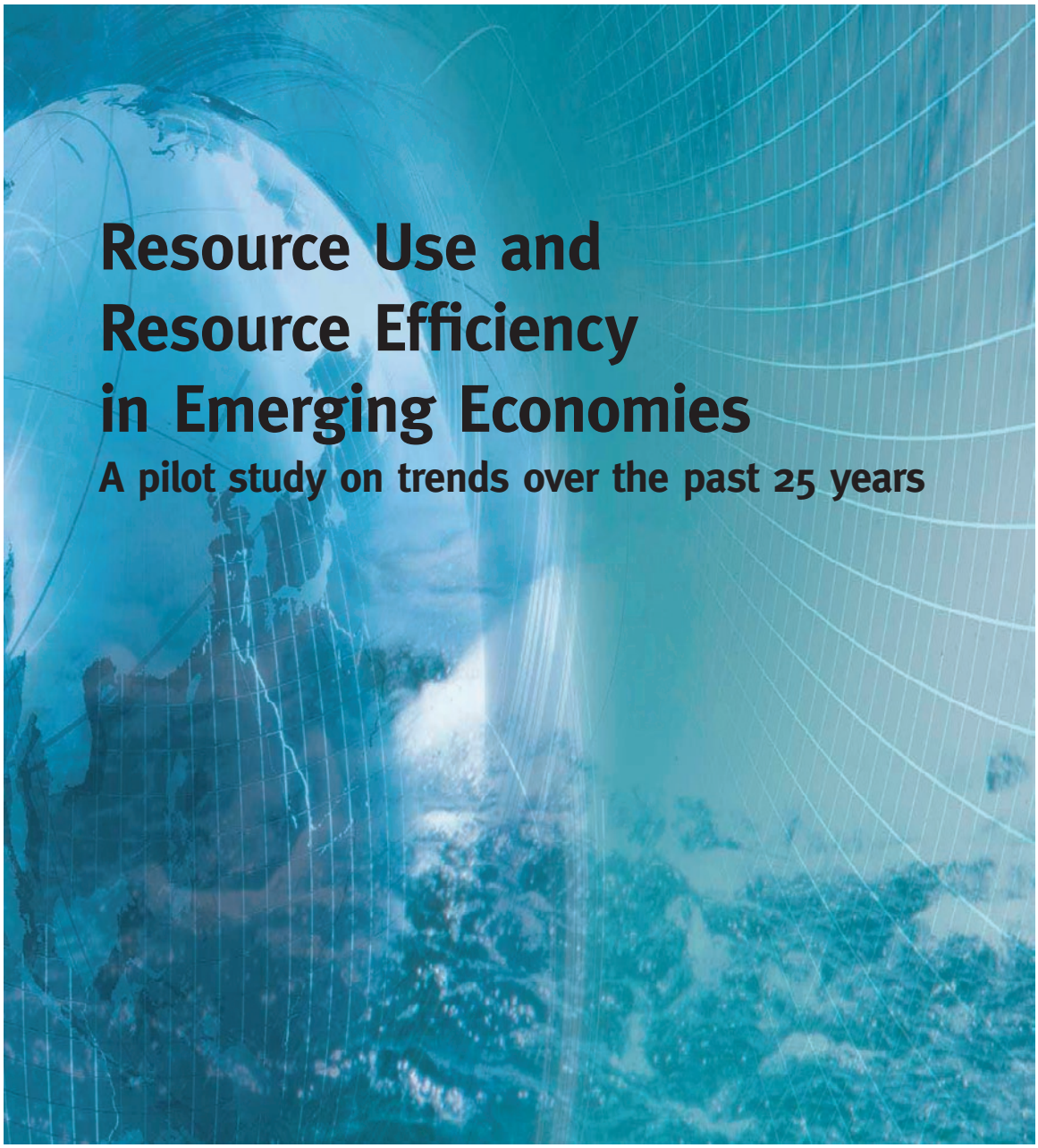
Green Industry

for a Low-Carbon Future



Resource Use and Resource Efficiency in Emerging Economies

A pilot study on trends over the past 25 years

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Executive summary

Resource use and resource efficiency are gaining increasing attention for industries and in policy discussions around the world. Improving resource efficiency is one of the main pillars of industrial efforts to tackle increasing resource prices and competition for scarce resources. At the political level, the growing attention also reflects concerns over resource dependency, resource security and environmental impacts, notably climate change and the growing degradation of the world's ecosystems and the services they provide. Some of the latest political initiatives include the "Manila Declaration on Green Industry in Asia" (2009) and the European Union's flagship initiative "Resource-efficient Europe" as part of the "Europe 2020" strategy for sustainable growth and jobs, which was adopted by the European heads of state in June 2010.

This report examines patterns and trends in resource use and resource efficiency in 16 selected emerging economies between 1985 and 2005. In order to facilitate comparison, we divided these countries into three different groups according to their dominant strategy of economic development since 1985: resource-based economies with a high ratio of raw materials in exports, including Algeria, Argentina, Brazil, Chile, Morocco, Russia and South Africa; industry-based economies which have been expanding their capacity to produce manufactured goods and related services, including China, Costa Rica, Malaysia, Mexico and the Republic of Korea; and services-based economies that have largely based their development since 1985 on services (e.g. tourism, financial or knowledge-based industries), including Barbados, Egypt, India and the Seychelles. While none of these three development paths is exclusive, they are useful categories for analytical purposes, as each is linked to specific physical or material profiles in terms of resource use and resource productivity.

Data and calculations in this report are based on two databases and their integration: (1) the global database on the extraction of used resources developed and maintained by the Sustainable Europe Research Institute (SERI), which is based on international statistics including the International Energy Agency, the Food and Agriculture Organisation of the UN (UN FAO) and the US and British Geological Surveys (www.materialflows.net); (2) the global database on resource trade developed by Dittrich (2010b) at the Wuppertal Institute in Germany, which is based on UN Comtrade data and includes global accounts of imports and exports in physical (mass) units. The methods applied are consistent with and fulfil international standards of material flow accounting.

Used resource extraction in the emerging economies more than doubled between 1985 and 2005, from around 10 billion tonnes to almost 22 billion tonnes, at a rate almost three times the global average. Today, more than one third of all globally used material resources are extracted in the emerging economies. The composition of resource extraction has changed significantly. The share of biomass from agriculture, forestry and fishing shrank from 55% to 40% between 1985 and 2005. Correspondingly, a remarkable growth occurred in the extraction of non-renewable resources, which contributed the remaining 60% to total resource use in 2005 (e.g. metal ore extraction increased by 205%, fossil fuels extraction by 183%, construction and industrial minerals extraction by 178%). In 2005, per capita extraction was highest in the resource-based emerging economies (e.g. Chile with 47 tonnes) and lowest in the service-based economies (e.g. India with 2.9 tonnes). With 6.8 tonnes, the average per capita resource use in the emerging economies was still lower than the world average (9 tonnes) and the average of the EU-27 (11 tonnes) in 2005.

Today, more than a quarter of all globally traded goods are imported or exported by the emerging economies. Over the past two decades, the emerging economies have experienced the highest growth rates in material trade in the world. Their trade volume in physical terms increased by a factor of almost 4.5 compared to a factor of 2.4 for average world trade. Imports have increased significantly across all material categories between 1985 and 2005, notably of fossil fuels (+504%),

which make up almost half of all imports of the emerging economies, but also of metal ores and products mainly produced out of metals (+535%), and biomass (+327%). Emerging economies following the industrialisation or service-oriented development path tend to be net-importers in physical terms, and those countries following the resource-based path are generally net-exporters.

Nowhere on the planet is material consumption growing faster than in the emerging economies. Material consumption of the group of 16 emerging economies has more than doubled from 1985 to 2005. Today, the 16 emerging economies, which are home to about half the world's population, consume about the same amount of material as OECD countries hosting only 14% of the world's population. Even though overall material consumption doubled in the 20-year period average, per capita consumption only increased by 52% (from 4.4 to 6.7 tonnes per capita) and still remains below the global average (around 8.5 tonnes per capita).

Resource efficiency in the emerging economies increased faster than the global average trend, albeit from a much lower absolute level. Between 1985 and 2005, material productivity has improved from 200 constant USD/t to 280 USD/t between 1985 and 2005. While some countries have experienced very strong improvements (China, India), others experienced relative stagnation (Mexico, Brazil) or even slight declines in material productivity (Chile, the Seychelles). The development of material productivity is determined by several interlinked factors, notably endowments of raw materials, economic structure, and international trade (extent to which countries import raw materials and material-intensive products from abroad). It is worth noting that the inclusion of unused material flows (e.g. overburden from mining) suggests that the differences in levels and dynamics of resource efficiency especially between resource importing and exporting countries are much lower than indicated by flows of used materials alone.

Material metabolism and energy-related CO_2 emissions are closely linked across emerging economies at different development stages and with very different levels of per capita GDP. On average, CO_2 emissions per capita grew even faster than material consumption per capita. This shows that future climate policies which aim at reducing CO_2 emissions should not ignore resource use. Resource efficiency policies may play a significant role in mitigating climate change.

The importance and influence of resource use and resource efficiency should be further analysed in the future. Questions arising from the results of this study include, inter alia: Given the limited availability of resources worldwide, to what extent will large emerging economies will be able to outsource their material requirements, following the pattern of industrialised countries? What development paths would be left to late-comers to industrialisation that are still strongly dominated by the extraction and export of natural resources? In the light of rising demand and rising prices for many raw materials, and increasing global scarcities of resources, what is the potential of resource-based development and how should it best be explored without jeopardising environmental sustainability? Finally, to what extent could climate policies help to reduce resource use and increase resource productivity, or vice versa, to what extent could resource efficiency policies contribute to the mitigation of climate change?

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1 Introduction

This report is a follow-up to the study "Resource Use and Resource Efficiency in Asia", which was commissioned by UNIDO under its programme on "Green Industry for a Low-Carbon Future" and finalised in April 2010 (see Giljum et al., 2010).

Resource use and efficiency are coming to the forefront in policy discussions around the world. In September 2009, 22 ministers from 21 Asian countries adopted the "Manila Declaration on Green Industry in Asia", the major outcome of the conference on "Green Industry in Asia" organized by UNIDO, the United Nations Environment Programme (UNEP), International Labour Organization (ILO) and the Economic and Social Commission on Asia and the Pacific (ESCAP). In this document, Governments expressed their support for and commitment to implementing policies, as well as regulatory and institutional frameworks conducive to making industries more resource-efficient and less carbon intensive in Asia. In Europe, resource efficiency is one of seven so-called flagship initiatives of "Europe 2020" - the EU's new 10-year strategy for sustainable growth and jobs - which was adopted by the European heads of state in June 2010. This EU strategy, envisages a transition towards a greener and more competitive economy through a significant increase in resource efficiency and a further decoupling of economic growth from the use of natural resources.

The Manila Declaration highlighted the importance of the emerging economies in Asia in shaping trends in resource use and resource efficiency at a regional as well as a global level. This study focuses exclusively on patterns and trends in resource use and resource efficiency in emerging economies. Although there is no common and fixed definition, emerging countries are usually understood as developing countries with high economic growth rates, which are in the transition from developing to developed status. In this study, 16 emerging economies, which belong to different groups have been selected and divided into three major categories according to their dominant strategy of economic development since 1985: resource-based, industry-based and services-based emerging economies[1]. In the selection of emerging economies, it has been attempted to cover an even spread among the different continents and among the different development paths.[2] The study covers the period between 1985 and 2005 and analyses the trends based on data in five-year increments.

Resource-based emerging economies are those with a high ratio of raw materials in exports (see for example Sachs and Warner, 1999). For various reasons, this development path was unattractive for a long time. However, with the rapidly increasing demand for raw materials and rising commodity prices over the past two decades[3], some emerging economies have managed to achieve a sustained path of economic growth based on the export of raw materials. Countries included in this study forming part of the resource-based group of emerging economies are Algeria, Argentina, Brazil, Chile, Morocco, Russia and South Africa.

The second, and most common, development path among the emerging economies is industrialisation, i.e., the process of expanding a country's capacity to produce manufactured goods and related services. Most industrialised countries have taken this path in the past (however, it is

[1] A colour-based system is used to separate the three groups: resource-based countries are in green, industry-based countries in orange and service-based emerging economies in blue.

[2] From Asia, only China, India, the Republic of Korea have been included. For an analysis of smaller Asian emerging economies such as Indonesia, the Philippines and Thailand, please see Giljum et al. (2010).

[3] In nominal terms, the general commodity prices rose by 300 per cent between 2002 and mid-2008 (the breakout of the financial crisis). Prices of crude petroleum as well as minerals and metals increased by 400–460 per cent. In real terms, the general commodity price level did not reach its average of the 1970s, and remained below the price hikes of those years (UNCTAD, 2010: 8).

worth noting that there is also a group of major OECD countries where exports of raw materials still dominate, including Australia, Canada and Norway). The emerging economies category is a very heterogeneous group which includes economies, ranging from basic industrialisation (simple manufacturing industry, based on low-wage labour) to very advanced industrialisation (knowledge-based, high value-added innovative industry). In this group, China, Costa Rica, Malaysia, Mexico and the Republic of Korea have been selected for further investigation.

The third category comprises those emerging economies that have largely based their development since 1985 on services such as tourism, financial or knowledge-based industries. Among the 16 emerging countries assessed in this study, Egypt and the Seychelles generate a high percentage of their GDP from tourism. Barbados also earns most of its revenues from services, notably tourism, offshore finance and information services. Although still considered a poor, developing country, India already generates about 60 per cent of its official GDP from services such as business process outsourcing and information technology and related services.It is important to note that none of the three categories outlined above are mutually exclusive. India, for example, is still an important resource exporter of iron, Mexico has noteworthy exports of petroleum, and Brazil has a significant industrial sector. Nevertheless, as this report will illustrate, the three dominant development paths are linked to specific physical or material profiles in terms of resource use and resource productivity. The main differences are exemplified by spotlighting selected countries with typical resource profiles: Chile as a resource-based emerging economy, China as a basic industry-based and the Republic of Korea as an advanced industry-based emerging economy, and the Seychelles as example of a service-based emerging economy.

The calculation of indicators on resource use and resource productivity in this report are based on the integration of two databases: (1) the global database on resource extraction developed and maintained by SERI, which is based on international statistics including the IEA, FAO and the US and British Geological Surveys (www.materialflows.net); (2) the global database on resource trade developed at the Wuppertal Institute in Germany, which is based on UN Comtrade data and includes global accounts of imports and exports in physical (mass) units. The applied methods are consistent with and confirm to international standards of material flow accounting (OECD, 2007). The results thus allow comparisons between countries. The methodology and data sources are explained in chapter 2.

Chapter 3 presents the main results. The first section compares the trends in resource extraction. The study on Asia (Giljum et al., 2010) demonstrated that countries with large deposits of exportable non-renewable resources (particularly fossil fuels and metal ores) significantly increased extraction between 1985 and 2005, and that emerging economies with large populations (such as China and India) had strongly increased their demand for minerals to build up infrastructure. Here, a global picture is provided and the question : “How much of the various types of resources do different emerging economies extract in absolute and per capita terms?” is addressed.

Section 3.2 looks at trade in materials. Asia, has the highest growth rates in trade due to its emerging economies. Here, the focus is on imports and exports of emerging countries worldwide between 1985 and 2005 and the questions: “To what extent are emerging economies dependent on imports of different types of resources to maintain levels and patterns of national production and consumption?” and “What types of resources do emerging economies supply to world markets?” are addressed.

Section 3.3 illustrates how material consumption has developed in the different emerging economies between 1985 and 2005 and answers the question: “To what extent are emerging economies dependent on imports of different types of resources to maintain levels and patterns of national production and consumption?”

In section 3.4, trends in resource efficiency are analysed.[4] In Asia, the large emerging economies of China and India were among the least resource efficient countries (Giljum et al., 2010). This phenomenon is examined and resource efficiencies across a range of emerging economies at different stages of economic development are compared. The main questions guiding this data analysis are: "How resource efficient are different emerging economies, and how has their performance developed since 1985?" and "What factors are responsible for the large differences in resource efficiency between different emerging economies?"

Section 3.5 illustrates the link between material consumption and CO_2 emissions in the emerging economies. This analysis may help to address the question to what extent climate policies could help to reduce resource use and to increase resource productivity. Or, vice versa, to what extent could resource efficiency policies contribute to the mitigation of climate change?

Section 4 summarizes the main results and concludes with policy-related questions and future assessments of global resource use and resource efficiency.

2 Methodology and data sources

This study is based on the methodological framework of Material Flow Accounting and Analysis (MFA). MFA builds on earlier concepts of material and energy balancing, as introduced in the 1970s. The MFA concept was developed as a reaction to the fact that it is the overall scale of industrial metabolism rather than the toxicities of specific substances that determine many persistent environmental problems, such as high material and energy consumption and related negative environmental consequences (such as climate change).

Since the beginning of the 1990s, when the earliest MFAs were presented on the national level (for example, in Japan, Environment Agency Japan, 1992), MFA has developed into a rapidly growing field of scientific and policy interest, and major efforts have been undertaken to harmonise the methodological approaches developed by different research teams. Today, the MFA methodology is internationally standardised and methodological handbooks are available, for example from the European Statistical Office (EUROSTAT, 2007) and the OECD (2007).

For MFAs on the national level, two main system boundaries for the accounting of material flows can be defined. The first is the boundary between the economy and the domestic natural environment from which raw materials are extracted. The second is the frontier to other economies with imports and exports as accounted flows.

In general, four major types of resources are considered in MFA studies. All types of resources are accounted for in terms of their mass flow (weight in tonnes) per year. This study presents data at this level of aggregation. If products are composed of different types of materials (e.g. steel and wood), the product is allocated to the dominant material group according to a standardised allocation key (EUROSTAT, 2007).

- Biomass (from agriculture, forestry, fishery, and hunting) and biomass products (including textiles and wood products such as paper);
- Fossil energy carriers (coal, oil, gas, peat), used for energy and non-energy purposes (including chemicals based on fossil materials);
- Minerals (industrial and construction minerals) and mineral products (such as glass or natural fertilizers);

[4] Please note that this study measures resource efficiency in terms of material productivity (measured as GDP per domestic material consumption).

- Metal ores and metal products (including, for example, machinery or coins).

The extraction of metal ores is accounted as “gross ore”, i.e. total amounts of metal-containing ore and not only the net metal content. Large parts of “gross ore” extraction become mining waste during the processing and concentration of the metals. This waste often remains in the source country of extraction.

It is also worth noting that this study focuses on economically used resources and does not consider so-called “unused extraction”, which is not processed further but becomes waste during mining, quarrying, agriculture, forestry and fisheries, such as overburden, crop residues or by-catch. Globally, unused extraction exceeds the used extraction by two to three times.

A large number of resource use indicators can be derived from economy-wide MFAs. These comprise indicators on material inputs, material outputs, material consumption and physical trade. In this study, the following MFA-based indicators are used:

- Domestic Extraction Used (DEU) is defined as all extracted and further processed raw materials within the border of a country;
- Domestic Material Consumption (DMC is the mass of materials such as biomass and minerals (but not water) extracted from a country’s environment (DEU), plus the mass of goods imported into the country, less the mass of goods exported; DMC is an important indicator of overall environmental pressure;
- Physical Trade Balance (PTB), calculated as imports minus exports.

The compatibility of MFA with data from the System of National Accounts (SNA) enables direct relation of material flow indicators with indicators of economic performance, such as GDP. These interlinkage indicators quantify the eco-efficiency (or material productivity) of an economic system by calculating economic output (measured in monetary units) generated per material consumption (in physical units), for example GDP/DMC. Material productivity indicators are thus suitable tools to monitor processes of de-linking or decoupling of material use from economic growth which contributes to lower resource consumption.

The calculations illustrated in this pilot study build on the integration of two existing databases. The first is the global database on resource extraction developed and maintained by SERI, which is based on international statistics including the International Energy Agency (IEA), UN FAO and the US and British Geological Surveys. This database is accessible in an aggregated form at www.materialflows.net, where a detailed technical report can also be downloaded (SERI, 2010b). Data quality varies for the different types of materials. It is generally of a high standard for the extraction of fossil fuels and metal ores; although with the latter, estimations have to be applied in some cases regarding the concentration of metals in crude ore extraction. With respect to biomass, it can be assumed that part of the biomass extraction for subsistence purposes is not covered in official statistics, therefore values are likely underestimated, particularly for the poor developing countries. As for mineral use, with the exception of Japan, statistics are very poor in all investigated countries. Thus, a method was used to estimate extraction of construction minerals depending on the per capita income. Therefore, the exact amounts of mineral extraction may be over- or underestimated in some of the countries. A more detailed study would be needed to develop better estimation methods.

The second database used in the study is the global database on resource trade developed at the Wuppertal Institute in Germany, which is based on UN Comtrade data and includes global accounts of imports and exports in physical (mass) units. A detailed methodological description is given by Dittrich (2010b) or Dittrich and Bringezu (2010). Additionally, a differenced analytical tool was developed to detect incorrect information and outliers within trade statistics. False values and values

of direct trade flows of outliers are corrected by adjusting the concerned values with regard to global prices, amount of global imports and exports and – as far as possible – bilateral trade data as well as with regard to national sector statistics (in particular trade with petroleum, see also first study about Asian countries).

In general, UN Comtrade trade statistics are reliable and recent trade statistics are more differentiated and absolute than older ones. The quality of the 16 emerging economies' trade statistics as a whole is of a high standard. Trade statistics for some countries are excellent (in particular South American countries) while others are moderate (Mexico and Malaysia).

Integrating these two components allows for a calculation of national material consumption, factoring in both the domestic extraction and use of resources as well as imported and exported materials. Based on these material consumption indicators, which include international trade, proper indicators on material productivity can then be calculated. This exercise was performed, for the first time ever, for the emerging economies covered in this study.

In order to link resource use issues to the dominant environmental policy issue of climate change, the correlations between material consumption and energy-related CO_2 emissions on the country level were also investigated. For energy-related CO_2 emissions, data from the IEA (2009) was used.

3 Results

This section presents the main results of the calculations of indicators on resource use and resource efficiency. It is divided into sub-sections on material extraction, trade, consumption, productivity, and use and CO_2 emissions. If not otherwise noted, the term emerging economies has been used for the 16 emerging countries assessed in this study.

3.1 Material extraction

The dynamic and resource intensive economic development of the emerging economies is clearly reflected in the growth of their used resource extraction.[5] Resource extraction more than doubled in the emerging economies in the 20-year period, from around 10 billion tonnes in 1985 to almost 22 billion tonnes in 2005. At 114 per cent, growth in used resource extraction in emerging economies was almost three times the global average (40 per cent) (see Table 1). The share of the emerging economies in global resource extraction also grew considerably. Today, more than one-third of all globally used material resources are extracted in the emerging economies.

Table 1: Global and emerging economies' used resource extraction (1985-2005)

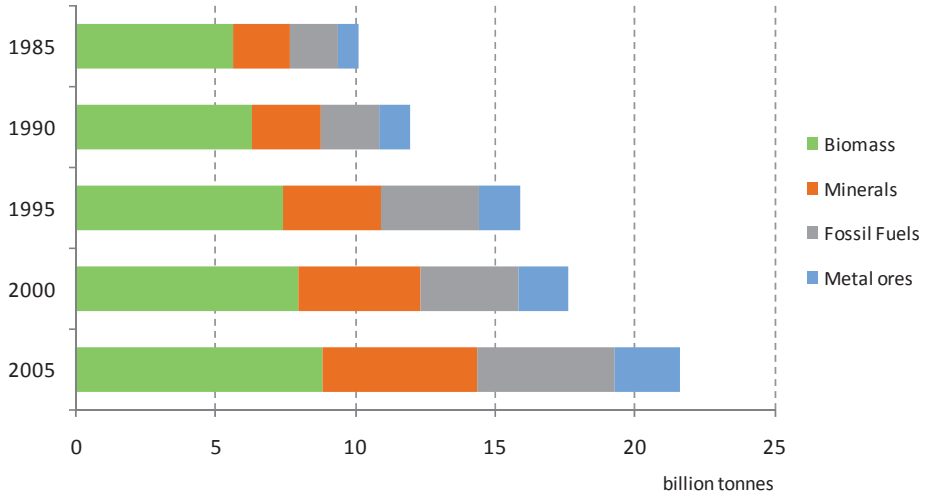
	Global extraction, billion tonnes	Global extraction, 1985 = 100	Extraction in 16 emerging economies, billion tonnes	Extraction in 16 emerging economies, 1985 = 100	Share of 16 countries in global extraction
1985	40.9	100	10.1	100	24.7 %
1995	46.7	114	15.9	149	34.0%
2005	57.5	140	21.6	214	37.6%

Source: SERI (2010a)

[5] The term "used resource extraction" is used to distinguish it from unused material, i.e. material that is extracted but not further processed in the production system (e.g. mining waste).

The composition of used material extraction has changed significantly in the past 25 years. Figure 1 illustrates the development in domestic extraction of used biomass, minerals, fossil fuels and metal ores in the 16 investigated emerging economies between 1985 and 2005. While in 1985, biomass from agriculture, forestry and fishing accounted for 55 per cent of overall material extraction, this share of renewable resources shrank to 40 per cent in 2005. At the same time, there was remarkable growth in the extraction of non-renewable resources, which constituted the remaining 60 per cent of total extraction in 2005. Between 1995 and 2005, extraction of construction and industrial minerals increased by 178 per cent; extraction of fossil fuels grew by 183 per cent, in particular due to rapidly expanding mining of hard coal in China; and metal ore extraction increased by 205 per cent, particularly due to increased iron ore extraction in Brazil, China and India and increased copper extraction in Chile.

Figure 1: Material extraction by material category in emerging economies (1985-2005)



Source: SERI (2010a)

On the national level, the largest extracting countries in the group of emerging economies in 2005 were China (8 billion tonnes), India (3.1 billion tonnes), Brazil (3 billion tonnes), Russia (2.3 billion tonnes) and Mexico (1.2 billion tonnes).

The structure of resource extraction in an emerging economy depends on the quantity and variety of available resources as well as its economic specialisation in specific sectors. China – the most important representative of an emerging economy on the path of industrialisation – leads the extraction of metal ores (690 million tonnes of crude ore), followed by Chile – a typical representative of a natural resource-based emerging economy, which has significantly expanded its mining sectors, in particular copper extraction. Today, total crude ore extraction in Chile stands at around 600 million tonnes, and it is the world's biggest copper exporter. Brazil, another resource-based economy, ranks third in the group of emerging countries, with a very diversified mining sector (367 million tonnes). Due to their high population and large country size, China and India also lead in biomass extraction (2.9 and 1.9 billion tonnes, respectively), followed by Brazil (1.8 billion tonnes), which has significant exports of biomass-based products (see section 3.2).

The average per capita resource extraction in emerging economies in 2005 was 6.8 tonnes, compared to a world average of 9 tonnes (SERI, 2010a) and an average of 11 tonnes in the EU-27 (EUROSTAT, 2010). Huge differences in per capita extraction can be observed. Countries in the group of resource-based emerging economies have the highest per capita extraction numbers. Chile is the

most typical example for this type of country and had a per capita resource extraction of almost 47 tonnes in 2005. With 22.7 tonnes per capita, Argentina ranks second, particularly due to its significant per capita extraction in the agricultural sector, which account for almost 60 per cent of overall extraction. Brazil, Russia and South Africa extract between 15 and 16 tonnes per capita. The lowest extraction per capita occurs in Morocco (4.6 tonnes), Egypt (4.5 tonnes) and India (2.9 tonnes).

Summarizing, resource extraction has grown significantly both in the resource-based emerging economies, such as Chile or Brazil, as well as in those emerging economies with rapid industrialisation and high population, such as China and India.

3.2 Material trade

From a global perspective, emerging economies have experienced the highest growth rates in material trade over the past two decades. From 1985 to 2005, trade volume in physical terms increased by a factor of almost 4.5 in the emerging economies, compared to a factor of 2.4 for average world trade (see Table 2). Though Russia's and South Africa's trade before 1995 is not included, trade volume of the remaining 14 emerging economies nearly quadrupled over this period even without including both countries. The share of the emerging economies in global trade volume thus enlarged, in contrast to the industrialized European countries, whose share declined (Dittrich, 2010b). Today, 26.4 per cent of all traded goods are imported or exported by the emerging economies.

Table 2: Global and emerging economies trade volume (1985-2005)[1]

	Global trade volume, billion tonnes[2,3]	Global trade volume[1] 1985=100	Emerging economies' trade volume[1] billion tonnes	Emerging economies' trade volume[1] 1985=100	Share of 16 emerging economies in global trade volume
1985	3.78	100	0.54	100	14.2%
1990	4.74	126	0.64	118	13.4%
1995	6.75	169	1.37	254	21.4%
2000	8.12	215	1.72	320	21.2%
2005	9.56	242	2.42	449	26.4%

[1] Russia's and South Africa's trade are not included before 1995

[2] Trade volume = (imports + exports)/2; to maintain comparability, traded water is excluded;

[3] Source: (Dittrich, 2010b)

Even though as a group, the emerging economies constantly export more than they import in physical terms, their imports increased at a faster rate than their exports between 1985 and 2005. Imports grew by a factor of 5.1 since 1985 (1.8 since 1995), to 2.2 billion tonnes in 2005, and exports increased by a factor of 4.5 since 1985 (1.7 since 1995), to 2.7 billion tonnes in 2005.

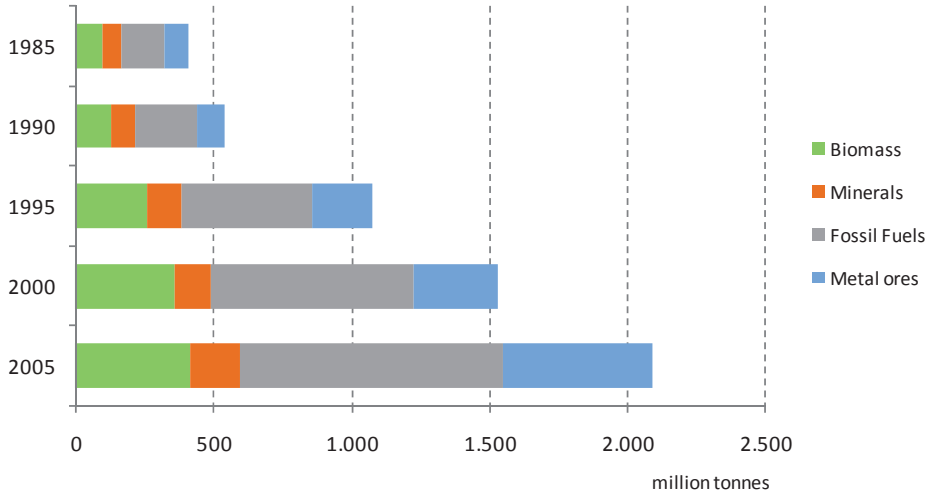
In terms of their material composition, imports of all material categories have increased significantly in absolute terms, especially when it comes to fossil fuels (see Figure 2). Fossil fuels, including oil as the predominant global trade product, are also the main imports of the emerging economies. Between 1985 and 2005, the share of fossil fuels in total imports rose above world average (+504 per cent) from 38.7 per cent to 45.7 per cent, which is almost equal to the share of fossil fuels in total imports of the EU-27 (around 50 per cent). The high growth rates of fossil fuels can be attributed mainly to China (+1,676 per cent), India (+787 per cent) and Chile (+722 per cent).

There was an above average increase in imports of metal ores and products produced mainly out of metals in the two decades (+535 per cent). These high growth rates can be ascribed mainly to China (+966 per cent) and Chile (+614 per cent, starting from a very low level), reflecting the growing demand from their metal manufacturing industry, for infrastructure development as well as for the production of consumer goods.

Biomass imports to the emerging economies grew significantly (+327 per cent) between 1985 and 2005. The highest growth in biomass imports took place in China (+729 per cent) and Chile (+514 per cent).

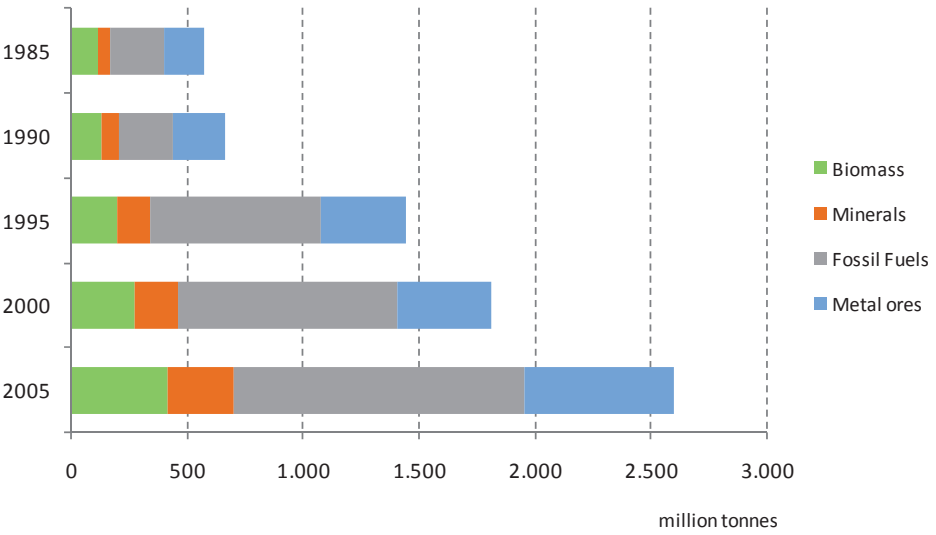
In general, minerals are traded less because most of them are available in almost all countries, such as sand and gravel for construction purposes. In absolute terms, China imports most minerals due to its high population and rapidly increasing demand for minerals (see Giljum et al., 2010).

Figure 2: Material imports of 16 emerging economies (1985-2005)



Source: own calculation based on UN Comtrade

Figure 3: Material exports of the 16 emerging economies (1985-2005)



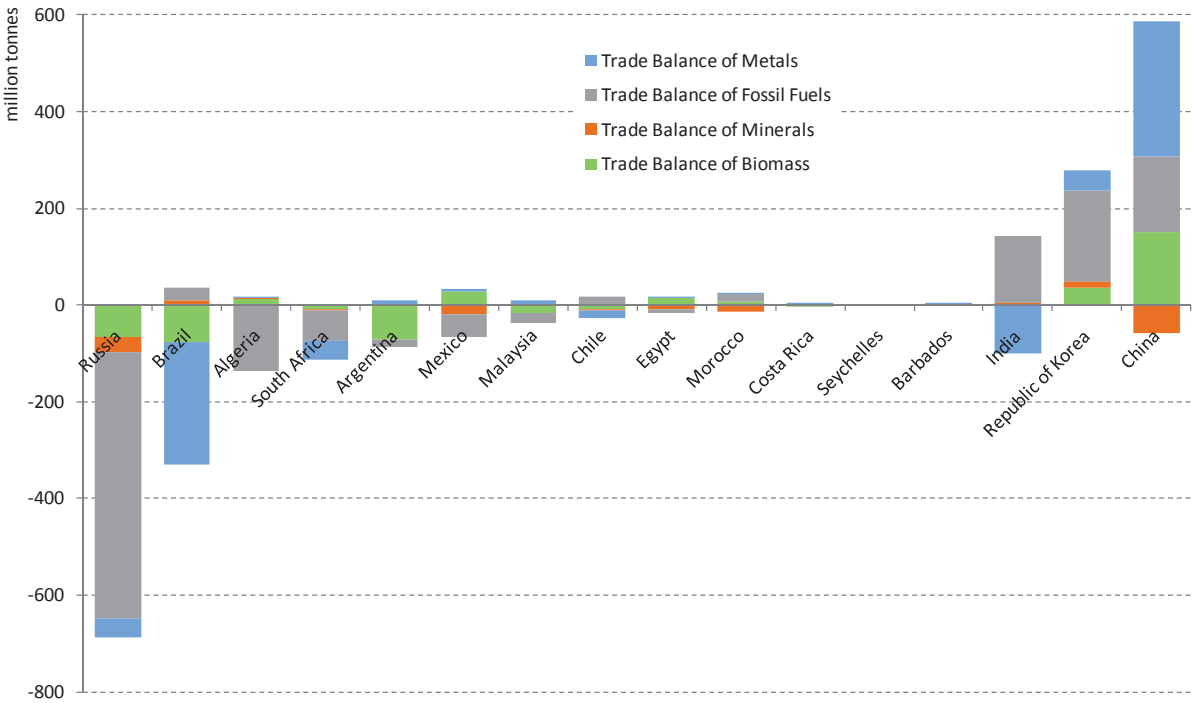
Source: own calculation based on UN Comtrade

In terms of quantity, fossil fuels (including oil, gas and coal) have made up about 50 per cent of all exports from the emerging economies since 1995. This relatively high share is mainly due to the inclusion of Russia in this study, which exported nearly half of all fossil fuels exports of the selected emerging economies between 1985 and 2005 (more than 580 million tonnes in 2005), followed by Algeria (137 million tons), China (131 million tonnes) and Mexico (101 million tonnes).

Exports of minerals also increased markedly, mainly pushed by China (see Giljum et al., 2010). Exports of metal ores and biomass grew in absolute terms, but "only" by a factor of 3.7 and 3.6, respectively. Metal exports of the emerging economies are clearly dominated by Brazil which exports between 40 per cent and 45 per cent of all metal exports of this group, mainly iron ores and concentrates. Nevertheless, its growth rate was moderate (+135 per cent) between 1985 and 2005. The highest growth rates of metal exports were observed in China (+2,602 per cent), Costa Rica (+709 per cent) and Mexico (+603 per cent), reflecting the rising exports of manufactured products produced mainly with metals. Egypt also has a high growth rate (+995 per cent), which is due to the very low level of metal exports in 1985. While there is no single emerging country in the field of biomass exports, Russia, Brazil, Argentina and China dominate with comparably high shares.

Together, the 16 emerging economies were net exporters of 530 million tonnes of different resources in 2005. This net amount is not high given their aggregate trade volume of more than 2.4 billion tonnes. Nevertheless, trade profiles differ significantly between the emerging economies (see Figure 4). Physical trade balances show net-redistribution of resources and allow identifying net consumers and net suppliers of resources on the global level. Note that the physical trade balance is calculated as imports minus exports, in contrast to standard monetary trade balances. Positive values therefore mean net-imports of materials and negative values indicate net-exports.

Figure 4: Physical net-imports and -exports by material category (2005)



Source: own calculation based on UN Comtrade

On a global level, the principal trade pattern – whether a country is a net-importer or a net-exporter of resources – has been relatively constant since 1962 (the first year of UNComtrade statistics), while

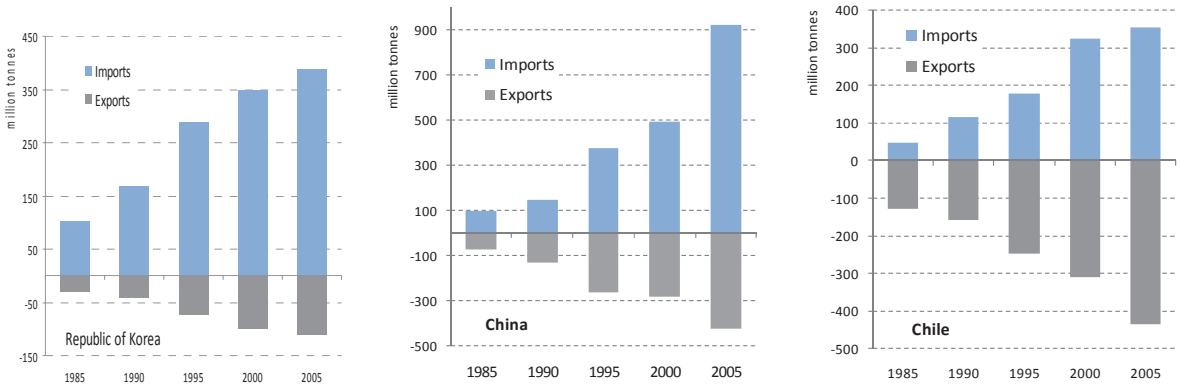
the absolute amounts of net-exports and –imports have increased (Dittrich, 2010b; Dittrich and Bringezu, 2010) (some exceptions are discussed below). In this context, it is important to note that generally speaking, net-importing of resources goes along with shifting environmental burden and net-exporting, with receiving environmental burden (for a global perspective, see Dittrich, 2010b; for a European study, see Schütz et al., 2004).

The process of increasing geographical division between net-importers and net-exporters can be clearly observed in the emerging economies: Countries that follow the industrialisation or service path, such as China, the Republic of Korea and India (see right side of Figure 4) are generally resource importers while countries following the resource path are physically net-exporters of resources (e.g. Russia and Brazil on the left side of Figure 4). On the one hand, absolute amounts as well as material composition reflect the demand of the country, and on the other, the specific resource base of the countries. For example, Algeria's exports of petroleum are naturally bulkier than Chile's exports of copper. The biomass imports of countries with large deserts such as Egypt or Morocco are another noticeable example.

In line with China's immense exports of manufactured products, it is also the third largest resource consumer worldwide which is largely due to the rapidly growing demand for its expanding industries, infrastructure and consumption (see Giljum et al., 2010). Since 1995, Russia has been the world's largest resource supplier and exports more resources than Australia, though the gap between both countries is small (around 10 million tonnes in 2005). Brazil, the second largest resource exporter among the group of the investigated emerging economies, was the fifth largest net resource supplier on a global level in 2005.

The increases of net-imports and net-exports since 1985 are illustrated for the three countries of the Republic of Korea, China and Chile (see Figure 5). The principle pattern is simple: in countries with a growing industrial sector, imports of bulky raw materials grow faster than exports of less bulky manufactured products. As a result, physical net-imports increase. For example, the Republic of Korea and China increased their net-imports by 283 per cent and 1.733 per cent respectively between 1985 and 2005. The opposite – increases in exports of bulky raw materials and increases in less bulky imports of manufactured products resulting in increased net-exports - can be observed in resource exporters such as Brazil (+202 per cent) or South Africa (+138 per cent, since 1995) and to a lesser extent in Chile (+2 per cent). The latter is due to the fact that Chile's huge imports of petroleum outweigh the exports of copper, which is exported more as concentrated copper ore or as basic copper products, such as copper plates.

Figure 5: Total physical imports and exports of the Republic of Korea, China and Chile (1985-2005)



Source: own calculation based on UN Comtrade

Besides the relatively constant global division of resource exporters and importers, there are some notable exceptions, mainly among the emerging economies, where some countries changed from net-exporters to net-importers of resources (Dittrich, 2009; Dittrich and Bringezu, 2010). Since 1962, five of the 16 emerging economies have changed from net-exporters to net-importers of resources, namely Barbados (1985), Costa Rica (1985), Egypt (1985), India (1990) and Morocco (1995). In Costa Rica and India, import growth was dominated by fossil fuels and metals, typical requirements for industrialisation. Egypt and Morocco, by contrast, experienced the strongest physical import increases in biomass, mainly reflecting population growth. Mexico switched several times between net-importer and net-exporter between 1985 and 2005, reflecting among other things, the import-to-export development strategy since 1980 as well as the Peso or so-called Tequila crisis in 1994 (see also Dittrich et al., 2009). Malaysia has been one of the very few countries worldwide since the beginning of modern trade statistics which changed from a net-importer in physical terms to a net-exporter (in 1985).

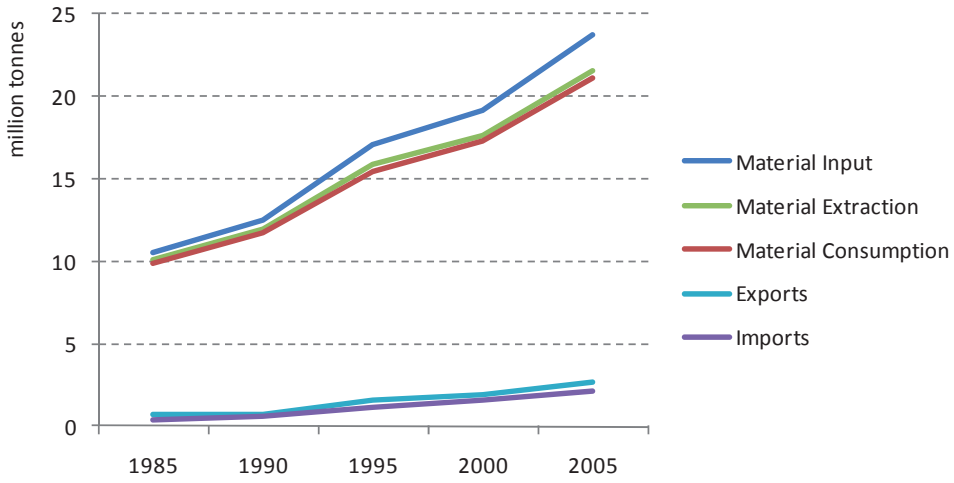
With two-thirds of the studied countries maintaining their role as either net importers or net exporters of resources, the question arises as to the limits of continuing this general trend in the future. If most developing countries aim to follow the industrialisation or service paths in the future, there will be fewer countries supplying world markets with raw materials and they will experience an increasing environmental burden.

3.3 Material consumption

In economic terms, Domestic Material Consumption (DMC) is related to the consumption activities within a country. DMC is therefore closely related to GDP (EUROSTAT, 2001). In environmental terms, DMC is an indicator for potential environmental pressures associated with the disposal of residual materials within the domestic environment.

The increasing extraction activities of the emerging economies have resulted in more than a doubling of their material input and consumption from 1985 to 2005, despite their rising net-exports. Figure 6 shows extractions, imports and exports at a glance as well as material input (extraction plus imports) and material consumption (extraction plus imports minus exports) over the period 1985 to 2005. Together, the 16 emerging economies consumed around 21 billion tonnes of materials in 2005.

Figure 6: Extraction, trade, input and consumption of materials in the 16 emerging economies (1985-2005)



Source: SERI (2010a) and own calculation based on UN Comtrade

Table 3 shows that some emerging economies depend highly on imports while others depend only on selected materials. Import dependency is usually measured by the portion of imports in material consumption. Figures of 100 per cent or below illustrate the extent of material imported for consumption, a figure above 100 per cent indicates that imports are re-exported (in general, after further processing). On an average, around 10 per cent of the emerging economies' material consumption was imported in 2005 (up from 4.2 per cent in 1985), however, there are sizeable differences among the countries when it comes to the material composition (see Table 3). The highest dependencies can be observed in islands and peninsulas (and on a global level also in city-states) while countries with a large domestic resource base are dependent to a lesser extent.

Countries with relatively small agricultural sectors such as the Seychelles or Barbados depend on imported biomass to a very large extent, while countries with strong agricultural sectors, such as Argentina or Brazil have no dependence at all. Minerals are mainly produced in the respective countries, thus import dependencies exist only to a minor degree in islands where only few different mineral-types are available. The highest dependencies can be observed for fossil fuels and metal ores. Though on average, only 21 per cent of consumed fossil fuels and 24 per cent of metal ores are of foreign origin, some countries such as the Republic of Korea and Costa Rica depend entirely on imports of fossils fuels and/or metals. Import dependencies of countries with large domestic reserves of fossil fuels (e.g. Russia) or metals (e.g. Chile or Brazil) are negligible.

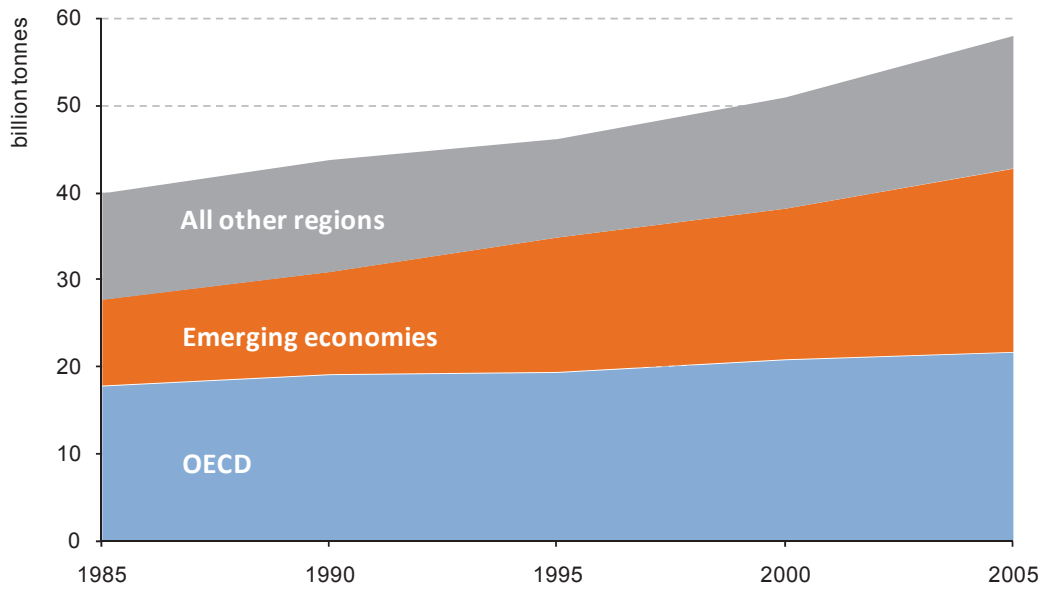
Table 3: Import dependencies of emerging economies in 2005 (% share of imports in DMC)

	All materials	Biomass	Minerals	Fossil fuels	Metal ores
Republic of Korea	55.2	44.1	6.5	128.2	168.6
Barbados	45.5	49.8	9.0	148.8	107.8
Seychelles	45.4	69.6	7.8	434.6	17.0
Malaysia	29.3	17.0	9.7	62.8	139.57
Costa Rica	16,1	10.7	4.6	111.9	126.31
Algeria	12.4	18.8	5.4	6.9	71.0
Mexico	12.4	12.4	2.0	29.4	18.0
China	10.8	6.4	2.9	11.8	36.8
Egypt	9.6	10.8	1.4	14.9	95.26
India	7.0	1.03	3.8	26.4	15.0
South Africa	6.8	3.8	2.5	12.9	5.4
Russia	6.3	5.6	3.8	4.6	63.7
Chile	4.7	6.5	4.5	114.1	0.4
Brazil	3.4	0.7	2.7	43.9	3.7
Argentina	3.0	0.57	1.6	12.7	19.7
Average	**10.2**	**4.7**	**3.4**	**20.76**	**24.0**

Source: SERI (2010a) and own calculation based on UN Comtrade

Nowhere in the world is material consumption growing faster than in the emerging economies. Compared to the doubling of absolute material consumption in the 16 emerging economies, absolute material consumption in OECD-countries (not including the Republic of Korea, Mexico and Chile) and other developing countries was less significant during the investigated period (22 per cent and 24 per cent, respectively; see Figure 6). Together, the 16 emerging economies, which are home to about half the world's population, are now consuming about the same amount of material as OECD countries, which host 14 per cent of the world's population (36.5 per cent versus 37.3 per cent of global material consumption).

Figure 6: Domestic Material Consumption (DMC) of main global country groups (1985-2005)



Sources for OECD and other countries: Dittrich (2010a), based on UN Comtrade and SERI (2010a)

The absolute amount of materials consumed varies significantly between the investigated countries. The populous countries of China, India and Brazil together accounted for around two-thirds of all materials consumed by the 16 emerging economies (around 14.5 billion tonnes in 2005, with China's share rising at the expense of India and Brazil (see Table 4).

Table 4: Absolute amounts of domestic material consumption (1985-2005), million tonnes

	1985	1990	1995	2000	2005
Algeria	139,264	115,047	135,427	133,363	161,514
Argentina	624,604	609,641	682,400	756,595	802,176
Barbados	2,684	3,217	2,684	2,910	3,202
Brazil	1,753,679	1,978,987	2,206,479	2,348,915	2,729,890
Chile	231,527	287,739	420,078	669,390	755,760
China	3,167,874	4,090,061	5,295,841	5,959,685	8,521,691
Costa Rica	29,279	31,461	35,297	39,365	38,360
Egypt	214,008	237,976	264,517	313,828	349,781
India	1,930,298	2,258,610	2,576,761	2,871,522	3,189,101
Malaysia	103,007	131,424	191,832	260,786	266,808
Mexico	784,611	913,972	920,534	1,177,288	1,197,841
Morocco	112,493	116,565	106,411	124,216	146,946
Russia (USSR)	-	-	1,522,742	1,473,136	1,617,742
Seychelles	397	490	610	749	844
South Africa	494,692	-	570,523	569,845	595,873
Rep. of Korea	311,158	410,752	551,528	640,698	704,420
Total	**9,899,574**	**11,185,939**	**15,483,665**	**17,342,291**	**21,081,950**

Source: SERI (2010a) and own calculation based on UN Comtrade

The highest growth rates of material consumption can be observed in Chile (+226 per cent), China (+169 per cent), Malaysia (+159 per cent) and the Republic of Korea (+126 per cent). All these countries have experienced intensive industrial development over the two decades since 1985. In the

Seychelles, the high growth rate in material consumption (+112 per cent) is largely due to the strong expansion of tourism, the primary industry of the islands. Other countries increased their absolute material consumption only slightly and below world average (+45 per cent), e.g. Algeria (+16 per cent), Barbados (+19 per cent), South Africa (+21 per cent), Argentina (+28 per cent), Morocco (+31 per cent) or Costa Rica (+31 per cent).

A very different picture of material consumption in emerging economies is revealed when the focus is on per capita figures. The average per capita consumption of the 16 emerging economies has increased from 4.4 tonnes per capita in 1985 to 6.7 tonnes in 2005. The average is clearly dominated by China (Figure 7). Average per capita consumption across the emerging economies as well as in China is still below the global average per capita consumption, which remained relatively stable over the same period at around 8.5 tonnes (SERI, 2010a).

Wide ranges between the countries and very different dynamics can be observed (see Figure 7a and 7b). The first general observation is that countries following the resource path (green lines) generally have a higher per capita consumption than the countries following the industrialisation or service path (orange and blue lines, respectively). To some extent, which cannot be expressed in quantitative terms due to a lack of available data, this is due to the fact that only direct material flows are considered in this study; this will be discussed in more detail below based on selected country examples. Furthermore, the level of per capita DMC of resource rich countries reflects the fact that many of the resource countries are large and therefore require greater infrastructure for extraction and export than small countries.

Within the groups of industry, service and resource-oriented emerging countries, it can be observed that per capita DMC is higher in more affluent countries. For example, advanced industrialising countries with a high level of affluence such as the Republic of Korea have a significantly higher material consumption per person than basic industrialising countries such as China. Another example is Argentina's per capita DMC of 20.7 tonnes compared to the material consumption of an average Moroccan of 4.9 tonnes in 2005.

With regard to the absolute amount of per capita DMC, it is worth noting that per capita consumption of most of the Latin American emerging countries, the Republic of Korea, South Africa and Russia was above the world average of 8.95 tonnes per capita in 2005 (SERI, 2010a) and nearly comparable to the majority of industrialised countries, which lies between 15 and 20 tonnes per person (OECD average was 18.9 tonnes in 2005, OECD, 2008). In contrast, per capita DMC in Egypt and India (4.5 tonnes and 2.9 tonnes respectively) was significantly lower than the worldwide average and the average of the emerging economies in 2005.

The second general observation concerns the temporal dynamics of per capita DMC. With the exception of Chile, which will be discussed in greater detail, the per capita DMC trend of countries following the resource path increased only slightly, stagnated or even declined, while per capita DMC of countries following the industrialisation or service path rose. Examples are Brazil (+14 per cent between 1985 and 2005) as a resource based economy, in comparison with the increase seen in the Republic of Korea (+92 per cent), the Seychelles (+73 per cent) or China (+116 per cent) as industry and service based economies. China has the highest growth in per capita consumption of used materials. Exceptions such as the relative stagnation of per capita DMC in India and Egypt mainly reflects population growth partly in combination with low increase of absolute material consumption. Vice versa, the rise of per capita DMC in Russia can, inter alia, be traced back to a decrease in population.

Figure 7a: Per capita Domestic Material Consumption (DMC), upper part (1985-2005)

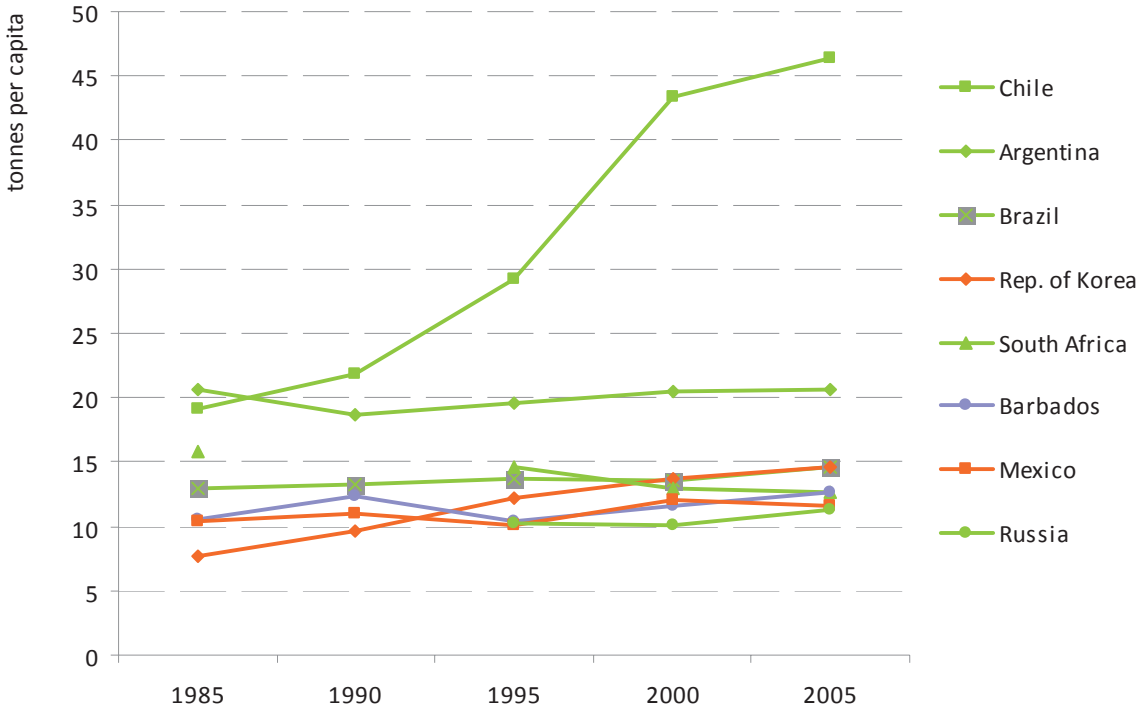
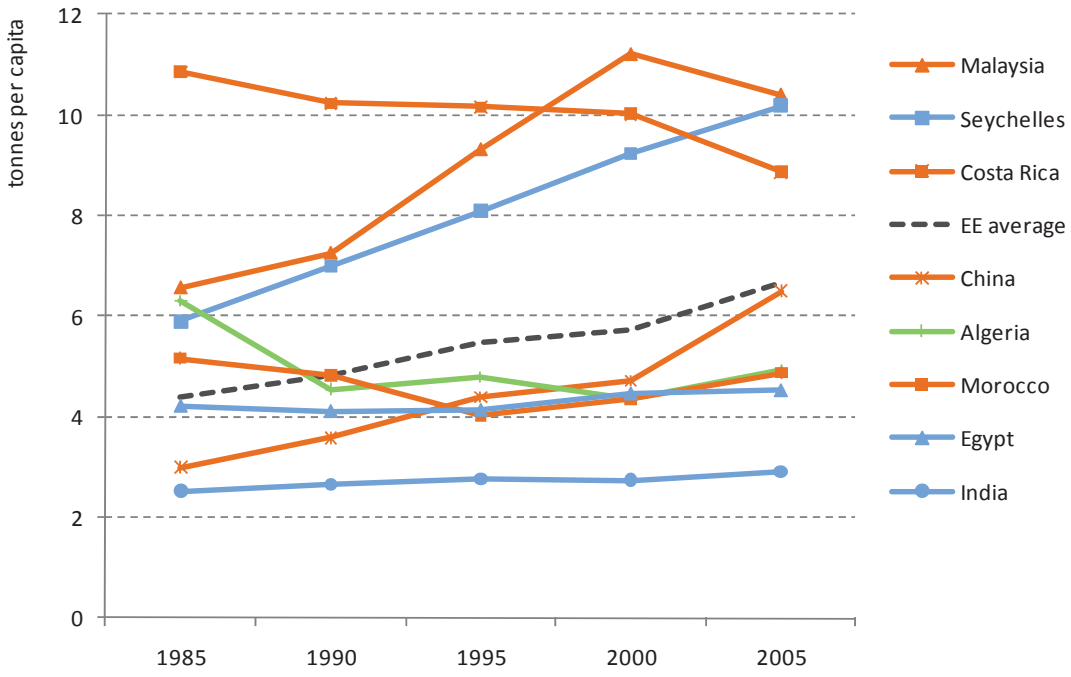


Figure 7b: Per capita domestic material consumption (DMC), lower part (1985-2005)



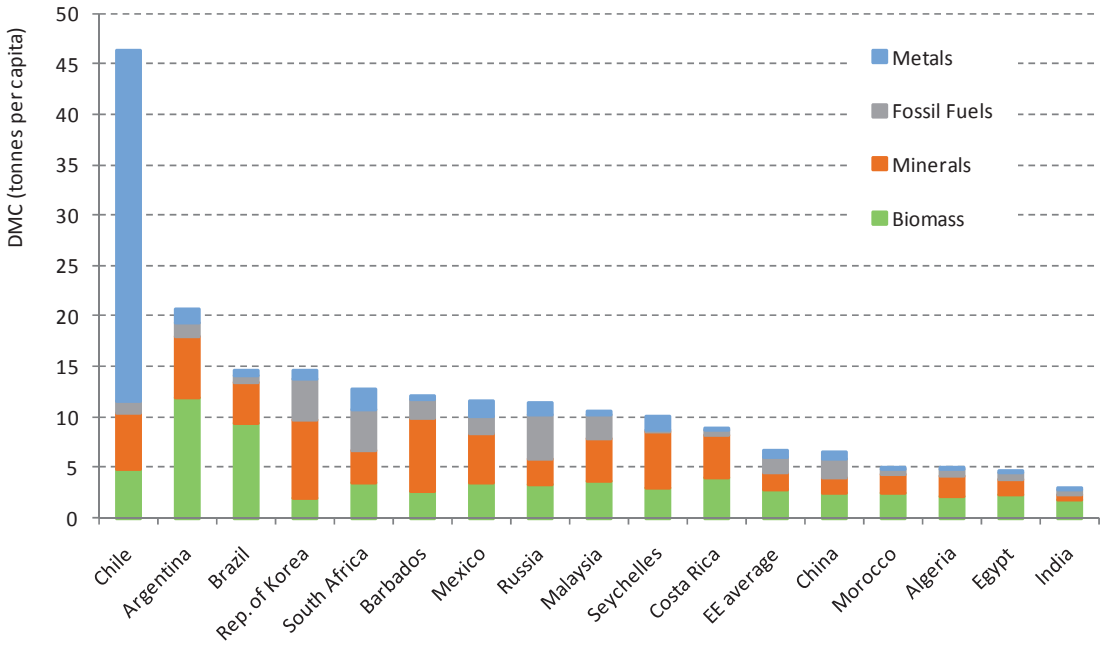
Source: Own calculations based on SERI (2010a) and UN Comtrade

An analysis of the per capita consumption in terms of material composition confirms typical patterns in Asian countries (Giljum et al., 2010): the poorer countries among the 16 emerging economies consume mainly biomass and non-metallic minerals (Figure 8). As explained in Section 2 and in the above-mentioned study of Asian countries, values of mineral extraction are estimated. Therefore, the exact amount of mineral consumption may be over- or underestimated in some countries, but

the overall trends can be considered accurate: a higher number of buildings and – to some extent – infrastructure is constructed completely or partly with biotic materials in poorer countries – a pattern which changes when countries become richer. Buildings and infrastructure are built increasingly with abiotic materials (concrete, steel, etc), and the richer countries become, the more infrastructure is constructed and has to be maintained.

The lower per capita consumption of biomass in the Republic of Korea and the two islands can be explained by the fact that food and biomass products (especially paper and paper-products) are imported to a high degree (see also Table 3 above, import dependencies of biomass), while the extractions for the corresponding production are attributed to the per capita consumption in the producing country. Thus, per capita consumption of biomass is higher in countries with a significant agricultural and forestry sector (in particular Argentina and Brazil).

Figure 8: Per capita Domestic Material Consumption (DMC) (2005)



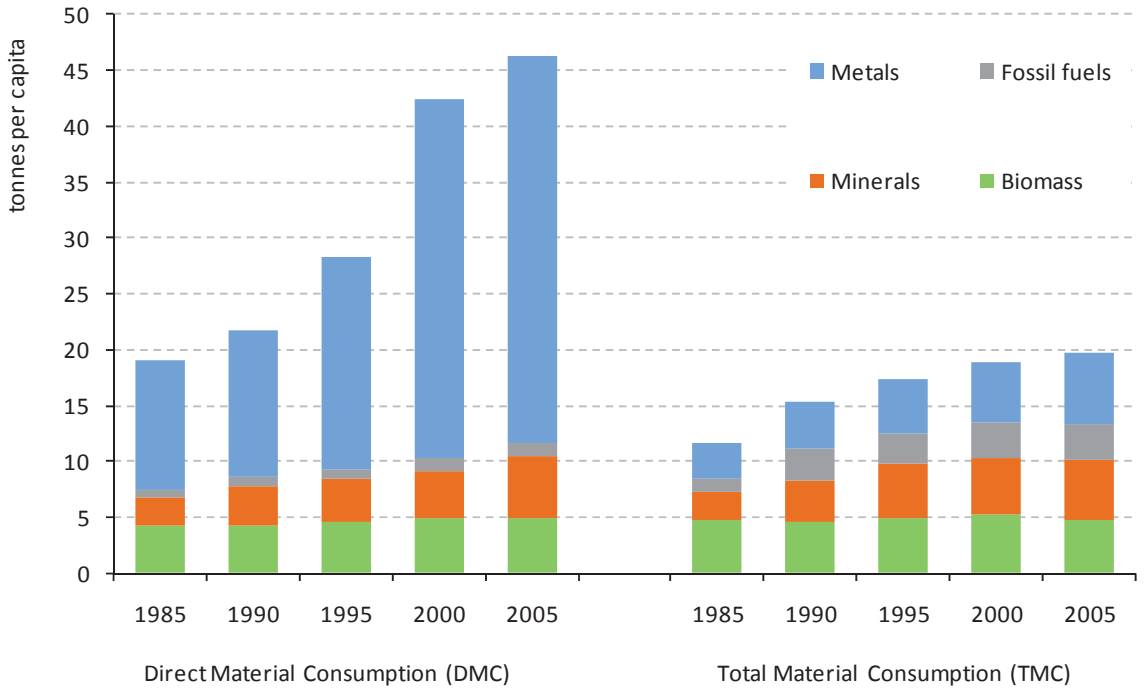
Source: Own calculations based on SERI (2010a) and UN Comtrade

By far, Chile has the highest material consumption per capita of 46.4 tonnes in 2005. This is mainly due to the fact that only direct material flows are considered in this study. In 2005, nearly 75 per cent of the material extraction in Chile was caused by the exploitation of copper, i.e. extraction of gross metal ores with a concentration of around 1 per cent of copper, whereas copper is exported as concentrated ore or as refined copper. The remaining 99 per cent of extracted materials, which remain as waste in the extracting country, are counted as domestic metal extraction. This picture would change significantly if indirect or upstream-flows are considered (Estrada Calvo, 2007; Giljum, 2004; Munoz et al., 2009). The remaining materials would be counted as so-called "upstream material flows" of exported copper, allocated and added to the consumption of the importing country and thus subtracted from DMC in Chile. Integrating indirect flows of both domestic material extraction and trade would result in a per capita material consumption of an estimated 12 tonnes per person in 1985 to 20 tonnes per person in 2005 (this is expressed by the indicator "Total Material Consumption" or TMC[6]). TMC is thus only half of the material consumption compared to a situation

[6] Please note that there are still open questions regarding the calculations of indirect flows and comprehensive

in which only direct flows are accounted for with the indicator DMC (see Figure 9a). This is particularly due to the high indirect flows of Chile's metal exports (in particular, copper), which are allocated to the metal importing country in TMC (see Giljum, 2004).

Figure 9a: DMC and estimated TMC per capita of Chile (1985-2005)

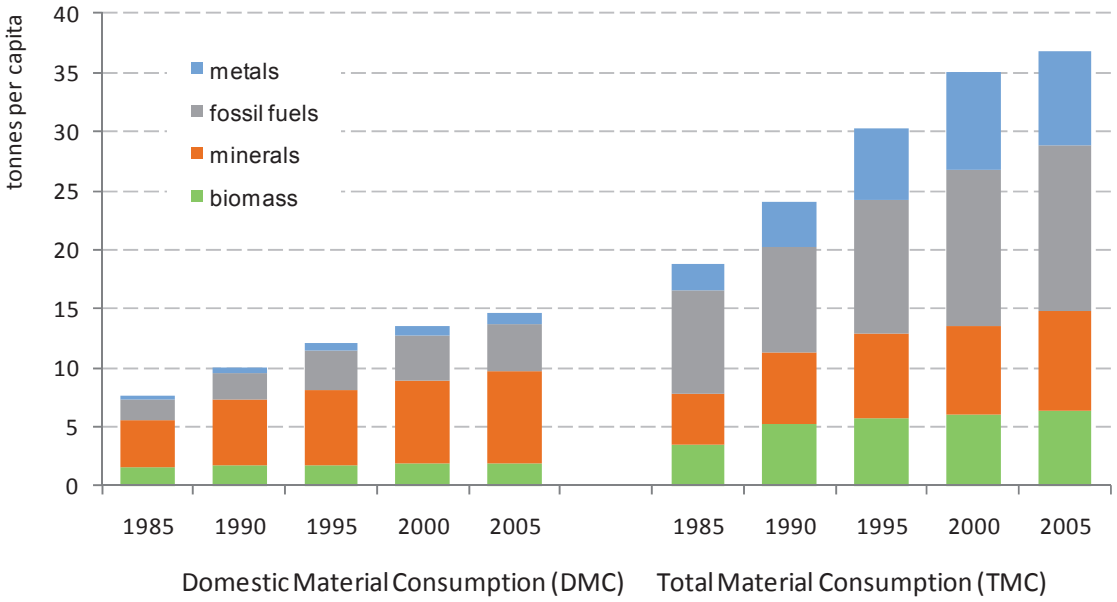


Source: Dittrich (2010a), based on SERI (2010a), UN Comtrade, Schütz and Bringezu (2008)

In the case of countries following the industrialising path, upstream or hidden flows of the imports together with the direct imports generally outweigh exports and their upstream flows. This is usually interpreted as shifting environmental burden.

indicators such as TMC (OECD 2008). Thus, the estimations presented in this study should be considered as preliminary and – as far as known – conservative estimations.

Figure 9b: DMC and estimated TMC per capita of the Republic of Korea (1985-2005)

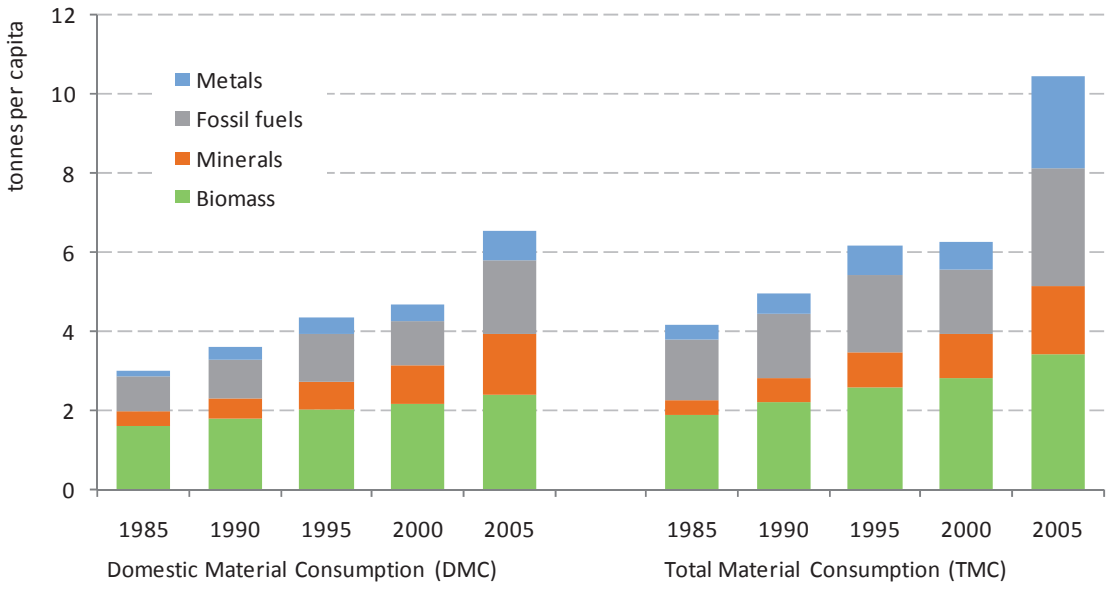


Source: Dittrich (2010a), based on SERI (2010a), UN Comtrade, Schütz and Bringezu (2008)

For example, if integrating upstream flows in the calculations for the Republic of Korea and China, the estimated (total) material consumption would rise up to around 37 tonnes and 10.4 tonnes, respectively. In the case of the Republic of Korea (Figure 9b) the increasing DMC is mainly due to increases of minerals and fossils; when upstream-flows are integrated, the growth of per capita TMC is mainly due to the upstream-flows of imported biomass, fossil fuels (coal) and metals. Furthermore, a deceleration of growth can be observed in the Republic of Korea since 2000, which might partly be a result of a slowdown in the construction of infrastructure and industry, or it may be in the initial stages of material saturation.

By contrast, the growth of fossil fuels and metals has accelerated in China since 2000 (Figure 9c), reflecting the increased build-up and expansion of industry and infrastructure (see also Giljum et al. 2010).

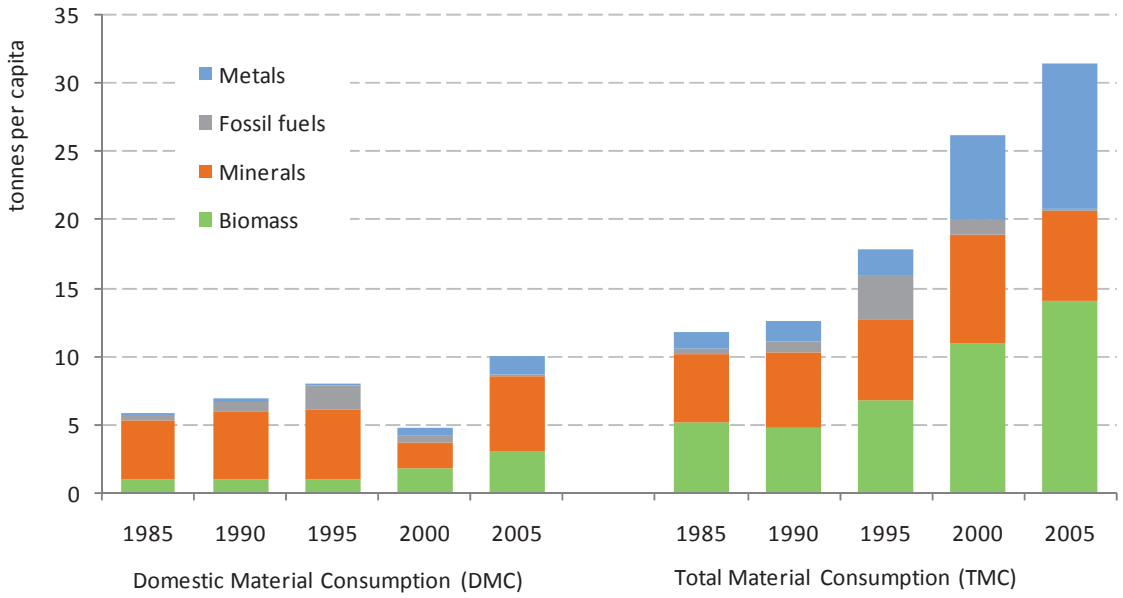
Figure 10c: DMC and estimated TMC per capita of China (1985-2005)



Source: Dittrich (2010a), based on SERI (2010a), UN Comtrade, Schütz and Bringezu 2008

Like the two examples before, the amount of material use of a service-oriented country also increases when indirect flows are integrated. The Seychelles are one example (Figure 9d). Including the upstream flows in TMC per capita is more than three times higher than the per capita DMC, which excludes the indirect material flows. Upstream flows increased mainly due to imported biomass, particularly of products such as vegetable fats and oils, spirits, wine and beer as well as processed food such as pasta. It can be assumed that these products are used mainly in the tourism sector. The increases of indirect flows of metals are caused by products made mainly made of metals, such as motor vehicles and electrical appliances, as well as by imports of gold and products made of gold.

Figure 9d: DMC and estimated TMC per capita of the Seychelles (1985-2005)



Source: own calculation based on SERI (2010a), UN Comtrade, Schütz and Bringezu (2008)

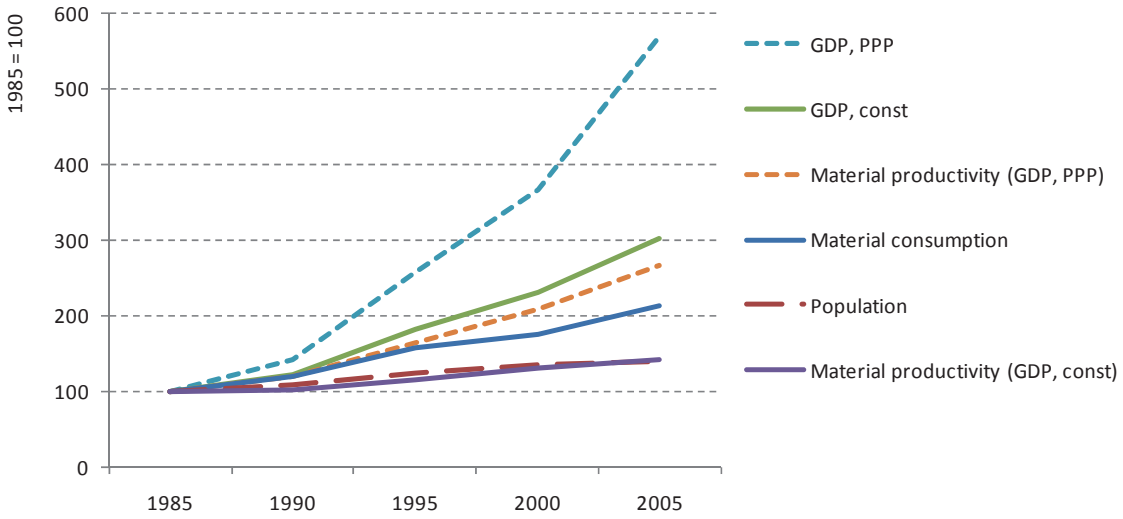
It must be emphasised that the numbers for indirect material flows are preliminary estimations which have to be improved further in the future. Nevertheless, the general picture shown by the four figures above can be considered accurate : including indirect flows clearly changes the general picture of material consumption. Chile as the country with the highest per capita DMC becomes a country with a medium TMC, while the Republic of Korea, a country with a medium per capita DMC is transformed into a country with a high TMC per capita. It can be assumed that in general, material consumption of industry- or service-oriented countries is significantly higher, and material consumption of resource-oriented countries is slightly higher or even lower when upstream flows are integrated into the analysis.

3.4 Material productivity

Combining data on GDP and Domestic Material Consumption (DMC) allows deriving a material productivity indicator (GDP/DMC), which illustrates how much economic value is being generated per unit of material consumption.

Figure 10 illustrates the overall trends in GDP, material productivity, material consumption, and population across the group of emerging economies. A comparison between GDP and material productivity based on Purchasing Power Parity (PPP) and in terms of constant US$ of the year 2000, calculated using Market Exchange Rates (MER).

Figure 10: GDP, material consumption, material productivity and population (1985-2005)*



* 1985 and 1990 without Russia; 1990 without South Africa

Source: Own calculations based on SERI (2010a), UN Comtrade, Worldbank

Between 1985 and 2005, Domestic Material Consumption (DMC) in the emerging economies increased by 113 per cent - more than twice as much as population growth during the same time (40 per cent). GDP based on constant 2000 US$ MER tripled over the period of investigation. However, with a growth factor of 5.7 between 1985 and 2005, GDP based on PPP values increased much faster than the MER-based GDP.

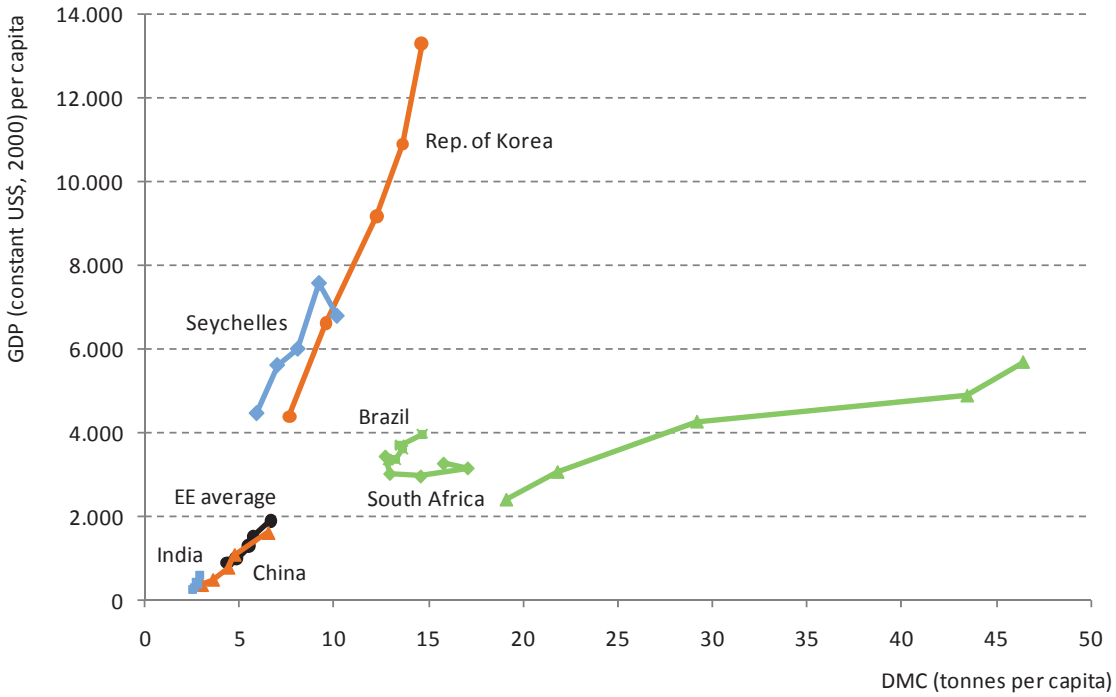
Consequently, there are significant differences between the results on material productivity based on the MER and PPP concept, respectively. Material productivity increased by almost twice as much when calculated with GDP data in PPP terms than in MER (by a factor of 2.7 compared to 1.4 respectively). Thus, PPP-based material productivity results show a significant relative decoupling, i.e. GDP in PPP growing at a much faster rate than material consumption, while MER-based GDP calculations reveal only a small relative decoupling.

When applying these types of indicators, a clear decision has yet to be taken in the scientific community on which GDP concepts should be used for such analyses. In most cases, it is argued that PPP numbers should be favoured for international comparisons of the economic performance of countries, while constant currencies in MER are better suited for time series analyses. However, in existing MFA studies, authors use both concepts. Official MFA data for European countries published by EUROSTAT (see EUROSTAT, 2010) is presented in constant Euro based on MER. In their forthcoming paper on resource use in the Asia-Pacific region, Schandl and West (forthcoming) apply MER-based GDP numbers, arguing that MER-based numbers y represent the value of economic activity more accurately than PPPs do and thus avoid inflating the productive capacity of developing countries compared to developed ones. In his recent study on material productivity across EU countries, Bleischwitz (2010) applies PPP-based GDP numbers. Clearly, using PPP-based GDP numbers, the productivity performance of emerging economies in relation to industrialised countries is illustrated more positively compared to MER-based GDP numbers.

The relationship between per capita GDP and DMC in the emerging economies is heterogeneous. Figure 11 shows this link for seven countries as well as r the average across the 16 emerging economies between 1985 and 2005. Overall, a rise in both GDP and DMC across all countries can be seen. In general, the growth of GDP is much higher than growth of DMC in service- and industry-

based countries and, vice versa, growth of material consumption rises faster than GDP in resource-based emerging economies.[7]

Figure 11: Per capita GDP and DMC in selected emerging economies (1985-2005)



Source: Own calculations based on SERI (2010a), UN Comtrade, Worldbank

The highest GDP per capita is seen in the Republic of Korea, reflecting the achievements of economic development during a time when the country had moved away from the manufacturing of value added goods (its focus during the 1950s and 60s) to an advanced stage of industrialisation during the 1970s and 80s, which saw the development of advanced steel, shipbuilding and automobile industry and to the high-tech and service industry in the 1990s and 2000s. Today, the Republic of Korea possesses world-class firms in all these four industries.

There are wide differences in per capita GDP and DMC between the different emerging economies. In some countries, a relative decoupling between per capita GDP and per capita material consumption can be observed (as the former has grown faster than the latter) over the entire period of time. This was notably the case in China, India and the Republic of Korea. This trend is in line with the recent developments in industrialised regions (for an overview, see Bringezu and Bleischwitz, 2009). Other countries, notably the resource-based economies of Chile and Brazil, did not follow this trend. In Costa Rica, an absolute decoupling can be observed: while DMC per capita declined during all five year increments and over the whole period, GDP clearly increased. Falling GDP per capita goes along with both falling material consumption (e.g. Algeria and Argentina, 1985-1990) and with rising

[7] It is worth noting that some emerging economies, which are not shown in the Figure 11, do not follow this positive correlation trend between the GDP and DMC during specific periods – usually of political or economical turmoil; for example Mexico between 1990 and 1995 (Mexican peso crisis in 1994) and between 2000 and 2005 (supplies to the US are increasingly being substituted with supplies from Asia), Argentina between 1985 and 1990 (the "lost decade"), and South Africa between 1985 and 1990 (economic sanctions were applied and a significant amount of foreign direct investment withdrawn in the mid-1980s to pressure the South African government to end apartheid) (see for example Manby, 1992).

material consumption (e.g. Algeria, 1990-1995; the Seychelles, 2000-2005). However, it does not last longer than five years as a trend in any country. The following Table 5 provides an overview of DMC and GDP growth numbers between 1985 and 2005.

Table 5: Growth rates of per capita DMC and per capita GDP (in constant USD, 2000)

	1985-1990		1990-1995		1995-2000		2000-2005		1985-2005	
	DMC growth (%)	GDP growth (%)	DMC growth (%)	GDP growth (%)	DMC growth (%)	GDP growth (%)	DMC growth (%)	GDP growth (%)	DMC growth (%)	GDP growth (%)
Algeria	-27,86	-9,29	5,29	-9,40	-8,76	8,09	12,45	18,12	-22,06	4,93
Argentina	-9,21	-9,15	4,69	28,46	4,68	7,22	0,96	5,08	0,45	31,48
Barbados	17,45	n/a	-16,00	n/a	11,14	n/a	9,32	n/a	19,87	n/a
Brazil	2,72	0,55	3,14	7,59	-1,17	2,55	8,79	7,16	13,90	18,89
Chile	14,13	27,17	33,66	38,86	48,83	14,49	6,78	16,32	142,43	135,16
China	19,56	34,45	22,65	59,01	7,38	39,22	37,71	48,00	116,84	340,49
Costa Rica	-5,79	12,35	-0,70	15,85	-1,36	12,51	-11,53	10,98	-18,35	62,51
Egypt	-2,52	7,78	0,58	6,78	7,96	17,41	1,37	9,06	7,31	47,37
India	5,39	21,82	3,97	17,44	-0,71	18,10	6,15	33,78	15,49	126,03
Malaysia	10,49	20,66	28,31	38,21	20,29	11,82	-7,18	12,97	58,29	110,65
Mexico	5,62	-1,47	-8,03	-1,50	18,99	21,33	-3,31	3,84	11,76	22,27
Morocco	-6,62	n/a	-16,54	n/a	8,40	n/a	11,72	n/a	-5,62	n/a
Russia (USSR)	n/a	n/a	n/a	-37,82	-2,04	9,70	12,24	37,64	9,94	51,00
Seychelles	18,63	25,84	15,73	6,95	14,05	26,22	10,32	-10,36	72,74	52,27
South Africa	8,14	-3,40	-14,65	-6,07	-11,20	2,01	-1,88	13,54	-19,58	5,09
Republic of Korea	25,66	50,82	27,65	38,47	11,44	18,84	7,36	22,03	91,91	202,85
Global Average	10,31	11,24	13,66	30,41	4,13	17,07	16,79	25,59	52,47	113,30

Source: Own calculations based on SERI (2010a), UN Comtrade, Worldbank

On average, material productivity in the emerging economies improved from 200 constant US$/tonne of resources in 1985 to 230 US$/tonne in 1995 to 280 US$/tonne in 2005. Material productivity thus increased faster than the global average trend, which improved from 500 US$/tonne in 1985 to 640 US$ in 2005, albeit from a much lower level. The global trend was mostly driven by high GDP growth in the rich industrialised countries (see Behrens et al., 2007).

As in the case of per capita material consumption, the average figures for material productivity conceal important variations (see Figures 12a and 12b). Generally, industry- and service-oriented countries have higher resource productivities than resource-based countries. Those industry-based emerging economies that are at a relatively advanced stage (e.g. Republic of Korea and Mexico) are most resource efficient, while those at an earlier stage of industrialisation show a below-average performance (e.g. China). In 2005, the lowest material productivities were found among the main resource-based emerging economies - Chile (120 US$/tonne) and Russia (220 US$/tonne) – as well as in the service-based economy of India (200 US$/tonne).

These low productivity results can be attributed to a variety of reasons. In the case of China and India, the building of highly material- and energy-intensive infrastructure (buildings, transport infrastructure, etc.) and basic industries, such as metal and chemical industries, has strongly increased material consumption with under-proportional increases in GDP. Thus, the low or lagging changes in material productivity of these emerging countries may be interpreted as a phase in a longer transition process from an agricultural-oriented profile to an industry-oriented profile (similar to the metabolic process observed in western countries, see Krausmann et al., 2008). This phase is characterised by building of a highly resource-intensive physical stock, and – in contrary to rich

countries – this transition in emerging economies takes place within a relatively short time period of a few decades. The low material productivity, especially of India, China and Egypt, could also reflect the fact that the the agricultural sector's share remains relatively high. In 2005, the industrialising emerging economies of Republic of Korea (910 US$/tonne) and Mexico (530 US$/tonne) were the most resource efficient countries. The general lower material productivity of emerging countries compared to industrialised countries, such as the EU-15 (1,700 US$/tonne in 2004) or Japan (2,400 US$/tonne in 2005) could partly also be a result of a dislocation of material-intensive industries from the industrial countries (see below for details).

Figure 12a: Material productivity by country, 1985-2005, upper end (above EE average in 2005)

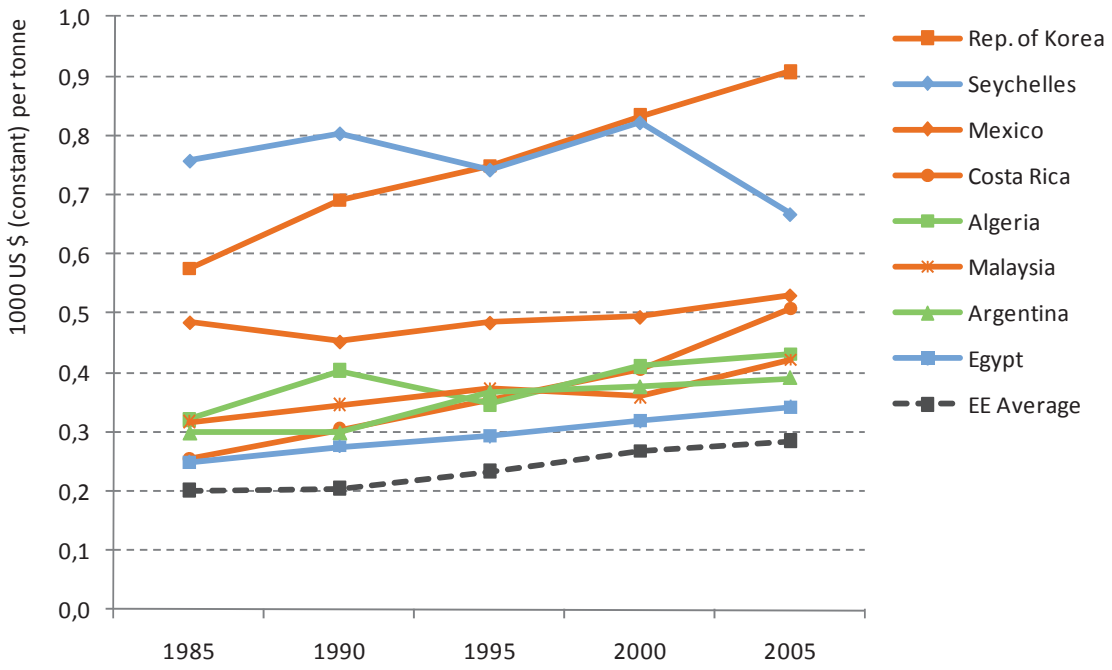
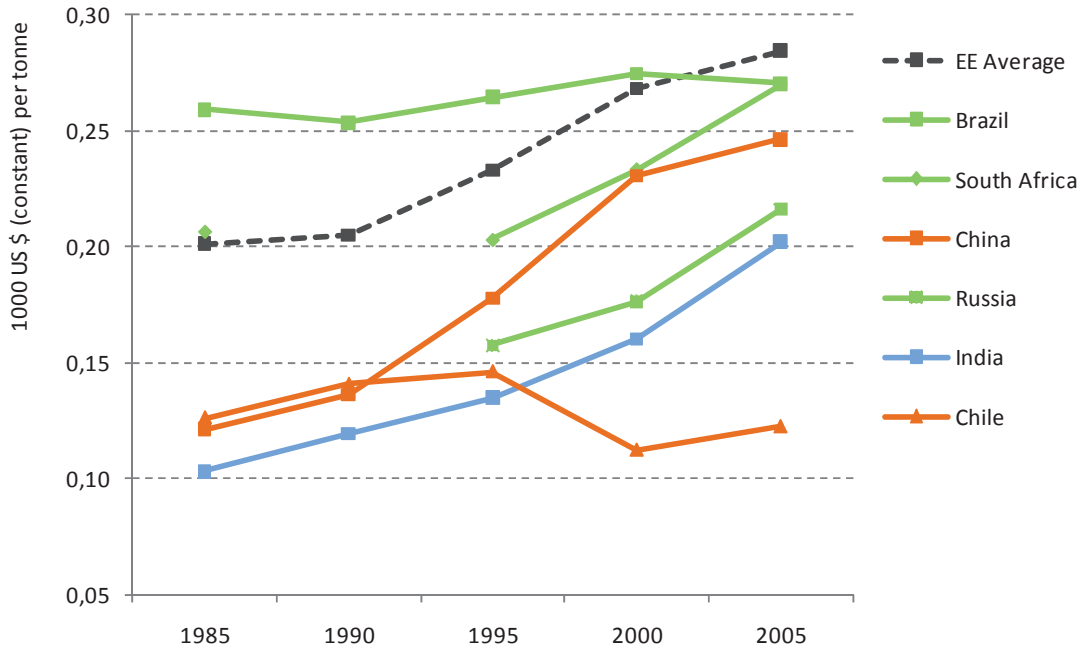


Figure 12b: Material productivity by country, 1985-2005, lower end (below EE average in 2005)



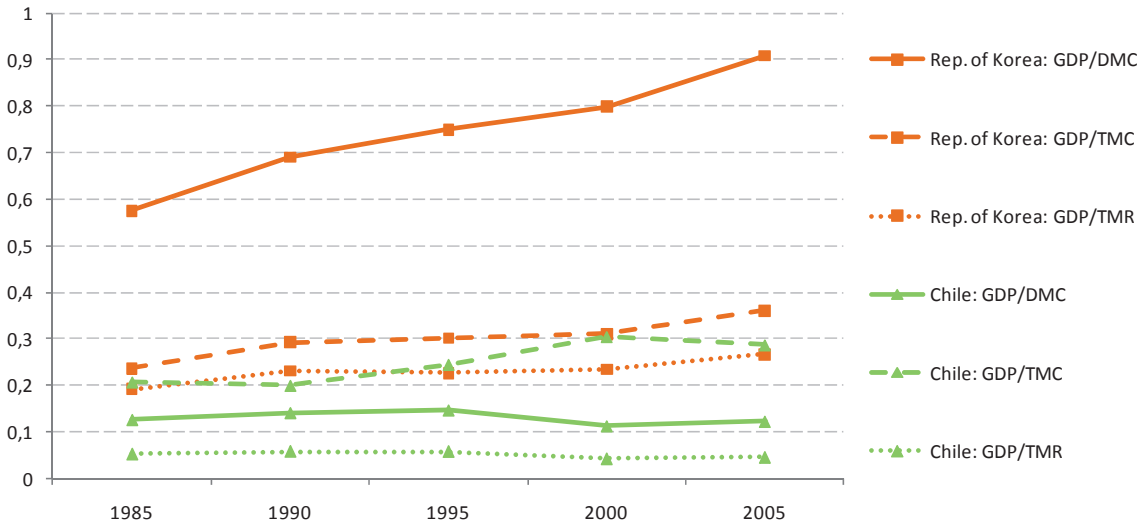
Source: Own calculations based on SERI (2010a), UN Comtrade and Worldbank

While some countries, notably China and India, have experienced very strong improvements in material productivity over the 20-year period (material productivity doubled in both countries), others experienced relative stagnation (e.g. Mexico, Brazil) or even slight declines (e.g. Chile, or the Seychelles whose material productivity is strongly fluctuating).

One of the key challenges for sustainable development arises from the fact that a sustainable situation in which high resource productivity and high levels of social and human development are combined with low per capita consumption has yet to be achieved by any country. In general terms, so far, high levels of material productivity have only been achieved at a certain level of industrialisation and affluence, although the level of resource consumption may differ considerably also among rich countries (Bringezu et al. 2003). Western European countries and Japan are the most resource efficient countries in the world when indirect flows are excluded (Behrens et al., 2007). However, these countries also have high levels of per capita material consumption and are therefore not environmentally sustainable.

Taking indirect material flows (the "ecological rucksacks of international trade") into account sheds light on the question of whether and how much the productivity of emerging countries is higher or lower due to the dislocation of industries from one country or world region to another. Countries with high levels of both productivity and per capita consumption, such as the Republic of Korea, have outsourced the resource-intensive basic industries to other world regions and substituted domestic resource extraction and processing by imports of raw materials and semi-manufactured products. Illustrating these shifts requires calculating material productivity indicators which not only include domestic material consumption but also the indirect (or up-stream) material flows related to international trade, such as TMC, which has already been discussed in the chapter on resource consumption.

Figure 13: Material productivity of the Republic of Korea and Chile, DMC versus estimated TMC (1985-2005)



Source: Dittrich (2010a), based on SERI (2010a), UN Comtrade, Schütz and Bringezu (2008)

When taking indirect material flows into account, generally higher resource productivities can be found in resource-based economies and lower resource productivities in industrialising economies. This difference is strikingly visible when comparing the Republic of Korea and Chile (see Figure 13). The comparison of material productivity without indirect material flows (in terms of GDP/DMC) demonstrates that the Republic of Korea was more than seven times as efficient as Chile in 2005. Including indirect material flows in these calculations shows that both countries are almost equally

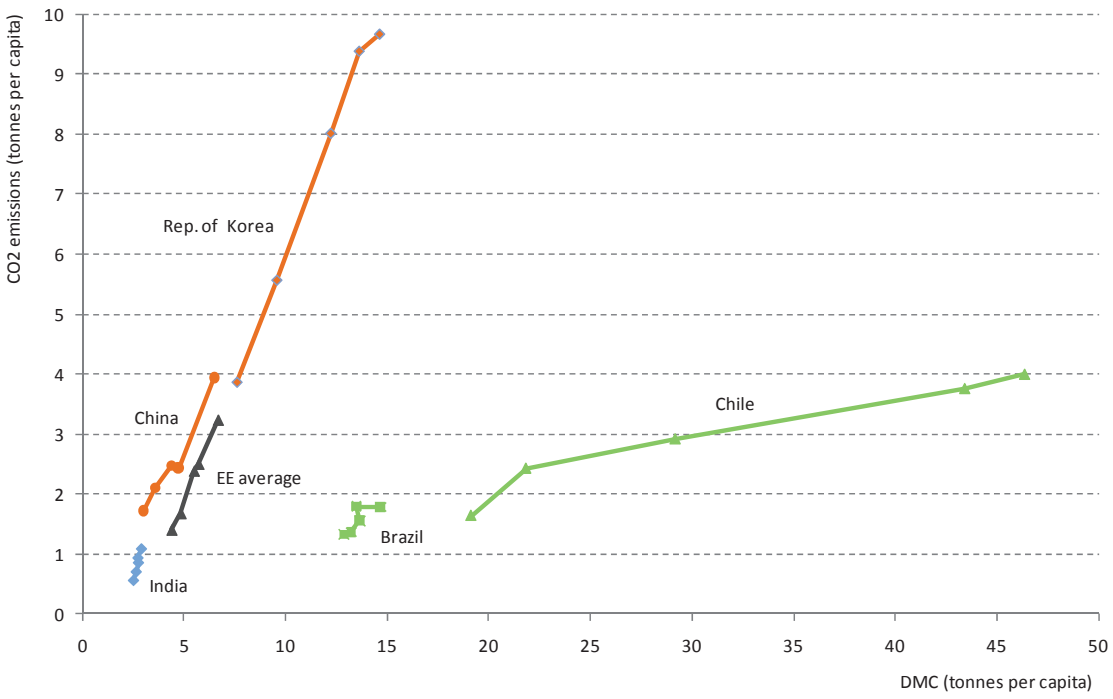
resource efficient (around 250 US$/tonne). Comprehensive material flow-based indicators are therefore a precondition for a comprehensive evaluation of the productivity of resource consumption in a country, which avoids producing artefacts due to international trade and outsourcing of industrial production.

3.5 Material consumption and CO_2 emissions

The link between material consumption and energy-related CO_2 emissions has received limited examination in the past (see, for example, Giljum et al., 2010). Analysing this link for all investigated emerging economies in the year 2005 shows that there is a high correlation between Domestic Material Consumption (DMC) and energy-related CO_2 emissions (Spearman coefficient: rs = 0.78). Growing levels of resource consumption therefore also imply increased CO_2 emissions. The results show that material metabolism and energy-related CO_2 emissions are closely linked across emerging economies at different development stages and with very different levels of per capita GDP.

Figure 14 illustrates this link (in per capita terms) for selected countries and the average across the emerging economies from 1985 to 2005. Per capita CO_2 emissions range significantly between the different emerging economies in 2005, from 1.1 tonne in India to 9.7 tonne in the Republic of Korea. Growth rates in CO_2 emissions also differed substantially over the two decades since 1985, from 18.6 per cent in the Republic of Korea to 166 per cent in Malaysia.

Figure 14: CO_2 emissions and Domestic Material Consumption (DMC), in tonnes per capita



Source: Own calculations based on SERI (2010a), UN Comtrade and IEA (2009)

On average, CO_2 emissions grew faster than material consumption per capita. This holds true for most services-based and industrialising emerging economies. In China, for example, CO_2 emissions rose from 1.7 to 3.9 tonnes per capita between 1985 and 2005 (129 per cent), while material consumption only increased from 3 to 6.5 tonnes per capita (117 per cent). The differences in growth rates between per capita emissions and material consumption were less pronounced in the resource-based emerging economies. In Chile, CO_2 emissions rose from 1.6 to 4 tonnes per capita between

1985 and 2005 (144 per cent), while resource consumption increased from 19.1 to 46.4 tonnes per capita (143 per cent). However, countries such as the Republic of Korea with comparatively lower growth rates in domestic material consumption would have a higher material consumption if indirect material consumption was included (see Section 3.3 above).

In India, the same positive correlation between emissions and material consumption cand be observed, albeit on a much smaller per capita scale. This could indicate that so far, India has supported the development of less material-intensive and service-based sectors, which increased energy consumption (and thus related CO_2 emissions) faster than material consumption.

4 Discussion and outlook

This final chapter provides a discussion of the key findings of this study and highlights important questions which need further investigation in in-depth studies on resource use and resource efficiency in the dynamic group of emerging economies.

Resource extraction, trade and consumption

Material extraction in the emerging economies more than doubled in the 20-year period (from 10 to almost 22 billion tonnes) as a result of their dynamic and largely resource intensive economic development. The importance of material extraction in the emerging economies is also reflected in their growing share in global resource extraction. Today, more than one third of all globally used material resources are extracted in these countries, led by China, Brazil and Russia. Per capita extraction in 2005 was highest in relatively rich resource-based emerging economies such as Chile (47 tonnes) and Argentina (22.7 tonnes), and lowest in the poorest emerging economies, such as Egypt (4.5 tonnes) and India (2.9 tonnes).

The growth rates and overall volumes of material trade in the emerging economies were equally remarkable. Material trade volume (in physical terms) in the emerging economies more than quadrupled between 1985 and 2005. Imports grew by a factor of 5.1, to 2.2 billion tonnes. Almost half of all imports are fossil fuels (in terms of quantity), a similar share as the one observed for industrialised countries, such as EU countries. Material exports increased by a factor of 4.5, to 2.7 billion tonnes in 2005.

Today, more than a quarter of all globally traded goods are imported or exported by the emerging economies. Emerging economies following the industrialisation or service-oriented development path tend to be net-importers in physical terms, and those countries following the resource-based path are generally net-exporters.

Nowhere on the planet is material consumption growing faster than in the emerging economies. Despite the rising net-exports of many emerging economies, material consumption of the group of 16 emerging economies has more than doubled from 1985 to 2005. The most notable increases in total resource consumption were observed in Chile (+226 per cent), China (+169 per cent) and Malaysia (+159), all of which have experienced intensive industrial development over the two decades since 1985 (Chile is a particular case due to its huge metal mining and export sectors). Today, the 16 emerging economies, which are home to about half the world's population, consume about the same amount of material as OECD countries, hosting 14 per cent of the world's population. Even though overall material consumption doubled in the 20-year period average, per capita consumption increased only by 52 per cent (from 4.4 to 6.7 tonnes per capita) and still remains below the global average (around 8.5 tonnes per capita).

Resource efficiency

Material productivity (measured as GDP per material consumption) in the emerging economies has improved significantly since 1985, by a factor of 2.7 based on PPP GDP or by a factor of 1.4 based on MER GDP. On average, material productivity in the emerging economies increased faster than the global average trend, albeit from a much lower absolute level (from a constant 200 US$/tonne to 280 US$/tonne between 1985 and 2005). While some countries have experienced very strong improvements in material productivity (China, India), others experienced relative stagnation (Mexico, Brazil) or even slight declines (Chile, the Seychelles).

The development of material productivity is determined by several interlinked factors. Emerging economies with limited reserves of raw materials (such as the Republic of Korea or the Seychelles) tend to follow the industrial or service-oriented development path. These countries are more resource efficient than countries with abundant resources, which in general follow the resource-oriented path. Different economic sectors generate a different value added per tonne of resource input. Material productivity in terms of value added per resource input is generally low in the primary resource extraction and processing sectors, and higher in manufacturing industries and service sectors. Comparisons of material productivity must therefore consider the role of the countries within the international division of labour (see also Giljum et al. (2010).

International trade also plays an important role. Countries that import a high share of their raw materials and material-intensive products (such as the Republic of Korea) have higher material productivities than countries that extract and process raw materials within their borders. As mentioned above, this calls for the application of comprehensive indicators to measure material consumption and evaluate material productivity, including the (upstream) indirect flows of international trade. As the examples of the Republic of Korea and Chile have illustrated, the efficiency performance will change considerably when indirect flows are integrated into the calculation.

In general, there is a positive correlation between GDP and DMC, except for periods of political or economical turmoil. Following the trend of today's industrialised countries, some emerging economies have achieved a relative decoupling of per capita GDP and per capita material consumption, notably China, India and the Republic of Korea. This was not possible for the resource-based economies of Chile and Brazil. The rising material consumption in the emerging economies goes together with an increase in their energy-related CO_2 emissions. Resource use and resource-efficiency improvements may thus play an important role in mitigating climate change.

Physical economic profiles of different emerging economies

The data analysis carried out in this study has highlighted the distinctions in the group of emerging economies according to some specific material profiles.

Resource-based emerging economies have relatively high resource extraction and DMC per capita, low and stagnating resource productivity and negative physical trade balances. In general, the growth of their material consumption rose faster than their GDP. Though indirect flows are only integrated in this study, it can be assumed that the resource-based emerging countries shoulder the environmental burden of other countries, especially those following the industrialisation path. In contrast to the services-based and industrialising emerging economies, their CO_2 emissions did not grow significantly faster than their material consumption per capita.

Industrialising emerging economies show patterns similar to most OECD countries in the past. Their GDP has increased faster than their material consumption. Industry-based economies at a relatively advanced stage, such as the Republic of Korea and Mexico, are the most resource efficient emerging

countries, while those at an earlier stage of industrialisation show a below-average performance (e.g. China).CO_2 emissions grew faster than material consumption per capita in most industrialising emerging economies.

The difference between the resource-based and the industrialisation path becomes clearer when indirect material flows are compared. When indirect material flows are taken into account and comprehensive indicators are calculated on material consumption, generally, there is increased resource productivities in resource-based economies and lower resource productivities in advanced industrialising economies, such as the Republic of Korea. Following the typical pattern of rich, industrialised countries, the latter group of emerging economies have outsourced (part of) the domestic industries to other world regions and substitute domestic resource extraction and processing by imports of raw materials and semi-manufactured products.

Service-based emerging economies such as India and the Seychelles have a relatively low per capita used resource extraction and stagnating or slightly increasing per capita material consumption, which is above average in richer economies such as Barbados and the Seychelles and below average in poorer economies such as India and Egypt. This group is also characterised by relatively high resource productivities, i.e. their GDP has increased faster than their material consumption. CO_2 emissions grew faster than in material consumption per capita in most services-based emerging economies due to the over-proportional increase in service sectors' demand for energy.

Questions to be addressed by future studies

Research is needed to analyse the patterns of industrialisation in emerging economies, in particular to assess increasing resource constraints for those countries, which aim to follow the same development path as the rich industrialised countries did in the past. The process of industrialisation in the OECD countries was highly intensive in material and energy use. Today, many OECD countries have largely outsourced energy and resource intensive production to other world regions. The high levels of resource productivity achieved across the OECD and measured with indicators such as DMC are therefore misleading, as they do not reflect the global material demand to satisfy domestic consumption.

A similar pattern of industrialisation and outsourcing can now be observed in the advanced emerging economies following the industrialisation path. However, given the limited availability of resources worldwide, it is important to investigate the extent to which large countries such as India and China will be able to outsource their material requirements, following the pattern of industrialised countries. Furthermore, what development paths would be left to those countries that are late-comers to industrialisation and which are still strongly dominated by the extraction and export of natural resources?

In the second half of the 20th century, a development path based on natural resources was often regarded as doomed to failure, given falling terms of trade of primary commodities and thus countries being locked in a situation of diminishing economic returns and increasing environmental pressures from resource extraction and exports (see, for example, Muradian and Martinez-Alier, 2001; Murshed, 2002; Raffer and Singer, 2001). However, the potential of resource-based development should be re-assessed in the light of rising demand and rising prices for many raw materials, and increasing global scarcities of resources. Resource prices may change more fundamentally than prices of manufactured goods in the future. An oversupply of manufactured goods and services may pull down their prices, while increasing scarcity of resources could raise the prices of raw materials. As a result, the resource-based path of economic development may become more economically attractive - at least in the medium term - than in the past decades. Whether or not (or when) these relative price changes will happen is uncertain. With the rise of China, India and

other emerging economies, there are initial signs that indicate that this process has already begun.

Given the link between material consumption and energy-related CO_2 emissions in the emerging economies and the importance of climate policy in the environmental policy area worldwide, the questions arise, to what extent could climate policies help to reduce resource use and to increase resource productivity, or vice versa, to what extent could resource efficiency policies contribute to the mitigation of climate change. Analysing these questions may provide more options for future climate policies.

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