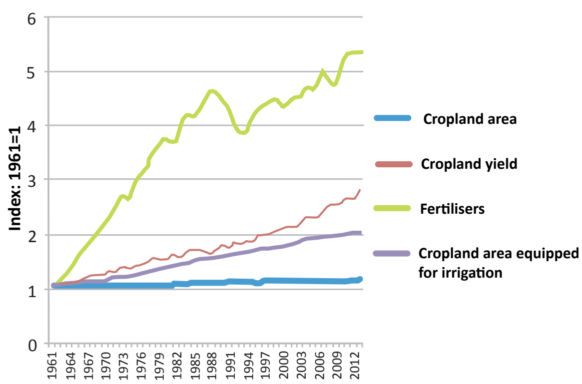
The third issue relates to the need for the sustainable use of renewable terrestrial and marine resources, such as soils, water, biodiversity and fish stocks. These resources critically underpin the viability of such vital sectors as agriculture, fisheries and forestry.

Vast areas of land are now cultivated to meet human needs and wants. According to FAO statistics, cropland covers 1,580 million hectares (Mha) or close to 11 per cent of the world's land area, with agricultural land in total (also including permanent pastures) covering 4,930 Mha, or a third of the world's land area. Total agricultural land increased by about 11 per cent from 1961 to 2013 (FAO, 2016). Globally in 2005 humans consumed around 25 per cent of the total biomass produced on Earth's land surface in that year (Haberl et al., 2014; Krausmann et al., 2013). Recently, increases in agricultural land in regions such as South-East Asia and South America have offset decreases in regions such as Europe and North America (FAO, 2016). Dalgaard et al. (2008) associate reductions in cropland in Europe with increased imports of soybean for cattle feed from Latin America, as these replace the domestic growing of fodder crops (Dalgaard et al. (2008), in UNEP (2014a), p. 25). The location of any expansion of agricultural land is significant in terms of what type of land use it replaces, with the loss of biodiversity-rich primary forests a particular concern in regions such as South America and South-East Asia (UNEP, 2014a).

Global production of primary crops more than tripled from 1961 to 2013 (FAO, 2016). Over the same period, global cropland area increased by around 14 per cent (FAO, 2016). This was possible due to steady increases in the

productivity of land, which in turn was delivered by substantial increases in agricultural inputs. As shown in Figure 7, the area of cropland equipped for irrigation doubled over the period, with the application of fertilizers increasing by around five times. Pesticides are also a significant input – their application grew almost three times between 1990 and 2011 (FAO, 2016).

Figure 7: Growth in cropland, agricultural inputs and crop yields, 1961-2013. Index: 1961=1.



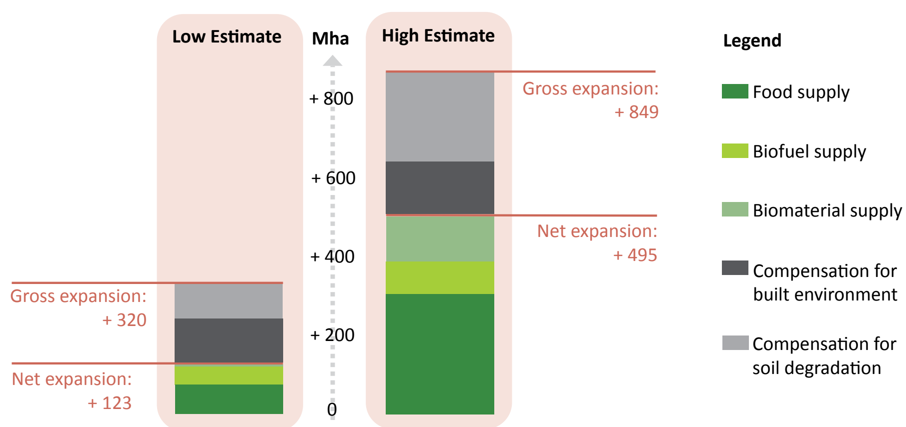
Source: Data from (FAO, 2016)

Although this productivity increase has been important to support a necessary global expansion in food production, it comes with challenges. Fertilizer inputs are finite and geographically concentrated resources, and resource shortages and price rises are a possible outcome of continued high production (BMUB, 2012; Senthilkumar et al., 2014). As will be discussed in the following section, the extraction and concentrated application of these compounds causes pollution. Furthermore, it is not clear that increasing application of fertilizers and pesticides can continue to increase yields indefinitely. There is evidence that yields for cereals are increasing at a slower rate than in previous decades, and experts expect yield growth rates to continue to slow (von Witzke et al., 2008; Bruinsma, 2009; UNEP, 2014a).

At the same time, an increased demand for food supply may be expected, driven by population increases, efforts to combat hunger and malnutrition, and dietary changes associated with rising affluence (Msangi and Rosegrant, 2009; UNEP, 2014a). Access to food is unevenly distributed. In 2015 about 795 million people, 11 per cent of the world's population, were undernourished. More than half of the undernourished people live in Asia, while sub-Saharan Africa has the highest prevalence, at 23 per cent. The number of undernourished people has decreased from around 1 billion in 1990, which at that time was almost 19 per cent of the global population. In the same period (1990-2015) global meat consumption increased by 90 per cent (FAO, 2015a). Food derived from rearing animals requires nearly five times more land for a given level of nutrition than plant-based food (UNEP, 2009).

Owing to the expected continued future growth in food demand, the OECD projects global agricultural land (cropland and permanent pastures) to increase by a further 10 per cent by 2030, and by 14 per cent by 2050 (OECD, 2008). UNEP (2014a) focuses on cropland expansion and considers – in addition to food demand – other pressures, including increasing demand for biofuels and biomaterials, and loss of land to the built environment and soil degradation. UNEP (2014a) estimates that from 2005 to 2050 current trends will lead to a gross expansion of 320 – 849 Mha (an increase of 21 per cent to 55 per cent) of global cropland.[5] The contribution of different drivers to this projected cropland expansion is shown in Figure 8.

Figure 8: Trend of global cropland expansion from 2005 to 2050 for satisfying food demand and compensation of soil loss.



Source: UNEP (2015c)
http://www.unep.org/resourcepanel/Portals/50244/publications/Poster1-LandUse-FinalScreen.pdf

[5] *Net expansion of cropland* results from rising demand for food and non-food biomass that cannot be compensated by higher yields. Gross expansion also includes the shift of cropland to other areas due to losses from severe land degradation – in particular from soil erosion – and built-up land.

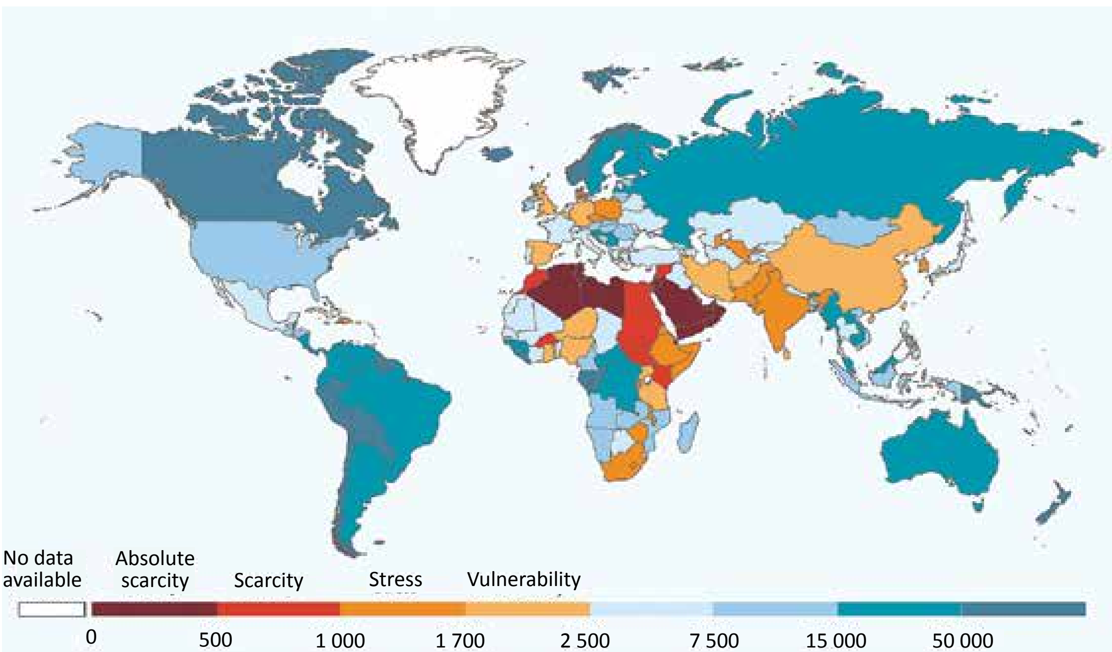
UNEP's estimate of the "safe operating space" for land only allows cropland to expand to up to 1,640 Mha. This represents an expansion of 140 Mha, or a 10 per cent increase from the 2005 cropland area used as the baseline for the study. With more recent FAO statistics suggesting that cropland now covers around 1,580 Mha (FAO, 2016), it is clear that the scope for further growth within the "safe operating space" is very limited.

Access to clean water is another fundamental human need. Water consumption for human use grew from 600 billion cubic metres per year in 1900 to 4,500 billion cubic metres per year in 2010. This rate of growth in water consumption was twice the rate of population growth (UNEP, 2012b), reflecting increasingly water-intensive lifestyles, as well as industrial and agricultural intensification. At present, agriculture accounts for 71 per cent of global water withdrawals, the remainder being divided fairly evenly between industrial and domestic demand (Addams et al., 2009; FAO, 2011). The importance of water to the intensification of agriculture is evidenced by the doubling of cropland equipped for irrigation between 1961 and 2013, as illustrated in Figure 7.

Though the total amount of water in the global water cycle is unchanging, water resources in particular areas can become contaminated, stressed or critically depleted. A rate of water

withdrawal above 20 per cent of a region's available internal renewable water resources (IRWR) "represents substantial pressure on water resources, and more than 40 per cent is 'critical'" (FAO, 2011). East and South-East Asia have withdrawal rates close to 20 per cent IRWR, while Western, Central and South Asia all have withdrawal rates greater than 50 per cent. In Northern Africa it is 201 per cent, which implies that water is being extracted at a much higher rate than it can be replenished, resulting in unsustainable depletion of rivers and aquifers (FAO, 2011). The risk of water stress is unevenly distributed, as shown by Figure 9.

Figure 9: Total renewable water resources per capita (2013)*.*



Note: The figures indicate total renewable water resources per capita in m³
Source: WWAP, with data from the FAO AQUASTAT database (http://www.fao.org/nr/water/aquastat/main/index.stm) (aggregate data for all countries except Andorra and Serbia, external data), and using UN-Water category thresholds.

Source: WWAP (2015), p.12

It is projected that, with average economic growth and no efficiency gains, by 2030 annual global water demand will rise from 4,500 billion cubic metres to 6,900 billion cubic metres. This is calculated to be 40 per cent higher than currently accessible, reliable supplies (Addams et al., 2009; WWAP, 2015). The result could be that "one-third of the population, concentrated in developing countries, will live in basins where this deficit is larger than 50 per cent" (Addams et al., 2009). This may lead to effects on food prices, and indeed to conflict. Increasing climate change could further exacerbate such problems (WWAP, 2015). Water scarcity is therefore a serious concern in many parts of the world.

Marine and aquatic ecosystems are also under pressure, with marine biomass threatened by unsustainable levels of exploitation. Of commercial fish populations, 61 per cent are fully fished and 29 per cent are fished at biologically unsustainable levels and are therefore overfished (FAO, 2014). These levels of extraction threaten serious collapse of some fish populations.

2.1.1.4 Environmental impacts of resource extraction and use

The fourth issue relates to the environmental impacts of resource extraction and use. Mobilizing billions of tonnes of raw materials each year has serious environmental effects, in terms of pollution, land degradation and loss of biodiversity.

The extraction and combustion of fossil fuels is the largest contributor to anthropogenic climate change. Global primary energy is dominated by fossil fuels: coal, oil and gas, which are a major source of a wide range of negative environmental impacts in addition to climate change. These include emissions of acid pollutants (nitrogen oxides – NOx, and sulphur oxides – SOx) that cause acid rain; the release of small particulates and other toxic pollutants, which are harmful to human health; and emissions of nitrogen, which causes "eutrophication" –the over-enrichment of environments such as lakes with nutrients, causing algal blooms that harm ecosystems UNEP (2010).

The extraction of metals and minerals also has significant environmental impacts, for example the release of toxic or acidic compounds into water, soils and the air, such as through smelter stack emissions, with corresponding effects on human health and biodiversity (UNEP, 2013b). As shown in Figure 7 the increase in the productivity of agricultural land has been achieved through considerable increases in agricultural inputs. The extraction of fertilizer inputs such as

phosphates can create pollution through the release of heavy metals and radionuclides (BMUB, 2012). The increased application of nitrogen and phosphorus fertilizers has resulted in considerable nutrient pollution, including eutrophication, increases in atmospheric ozone, fine particulate matter, acidification of surface waters, which contributes to biodiversity loss, and GHG emissions due to the production of nitrous oxide (N2O) (UNEP, 2014a). Moreover, the production of fertilizers is energy-intensive and generates energy-related CO_2. Pesticides, fungicides and bactericides, which have grown in use substantially since 1990 (FAO, 2016), also have negative environmental impacts.
Intensive land use can also degrade the "productive capacity" of the land itself, as well as its environmental quality (UNEP, 1997). The main causes of land degradation are water erosion, wind erosion, nutrient mining, water logging and salinization caused by irrigation, lowering of the water table, over-use of chemical inputs, soil compaction and loss of organic matter (FAO, 2015b; Scherr, 1999). Globally, according to FAO, about 25 per cent of all land is highly degraded or fast degrading. Around 8 per cent is moderately degraded with a moderate degradation trend, while 36 per cent is slightly or moderately degraded but stable. Only 10 per cent of land has started improving (FAO, 2011).

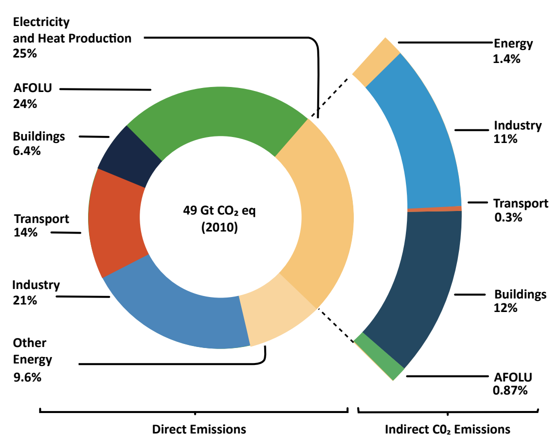
Overall, the four issues discussed above constitute significant threats to achieving

the SDGs. Resource efficiency is central to diminishing these threats by increasing the availability of resources that are crucial to human development; improving the ability of all the world's people to gain equitable and affordable access to those resources; and protecting the ecological systems that underpin those resources and related provisioning services.

2.1.2 Substantial increases in resource efficiency are essential for meeting climate change targets in a cost-effective manner

Meeting at the 21st Conference of Parties *(COP 21)* to the UN Framework Convention on Climate Change *(UNFCCC)* in Paris in 2015, the world's governments pledged to keep global temperature rise to less than 2°C above pre-industrial levels. According to the Intergovernmental Panel on Climate Change *(IPCC)*, scenarios in which it is "likely" that this goal is achieved, "are characterized by atmospheric concentrations in 2100 of about 450 parts per million (ppm) CO_2eq". Such scenarios require global GHG emissions in 2050 to be 40-70 per cent lower than in 2010, and for GHG emissions to be "near zero Gt CO_2eq[6] or below in 2100" (IPCC, 2014). Figure 10 shows the breakdown of anthropogenic GHG emissions in 2010 by economic sector. Direct emissions refer to emissions generated within the economic sector listed. Indirect CO_2 emissions refer to the emissions arising from the production of an intermediary fuel or energy vector – such as heat or electricity – which is then used in one of the sectors.

Figure 10: Total anthropogenic GHG emissions (Gt CO_2eq per year) by economic sector: energy, industry, transport, buildings, and agriculture, forestry and other land use *(AFOLU)*.



Source: IPCC (2014)

[6] Gigatonnes carbon dioxide equivalent.

In order to achieve the emissions reductions consistent with a 450 ppm scenario, the large-scale deployment of low-carbon technologies in energy and land use systems will be critical, as is explored in detail in numerous scenarios by the IPCC and others (IEA, 2010, 2012a; IPCC, 2014). However, in addition to supply-side decarbonization, energy demand reduction through resource efficiency will also have a crucial role. The IPCC states that "efficiency enhancements and behavioural changes, in order to reduce energy demand compared to baseline scenarios without compromising development, are a key mitigation strategy in scenarios reaching atmospheric CO_2eq concentrations of about 450 to about 500 ppm by 2100 (robust evidence, high agreement)" (IPCC, 2014). Among such scenarios, the median level of demand reduction relative to baselines in the transport, buildings and industry sectors is between 20 per cent and 30 per cent in each case. Some of the scenarios analysed show even higher sectoral demand reductions of up to 60 per cent (IPCC, 2014). Increasing resource efficiency is a critical strategy to enable such necessary demand reductions to be achieved, without negatively affecting human development and well-being.

In the light of this conclusion, the International Resource Panel (IRP) sent 10 Key Messages on Climate Change to the COP21 Climate Summit in Paris. The IRP concluded these messages as follows: "Raising resource productivity through improved efficiency and reducing resource waste … can greatly lower both resource consumption and GHG emissions. Such measures also confer additional, highly desirable social benefits such as more equitable access to resources and invaluable environmental gains such as reduced pollution. Decoupling economic growth and human wellbeing from resource use has, therefore, to be an integral part and prime concern of climate policy" (UNEP, 2015a).

Taken together, the challenges of achieving the SDGs and meeting climate change targets provide a strong imperative for resource efficiency, which will be needed to reduce the threats arising from unsustainable resource consumption.

But there is also evidence that resource efficiency can bring substantial economic benefits, including higher rates of economic growth and increased employment. This evidence is documented below.

2.2 The economic opportunity of increased resource efficiency

The economic opportunity of increased resource efficiency may be expressed in three ways. First, there are ways to increase resource efficiency that would provide net cost savings. Second, the negative environmental effects of inefficient resource use bring substantial external costs. And third, the cost reductions arising from increased resource efficiency have positive macroeconomic implications, with the potential to increase economic output and employment.

2.2.1 Costs and benefits of increasing resource efficiency

There have been a number of estimates of the costs of increasing resource efficiency, of which one of the most often cited is from Dobbs et al. (2011). This states that from the perspective of a private investor, the savings in 2030 arising from implementing all the technologies considered would be $2.9 trillion per year. In 70 per cent of cases, the required resource-efficient investment would offer a rate of return greater than 10 per cent per year. The total $900 billion investment required "could potentially create 9 million to 25 million jobs" (Dobbs et al., 2011, p. 12).[7]

It may immediately be asked why, if there are such beneficial cost-saving opportunities from investments in resource efficiency, investors do not make the necessary investments to realize these benefits. This issue has been most thoroughly explored for energy efficiency, but the arguments apply equally well to other resources. Sorrell et al. (2004) suggest that the failure to make cost-effective energy efficiency investments is the product of three phenomena:

- *Market failure*, normally identified as a result of incomplete property rights, positive and negative externalities, imperfect competition and asymmetric or imperfect information;
- *Organizational failure*, as a result of imperfect organizational structure and policy[8]; and

[7] These benefits have been calculated at the market prices of resources prevailing in 2010. To the extent that resource prices have declined since 2010, and this is especially true of fossil fuels, the benefits of resource efficiency will be proportionally less. But even then resource efficiency can present opportunities to reduce firms' and countries' vulnerability to price volatility, and may provide ways to achieve environmental improvements at lower cost than through other means.

[8] While Sorrell et al. (2004) seem to be thinking of private organizations in this connection, such failure could apply to public bodies as well.

- *Non-failure,* where organizations and individuals are in fact behaving rationally in not taking up the efficiency opportunities because of hidden costs. These may include "overhead costs for management, disruptions to production, staff replacement and training, and the costs associated with gathering, analysing and applying information" (Sorrell et al., 2004, p.55).

The existence, strength and persistence of these barriers vary from issue to issue. Therefore, attempts to improve resource efficiency should seek to understand the barriers individually, in order to correctly identify the most appropriate measures to surmount them. In doing so, there is evidence that increasing resource efficiency will tend to strengthen the innovation capacity of economies (Bringezu, 2015).

2.2.2 The benefits of reducing externalities

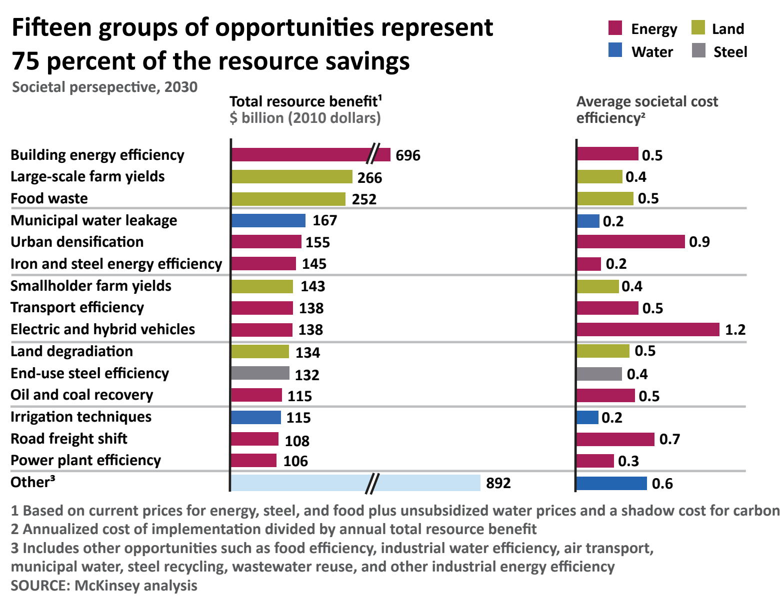
The extraction and use of resources often results in negative externalities – that is, negative impacts, for example on the environment, that are not taken into account in market transactions. Resource efficiency measures that reduce these externalities will improve economic efficiency, over and above any other benefits (such as cost savings) in which they may result.

The environmental externalities of resource use, which may also be considered subsidies to that use, are very large indeed. The IMF (Coady et al., 2015) estimated the external costs related to climate change and local air pollution from burning fossil fuels in 2015 to be around US $4 trillion. The potential global gain in economic welfare from eliminating all fossil fuel subsidies (that is, those due to both financial subsidies and externalities) is estimated to be US $1.4 trillion, equivalent to 2 per cent of global GDP in 2013. Most of this gain would accrue to the more than 50 per cent of the world's population living in Asia, which experiences a welfare gain equivalent to 6.9 per cent of regional GDP with subsidy elimination (Coady et al., 2015). Much of the required reduction in fossil fuel consumption could be achieved

through increased energy efficiency rather than reduction in energy service delivery (IEA, 2012b).

Dobbs et al. (2011) calculate that savings to society from resource efficiency would increase from US $2.9 trillion from a private investor perspective to US $3.7 trillion from a social perspective if carbon were priced at US $30 per tonne, energy taxes were eliminated, and financial subsidies to energy, agriculture and water were removed. 90 per cent of this US $3.7 trillion saving would yield an investment return of more than 4 per cent. The authors group their resource efficiency "opportunities" into 15 categories that capture approximately 75 per cent of this US $3.7 trillion saving. These categories are shown in Figure 11. Of these 15 categories, only electric and hybrid vehicles have a cost that is greater than the benefit.

Figure 11: The top 15 categories of resource efficiency potential.



Source: Dobbs et al. (2011), Exhibit 4, p. 14
Note: in the figure above, 'resource savings' refers to the financial benefits of resource efficiency

2.2.3 The macroeconomic benefits of resource efficiency

Investigations into the macroeconomic implications of increased resource efficiency have been undertaken using different models. All suggest that increasing resource efficiency yields macroeconomic benefits.
In respect of modelling studies of the macroeconomic effects of increasing energy efficiency, an example is IEA (2012b), which calculated the macroeconomic implications of its Efficient World Scenario. It found that, compared with the IEA New Policies Scenario, global GDP would increase by 0.4 per cent by 2035, with energy efficiency policies benefitting energy-importing countries, but making energy exporters worse off.

Another example is a report on the circular economy, which found that implementing resource efficiency opportunities in buildings, food waste and transport could increase European GDP by 11 per cent by 2030 and 27 per cent by 2050 in a circular scenario, compared with 4 per cent and 15 per cent under current trends (Ellen MacArthur Foundation and McKinsey Center for Business and Environment, 2015). In this case the result was driven by technical progress leading to cost reductions in the use of resources. However, it should be noted that in the execution of this modelling no account is taken of any costs that may be incurred in achieving this technical change, or overcoming the barriers to increased efficiency mentioned above (Böhringer and Rutherford, 2015).

A different macro-econometric modelling exercise undertaken for the European Commission found that resource productivity improvements of around 2 per cent to 2.5 per cent per annum could be achieved with net positive impacts on EU28 GDP (CE and BioIS, 2014). However, in this case the increase in GDP is driven not so much by the increase in resource productivity as by the policy mechanism used to bring it about – an environmental tax reform (ETR).[10] Another study using a similar model found that the resource efficiency measures increase global GDP by 5.2 per cent in 2050, while the use of abiotic raw materials falls by more than 50 per cent, driven largely by higher investment than in the reference scenario (Meyer et al., 2015).

Finally, UNEP compared the economic outcomes of Green and Business as Usual (BAU) investment paths UNEP (2011b). The

[10] The analysis assumes that: "an environmental tax such as an emission tax is used to cut GHG emissions, but revenues generated are used to stimulate the economy at the same time." (CE and BioIS, 2014, p.46).

study found that economic growth in the Green scenario became higher than that in the BAU run after about 2017, with the green investments proving more productive than the conventional investments they replaced (UNEP 2011b, Figure 14, p.523).

If increased resource efficiency leads to increased output, then other things being equal it might be expected that it would also lead to increased employment, and this is indeed the result of some studies. Thus the CE and BioIS (2014) study reports a 1 per cent increase in EU employment (about 2 million net extra jobs) in its resource efficiency scenario by 2030, with similar gains reported by Meyer et al. (2015). In the UNEP (2011b) Green scenario, global employment is 0.6 per cent (21 million) lower in 2020 than in the comparable BAU case, but 28 million higher by 2050. A report by the Club of Rome that uses an input-output model rather than a full macroeconomic model finds that measures to increase energy and resource efficiency, and the deployment of renewables, can reduce unemployment by up to a third in the five European countries studied (Wijkman and Skånberg, 2015)

It should be noted that, if increased resource efficiency is achieved, there is a danger that the economic growth it has stimulated will increase resource use and environmental impacts through what is called the "rebound effect". This arises because money saved through resource efficiency can be spent either on more of the same good or service, or on other goods or services, both of which may increase resource use. Rebound effects can be mitigated by policy measures (Herring and Sorrell, 2009), most obviously where these measures increase the cost of the resource that has been the subject of the efficiency measure (for example, through resource or environmental taxation). This will be required where the objective of resource efficiency improvements is actually to reduce the quantity of resources used or its associated environmental impacts by a given amount (for example, if increases in energy efficiency are intended to aid the attainment of fixed carbon reduction targets), and explains why publications focusing on green growth or increased resource efficiency often advocate a shift of taxation from labour or capital to pollution or the use of resources (for example, OECD, 2015; UNIDO, 2013; World Bank, 2015). Macroeconomic modelling results such as those reported above should include any rebound effects, which are likely to counteract to some extent the impact of resource efficiency on reducing consumption and related environmental impacts.

3. Best practices for increasing resource efficiency

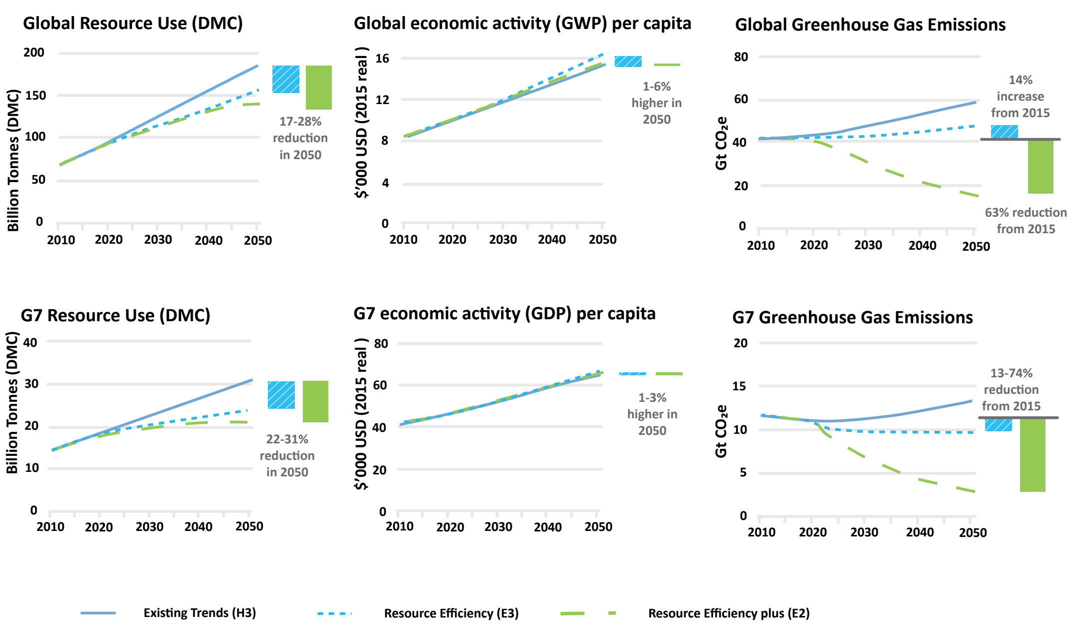
The modelling studies cited in the previous section differ in the size of their estimates, but all of them show that increasing resource efficiency can lead to higher economic growth and employment, for most of them even when environmental benefits are not taken into account.

Original economic modelling of resource efficiency carried out for this study further confirms such trends. The novel analysis adopts an integrated multi-model framework to explore potential future pathways for global resource use, greenhouse emissions, and economic activity to 2050, through ambitious action to improve resource efficiency and address climate change.[11] The results of this work are summarised in the six graphs of Figure 12, which show that there is substantial potential to achieve economically attractive resource efficiency, providing win-win outcomes that reduce

[11]The scenario projections are developed using a multi-model framework, linking a global computable general equilibrium (CGE) economic model (GTEM) to two other models: GLOBOIM, providing additional detail on land use and biofuels, and MEFISTO, a stock-flow model providing insights into resource efficiency potential. This builds on internationally recognized integrated nexus modelling approach used in the Australian National Outlook (see Hatfield-Dodds et al. 2015). Further details of the analytical approach and results of this modelling exercise will feature in the forthcoming full IRP Assessment Report summarized here (UNEP, 2017).

environmental pressures while increasing economic growth. The modelling projects that, under existing trends, natural resource extraction will increase from 85 to 186 billion tonnes over the next 34 years to 2050 (top left graph), reflecting a 28 per cent increase in population and a 71 per cent increase in per capita resource use. In contrast, the modelling

Figure 12: Global and G7 projected resource use, economic activity and GHG emissions under existing trends, resource efficiency policies, and resource efficiency plus a 2°C climate pathway, 2010-2050.



Policy impacts are for Resource Efficiency (blue stripes) and Efficiency Plus (green solid) scenarios in 2050, relative to 2015 or to Existing Trends scenarios in 2050

Source: UNEP (2017).

suggests that resource efficiency policies and initiatives alone could reduce global resource extraction by around 17 per cent globally in 2050 (top left graph), against the baseline. When resource efficiency is implemented in combination with ambitious global action on climate change, global resource extraction can be reduced even further by up to 28 per cent, compared to existing trends (top left graph). In this scenario, the modelling also finds that the stronger economic growth associated with resource efficiency policies more than offsets the near-term economic costs of ambitious climate action, helping to achieve emission reductions of 74 per cent globally in 2050, compared to the baseline. This reflects a reduction of around 60 per cent of global GHG emissions in 2050 relative to 2015 (top right graph). G7 nations could see their emissions fall by up to 74 per cent by 2050, compared to levels in 2015 (bottom right graph).

Though analysis of policy options to support resource efficiency improvements is beyond the scope of this report,[12] it nonetheless provides valuable information and knowledge for policy-makers and other stakeholders on how increased resource efficiency can be realized in practice. The ensuing part of the report presents examples of how barriers to increased resource efficiency are being successfully addressed, through international and national programmes, the implementation of new concepts, and the committed actions of local and national governments, businesses and citizens and communities. The main part of this section explores best-practice examples of how resource efficiency has been successfully increased across the four main categories of resources – materials, land and soils, water, and energy. It concludes by stressing the importance of cross-cutting, systemic or “resource nexus” issues.

3.1 Overcoming barriers to resource efficiency

Section 2 of this report showed that there are market and organizational failures and hidden costs that prevent increases in resource efficiency, even when they seem to be cost-effective. But there are many other barriers to resource efficiency that arise because of the basic difference between economic efficiency, as expressed through well-functioning markets, and resource efficiency, expressed through low wastage of materials and their retention of value over long periods of time.

[12] This task is being undertaken by the Organisation for Economic Co-operation and Development (OECD), which was invited by the G7 to develop policy guidance to supplement the IRP’s scientific synthesis report on *Resource Efficiency: Potential and Economic Implications.*

The most important of these barriers arises because of the relatively low cost of materials and of generating waste, compared to the costs of labour and logistics. Components and products could in many cases be designed with less material to meet their design purpose, with less material wastage during the manufacturing process, to last longer and to be repaired more easily. However, this sometimes does not happen because the added costs in terms of labour and logistics to design, manage and repair the components and products does not justify the saved material cost or the avoidance of a new purchase. For example, in the construction sector, materials are often found to be over-specified beyond the needs of the safety standards (UNEP, 2014b). Material wastage during manufacture of products and components can also occur when parts are cut from standardized intermediate products such as metal sheets, leaving as much as half of the original material behind as waste. In many situations, "counter to expectations, it makes good business sense to over-specify materials when doing so allows a greater saving in labour costs, and this is a difficult issue to overcome" (Allwood, 2014).

There are also innumerable examples in daily experience of when it is cheaper to throw away even relatively new products than to have them repaired, even when repair is possible. Such resource-inefficient outcomes frequently reflect an economically efficient calculus of the relative magnitude of the costs of materials, and the costs of design, logistics and repair.

Remedying such situations requires public policies either that change directly the relative prices of labour and materials, for example through reduced labour and increased resource taxation, or which in other ways give greater value to materials during and at the end of the lives of the components and products in which they are embodied. Such policies are outside the scope of this report, but it should be noted that it will be impossible to achieve considerable increases in resource efficiency across the economy in their absence.

3.2 Initiatives and programmes for increased resource efficiency

There are numerous international programmes and initiatives to increase resource efficiency, and even more at national levels. This report mentions a few important initiatives to exemplify what public policy and committed corporate and citizen action can achieve.

One of the most systematic approaches to increasing resource efficiency at the international level has been through the concept of Sustainable Consumption and Production (SCP). The 10-Year Framework

of Programmes on Sustainable Consumption and Production (10YFP) was adopted at the Rio+20 conference in 2012 as a mechanism for achieving this shift in consumption and production patterns (UN, 2012). The 10YFP programmes are organized around thematic areas, which aim to build capacity to implement policies, voluntary instruments, management practices, information and awareness-raising activities to promote the shift to SCP patterns. Another global programme is the Resource Efficient and Cleaner Production (RECP) initiative, which seeks to improve industrial productivity while reducing industry's dependence on natural resources and diminishing the generation of waste and harmful emissions. There are now around 60 National Cleaner Production Centres that pursue RECP practices in many developing and transition economies. Activities include industrial waste minimization, eco-innovation, eco-industrial parks, transfer of environmentally sound technologies, responsible production and safe and innovative chemicals management (including chemical leasing), new business models, water stewardship, life-cycle based approaches, product and organizational foot-printing, eco-labelling and corporate reposting (UNEP, 2016a; UNIDO and UNEP, 2015).

The idea of a "circular economy" is also promoted internationally, including by China, the European Commission, Japan and many others. A recent example is the initiative of the Ellen MacArthur Foundation. The Foundation – which defines circular economy as "one that is restorative and regenerative by design, and which aims to keep products, components and materials at their highest utility and value at all times, distinguishing between technical and

biological cycles" – works through a number of programmes. These seek to bring together businesses, governments, cities and universities, so as to accelerate a shift towards and build capacity around a circular economy (Ellen MacArthur Foundation, 2016).

China adopted the Circular Economy Promotion Law in 2008. The legislation aims to decrease the use, and maximize the recycling and recovery of materials in production and consumption. As part of its implementation, the country has launched a large number of programmes and projects.[13]

In 2015 the European Commission adopted a Circular Economy Package to stimulate the transition of European businesses and consumers towards a circular economy, where resources are used in a more sustainable manner. The mix of regulation and incentives to encourage greater recycling and reuse is envisaged to help protect the environment and mitigate climate change, alongside fostering economic growth, job creation, investment and social fairness (European Commission, 2015).

Many countries have found it useful to frame their policies for resource efficiency in terms of a resource management hierarchy, one of the most influential of which has been "the 3Rs" – reduce, reuse, recycle. In the context of the G7, the 3R concept has played a key role within resource efficiency strategies. The 3R Initiative to encourage more efficient use of resources and materials was launched at the 3R Ministerial Conference in Tokyo in April 2005 (Moriguchi, 2007; Takiguchi and Takemoto, 2008). Later in 2008, the Kobe 3R Action Plan was adopted under the Japanese presidency of the G8.

The 3Rs concept can of course be built upon and expanded. Each of the terms can be considered a broad designator for a variety of activities. In Japan, the sound material-cycle society (SMCS) policy sets out five steps in order of priority: reduce, reuse, recycle, energy recovery and final disposal. A similar waste hierarchy is adopted in the EU's Waste Framework Directive.

The Kobe 3R Action Plan was also the building block for the G7 Alliance on Resource Efficiency, established in 2015 as a forum to share knowledge, and to collaborate with businesses, small and medium enterprises (SMEs) and other relevant stakeholders to advance resource efficiency opportunities, practices and innovation (G7, 2015).

[13] Circular Economy Promotion Law of the People's Republic of China, http://www.fdi.gov.cn/1800000121_39_597_0_7.html

3.3 Best practice examples of successful resource efficiency

The ensuing part of the report documents a number of best practices and solutions for increasing resource efficiency. It distinguishes between different categories of resources (namely, materials, land and soils, water, and energy), but without losing sight of their critical and complex interactions, synergies and trade-offs.

3.3.1 Materials

In the area of materials, recycling has to date received the greater part of policy attention through national and local government strategies and targets. However, governments are becoming increasingly aware of the benefits of moving upwards through the resource management hierarchy, and seeing material efficiency policy not just as a fixed target, but as a transition path. Ideally, reducing demand would be the first priority of material management strategies, as it reduces the energy use and environmental impacts of extracting and processing materials. Experience in Germany suggests that, with guidance, improving material efficiency can yield quick benefits for some businesses. The German government's material efficiency agency (demea) offers quantified material flow analysis to help small and medium-sized enterprises (SMEs) to identify material savings potentials. On average, companies saved 2.3 per cent of annual company turnover, with smaller companies saving a greater proportion. Investments generally paid off within 13 months (UNIDO, 2013).

More substantial material reductions in product manufacturing are likely through improved innovative design approaches. An important development in this regard may be advances in 3D printing. This allows highly customized components to be produced to specification with no wastage. General Electric is now producing nozzles for jet engines in this manner, with significant material saving reducing the weight of the component by 25 per cent (Despeisse and Ford, 2015). Computerization can also assist better design of the arrangement of blanks to fit more closely on a fixed width sheet, reducing material wastage during component manufacturing. Such techniques are used in the textile industry and are also being adopted for metals (Allwood, 2014; UNEP, 2014b).

Synergies between companies also offer potential for mutual benefit. For example, Abbey Steel in the UK has found a niche using off-cuts left over from material blanking sheets. It purchases blanking scrap from car body manufacturers and cuts it into regular blanks for manufacturers of smaller components

(Allwood, 2014). This is an example of industrial symbiosis.[14]

The industrial symbiosis concept is also at the heart of the Japanese Eco-Town programme, which has led to the establishment of 26 Eco-Towns across Japan. The aim of this government-led programme was to reduce waste going to landfill sites, of which there was a serious shortage, and to regenerate local industries. As such a key strategy was the conversion of waste from one industrial process into a valuable input for another (Van Berkel et al., 2009).

For example, the Kawasaki Eco-Town "aims primarily for effective utilization of residential, commercial and industrial wastes generated in the city and recycling these into raw materials that can be used by industries located in the city (for example, cement and iron and steel works)" (Van Berkel et al., 2009). Specific examples of recycling activities in Kawasaki are recycling of plastic as a reductant for blast furnaces, for concrete formwork and for ammonia production; as well as paper recycling and PET-to-PET[15] plastic recycling. As well as reducing material waste, Dong et al. (2014) estimate that the industrial symbiosis strategy

[14] The classic definition of industrial symbiosis comes from Chertow (2000, p.313): "[I]ndustrial symbiosis engages traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water and by-products." There are numerous case studies of successful applications of industrial symbiosis, through the work of the National Industrial Symbiosis Programme (NISP), which was pioneered in the UK but has now been replicated across 25 countries (see NISP 2009 and http://www.nispnetwork.com/media-centre/case-studies).

[15] PET stands for polyethylene terephthalate.

in Kawasaki reduced life-cycle carbon emissions by around 14 per cent, mainly from iron and steel, cement and paper manufacture.

As a result of government subsidies, 61 recycling facilities have been established across the 26 Eco-Towns, with a combined capacity of nearly 2 million tonnes of waste per year. However, Van Berkel et al. (2009) find that for every government-subsidized recycling plant, a further 1.5 plants were built by the private sector without subsidy. This suggests that government actions to establish an industrial symbiosis "ecosystem" can act as a springboard for further private sector-led development of environmental industries.

Industrial symbiosis is also well established in other countries. In the case of China, Yu et al. (2014) report on the Xinfa group of industries, a cluster of various process plants with aluminium production at its core. The cluster has established 11 industrial symbiosis links, including coal ash from power plants used to make bricks; carbide slag used as a substitute for slaked lime in alumina production; carbon monoxide off-gas from the calcium carbide factory burned for energy; red mud from alumina production reused as a building material. The measures have been estimated to reduce carbon emissions by 11 per cent (Yu et al., 2014; Yu et al., 2015).

Park et al. (2016) report on the first phase of the Eco-Industrial Park (EIP) programme in Korea, from 2005 to 2010. The projects involved product, energy and water reuse between industries. They calculate that the 47 projects reduced material waste by 477,633 tonnes, as well as saving energy and reducing emissions and wastewater. The projects also generated around US $97 million of cost reduction from energy and material savings, and US $92 million of revenue generation from selling by-products. The authors observe that projects to generate revenue from by-products tend to have a higher rate of return than projects to generate savings from material and energy efficiencies, due to the larger upfront investment typically required in the latter case (Park et al., 2016).

Remanufacturing is another concept with growing interest. It involves the disassembly of product components and their remanufacture into modules or products with "as new" qualities. Potential barriers to remanufacturing are the public perception of the goods as second hand, regulations that inhibit re-entry of material once classified as waste into the supply chain, as well as market access restrictions of remanufactured products.

Allwood et al. (2011) list some examples of remanufacturing, including remanufacturing of engine blocks, tyre remanufacture, the remanufacture of appliances, packaging and automotive parts. A related observation is that "successful remanufacturing tends to occur in more vertically integrated companies, but it is not clear if this is cause or effect". Products that have been amenable to successful remanufacturing "are typically at the mature end of their life cycle, in a market with slow technology development" (Allwood et al., 2011, p. 370). This guards against components becoming redundant before the remanufacturing cycle is complete.
The frequent coincidence of remanufacturing with vertical integration and mature technologies suggest that potential barriers, in addition to waste regulation, may be the multi-actor and fast-evolving nature of many product markets and their supply chains. Considerable attention to cross- and within-industry coordination and communication between various, sometimes competing, actors, may be crucial to facilitate further development of this promising area.

Many of the novel approaches to material efficiency discussed in this section could be assisted by the emergence of new business models. Product service systems such as leasing are important and widely transferable models. In general terms, rather than a customer buying and owning an individual product, a leasing model involves a customer contracting with

a company for the provision of a service. The ongoing contract places a greater incentive on the company to design and provide products that can be operated, maintained or replaced in a more resource-efficient manner. Examples of leasing models can be seen in car-sharing clubs, building services and office supplies (UNIDO, 2013; WRAP, 2016a). At the industrial scale an interesting example is chemical leasing. With chemical leasing the producer sells the functions performed by the chemicals – such as number of pieces cleaned, or area of products coated – rather than the chemicals themselves. The responsibility of the producer is thus extended “and may include the management of the entire life-cycle” of the chemical products (UNIDO, 2013). One such project, reported by Erbel (2008), is a collaboration between PERO, an Austrian manufacturer of metal-cleaning machines, and SAFECHEM, a subsidiary of the Dow Chemical Company of Düsseldorf, Germany.

These partners were contracted to provide chemical cleaning services for an Austrian manufacturer of car parts, Automobiltechnik Blau. The model allowed the customer to outsource the chemical cleaning activities that were not within its core competencies. The stability of the contract enabled the contractors to invest in high-quality cleaning equipment, which would not normally be chosen in typical market conditions due to their high upfront cost, but which yield longer-term returns. This pilot project was expected to be generating positive returns by its second year. It is estimated that arrangements of this kind can reduce energy use by around 50 per cent and solvent use by around 70 per cent (Erbel, 2008).

Recycling rates vary highly among countries for administrative, economic and technical reasons. For some countries lack of access to and cost of technologies are a barrier. Recycling rates also vary among materials, largely driven by the convenience with which the materials can be accessed from waste streams, and the value of those materials. Recycling rates of some bulk metals such as iron, zinc, copper and aluminium are already high (60 to 90 per cent), and rates for precious metals such as gold, silver and platinum are also quite high (50 to 70 per cent) (UNEP, 2015a). Recycling of bulk metals has significant energy benefits compared to production from extracted raw material: steel, copper, and aluminium recycling can reduce 60-75 per cent, 84-88 per cent, and 90-97 per cent of energy used for primary metal production, respectively (UNEP, 2013b). However, according to a study by UNEP (2011c), less than one-third of some 60 metals studied have an end-of-life recycling rate above 50 per cent and 34 elements are below one per cent recycling. Specialty metals such as lithium, gallium, germanium, indium

and tellurium are amongst those with lower recycling rates. They are typically used in very small quantities in individual products, which are often not designed in a way that facilitates disassembly for recycling. They also do not have the inherent value of precious metals, so that there is insufficient economic incentive to collect, extract and recycle them. Increases in the recycling rates of such metals may be facilitated if products were designed with a view to their disassembly and recycling at the end of their lives. Recycling of specialty metals may become increasingly important as a number of such metals are key constituents of low-carbon technologies such as solar PV cells, wind turbines and batteries.

Incentives for resource efficiency are also important for waste management. For example, in the 1990s the great majority of UK waste was sent to landfills, because this was the cheapest mode of waste disposal, once the costs of collection and infrastructure for recycling were taken into account. In 1996 the UK introduced a landfill tax for non-inert waste at the rate of GBP £7 per tonne, which increased steadily in the following years, reaching GBP £82 per tonne in 2015. Recycling rates in the UK have also increased greatly, reaching nearly 45 per cent for household waste in 2014,[16] while the overall proportion of UK waste that was landfilled in 2012 was 26 per cent.[17] While other policies will certainly have contributed to this major change in waste management practices, the landfill tax is likely to have played a very significant role.

Zero Waste Europe reported two case studies from different regions of Northern Italy. In the town of Capannori and in the city of Treviso, rates of domestic waste segregation for recycling now exceed 80 per cent. In both areas, residents segregate their recyclable waste into multiple streams. They are incentivized by "pay as you throw" systems, under which they are charged according to the weight of non-recyclable waste. Incentives are also provided in both municipalities to encourage composting. Transparency and communication are also important to the success of the schemes. In Capannori residents were extensively consulted and provided with information prior to the introduction of the measures, and in Treviso an online database allows residents to track what waste has been collected from them and to understand how their charges have been calculated (Simon, 2015; Van Vliet, 2013).

[16] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/496508/Digest_waste_resource_2016_v2.pdf

[17] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/487916/UK_Statistics_on_Waste_statistical_notice_15_12_2015_update_f2.pdf

3.3.2 Land and soils

As noted in Section 2, continuation of current trends in land degradation could result in a considerable loss of arable land and need for further cropland expansion. Hence, the restoration of degraded agricultural land, and the protection of currently stable or mildly degraded land through practices that retain soil nutrients, are important strategies towards improving the overall productivity of agriculture whilst reducing resource and environmental impacts. UNEP (2014a) estimate that a mix of such resource efficiency strategies could reduce the projected 320-849 Mha increase in gross global cropland shown in Figure 8 by about 160-320 Mha.

High-input agricultural systems tend to entail greater environmental impacts, and may in any case be unaffordable for low-income farmers. Monteith (1990) describes a sustainable land management system as one in which “outputs do not decrease when inputs are not increased”. There are a number of integrated approaches that aim towards this ideal, such as agro-ecological approaches, conservation agriculture, organic agriculture, agroforestry and integrated

crop-livestock systems (FAO, 2011). As one example, Altieri (2002) identifies a number of principles of sustainable agroecology:

- Recycle and reuse all available biomass within the farming system.
- Grow plants by building soils, soil organic material and biotic activity.
- Minimize soil losses by protecting from direct solar radiation, strong winds and erosive water flows.
- Maximize diversity to increase resilience.
- Enhance biological interactions and synergies.

The specifics of implementing these principles vary in different contexts. Plant diversity has been shown to improve soil health, nutrient cycling and biodiversity – for example the planting of legumes among other crops can enhance nitrogen fixation. Planting trees alongside crops can improve soil fertility through nitrogen fixation, by creating more soil organic matter, and due to the fertilizing effect of dung from animals that graze in the shade of the tree. In Zambia, 160,000 famers have planted nitrogen-fixing acacia trees among their crops. They shed their leaves during the early rainy season and remain dormant during the crop-growing period. This means they do not compete for light, nutrients or water during the crop growing season. According to Zambia's Conservation Farming Unit, maize yields from fields planted with acacias averaged 4.1 t/ha, compared to 1.3 t/ha outside of the tree canopy (FAO, 2011).

Zero- or no-till practices can help to protect soils and reduce moisture loss. The benefits of reusing all available biomass may pay particular dividends in integrated crop-livestock systems. In such systems manure from livestock may be transferred to the soil to improve its fertility, and crop residues may provide additional feed for animals (FAO, 2011).

Restoring degraded land can be capital-intensive, and this can constitute a barrier in regions where the ownership of land is not clear, and where farmers occupying the land do not have the capital to make the required investments. However, many of the principles described above do not necessarily require major capital investment. Nonetheless, they do require knowledge, in order to implement the right combination of measures given each specific context, to maximize synergies. Thus, another important barrier is lack of information and education. As UNEP (2014a) notes, "there is a large need to expand the outreach and extension education efforts to ensure that research results on improved management practices are transferred and adopted rapidly by farmers".

Numerous efforts to improve farming practices focus on improving knowledge sharing and communication between farmers. In many cases progress can be made with interventions of low capital intensity. For example, projects in Tanzania and Malawi showed the importance of networking between farmers for disseminating knowledge (Majule, 2011). "Plant clinics" have been set up in 14 countries, as local meeting places where farmers can seek advice from local experts. Boa and Bentley (2009) estimate increases of income averaging US $801 per hectare for farmers receiving advice from plant clinics. In Central America, the Campesino a Campesino (farmer to farmer) network is another example of knowledge sharing (UNEP, 2014a).

The most cost-effective strategy for sustainably increasing production is often simply better matching land use with land potential through effective land use planning (UNEP, 2014a). This both limits the need for restoration by minimizing degradation, and focuses intensification and climate change adaptation investments where they are likely to yield the highest financial returns (Herrick et al., 2016).

There are numerous environmental benefits associated with less-intensive farming methods. In a comparison of conventional and organic farming systems, Hülsbergen and Küstermann (2007) found the GHG emissions to be three times higher in the conventional case. However, in developed countries the market pressures and tight margins experienced by farmers mean that high-input systems are incentivized. A challenge of organic farming in this context is that yields can be significantly lower, depending on soil type and other conditions (Seufert et al., 2012). However, Ponisio et al. (2014) find that diversification techniques such as multi-cropping and crop rotation can substantially reduce the yield gap between organic and conventional systems.

In the EU context, Buckwell et al. (2014) also call for "added knowledge which will affect how physical inputs are combined and managed", or in shorthand "more knowledge per hectare". Buckwell et al. (2014) report on a study by Elliot et al. (2013) comparing 20 UK farms on five indicators: food production intensity, carbon footprint, nitrate losses to water, ammonia losses to air and biodiversity. One of the farms (a mixed farm) was performing well on all indicators, and three others were performing well on at least three criteria and moderately on the others. The study shows, first of all, that measuring performance is possible and may be a useful guide to improving performance; it also shows that good performance across a range of environmental criteria at the same time as achieving high food productivity is possible.

Buckwell et al. (2014) describe this outcome as "sustainable intensification".

Nutrient loss from soils can be mitigated by efforts to recapture nutrients from food chain waste, as well as other waste streams, and reapply them to soils. Senthilkumar et al. (2014) report that, in the case of France, the recycling efficiency of phosphorus is 51 per cent across all waste streams. BMUB (2012) reports that the German government is examining potential measures to increase rates of phosphorus recovery from waste streams such as sewage sludge, waste water, slurry and fermentation residues. Significant dissipation of phosphorus also occurs in industrial processes. In Japan the quantity of phosphorus contained in dephosphorization slag from steel making is comparable to its total imports of phosphate ore. Technologies are being proposed to recover phosphorus from this source, which could create a significant new phosphorus stream (UNEP, 2013c).

Health, climate and land pressure issues can all be ameliorated by reducing the over-consumption of meat, and excess calories more generally. Barriers to progress in this area are the preference and increasing ability of people to pay for meat-intensive diets; the low prices of meat available through mass production; and general habits and cultural factors. However, a potential "win-win" is that less resource-intensive diets would in many cases have significant health benefits to the individuals concerned. In particular, meat consumption in most industrialized nations is much higher than is deemed to be healthy. In the EU currently, protein intake is 70 per cent higher, and saturated fats 42 per cent higher, than the World Health Organization (WHO) recommendation (WHO, 2007); red meat consumption is more than twice the maximum recommended by the World Cancer Research Fund (WCRF and AICR, 2007; Westhoek et al., 2015).

The provision of nutritional guidelines is a clear way to address this issue. For example, the official Nordic nutritional recommendations give strong guidance towards less meat-intensive diets, citing environmental arguments as well as health reasons (Fogelholm, 2013). There are examples of voluntary information-raising schemes that aim to improve consumers' understanding of healthy diets. One example is the "Livewell for Life" project (WWF and Friends of Europe, 2015). This makes suggestions for different healthy diet combinations, tailored to the cooking cultures of three different countries – France, Spain and Sweden. As well as being nutritionally beneficial, it is calculated that the proposed country-specific "LiveWell plates" if widely adopted would cut GHGs

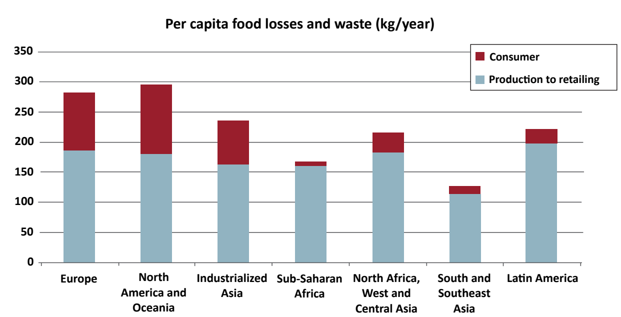
from food supply chains by 25 per cent by 2020. There is currently very little information about what, if any, impact such schemes have had – nonetheless there seems to be very substantial potential for co-benefits of improved health from more resource-efficient diets.

Reduction of food waste is also a major resource efficiency opportunity. Figure 13 shows the quantities of food losses and waste per capita, at consumption and pre-consumption stages, in different world regions. It shows that there are high levels of consumer waste (consumers throwing away unwanted food) in industrialized countries. Supply chain waste is also significant in industrialized countries, due to economies of scale and the "supermarketization" process, where high levels of waste are a by-product of a system geared towards ensuring shelves are continuously stocked with products that meet high uniform cosmetic standards, as well as basic food quality standards.

The Courtauld Commitment, convened by WRAP in the UK, is an agreement among retailers and suppliers designed to reduce waste. During its second phase (2010-2012) it worked with retailers to reduce packaging and increase the shelf-life and fridge-life of foods. It reports that during the same period, food packaging was reduced by 10 per cent, wasted household food and drink by 3.7 per cent, and supply chain wastage by 7.4 per cent (WRAP, 2016b).

Supply chain waste also occurs in developing countries. Feedback (2015) reports on factors driving food wastage in the Kenyan horticultural export sector, which include the need to discard edible food due to exacting cosmetic specifications, market volatility causing cancellation of orders after crops have been grown, and the lack of domestic markets for export products. One example is given of the effectiveness of simply relaxing cosmetic standards. Supermarket retailers of French

Figure 13: Per capita food losses and waste, at consumption and pre-consumption stages, in different regions.



Source: Gustavsson et al. (2011)

beans typically require the beans to be of a specific length to fit uniformly into packaging. This means that farmers must grow long bean varieties and then “top and tail” them to the required length. Feedback (2015) report that this results in an average wastage of 30-40 per cent of the usable mass of beans. However, one major customer was persuaded to change its buying policy and opt for just topped beans, enabling Kenyan exporters to reduce waste by a third. Further gains would be available if “topping” of French beans were also eliminated; and more still, if cosmetic standards on other products were also relaxed.

Supply chain waste in developing countries can also be caused by poor storage and processing conditions. In such cases, significant resource efficiency gains may be available with relatively simple measures. The Rathkerewwa Dessicated Coconut mill in Sri Lanka was assisted under UNIDO’s RECP programme to identify material efficiency measures. These included laying rubber carpets on the floor of the loading bays to reduce the likelihood of damage to coconuts during loading and unloading, which would cause them to be thrown away; awareness raising among employees to avoid waste at the paring stage; reduction of wash water; and re-using coconut shells to fire the boiler. These measures enabled significant reductions of biomass wastage, and also saved energy. The combined measures provided savings of US $200,000 for an investment of less than US $5,000 (UNIDO, 2013).

3.3.3 Water

There are examples of relative and absolute decoupling of water use from GDP, particularly in countries and cities in which water shortage and scarcity are issues of concern. Between 2001 and 2009 Australia’s GDP grew by 30 per cent, while its water consumption reduced by around 40 per cent. This was achieved at negligible cost, through cost-effective measures in water efficiency and demand reduction (UNEP, 2014b).

Around 70 per cent of water extraction is for agriculture, hence more efficient irrigation techniques offer major potential for water saving. Frequently such techniques also offer the co-benefit of increasing agricultural yields. Compared to traditional flood irrigation, irrigation techniques such as sprinklers or drip irrigation can reduce water consumption and increase yields, by applying the irrigation more directly to where it is needed. Drip irrigation involves providing water through a system of perforated pipes that are laid on or beneath the ground. Water drips slowly through the perforations directly to the roots of the crop

(Rejwan, 2011). Dobbs et al. (2011) estimate that sprinklers can reduce water use by 15 per cent while increasing yields by 5 per cent to 20 per cent, and drip irrigation can reduce water use by 20 per cent to 60 per cent, while increasing yields by 15 per cent to 30 per cent. However, this is dependent on soils, crop, climate and how the irrigation system is implemented (van der Kooij et al., 2013). Sustaining drip irrigation systems is limited in many areas by salinization associated with soil and water quality issues (Hanson and May, 2011).

In Israel, major constraints on water supply have encouraged a range of water-saving innovations. About 84 per cent of the country's domestic wastewater is reclaimed for irrigation purposes. This helps to ensure that about 52 per cent of agricultural water demand comes from non-potable sources – the domestic wastewater supplemented with brackish (salty) water. Israel has extensively adopted drip irrigation in its agriculture sector, in combination with computerized control systems that provide the exact required amount of water directly to the plant roots. The uptake of water efficiency measures across sectors is stimulated by a range of incentives as well as penalties targeted at different users. A water quota system for farmers places a strict limit on consumption of potable water, but also rewards under-consumption. For domestic users, differentiated tariffs are available, allowing low users to benefit from a lower charge, with extensive metering providing consumers with the information to monitor their consumption. Farmers benefit from a lower tariff for using non-potable water for irrigation. Incentives and penalties are also directed at the water supply utilities, who are charged for avoidable losses. They are allowed to keep low water pressures as this reduces leak-loss rates. The government also supports the research and development of new technological innovations in the area of irrigation (Rejwan, 2011).

Significant barriers to the application of advanced irrigation techniques include lack of information and lack of capital to invest in such technologies, especially for smallholders and farmers on marginal land. However, there are other less capital-intensive ways of achieving a similar aim. Tensiometers are devices that can precisely measure the moisture content of the soil, thus allowing more precise irrigation. These have been employed by rice farmers in Punjab, India, who have reported 33 per cent water savings (UNEP, 2014a). "Smart irrigation scheduling" aims to provide the specific amount of required water at the specific time it is required, to avoid over-irrigating (McCready et al., 2009). Modern ICTs have also been used in Uganda to enable farmers to access information on weather forecasts, improving

timing of irrigation and water management (UNCTAD, 2011).

Even relatively simple interventions, where advanced technologies are not available, can improve water efficiency. Action Aid report that in West Africa stone barriers built alongside fields can reduce the flow of water runoff during the rainy season. This improves soil moisture, reduces soil erosion and replenishes groundwater. This simple technique can improve water retention by the land by 5 to 10 times, and the biomass yield by as much as 10 to 15 times where runoff can be captured from upslope areas (ActionAid, 2011). Other effective soil moisture management techniques for rain-fed areas are structures such as furrows, vegetative strips or bench terraces (FAO, 2011).

Reducing water consumption in toilets and bathrooms, and reducing leakages in the pipeline distribution system, are considered the most efficient approaches to water conservation in urban areas (Sharma and Vairavamoorthy, 2009). Specific technologies include low-consumption toilets, low-flow showers and water-saving sinks (Sharma and Vairavamoorthy, 2009). Fittings on appliances that reduce their water flow have been implemented in Australia in cities such as Melbourne (UNEP, 2013a); in New South Wales, new building developments and renovations must submit a certificate showing 40 per cent reduction in potable water use (Burgin and Webb, 2011).

Reducing leaks from water supply is also a priority in many areas. Water losses due to leaks and unaccounted flows range widely, with estimates ranging from 5 per cent to 80 per cent of supply. The variation depends on the level of infrastructure development, as well as management and operational practices (UNEP, 2016b). Dobbs et al. (2011) estimate that there is significant potential to reduce water leakage from municipal sources, calculating that 100-120 billion cubic metres of water could be saved by 2030 as a result of reducing leakages in the supply to commercial, residential and public buildings. Persistence of high water losses has been linked to lack of revenue collection for water. The World Bank estimates that 40 per cent of water produced in Indian cities is either lost in leaks or not billed to the customer (Agrawal, 2008), and UNEP estimates that non-revenue water proportions can be as high as 70 per cent in some countries (UNEP, 2014b). Also due to lack of revenue collection, water utilities may have little incentive or available capital to make timely investments in infrastructure (Dobbs et al., 2011).

Water is subsidized in many countries. Kochhar et al. (2015) estimate that in 2012 global

water subsidies totalled $456 billion. This means that there is little incentive to conserve water, and if the utility is unable to capture sufficient revenue to enable re-investment in the infrastructure, this can in the long run make the efficiency of the system even worse, and undermine its financial sustainability. Kochhar et al. (2015) note that whereas "getting incentives right, notably by reforming water pricing, can help rationalize water use, promote needed investment, and protect the poor", subsidies may in contrast be inequitable, as they disproportionally benefit upper-income groups, who have better access to, and use more water. If the purpose of the subsidy is to protect the access of the poor to water, this can be achieved in other ways that are more cost-effective, provide funds for re-investment and maintain incentives for conservation.

In the Paraiba do Sul river watershed in south-east Brazil, gradual increases in the price of water began in 2003. The higher prices increased the income earned by the water utility, which then invested the additional money into water management. The higher prices also prompted more water conservation – extraction was reduced by 16 per cent and consumption by 29 per cent between 2006 and 2008. Companies were motivated to invest in water-saving and reuse technologies (UNEP, 2014a).

An important principle for further improving the efficiency of water use is that of cascading

uses of water. This principle suggests that not all uses of water will require a water quality as high as that required for drinking water. Harvested rainwater can be used for various purposes, and is now common in Australia (Burgin and Webb, 2011). Grey water – water that has been used for washing – can be reused without treatment for other uses, such as watering plants or flushing toilets. More than half of all households in Australia reuse grey water in some form (Maheshwari, 2006). In California in the mid-1990s, grey water was used for irrigating landscapes, golf courses and crops, supplying industrial processes and flushing toilets (Weizsäcker et al., 2009). In Accra, Ghana, a kind of cascading water use has emerged, albeit an unsafe one – domestic wastewater was flowing untreated through streams that were the primary source of irrigation for small-scale urban farmers. A project intervened to set up a low-cost natural treatment system to treat the wastewater sufficiently to make it safe for irrigative uses (Reymond et al., 2009). If contaminants can be removed to avoid health risks, wastewater can be highly suited to irrigation, as it has the advantage of being rich in nutrients (FAO, 2011).

Given the trends of population increase and urbanization, efficient use and application of water, and its reuse through recycling or cascading systems, as discussed above, are crucial strategies. However water-use efficiency has to be seen in the context of the complete hydrological cycle. In those parts of the world where withdrawals of groundwater are unsustainable (FAO, 2011; WWAP, 2015), sub-basin level recharge strategies, including watershed management, have to be made part of water-use efficiency.

Rivers and oceans are also sources of biomass, and in many cases these are being depleted at unsustainable rates. As discussed in Section 2, the majority of the world's commercial fisheries are either fully fished or over-fished. The problem is a result of a complex food system comprising multiple actors from fishermen to retailers, food companies and consumers, all of whom are locked into a highly competitive market in which typically only price matters. One possible response to this is shown in the emergence of quality assurance labels and standards, such as the Marine Stewardship Council (MSC) label. This label is intended to signify to consumers that the product was responsibly caught from a sustainable source (MSC, 2016). Information labels such as this can enable consumers to make sustainability-led purchasing decisions. In highly competitive industries this opens up the possibility for consumers to drive the industry in a more sustainable direction.

3.3.4 Energy

Energy use is the largest source of demand for fossil fuels. Therefore the energy sector has a central role in addressing climate change, as well as other environmental impacts associated with fossil fuel use. Scenarios produced by bodies such as the IPCC and IEA show the importance of technological change in energy systems to replace fossil fuel energy sources with low-carbon alternatives. However, such scenarios also emphasize the importance of demand reduction (IEA, 2010, 2012a; IPCC, 2014). Increasing resource efficiency in the energy sector is a critical strategy to enable such necessary demand reductions to be achieved without negatively affecting human development and well-being. Such considerations provided the evidence base for the IRP's 10 Key Messages on Climate Change to the COP21 climate summit in Paris (UNEP, 2015a), which, as noted in Part One, stressed the role of resource efficiency in the cost-effective achievement of the climate targets in the Paris Agreement. This conclusion also emerged from the modelling carried out for this study, as reported at the beginning of Section 3.

As shown in Figure 10, buildings account for around 18 per cent of global GHG emissions (IPCC, 2014). Investments in improving the energy efficiency of buildings are common. Finnish municipalities have made substantial energy efficiency improvements in buildings to reduce CO_2 emissions, aided by mandatory energy efficiency performance codes and subsidies for measures to improve energy efficiency (UNEP, 2013a). Building efficiencies in Melbourne, Australia, have been raised through mandatory energy efficiency performance codes, implementation of energy efficiency measures in public buildings and lighting, a house-auditing programme, and a green office alliance that works with commercial tenants (UNEP, 2013a).

The Four Centres building at Red Deer College, Alberta, Canada shows the importance of design and simulation modelling in optimizing the energy performance of buildings. The buildings are designed to optimize natural lighting, with sensors automatically dimming electric lights when they are not required. Efficient ventilation design is combined with heat exchange to recapture heat from exhaust air, and the building fabric has high thermal resistance. The design process was guided by the Green Building Council's LEED certification process, and by computer modelling and simulation, that helped to test the energy and cost savings of alternative strategies. The result was a building that exceeds the minimum mandated efficiency standards by 61 per cent (National Resources Canada, 2015).

In addition to reducing emissions, an important objective for improving building efficiencies is in many cases to improve the health and well-being of vulnerable, low-income citizens. The Residential Energy Programme in Boston and the Public Housing Fund in Ljubljana, Slovenia (both discussed in greater detail in the Scientific Assessment Report – UNEP, 2017) show ways in which programmes for local authority-led sustainable housing, with lower energy consumption and lower carbon emissions, can reach low-income households in developed country cities. In countries of the Global South, improvements in the building and construction sector are also crucial to address needs for housing, employment and public infrastructure, but in this case in a context of rapid urbanization and urban population growth. As an example, the Kuyasa project in Cape Town, South Africa, has seen energy-efficient lightbulbs, insulated ceilings and solar water heaters installed in low-income housing buildings, reducing bills and improving the comfort of homes for the residents. Due to its CO_2 savings, the project qualifies under the clean development mechanism (CDM[18]). The project has also provided opportunities for local employment and skills development (UNEP, 2013a).

A barrier to increasing the efficiency of consumer energy use is the lack of information available to customers, and their cost-sensitivity. This has been addressed within the EU with energy-efficiency labelling. The effect of the Energy Labelling and Ecodesign Directives has been projected to deliver an energy saving of 19 per cent below business as usual by 2020 (Molenbroek et al., 2014). Mandatory standards are also possible. In Japan the "Top Runner" scheme uses the performance of the highest-performing energy-efficient appliances as a guide for setting the required average standard in a future year. A review of the first 12 years of this programme confirmed it had been successful in driving up energy efficiency performance and encouraging innovation – each targeted product group has met the required Top Runner standard, often in excess. Efficiency improvements in different product groups have ranged from 16 per cent to 80 per cent in the target year (Kimura, 2012). Some cities are undertaking investments in computer-controlled technologies that can reduce electricity

[18] A mechanism established within the Kyoto Protocol of the UN Framework Convention on Climate Change, to facilitate countries with emission reduction commitments to transfer investment to emission reduction projects in developing countries. The projects create certified emission reduction (CER) credits, which could be counted towards meeting Kyoto targets. See: http://unfccc.int/kyoto_protocol/mechanisms/clean_development_mechanism/items/2718.php

wastage. In Songdo, Republic of Korea, buildings have been fitted with computer-controlled lighting and temperature controls to minimize energy wastage, and San Jose, California has invested in LED street lighting connected via a smart network (UNEP, 2013a).

Transport accounts for around 14 per cent of global GHG emissions (IPCC, 2014). There is considerable potential to reduce transport demand through design and planning of transportation infrastructures. For example, Vauban, Germany, is an eco-city development near the city of Freiburg. It was brought about when the city bought a former army barracks in order to develop needed housing. This provided an opportunity to embed sustainability into the design of the project itself. The area is designed to enable sustainable transport, with a tram line connecting to the centre of Freiburg, and all homes within easy walking distance of a tram stop. The layout of the district has also been designed to actively encourage walking and cycling and discourage car use. This is achieved by reducing the number of streets through which cars can pass continuously through the neighbourhood. Most local streets are crescents and cul-de-sacs, which create dead-ends for cars – however these car dead-ends connect to a network of pedestrian and bicycle paths that permeate the neighbourhood. Thus, transport is primarily on foot or bicycle.

Research conducted and summarized by the United States National Research Council (NRC, 2009) finds that five “Ds” are important in shaping energy use and transportation: population density; diversity of uses (such as mixed residential/commercial); distance to public transit; design to support multiple modes of travel, including pedestrian, bicycle, automobile and public transit; and access to destinations, with focus on job locations.

The city of Ahmedabad in India has used planning successfully to reduce vehicle miles travelled (VMT) through both mixed use development (diversity), design (for multi-modal transport), access to destinations, having a short distance to public transit, and more compact, higher density development. This illustrates all five Ds in a developing world setting. An important factor was the decision of the municipality to undertake its transportation planning alongside its broader development plan, and to give the resulting Integrated Mobility Plan a time horizon of 20 years. This integrated plan therefore considered mobility in the context of high density, mixed-use urban infrastructure. It chose to use all forms of transportation as complementary to each other,

with local public transit systems connecting to mass transit systems at hub points. Dedicated pedestrian and bicycle lanes were also included alongside the bus rapid transit corridors (Swamy and Bhakuni, 2014).

In large cities with extensive existing urban infrastructure, it can be difficult to implement the 5Ds extensively. Nonetheless, low-energy transport innovations are still possible. An example of this is the concept of the bicycle-sharing scheme, which has now been developed in a number of cities in various countries. Though taking different forms, the essence of such schemes is to provide cheap, quick and spontaneous access to bicycles to cover short urban distances. A pioneering example of this is the Velib initiative in Paris. It comprises a network of 1,200 automated hire points and a total of 20,000 bicycles across the city, available 24 hours a day. Users can pay on demand for a day or a week of access, or sign up for a longer subscription (UNIDO, 2013).

There are considerable untapped opportunities for increased resource efficiency in many major energy-using industries, but they differ by country, by industry, and by process within industries. According to IEA (2012a), the implementation of best-available technologies could reduce industry energy consumption by 20 per cent from today's level. Here, examples of increased efficiency potential are given for two important sectors: steel-making and mining.

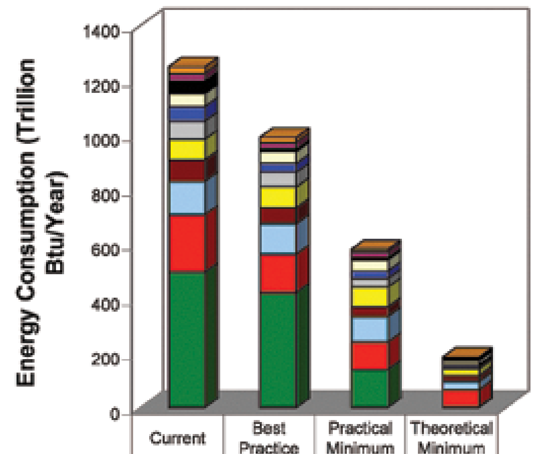
The steel industry accounts for around 6 per cent of global final energy consumption. The energy efficiency of steel production has consistently improved, but at a declining rate. Between 1960 and 1980 annual efficiency improvements were in the range of 2 to 4 per cent, but between 1980 and 2005 the annual rate of efficiency improvements fell to 0.5 to 1 per cent. McKinsey's base case assumption is that efficiency will improve at the rate of 0.7 per cent per year between 2010 and 2030, mainly driven by a shift from blast furnaces and basic oxygen furnaces (BOF) to electric arc furnaces (EAF) (Dobbs et al., 2011).

Opportunities for increased efficiency include cogeneration, and the recapture of waste heat, to be reused at various stages in the process. Other measures within different phases of the process include sinter plant heat recovery, the use of waste fuel, and coal moisture control – these can reduce direct energy use by 50 per cent. In BOF steelmaking, rolling (for example, "hot charging, recuperative burners, and controlled oxygen levels") can reduce direct energy use by 88 per cent and electricity by 5 per cent. Pulverized coal injection, top pressure recovery turbines and blast furnace control systems can reduce direct energy by 10 per cent and electricity by 35 per cent. In EAF steelmaking, improved process control, oxy fuel burners and scrap preheating can reduce electricity consumption by 76 per cent (Dobbs et al., 2011).

Another optimistic account of the potential for energy saving in heavy industry is given by BCS (2007) in relation to the US mining industry. As shown in Figure 14, the widespread adoption of best practices would reduce energy demand from the industry by 258 trillion Btu per year, a reduction of around 20 per cent. Targeted investment in R&D to develop improved technologies would deliver a further saving of 409 trillion Btu per year, providing a total reduction of over 50 per cent from current energy consumption levels.

Barriers to implementing such new technologies and best practice techniques in heavy industry include, in some regions, information failures and lack of access to appropriate engineering resources. They also require capital investment, which can be deterred by volatility in both energy and material prices, which creates uncertainty about the future of specific operations.

Figure 14: Energy consumption and saving potential by equipment type in the US mining industry.



	Current	Best Practice	Practical Minimum	Theoretical Minimum
Blasting	24	18	10	5
Dewatering	28	25	23	7
Separations	46	8	7	2
Electric Equipment	48	43	40	13
Crushing	52	32	27	8
Drilling	67	54	32	9
Ancillary Operations	75	75	72	24
Digging	79	60	35	22
Ventilation	122	111	94	29
Materials Handling-Diesel	211	141	101	63
Grinding	494	420	138	2

Source: BCS (2007), p. 23, Exhibit 18

3.4 Systems thinking and nexus issues

The best practices explored above have been categorized according to the four critical resources – materials, land and soils, water and energy. However, it is also important to consider resource and resource efficiency challenges in terms of overlapping and interdependent systems.

Energy systems are highly interconnected, with demand changes or fuel substitution in one sector having impacts on another. Food systems are complex webs of interacting actors in which powerful multi-national companies have significant influence. Cities are themselves systems of major importance through which all of the major resources flow.

The overlaps and synergies between resources, or “nexus” interactions, create important effects and are potentially valuable sources of win-win opportunities. For example, water-stressed areas may resort to energy-intensive water production measures such as desalination – therefore water-saving measures would save both water and energy. Increased efficiency in food production and consumption can save land, water and energy.

It is also important to consider resources from a supply chain perspective, using life-cycle analysis. This, for example, affects the perceived resource efficiency of service-based economies, much of whose resource footprint is felt in other countries. It can also affect the perceived benefits of resource substitutions. For example, bioenergy products can substitute for fossil fuels in energy demand – however the full life-cycle impacts of both options need to be compared, in terms of land use, processing and transportation emissions, before it can be clearly established which has the lowest impact.

All of these issues present considerable complexities for policy-makers. For purely practical reasons, different ministries typically take responsibility for each of the resources and systems described in this report. This is understandable and largely beneficial as it allows policy-makers to achieve tractable and demonstrable progress on particular issues. However, it is also highly desirable that policy-makers should attempt to balance a resource- or sector-focused approach with a more cross-sectoral, cross-resource and full supply chain perspective. This is both to avoid undesired consequences of individual policy actions going unnoticed, and to maintain awareness of the potential for win-win opportunities if sectors or resources are considered in a more holistic way.

4. Conclusions

4.1 The imperative and opportunity of resource efficiency

The imperative for increased resource efficiency arises from the pressures that population and economic growth, combined with current patterns of production and consumption, are putting on natural resources and the environment. These pressures amount to threats which, if not addressed, could make it impossible, or much more expensive, for the global community to achieve the SDGs and the Paris Agreement climate targets, thereby hindering sustainable development and a better future for all.

These threats need to be addressed and averted as far as possible, inter alia by a systematic effort by policy-makers to achieve both incremental as well as larger innovation-driven increases in the resource efficiency with which their economies operate. This would entail an increase in the technical efficiency with which economic processes turn material and energy inputs into useful outputs, a reduction in associated environmental impacts, and an increase in resource productivity, or the value that economic processes add to each unit of material and energy input.

The opportunities offered by increased resource efficiency arise from its potential

to result in higher economic growth and employment. The benefits from increased resource efficiency would be even greater if the avoided costs of resource bottlenecks, pollution and climate change were taken into account.

However, markets will not achieve these higher levels of resource efficiency unaided. The studies that show higher growth and employment from greater resource efficiency suggest that this is driven by a number of mechanisms. These include higher rates of innovation and technical change than markets alone can achieve. They involve policy-led higher investments in resource-efficient infrastructure and products, intelligent and targeted regulation, as well as environmental tax and other fiscal policy reform that adjusts the balance between the costs of labour and materials, thereby increasing the economic return to resource-efficient products and processes. Environmental tax reform is especially important as a means of avoiding the rebound effect, whereby increased economic activity arising from increased resource efficiency reduces the benefits from lower resource use and pollution that would otherwise have been achieved. For detailed analysis and guidance on policy options to support improvements in resource efficiency, readers should refer to the complementary OECD report on this precise topic as requested by the G7 as well.

The financial and employment benefits from increased resource efficiency are much enhanced by the non-financial benefits that are often invaluable for human well-being. These benefits derive, inter alia, from resource security, reduced pollution, improved health, enhanced environmental quality and lower loss of biodiversity. Moreover, resource efficiency provides opportunities for improving the social allocation of resources. Reducing the stress on the quantity and quality of resources will enable the disadvantaged and the poor to access more easily the resources that they need. The resource efficiency agenda is therefore also one that offers the potential to reduce inequalities and poverty in all countries through more secure and equitable access to resources. Pursued through well-informed and appropriate public policy, increased resource efficiency can therefore deliver multiple benefits across all the dimensions – economic, social and environmental – of sustainable development.

4.2 Best practices for increasing resource efficiency

There are no magic bullets to increase resource efficiency. The necessary measures – technical, economic and other policy-related – vary from sector to sector and from resource to resource. The evidence in this Summary for Policy-Makers, and in the Assessment Report upon

which it is based, has provided many examples of resource efficiency solutions, showing how greater efficiency in the management of resources can be achieved. The measures differ in detail – dealing as they do with different resources, economic sectors and processes – but some common messages emerge, which are highlighted here.

There are significant barriers to increases in resource efficiency. Such increases will not emerge through the operation of market forces alone. Were this not the case, much greater levels of resource efficiency would already be the norm. Different economic actors, in collaboration with policy-makers, must take concerted action for rates of resource efficiency to increase. For this to happen, there must be strong new incentives for more resource-efficient practices.

There is the issue of short-term versus long-term returns. For firms in industries with volatile prices requiring short payback times, or for other actors with limited capital availability, some investments in resource efficiency are not possible. This may also be an issue with developing economies, which are expanding rapidly but lack the resources to make strategic resource-efficient interventions, for example in urban areas. This issue can be addressed in a number of ways: by providing "patient" capital or development funding that focuses on improving long-term productivity and maintaining or restoring land quality, and not on generating quick returns from high inputs; by offering support for businesses in price-volatile sectors, or providing a clear outlook on future policy trajectories across sectors, to help businesses make or justify long-term investments; and by providing financial support to enable developing countries and cities to make long-term resource-efficient infrastructure planning decisions.

Resource efficiency and economic efficiency are not always linked. For example, the trade-off between low material costs and high labour costs can make it cheaper to waste materials than invest in the labour required to avoid such wastage. There are numerous possible ways to overcome this barrier: by pricing externalities; by introducing resource extraction taxes to increase prices of materials and thereby the economic incentive to use them efficiently; by using dynamic taxes to buffer price fluctuations, thereby reducing volatility and future uncertainty; or by creating other incentives to encourage actors to pay for labour to save on materials, rather than pay for materials to save on labour.

Ongoing processes of urbanization must become more resource-efficient. Resource

efficiency needs to be a guiding principle for the towns and cities springing up and being extended in many countries around the world. This applies to buildings, transport systems and infrastructure to enable the coordinated management of materials, water and energy, making full use of modern information and communication technologies. Public as well as private investment in such infrastructure may be required.

A range of issues must be addressed around logistics and supply chains. The reuse and recycling of resources require used materials to flow in the opposite direction to product supply chains. This requires various actors to adopt a coordinated approach to the planning of resource management, and to the logistics of material and product supply and return. Synergies and benefits can occur from considering these areas in an integrated way, for example through industrial symbiosis.

Regulations that discourage resource efficiency should be changed. For example, rules set up to manage a linear material management chain may prevent materials classified as waste from re-entering the supply chain. This suggests that regulations that govern materials, water and energy flows, while continuing to safeguard human health and the environment, should be revised to enable more circular resource flows. This could include revisiting definitions and provisions for waste management, and removing counter-productive subsidies.

The issue of possible “losers” from resource efficiency needs to be addressed. In some industries reduced material extraction will translate into reduced revenues and job losses. In this context it is important that transitional issues are properly addressed and appropriate compensation for “losers” considered. However, it should be noted that resource efficiency has the potential to create jobs in other areas, so that rather than resist resource efficiency or support resource-inefficient activities, which may anyway be in decline, it may be preferable to set up programmes to transfer redundant workers to, and re-train them for, resource-efficient sectors and activities.

There may be limits to some aspects of resource efficiency. In particular, there may be points after which recycling is no longer energy efficient. There may also be complexities and unintended consequences, in terms of other environmental impacts of resource-efficient initiatives, and from the interactions between different resources. To guard against such situations, a whole-system approach needs to assess resource use and the impacts of products on a life-cycle and consumption-production basis, with the insights used to inform and amend policy where necessary.

National and international targets for resource efficiency should be adopted and progress towards them monitored. This would give a greater incentive to policy-makers and businesses to prioritize resource efficiency. To some extent this situation will be improved if it is realized that resource efficiency is in fact essential to the attainment of the SDGs. However, it should also be recognized that a specific resource efficiency target, or a small set of targets covering key resources such as materials, water, land and carbon, could be effective in driving performance, and establishing a common view of the future between government, industry and society. A monitoring process to assess the resource use and resource efficiency of countries, with harmonized metrics and results published at regular intervals, could give resource efficiency a higher profile and lead to greater ambition to increase it, in the same way as currently occurs for GDP growth.

Given its links to the attainment of the SDGs and the aspirations for GHG emissions reduction in the Paris Agreement, an increase in global resource efficiency ranks among the top priorities for enabling sustainable development now and in the future.

The new G7 Alliance for Resource Efficiency is a welcome initiative, with G7 nations well placed to take a leading role in demonstrating what is possible in some of the world's wealthiest and most dynamic economies. At the same time, there is both significant room and a pressing need for further concerted action in these and other industrialized, emerging and developing nations to adopt a more resource-efficient and sustainable path of development, to the benefit of all humankind. The global community can support this through a process of continuous exchange, partnership and cooperation at all levels, involving mutual support, learning and capacity building that gives practical expression to the spirit and common aspirations that led to the agreement of the SDGs.

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Despite enormous progress in the past decades towards improving human prosperity and well-being, this has come at the lasting cost of degradation of the natural environment and depletion of natural resources. Meeting the needs of a growing and increasingly affluent population, will require natural resource extraction to increase from 85 to 186 billion tonnes by 2050. This can cause irreversible environmental damage and endanger the capacity of Earth to continue to provide resources which are essential for human survival and development.

Analysis in the report shows that policies and initiatives to improve resource efficiency and tackle climate change can reduce global resource extraction by up to 28 per cent while also boosting the value of world economic activity by 1 per cent in 2050, against the baseline. Such policy actions can also cut global greenhouse gas emissions by around 60 per cent in 2050 relative to 2015 levels.

This report has been produced by the UNEP's International Resource Panel in response to a request by leaders of the G7 nations in the context of efforts to promote resource efficiency as a core element of sustainable development. The report conducts a rigorous survey to assess and articulate the prospects and solutions for resource efficiency. It considers how more efficient use of resources can contribute to economic growth, employment and development, at the same time as reducing the world's use of materials, energy, biomass and water, and the resulting environmental impacts.

The report documents many examples of best practices for increasing the resource efficiency of different sectors from countries around the world. The challenge for policy-makers is to learn from and scale up these good practices, and to conceive and implement a set of transformative policies that will enable countries to reap the associated social, environmental and economic benefits. Ambitious action to use resources in a more efficient and sustainable manner can help place the world on the right track to meet its commitments under the 2030 Agenda on Sustainable Development and the Paris Climate Change Agreement, and thereby to realise a more equitable and sustainable future.

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