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Resource efficiency for sustainable growth: global trends and European policy scenarios

Background paper for the

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Executive summary

In Asia and worldwide, improved resource efficiency of production and consumption is a key requirement for sustainable growth. Global extraction and use of natural resources has significantly increased over the past decades. Today, humans extract around 60 billion tonnes of resources each year, 50% more than only 30 years ago. Almost half of this global resource extraction takes place in Asia. Growing demand for natural resources, particular from emerging economies in Asia, led to increasing commodity prices and increasing competition of world regions regarding access to resources. Furthermore, some Asian countries are increasingly dependent on imports of raw materials (such as metal ores and timber) and fossil fuels from other world regions. Higher extraction and consumption of natural resources also entails a number of global and regional environmental problems, such as climate change, deforestation, loss of biodiversity and pollution. This often causes negative health effects. Increasing the resource efficiency is therefore an integrated strategy to tackle economic, environmental and social issues at the same time and a requirement for a more sustainable path of economic growth.

Per capita consumption of natural resources in Asia is significantly lower than in rich OECD countries. However, in absolute terms, Asia is already consuming beyond its own resource capacities. With around 15 kilograms of resources per day, Asians on average consume only around one third of resources compared to an average European and around one sixth of resources compared to an inhabitant of North America. Europe and other industrialised countries with high per capita consumption must therefore find ways of reducing their overall resource consumption in absolute terms. However, at current levels of resource use, also Asia is already appropriating around twice the biological resource capacity available on the continent. Moreover, Asia's population is growing and people aspire a higher standard of living, which will further increase resource consumption. This underlines the urgent need to orient future growth strategies towards increased resource efficiency.

Economies in Asia have significantly improved their resource efficiency in the past decades. However, absolute levels of resource use are still growing rapidly. Today, around 25% less domestic resources are necessary to produce one unit of GDP in Asia compared to the year 1980. However, economic growth in Asia was much higher than growth in resource efficiency. Absolute levels of resource extraction and consumption are therefore still rising fast. There is still high potential to improve resource efficiency in Asia, as Asian economies use around twice the amount of resources per GDP than economies in Europe and North America.

Resource efficiency measures are a key element of sustainability policy packages, realising win-win situations for both the economy and the environment. Scenario simulations from Europe illustrate that policies to increase resource efficiency in industrial sectors could significantly reduce production costs and thus increase economic output and domestic and foreign demand. This accelerates economic growth and improves international competitiveness. In order to achieve environmental policy targets as well, such as a reduction of CO₂ emissions, these resource efficiency policies need to be combined with other policy measures, in order to limit so-called "rebound effects".

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1. Introduction

Industries are essential drivers of economic progress in Asia and worldwide. Their activities and performance depend crucially on the availability and quality of raw materials and can only be sustainable if the ecosystems can regenerate from the environmental impacts stemming from production and consumption of goods and services. As this paper will argue, the resource efficiency of industrial development must be improved significantly if the resource base of industrial activities is to be maintained.

Global trends show a steady increase in worldwide demand for natural resources, particularly in Asia. In absolute terms, almost half the world's resources are extracted in Asia and an increasing number of countries are becoming net importers of raw materials. Yet, a lot of these resources are exported to industrialised countries, which still have by far the highest resource consumption per capita. At the same time, resource efficiency has increased significantly over the past 30 years, both in Asia and globally.

Despite the gains in resource efficiency, however, global trends in resource consumption indicate that the natural resource base, on which all economies depend, is in severe danger of overexploitation and collapse. Asia, for example, already demands around twice the biocapacity that is available on the continent. The extraction, processing and use of natural resources is a key source of a number of environmental problems and causes increasing environmental costs for Asian economies as well as the world economy. In some Asian countries, these costs are estimated to reach the annual increase in Gross Domestic Product (GDP). Generating sustainable economic growth is one of the key challenges for Asia over the next decades. Improving the efficient use of material and energy, i.e. resource efficiency, should be one key objective in industrial and environmental policies.

Achieving sustainable development is also a key challenge for policy makers in industrialised countries. With its high levels of per capita resource consumption, industrialised countries hold a particular responsibility in achieving sustainable patterns of resource use. Europe has started addressing issues of resource efficiency and environmental impacts of resource use in several policy processes. The European Commission has also commissioned research projects, in order to evaluate the potential economic and environmental impacts of resource efficiency policies. Some of the key results will be presented in this background paper.

This paper aims to address the following questions:

- How have resource use and economic growth developed in Asia and worldwide?
- To what extent have resource use and economic growth de-coupled?
- Why is resource efficiency important for sustainable growth?
- What are the global trends and scenarios for resource extraction and consumption?
- What is the rationale for industries to address resource use and resource efficiency?
- What are the economic and environmental consequences of policies aiming to increase resource efficiency?

These questions will be elaborated with the following structure. Section 2 will provide arguments for the need to address resource use at the macro and industry level. Section 3 describes and illustrates the main global and Asian trends in resource extraction and resource consumption. This is followed, in Section 4, by the trends in resource efficiency and de-coupling. Section 5 presents and discusses

the potential economic and environmental impacts of policies aimed at increased resource and energy efficiency. The paper ends with a concluding section summarising the main trends in resource use and resource efficiency and the ensuing policy lessons for realising more sustainable growth.

2. Rationale for addressing resource use at the macro and industry level

Measuring and evaluating resource use is important for a number of interlinked economic, environmental and social reasons. While not claiming to be exhaustive, some of the most pertinent arguments from a macroeconomic and industry perspective include the following.

Industrial development and economic growth are tightly linked to resource use and contribute to rising commodity prices. The rapidly increasing demand for resources has already caused a boost in certain resource prices, especially since 2003 (Bleischwitz et al., 2009). Although the current economic crises led to a temporal downturn of resource prices, it is generally expected that the age of cheap resources is over (IEA, 2008). Countries with large raw material deposits will profit from these price developments while those countries or regions with relative resource scarcity will be negatively affected. Price increases have been most pronounced in important raw materials (e.g. prices of iron ore rose by 380% between 1980 and 2008) and fossil energy (the price of crude oil increased by 170% between 1980 and 2008).¹ As fossil fuels also drive most metallurgical and chemical processes that create modern materials (Ayres et al., 2007) the prices of such materials (from steel to plastics) can also be expected to rise in the future.

As a result of resource-intensive economic development, many countries have become more dependent on natural resource imports. As their industries develop, even countries with rich resource endowments require certain natural resources from abroad. China, for example, has become the world's leading importer of plastic materials, metal ores, oil seeds, textile fibres and pulp and paper (Deutsche Bank Research, 2006a). For example, Chinese imports of wood, articles of wood and wood charcoal have increased from USD 3.7 billion in 2000 to USD 8.0 billion in 2008, in order to meet the demand of its rapidly growing furniture industry as well as construction and paper industries.² This trend is likely to continue as forest resources in China are limited (Deutsche Bank Research, 2006b). The WWF predicts that by 2010, China will only be able to meet half of its demand for industrial wood with domestic production (WWF, 2004).

Increased demand for resources has also intensified global competition over limited resources and may jeopardise growth and stability in the future. Despite the fact that there is no imminent physical danger of depletion of the majority of raw materials in the world, it is expected that worldwide competition for these resources will significantly increase in the near future (BP, 2007; Cohen, 2007; USGS, 2006, 2008). As more and more countries in Asia are becoming net importers of resources, resource scarcities will have an important impact on the development of the continent. Some analysts warn that intensified climate change and its impacts in Asia (such as desertification, rising sea-levels, extreme weather events, and shortages of fresh water) 'could lead to violence over scarce necessities' (ADB, 2009: 13). These necessities especially include fresh water and fertile land.

Apart from its economic impacts, resource use is also the key driver for a number of global and regional environmental problems. Resource use is not only the physical basis of production and consumption but also has a number of negative environmental consequences. Our climate is

¹ Data taken from UNCTAD Commodity Price Statistics online, available at www.unctad.org.

² Data taken from UN Comtrade database, available at www.comtrade.un.org/db.

changing, fresh water reserves, fish stocks and forests are shrinking, fertile land is being destructed and species are being extinct. These are all examples of problems caused by our increasing use of natural resources.

Industrial development without resource efficiency policies may overuse certain raw materials and thus create shortages, pollution, and environmental degradation. Since resource availability and resource use are not sufficiently measured or controlled, overuse of biotic resources and peak extraction points of abiotic resources are rarely noticed by individual actors. In the fisheries industry, for example, collective overuse has led to declining catch rates and degraded marine ecosystems over the past ten years. Integrating aspects of resource use into industrial policies and adopting proper resource accounting and management systems at the industry level can create awareness, improve monitoring and planning of resource use and thus help ensure more sustainable economic growth.

Among many other social costs, resource-use related environmental degradation is also exacting a heavy toll on human health and straining national health care systems. The World Bank estimates that air and water pollution alone cost China USD 100 billion and about 750,000 deaths a year. The Chinese State Environmental Protection Administration (SEPA) estimates the annual cost of environmental damage at 8-13% of GDP – about the same as the annual economic growth rate (The Economist, 2008). Reducing the quantities of resource use and substituting materials and substances with high environmental and health impacts for those with lower impacts therefore constitutes an effective strategy to reduce environmental damage and health costs.

Forward-looking economic and environmental policy strategies are oriented towards increased resource efficiency. Many studies have shown that there is significant potential to increase resource efficiency along the life cycle of products and services (Kuhndt et al., 2008). So-called Life-Cycle Assessments (LCA), which look at the resource use and environmental impacts along the full product life cycle from cradle to grave (i.e. from resource extraction to recycling or disposal), indicate where the hot spots of resource use can be found. In the production process, efficiency may be increased by reducing resource use and waste in producing the same amounts of goods and services. Such assessments also allow comparing recycling of resources with the extraction and production of materials from virgin resources. Recycling aluminium, for example, saves 95% of the energy necessary to mine bauxite ore and extract alumina. Recycling one ton of aluminium saves the equivalent in energy of 8,900 litres of gasoline (Chiras, 2006). The amount of materials that the recycling industry provides to the manufacturing industry is increasing. In the EU, at least 50% of the paper and steel, 43% of the glass and 40% of the non-ferrous metal produced in the member states are currently derived from recycled materials (European Commission, 2005a).

3. Extraction and consumption of resources

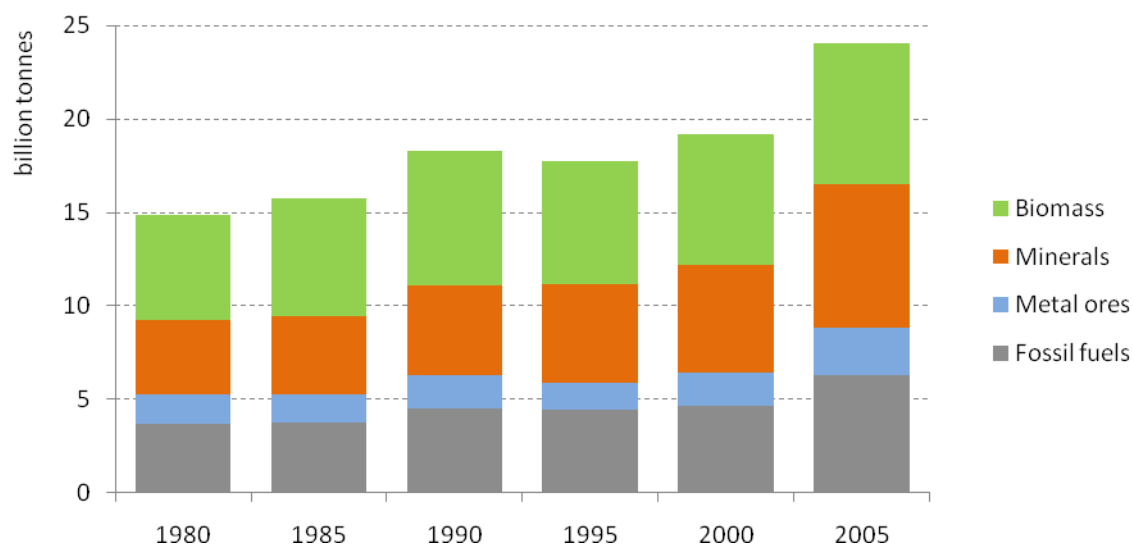
Resource extraction

As a result of increasing levels of production and consumption activities around the world, the amount of annual extraction of natural resources has been steadily increasing over the past three decades. With around 60 billion tonnes of extracted resources each year, the world economy today uses around 50% more resources than in 1980. Additional materials are extracted or removed from the soil surface in order to get access to valuable resources, but are not used in production processes themselves. Overburden from mining activities is the most prominent example of this. These

materials account for a further annual extraction of 40 billion tonnes. All in all, the world economy moves over 100 billion tonnes of material each year.

Also in Asia, the extraction of raw materials has increased significantly in the past 30 years: from around 15 billion tonnes in 1980 to 24 billion tonnes in 2005 (see Figure 1). A particular increase could be observed for the period between 2000 and 2005. In this period, economic growth rates in Asia were high and demand for fossil energy, for metal ores as well as for construction minerals to build up infrastructure grew fast.

Figure 1: Resource extraction in Asia, 1980 to 2005



Source: SERI Global Material Flow Database. 2008 Version. See www.materialflows.net.

Table 1 illustrates that resource extraction is very differently distributed across the world. In 2005, by far the largest share of all natural resource extraction took place in Asia (43%), where more than half of world's population lives. With 16%, Latin America ranked second, followed by North America (15%), Europe (14%), Africa (9%) and Oceania (3%). How many natural resources are extracted in one continent, depends on several factors, including land area, availability of resources, size of the population as well as the level of affluence. Asia is the leading extractor in all major material categories: minerals (41%), metal ores (41%), fossil fuels (54%) and biomass (38%).

Table 1: Shares of different world regions in global resource extraction, 2005

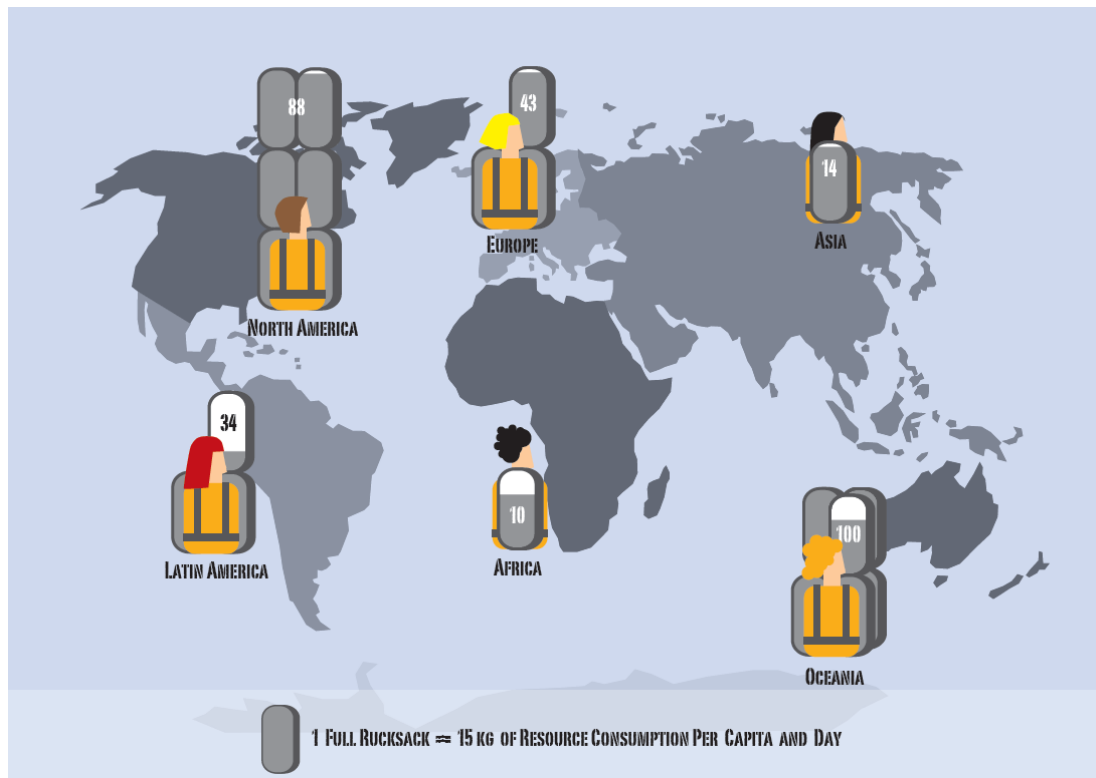
	All resources	Minerals	Metal ores	Fossil fuels	Biomass
Asia	43%	41%	41%	54%	38%
Latin America	16%	12%	28%	7%	21%
North America	15%	18%	9%	17%	11%
Europe	14%	21%	5%	11%	12%
Africa	9%	5%	7%	7%	15%
Oceania	3%	2%	11%	4%	3%

Source: SERI Global Material Flow Database. 2008 Version. See www.materialflows.net.

Resource consumption

Huge differences can also be observed regarding resource consumption. Resource consumption per capita is up to ten times higher in some industrialised countries than in economically deprived countries. Figure 2 shows the numbers for resource consumption per capita per day in different world regions in the year 2000 (unfortunately, more recent global data is not currently available).

Figure 2: Consumption of resources per capita per day, 2000



Source: Calculations based on Giljum et al., 2008b.

On average, each inhabitant of the planet uses more than eight tonnes of natural resources per year, or 22 kg per day. With around 15 kilograms per day, Asia's per capita consumption is (still) comparatively low: only Africans consume fewer resources (10 kilograms per day), while Europeans consume around three times more resources (around 43 kilograms), and North Americans as well as Australians up to eight times more (88 kilograms and 100 kilograms, respectively).

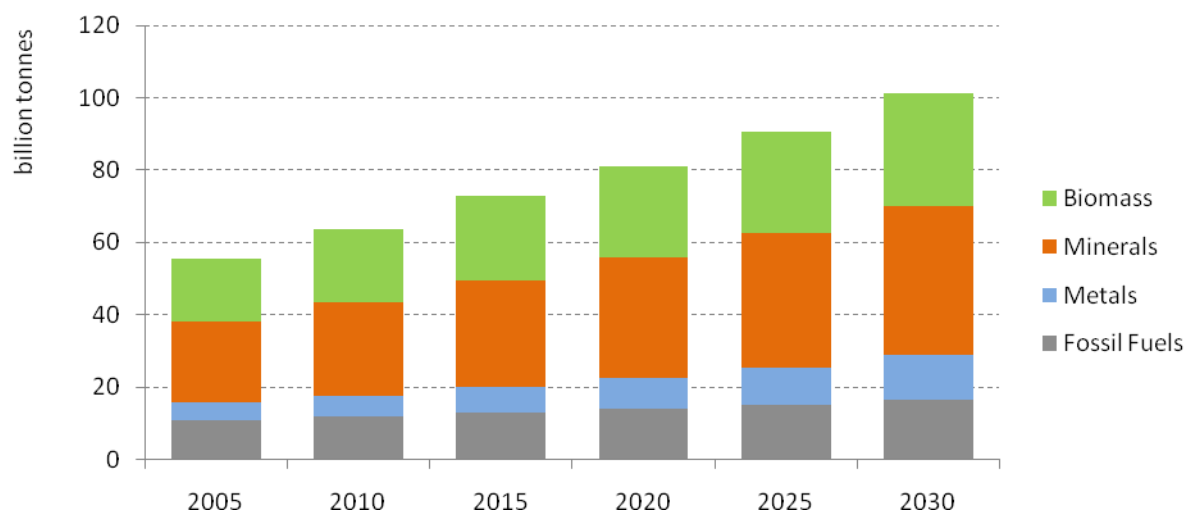
However, in absolute amounts, resource consumption of Asia is already significant and Asia has experienced a particularly strong growth in resource use over the past two decades. This growth was especially driven by demand in the emerging markets in the region. Since major economic policy reforms in the 1990s, both China, and to a lesser extent India, have become large consumers of raw materials from Southeast Asia and other regions. Both are major importers of timber and wood products from the neighbouring region and constitute the most important markets for coal, coke, copper, and other minerals, as well as rubber and edible oils from Southeast Asia (Cronin, 2009).

Scenarios on future resource use

Scenario calculations suggest that the growth in resource demand will further grow significantly in the future if no measures are implemented to substantially increase resource efficiency and reduce the demand for natural resources (Lutz and Giljum, 2009). Some calculations show that used material

extraction will more than double at the global level between 2000 and 2030 to reach more than 100 billion tonnes (see Figure 3). Extraction will increase in all major resource categories. With annual average growth of around 2.6%, agriculture and construction will constitute the fastest growing extraction sectors until 2030. The lowest increase is expected in the extraction of energy carriers, whereas high growth rates are foreseen for the category of metal ores, with particularly high growth of production in emerging economies such as Brazil, India, China, Russia and South Africa.

Figure 3: “Business-as-usual” scenario on worldwide resource extraction, 2005 to 2030



Source: Lutz and Giljum, 2009

Resource scarcities will be increasingly observed in the future, with potentially far-reaching economic impacts, in particular for resource-intensive industries. Global reserves of fossil fuels, metals and minerals are unevenly distributed across the world. Regions with highly developed economies, such as Europe and North America, but also emerging economies in Asia (e.g. China and India) with rapidly growing demand for resources, do not possess large domestic deposits of all required raw materials and will increasingly depend on resource imports from other world regions (European Parliament, 2009).

Apart from resource scarcities (which are not all imminent), the physical limitation of the global ecosystems will pose another limitation to future economic development and sustained economic growth. Humanity’s annual demand for biological capacity (i.e. the ability of ecosystems to provide renewable resources and absorb waste and emissions) is already exceeding the planet’s regenerative (biological) capacity by more than 30% (WWF, 2008). We are thus already liquidating the earth’s natural capital.

The Asia-Pacific region will play an increasingly central role in addressing global resource use as the region’s population and economy continue to grow in a world with limited resources. Even though per-capita resource consumption levels are low compared to industrialised countries, the Asian region already demands around twice the biocapacity that is available on the Asian continent (WWF et al., 2005). This underlines the urgent need to increase significantly the resource efficiency of the Asian economies in order to turn to a sustainable growth path in the future.

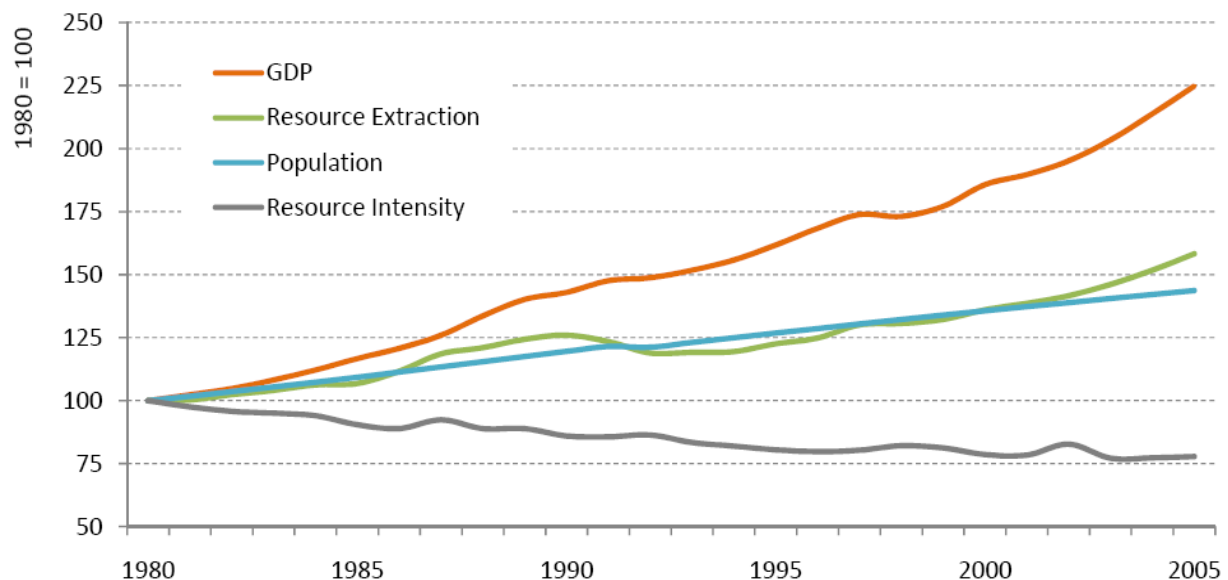
4. Resource efficiency and de-coupling

Resource efficiency and de-coupling are becoming the buzz words in industrial policy and strategy making. Resource efficiency illustrates economic output generated per unit of natural resources and can be calculated at the product, sector and macroeconomic level.

For most industries, increasing resource efficiency in production is not simply a response to environmental objectives. It has become a core determinant of economic competitiveness and sustainable growth. Relative de-coupling of economic growth from resource use leads to a decline in the resource intensity per unit of economic output. Absolute de-coupling refers to a decline of resource use in absolute terms. There is good reason to explore efficiency potentials as the trends show that there is still room for improvements in resource efficiency and that absolute de-coupling has not yet been achieved.

Resource efficiency has increased significantly over the past years. Today, the world economy uses around 30% less resources to produce on unit of world GDP than 30 years ago. The world economy has therefore successfully achieved a relative de-coupling of resource use from economic growth. Global resource extraction increased by about 45% between 1980 and 2005, much in line with worldwide population growth. At the same time, global GDP has increased by 110%. As economic growth was higher than growth in resource extraction, a de-coupling of resource extraction from economic growth was achieved. Thus the resource intensity of the global economy is declining. A similar trend can be observed for Asia where resource extraction increased by 58% between 1980 and 2005, population grew by 44% and GDP by 125%. Over the same period, resource intensity fell by 22% (see Figure 4).

Figure 4: Relative de-coupling of economic growth from resource extraction in Asia, 1980 to 2005 ³



Source: SERI Global Material Flow Database. 2008 Version. See www.materialflows.net.

³ Due to data availability reasons, GDP figures are based on constant 2000 USD market exchange rates (MER) and not on purchasing power parity (PPP) exchange rates.

De-coupling can have positive economic and environmental effects. Since resource inputs represent an important cost of production for industries, efficiency improvements can be a significant lever for competitive advantage. The long term trends in energy and material intensities provide strong evidence for relative de-coupling. The amount of primary energy needed to produce each unit of the world's economic output has fallen by 33% between 1970 and 2004 (IPCC, 2007), while material intensities more generally have fallen by up to 50% in some OECD countries (Jackson, 2009: 48-49). Improved resource efficiency, in turn, has also reduced emission intensities. The global carbon intensity thus declined by almost a quarter between 1980 and 2006 (Jackson, 2009: 49).

Despite the gains in resource efficiency, no evidence exists that the necessary absolute de-coupling has yet been achieved. So far, the increases in resource efficiency have not kept up with the rates of economic growth (Bringezu et al., 2004; Jackson, 2009). The absolute amount of resource extraction and resource use is still rising on the global level as well as in Asia. Economic growth and rising levels of production and consumption are thus over-compensating the relative gains in resource efficiency.

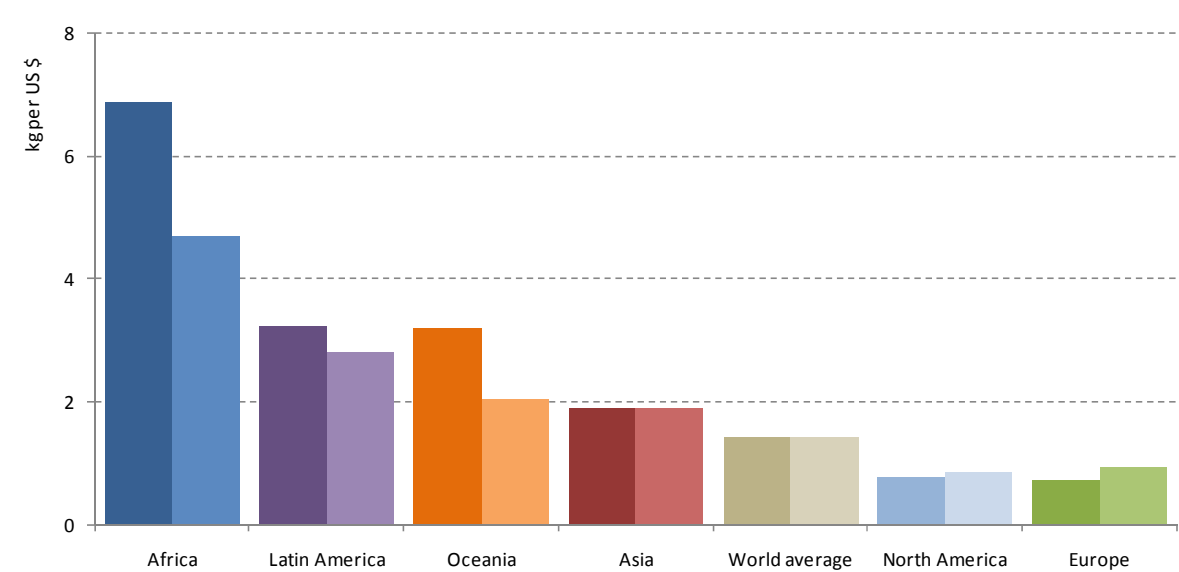
One of the reasons why efficiency increases on the level of products and industries have not solved environmental problems is the so-called "rebound effect". When enterprises use less materials and energy to produce their products and services, the production costs decrease, which lower the prices of products and services. And lower prices for consumers mean that – with the same budget – consumers can purchase more of the cheaper product or other products. The historical development of mobile communication is one example for this phenomenon. A mobile phone today uses fewer raw materials than the first mobile phones, introduced around 25 years ago. However, as the overall number of mobile phones increased steeply and people replace their mobile phone more frequently, the absolute resource use for mobile communication actually increased. This rebound effect thereby counteracts the necessary reduction of resource consumption in societies with high per-capita resource consumption, such as Europe (see for example Binswanger, 2001).

The current quantities of resource consumption are one key obstacle to achieve a sustainable resource use. The possibilities of de-linking the quantities of resource use from environmental impacts at the current levels of resource consumption are limited. For example, it is impossible to fully substitute the fossil energy needed for transport by biofuels, as the fertile area available for biofuels production is not sufficient. In order to achieve sustainable paths of development an absolute reduction of our resource use will be necessary on the global level (Alcott, 2005; Giljum et al., 2005).

World regions use very different quantities of domestic and foreign resources to produce one unit of GDP. Figure 5 shows the resource intensity of GDP in relation to domestic resource extraction (darker column) and in relation to resource consumption (lighter column), both in kilogram (kg) per US Dollar. Resource consumption includes international trade and is calculated as domestic extraction plus imported resources minus exported resources. On world average, intensities of resource extraction and resource consumption are the same. To produce one US Dollar of output, 1.42 kg of natural resources were needed in the year 2000. Africa was the continent with the highest material intensity. African countries on average needed almost 7 kg of domestic resources to produce one US Dollar of GDP. The economy of the continent as a whole is dominated by resource-intensive economic activities, such as mining and agriculture, while the technologies in use are generally less efficient than those in other world regions. However, Africa is a net-exporter of resources to other countries. Therefore, resource consumption related to GDP in Africa was less resource intensive than resource extraction. Natural resources also play an important role in the economies of Latin America and Oceania (especially Australia). Consequently, material intensities for

those two continents were also above the world average. With its significant share of industrial and service sectors, Asia was more resource efficient than Africa or Latin America in 2000. Including international trade did not affect the resource intensity numbers, as imports and exports of resources were of the same size. At around 1.9 kg per Dollar, resource intensity of GDP related to domestic extraction was therefore very similar to the resource intensity of consumption. However, as shown in Figure 5, production and consumption in Asia were still around twice as resource intensive as in Europe or the US. The latter economies were relatively more resource efficient, as the service sectors contributed the largest part to GDP. Services, such as banking or health care, are less resource intensive than mining, agriculture or manufacturing. However, since Europe and North America needed resources from other world regions to maintain their economic system, resource intensity is higher for consumption than for extraction of resources.

Figure 5: Resource extraction (darker column) and resource consumption (lighter column) of different world regions related to GDP (in kg per constant 2000 US \$)



Source: Calculations based on Giljum et al., 2008b

Some countries in Asia have achieved remarkable improvements in their resource efficiencies in the past three decades (see Table 3). Today, China and Thailand only use a third of the domestic resources to produce the same value of economic output than 30 years ago. In India, the resource efficiency of domestic extraction has improved by a factor of about two.

Table 3: Resource intensity in selected Asian countries (in kg of domestic extraction/USD), 1980 to 2005 ⁴

	1980	2005	Change (%)
China	12.3	3.9	-68
Indonesia	11.4	8.3	-27
India	8.3	4.6	-45
Malaysia	4.0	3.0	-26
Philippines	4.6	2.7	-42
Thailand	15.2	4.4	-71

Source: SERI Global Material Flow Database. 2008 Version. See www.materialflows.net.

Four main factors can change the resource efficiency of countries: technological changes, structural changes in the economy, outsourcing through international trade, and changes of resource prices. First, technological changes may enable firms to produce the same amount of output with fewer resources. In China, for example, the total energy consumption to produce a ton of crude steel from iron ore has declined from 1.430 to 0.519 ton of oil equivalent during 1980–2005 (Wei et al., 2007). Secondly, structural transformations have occurred in many Asian economies in favour of less material intensive sectors. India's growth in recent years, for example, was mainly driven by the services sector, which has become the dominant contributor to the economy, accounting for 54 per cent of GDP in 2005 (ADB, 2006). The Indian services sector grew at an average annual rate of 6.1%, compared with 5.6% in industry and 2.6% in agriculture between 1960 and 2005 (ibid.). The third influence on the resource efficiency results is international trade. For individual countries the same situation applies as for continents (see Figure 5). If trade flows are considered, the values for resource efficiency of net-exporters look more positive than that of net-importers. Studies on China have shown that imports were approximately as high as exports between 1990 and 2002 (Xu and Zhang, 2007). This implies that the resource efficiency of domestic extraction is the same as that of consumption. The last factor – changes in the prices of raw materials – should not have distorted the data on efficiency shown above as GDP was measured in constant USD of the year 2000.

5. Economic and environmental impacts of resource efficiency policies

Issues of resource productivity, resource consumption and related environmental impacts as well as resource security have significantly gained in policy importance in the past ten years. A number of European and international institutions have established policy processes aimed at increasing resource productivity in different levels of economic activity (products, sectors, and countries) and reducing the negative environmental impacts related to resource use along the whole life-cycle of products and services. Examples for policy initiatives by the European Commission include the “Thematic Strategy for the Sustainable Use of Natural Resources” (European Commission, 2005b) and the “Action Plan for Sustainable Consumption and Production” (European Commission, 2008).

The challenging task of moving towards a sustainable and resource efficient path of development is also a topic of intense research around the world. From 2003 to 2006, the European Commission funded an international research project entitled “Modelling opportunities and limits for restructuring Europe towards sustainability” (MOSUS), in which a consortium of 12 research institutions from seven EU member countries investigated this challenge.

⁴ GDP is based on constant 2000 prices in USD.

The project was able to illustrate the economic, environmental and (partly) social impacts of key policy measures to increase energy and resource efficiency. The most important conclusion from the scenario simulations performed in this project is that the implementation of a well-designed mix of environmental and resource efficiency policies can result in a win-win situation for the economy and the environment. Environmental policy measures primarily geared towards decoupling economic activity from material and energy throughput can be conducive to economic growth, contrary to the popular assumption that such policies will mainly raise costs for enterprises, decrease competitiveness and thus have an opportunity cost in terms of reduced economic performance. The following sections will describe the purpose of the project, the model and its scenarios, as well as the results.

Description of the project and the model

The EU research project MOSUS developed and applied a global simulation model to evaluate the economic, environmental and social impacts of key policy measures to increase energy and resource efficiency in Europe. The project formulated European development scenarios up to the year 2020 and assessed the effects of policy measures on economic and environmental trends. The project also developed the first global database for raw material extraction (material inputs) in all countries of the world. This global data set is available at the online portal for material flow data (www.materialflows.net).

In order to quantify the interrelations between socio-economic driving forces and the state of the environment, the MOSUS project applied an integrated econometric environmental-economic simulation model, the Global Interindustry Forecasting System (GINFORS) (Lutz and Giljum, 2009; Meyer et al., 2008). The GINFORS model is the first tool to directly integrate comprehensive bio-physical data (material and energy flows, CO₂ emissions) in European and global simulations up to the year 2020/2030 and to put them in relation to structural indicators of social and economic development. It enables the formulation and evaluation of scenarios for the economic and social/distributional impacts of key environmental policy measures and the presentation of validated policy recommendations for responding to environmental changes. Such evaluation of sustainability scenarios for Europe can significantly enhance understanding of the interactions between environmental changes and socio-economic trends that are often the driving forces of undesirable environmental impacts.

The model includes very detailed economic and environmental data and distinguishes 50 countries and two world regions (OPEC and the rest of the world) which are interlinked by bilateral trade. For many countries, the model also includes input-output tables for different economic sectors. The model uses historical time series data to estimate historical trends; currently from 1980 to 2005. The energy-emissions part of the GINFORS model is based on energy balances data from the International Energy Agency (IEA) for all countries included in the model. Energy supply, energy transformation and energy consumption are linked to economic driving forces, which are put in relation to environmental indicators. The GINFORS model also includes data on resource extraction for all countries and world regions. Resource extraction data are aggregated into nine material categories (agricultural products and fish, forestry products, coal, crude oil, natural gas, iron ores, non-ferrous metals, industrial minerals and construction minerals). Each of these material groups is linked to the GINFORS model through economic driver variables which explain the development of extraction of a particular resource. For example, growing output of the agricultural sectors translates into growing extraction of agricultural products (biomass).

GINFORS is an econometric model based on historical data and includes estimations, which explain how different actors in society (e.g. companies) reacted to changes of economic variables (e.g. changes in oil price). GINFORS therefore does not endogenously produce radical changes in the economy or the society, for example the implementation of new environmental policy measures or radical technological changes; GINFORS in general generates conservative results. Such technological changes or changes of environmental policies are not endogenous outcomes of the model calculations, but have to be introduced exogenously in the form of scenario assumptions.

Description of scenarios

To identify a suitable mix of different environmental policies, the MOSUS project formulated three different EU development scenarios up to the year 2020 and evaluated the economic, environmental and (partly) social impacts of key environmental policy measures to increase energy and resource efficiency (Giljum et al., 2008a).

The **business-as-usual scenario** (baseline scenario) projected past trends into the future, without additional sustainability-oriented policy strategies and instruments.

The **industrial resource efficiency scenario** (Aachener Stiftung Kathy Beys, 2005) was based on earlier studies which have evaluated the potentials of resource efficiency in industrial sectors (for example, Fischer et al., 2004). The scenario assumed that governments support information and consulting programmes, enabling firms in the manufacturing sectors to exploit potentials for reducing material inputs (and related material costs) of production processes. A linear reduction of inputs from sectors supplying raw materials (except energy) to the industrial sector was modelled, starting from 1% in 2006 to 20% in 2020. Costs associated with such programmes were modelled as additional inputs from the service (consulting) sector to the manufacturing sector.

After modelling the results of the industrial resource efficiency scenario, it was combined with the following policy measures aimed at achieving more environmentally sustainable economic growth. Together with the industrial resource efficiency scenarios, these measures formed an **integrated sustainability scenario**.

- **Technological Change:** changes of the input coefficients in selected sectors and supply-chains, such as a reduction of the consumption of chemicals in agriculture due to biotechnology and the introduction of new materials in the automotive sector.
- **Transport Costs:** replacement of all existing taxes in the transportation sector by a kilometre charge, covering the social costs of transportation (with a price mark-up of 10% in all European countries), while reducing other taxes in the transportation sector.
- **Recycling and Material Efficiency:** increase of metal recycling and higher resource efficiency in the use of industrial and construction minerals, as the result of the introduction of a material input tax and further increases of raw material prices on world markets.
- **R&D and technical progress:** subsidy of research and development of firms with a total of 1% of public consumption, financed by a corresponding reduction in public consumption.
- **CO₂ taxation:** introduction of a significant tax on CO₂ emissions, borne by producers and importers of fossil fuels through increased prices. Governments offset carbon tax revenues by reducing other taxes on enterprises.

Results from the scenarios

The **industrial resource efficiency scenario** is very beneficial from the perspective of economic growth. In this scenario, EU Member State governments introduce an information and consulting programme to increase material efficiency in the manufacturing sector. This exerts a strong positive effect on growth through productivity gains that drive prices down and increase profit margins. As Table 4 illustrates, the resource efficiency scenario had positive effects (+) on exports and employment and very positive effects (++) on GDP and resource productivity. However, it could not reduce the levels of CO₂ emissions or material extraction (0), as the above described “rebound effects” occur. More sustainable economic growth was achieved with the **integrated sustainability scenario** which combines resource efficiency policies with the environmental sustainability measures described above.

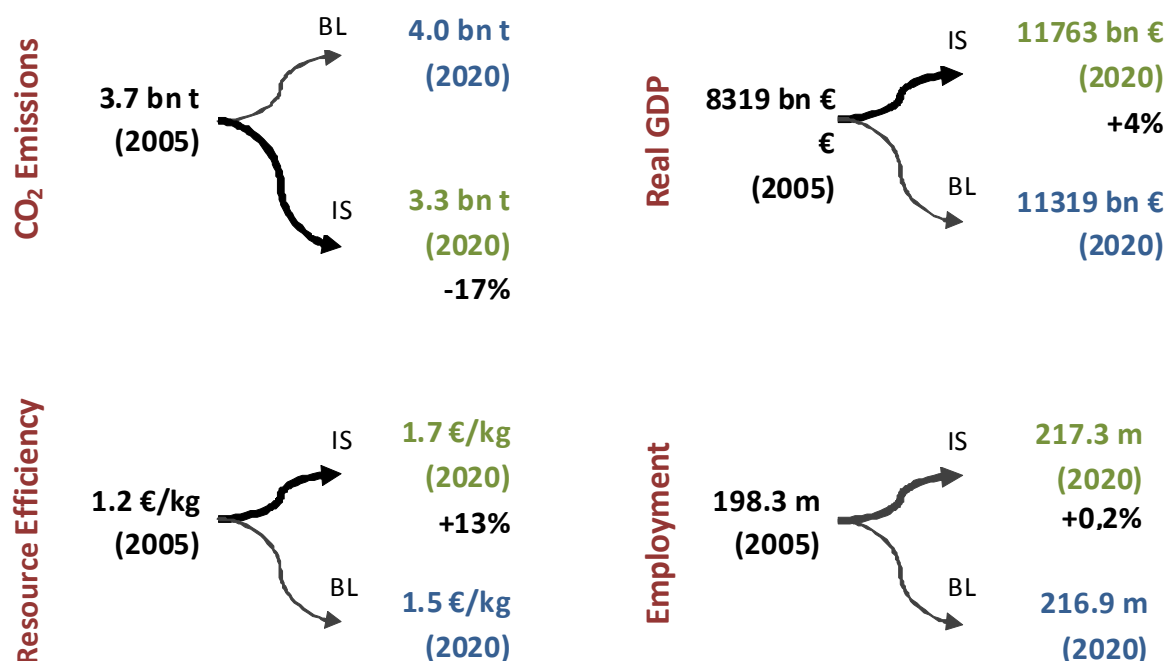
Table 4: Qualitative comparison of the results of the two scenarios

	Resource efficiency scenario	Integrated sustainability scenario
GDP	++	+
Exports	+	-
Employment	+	0
CO ₂ emissions	0	--
Material extraction	0	-
Resource efficiency	++	+

++ ... strong increase; + ... increase; 0 ... no significant effect; - ... decrease; -- ... strong decrease

Figure 6 illustrates the main results of the integrated sustainability scenario (IS) in comparison to the baseline scenario (BL). The CO₂ emissions in 2020 can be reduced by 17% compared to the baseline scenario in 2020 due to significant improvements in the energy and resource efficiency in the European economy. Moreover, resource efficiency is about 13% higher than in the baseline. The economic indicators also show positive results: in 2020, real GDP is 4% higher than in the baseline scenario. Minor impacts could be observed for employment numbers (+0.2% in the integrated sustainability scenario compared to the baseline scenario).

Fig. 6: Comparing the results of the integrated sustainability scenario (IS) with the baseline scenario (BL)



BL = baseline scenario

IS = Integrated sustainability scenario

Policy implications

The scenario simulations show that the implementation of policies geared towards decoupling economic activity from material and energy throughput are conducive to economic growth. The modelling results thus counter the popular assumption that such policies will have an opportunity cost in terms of foregone output. Resource efficiency measures decrease material costs for industries and thus reduce unit costs. Industries are able to produce and sell cheaper and demand by consumers increase. This has positive impacts on economic growth and on international competitiveness.

Governments should support industries in exploiting existing resource efficiency potentials, for example through the establishment of “Resource Efficiency Agencies”. Governments can play an active role in supporting companies to identify and realise resource efficiency potentials. In Europe and worldwide, several agencies exist which are dedicated to improving resource efficiency⁵. These institutions, partly financed by governments, provide consulting to enterprises, for example, through performing resource flow assessments and illustrating potentials for the development of new, resource-efficient business opportunities.

Proper resource accounting systems need to be established on the company and industry level. Companies play a key role in the transformation of economies towards a sustainable resource use. However, many enterprises do not know in detail how much resources and energy they purchase and

⁵ See, for example, the UNIDO/UNEP Programme for National Cleaner Production Centres (<http://www.unido.org/index.php?id=o5133>), or the Efficiency Agency of the German State of North Rhine Westfalia (www.efanrw.de).

what they cost. The potential for saving resources – and often money – therefore often remains undetected. Therefore, proper resource accounting systems in enterprises on the national and international level should be established⁶. This would help identifying “hot spots” of resource use in the up-stream supply chains of raw materials and intermediate products as well as in the production sites of companies.

Resource efficiency measures cause so-called “rebound effects”, which limit the positive environmental impacts of de-coupling. Despite all these positive economic effects, it has to emphasise that the environmental problems related to resource use, such as climate change, depletion of abiotic and biotic resources or the production of waste and emissions cannot be solved only through resource efficiency measures for companies and products. One main reason is the so-called “rebound effect” (see above).

In order to achieve positive results for the economy *and* the environment, resource efficiency measures for companies and products need to be combined with environmental policies on the macro-economic level. Integrated sustainability policy needs to consider both economic and environmental policy objectives. Increasing resource efficiency in companies and of products is crucial, but not enough to achieve environmental objectives, such as a reduction of CO₂ emissions. Macro-level policy instruments need to be implemented which limit the “rebound effects”. Such policies should aim at increasing the prices for raw materials and energy in order to account for the external environmental and social costs related to resource use. Such policies could be energy or material taxes or cap and trade systems, as implemented in the Kyoto Protocol for the area of greenhouse gas emissions. The results from the simulation of the integrated sustainability scenario for Europe illustrate that a well-designed mix of efficiency and other policies can deliver win-win results: higher economic growth, higher employment and improved environmental performance. The results of the modelling may have been even more positive, if the scenarios covered even more radical changes in the technological or policy environment.

6. Conclusions

Rapid economic growth through industrial development has been enabled by growing rates of resource extraction and use around the world and increased resource efficiency. With around 60 billion tonnes of extracted resources each year, the world economy used around 50% more resources in 2005 than in 1980. In Asia, extraction of resources has increased by 58% since 1980, to 24 billion tonnes in 2005. While almost half of the world’s resources (43% in 2005) is extracted in Asia, extraction per capita is still very small compared to Western industrialised countries. Along with Africa, Asia extracts the smallest amounts per capita (6 tonnes per year or 15 kg per day). Asia’s per capita consumption of natural resources is still similarly low (14kg/day in the year 2000), in contrast to Europeans (43kg/day) and North Americans (88kg/day). Meanwhile, resource intensity in Asia fell by around 22% over the past 30 years, and GDP grew by 125%. Thus, despite widespread evidence for relative de-coupling of resource extraction from economic growth, increases in resource efficiency have not kept up with the rates of economic growth.

The traditional resource-intensive growth trajectory has led to negative economic and environmental consequences. Many countries have experienced the ensuing consequences of

⁶ In a project for the NGO Friends of the Earth, SERI has recently suggested such a set of resource use indicators, which can be applied from the product to the national level (Giljum et al., 2009).

increased prices of crucial resources such as fossil fuels, of increasing import dependencies and of intensified global competition over limited resources. In addition, environmental pressures related to resource use have increased. These include global warming, deforestation, desertification, loss of biodiversity and pollution.

Notwithstanding the heavy economic and environmental costs, global resource use trends in a business-as-usual scenario forecast a significant growth of resource extraction, particularly in the Asia-Pacific region. These trends largely reflect the growing demand for natural resources of emerging economies such as China and India. Yet, given the economic and environmental consequences of increasing resource consumption, the present trajectory of economic growth puts economic, environmental, and social sustainability at risk.

Future strategies for sustainable economic growth must address natural resource use and achieve an absolute de-coupling of resource extraction from economic growth. For Europe and other industrialised countries with high per capita consumption, this means not only improving resource efficiency in relative terms, but also significantly reducing their resource consumption in absolute terms while maintaining their current quality of life. For most Asian countries, the key challenge lies in finding new paths to economic development that can provide best living conditions without liquidating their ecological wealth. Given that the Asian population will continue to grow and people aspire a higher standard of living, resource efficiency must play a key part on these development paths.

An integrated policy mix geared towards resource efficiency supports economic growth as well as environmental policy objectives. The integrated sustainability scenario which was modelled in the European “MOSUS” project illustrated that policy instruments aimed at raising resource efficiency on the level of companies and products can clearly foster economic growth and international competitiveness. However, to limit rebound effects on the macro level, these instruments must be accompanied by other policies influencing the prices of energy and materials. Given the limits to resource availability and biocapacity, such policies are key necessities for sustained and sustainable economic growth. A strategy of reducing resource use will not only diminish the pressures on the global environment. Running a resource-efficient economy will also be a competitive advantage in a world with rising commodity prices and increased resource constraints.

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