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ANALYSIS

The material basis of the global economy
Worldwide patterns of natural resource extraction and their implications for sustainable resource use policies

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ABSTRACT

Material flow accounting and analysis (MFA) has been established as an influential framework for quantifying the use of natural resources by modern societies. So far, however, no reference data for overall scale and trends of global extraction of natural resources and their distribution between different world regions has been available. This paper presents the first comprehensive quantification of the material basis of the global economy, i.e. used domestic extraction in a time series from 1980 to 2002. We analyse time trends for major material groups (fossil fuels, metals, industrial and construction minerals, and biomass) disaggregated into seven world regions. This allows for (a) an illustration of the global economy's physical growth driven by worldwide processes of economic integration over the past decades, and (b) an indication of the worldwide distribution of environmental pressures associated with material extraction. The results show that annual resource consumption of the world economy increased by about one third between 1980 and 2002. This indicates that scale effects due to economic growth more than compensated for other effects, such as the relative increase of the service sectors' contribution to GDP (structural effect) and the use of new production technologies with higher material and energy efficiency (technology effect). The observed growth of natural resource extraction is unevenly distributed over the main material categories, with metals showing the highest growth rate. The regional analysis shows the increasing importance of Asia and Latin America in global resource extraction. On the global level, material intensity, i.e. resource extraction per unit of GDP, decreased by about 25%, indicating relative decoupling of resource extraction from economic growth. The paper concludes with policy recommendations for a more sustainable use of natural resources.

1. Introduction

Human history has always been closely linked to the control, extraction and use of natural resources. Over the past decades, however, demand for natural resources has accelerated to the extent that it is now widely considered a serious threat to the well-functioning of economies and societies due to associated environmental problems such as climate change, biodiversity loss, desertification, and ecosystem degradation (IPCC, 2007; EPA Network, 2006; Stern Review, 2006; Millennium Ecosystem

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Assessment, 2005; Wuppertal Institute, 2005; WWF, 2004; UNEP, 2002). The Millennium Ecosystem Assessment Synthesis Report (2005, p. 16), for example, states that “over the past 50 years, humans have changed ecosystems more rapidly and extensively than in any comparable period of time in human history, largely to meet rapidly growing demands for food, fresh water, fibre and fuel. This has resulted in a substantial and largely irreversible loss in the diversity of life on Earth.” One of the key sustainability challenges for the coming decades will thus be to improve the management of natural resources in order to reduce current levels of anthropogenic environmental pressures.

In the past 20 years, several methods have been developed which allow for the quantification of the use of natural resources by modern societies (Daniels and Moore, 2002). One of the key methods is Material Flow Accounting and Analysis (MFA), internationally recognised as an important tool for evaluating environmental and resource use policies (e.g. OECD, 2004). The principle concept underlying MFA is a simple model of the interrelation between the economy and the environment, in which the economy is an embedded subsystem of the environment. Similar to living beings, this subsystem is dependent on a constant throughput of materials and energy. To highlight the similarity to natural metabolic processes, the terms “industrial” (Ayres, 1989) or “societal” (Fischer-Kowalski, 1998) metabolism have been introduced.

Total material inputs to the economy as a whole as well as to any subsystem (an economic sector, a company, a household) must by definition equal total outputs plus net accumulation of materials in the system. It thus follows that increasing problems associated with waste generation and emissions are related to the scale of material input. From this point of view, an overall reduction of global material use (i.e. dematerialisation) by means of increased resource efficiency will represent a key strategy to combat global environmental problems[1] (e.g. Behrens et al., 2005; Giljum et al., 2005; Hekkert, 2000; Matthews et al., 2000).

A distinction must be made between absolute and relative dematerialisation. Absolute dematerialisation, also referred to as strong dematerialisation, occurs when total material input to an economy decreases in absolute terms. Relative dematerialisation, or weak dematerialisation, refers to a decrease in the intensity of use, requiring the ratio between material input and GDP to fall over time. This can only be achieved if growth in resource use is slower than economic growth (Moll et al., 2003).

The importance of improved material management for sustainable development is recognised by various institutions in international politics. Facilitating and stimulating economic growth while reducing environmental impacts associated with resource use in Europe and beyond is central to the European “Thematic Strategy on the sustainable use of natural resources” (European Commission, 2005). Taking into consideration the entire life cycle of resource use, this strategy focuses on three main goals, summarised under the heading “more value – less impact – better alternatives”. These refer to increasing resource productivity, increasing eco-efficiency and – if cleaner use is not achievable – the substitution of currently used resources with more environmentally benign alternatives. The strategy defines a time horizon of 25 years, without, however, mentioning any quantitative reduction targets. The German Strategy for Sustainable Development (German Federal Government, 2002), on the other hand, includes targets with respect to energy and resource productivity. Aiming for an absolute reduction of resource use, this strategy calls for doubling the 1990 levels of energy productivity and the 1994 levels of resource productivity until 2020. In the long run, Germany aims for a “Factor 4” development — doubling wealth while halving resource use. A similar approach has been adopted in Japan, where a number of quantitative targets for material flow indicators to be reached until 2010 have been agreed upon in the national plan for a recycling-based society (Government of Japan, 2003). These include a 40% improvement in resource productivity calculated as GDP per Direct Material Input (DMI), a 40% increase in the cyclical use ratio, calculated as the amount of materials reused and/or recycled in total materials used, and a 50% reduction of the final disposal amount of waste (landfill). Targets refer to 2000 as the base year. Japan has also been leading the promotion of the “3R Initiative” (reduce, reuse and recycle) on the global level. Following agreement at the G8 Sea Island Summit in 2004, the initiative was formally launched in early 2005 and reaffirmed at the G8 Gleneagles Summit in 2005 (G8 Summit of Heads of State and of Government, 2005).

The increasing interest in the physical basis of economies is also reflected in the large and growing number of economy-wide material flow accounts on the national level. Full MFAs have been presented for the USA, Japan, Austria, Germany and the Netherlands (Matthews et al., 2000; Adriaanse et al., 1997). In Europe, national studies have been presented by a large number of national statistical offices and research institutions. The latest comprehensive analysis of material use in the EU-15 has been presented by EUROSTAT (Weisz et al., 2006). Additionally, MFAs have been compiled for Australia and selected countries in Asia, Eastern Europe and Latin America. A first account of global resource extraction has been presented by Schandl and Eisenmenger (2006) for the year 1999. In this paper, we present the first time series (1980–2002) of domestic extraction for all countries of the world.

Material input indicators providing for a physical description of the economy include Direct Material Input (DMI), Total Material Input (TMI), and Total Material Requirement (TMR) (EUROSTAT, 2001). A mutual basis of these indicators is domestic extraction (DE), which refers to the annual amount of raw materials extracted from a given territory. It includes all materials except water and air, which EUROSTAT recommends to present in separate accounts, as amounts exceed solid materials by a factor of 10 or more. A distinction is made between used DE and unused DE. The category of used DE refers to the amount of extracted resources, which acquires value within the economic system by being used for further processing or direct consumption. Unused DE, on the other hand, never enters the economic system. Also referred to as “hidden flows”, this category comprises overburden,

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[1] Several authors (e.g. Hueseman, 2003), however, suggest that increasing efficiency of resource and/or energy use will not be enough to reduce environmental problems due to scale effects of economic growth and consumption levels (also known as “rebound effect”). A culture of sufficiency in modern societies has therefore repeatedly been mentioned as another prerequisite for sustainable development.

interburden and parting materials from mining and quarrying, discarded by-catch and wood harvesting losses from biomass harvest, as well as soil (and rock) excavation and dredged materials resulting from construction and dredging activities.

It should be noted that aggregated MFA indicators do not take into account qualitative aspects (such as the potential for specific environmental damages) of different types of material flows, as all flows are accounted for in unweighted mass units (tons). MFA indicators thus reflect environmental pressures stemming from human activities, but cannot provide information on specific environmental impacts (see, for example, van der Voet et al., 2005; Reijnders, 1998, for a discussion on qualitative aspects of material flows).

The data presented in this paper mainly focuses on global and regional used DE, with occasional references to unused DE. On the global level, used DE equals material consumption plus net additions to stocks. Our analysis thus allows for robust conclusions on this level. Due to the fact that physical trade data is not yet included in this data set, we are not able to present numbers for resource consumption of single countries or world regions. However, the data presented is of relevance on the regional and country level, allowing for conclusions regarding the allocation of environmental pressures associated with DE, as well as trends regarding their development.

2. Methodology

The comprehensive assessment of global resource extraction presented in this paper has been performed in the course of a European Union research project entitled “Modelling opportunities and limits for restructuring Europe towards sustainability” (MOSUS)[2]. Resource extraction data, disaggregated into more than 200 material categories, has been compiled for 188 countries in a time series from 1980 to 2002, taking into account changes in frontiers due to splitting up of former USSR, Czechoslovakia, Yugoslavia and PDR of Ethiopia, as well as reunification of Germany in 1990. In the MOSUS project, this data has been integrated into a multi-sectoral, multi-country system of economic input–output models (see Lutz et al., 2005), which includes monetary trade flows within Europe and between Europe and all other world regions. The model has been used to forecast different EU development scenarios and to evaluate the economic and social impacts of key environmental policy measures resulting in quantified policy recommendations for responding to European and global environmental challenges and changes (IIASA et al., 2006).

The compilation of material input data followed the nomenclature and categorisation of materials listed in the handbook for economy-wide material flow accounting published by the Statistical Office of the European Union (EUROSTAT, 2001) and covers four aggregated material groups:

- Fossil fuels (coal, oil, gas, peat)
- Metal ores
- Industrial and construction minerals
- Biomass (agriculture, forestry, and fishery)

Furthermore, countries were aggregated into seven world regions: Africa, Asia, Latin America & Caribbean, North America, Oceania, Transition Countries (covering ex-USSR and Eastern European countries), and Western Europe. An eighth group “World” was introduced to show the global average data for used DE per capita and used DE per unit of GDP.

All data is given in units of 1000 tons. In cases where primary data from original sources was given in other units (e.g. tons, kilograms, cubic metres, carat, etc.) conversion factors were applied. Unused DE was calculated by multiplying used DE with factors expressing amounts of unused materials per used materials (in tons per ton). In spite of a variety of sources existing for these factors (e.g. Bringezu and Schütz, 2001a,b; Jölli and Giljum, 2005; Kippenberger, 1999), country and material-specific data availability is still largely unsatisfactory. The results presented in this paper thus focus on used DE.

Our international database on natural resource extraction was developed from international statistics available from the International Energy Agency (IEA), the US Energy Information Administration (US EIA), the Food and Agricultural Organisation of the United Nations (FAO), the United Nations Industrial Commodity Statistics, United States Geological Survey (USGS), the World Mining Congress (WMC), and the German Federal Institute for Geosciences and Natural Resources (BGR).

It should be noted that coverage of construction minerals in official statistics is still insufficient, particularly in non-OECD countries. An estimation procedure based on GDP/capita levels and trends in population growth was thus applied for all countries in this data set. According to experts and information from geological institutes, the resulting numbers for per capita extraction of construction minerals, ranging from 1 ton in developing countries to 10 tons in industrialised countries, can be assumed to be realistic for different world regions.

3. Results

In this section we present the results of our analysis by means of four indicators of global natural resource extraction: extraction by material category and by world region, extraction per capita, and intensity of material extraction.

Fig. 1 presents the overall material basis of the global economy (including only used materials) between 1980 and 2002.

This figure illustrates that global used resource extraction grew more or less steadily over the past two decades, from 40 billion tons in 1980 to 55 billion tons in 2002, representing an aggregated growth rate of almost 36%. However, growth rates are unevenly distributed among the four material categories. In relative terms, the extraction of metals increased disproportionately (56%), indicating the continued and growing importance of this resource category for industrial development. Extraction of industrial and construction minerals also grew considerably in the period under consideration (40%). Increases in fossil fuel (30%) and biomass extraction (28%), on the other hand, were below average. The

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[2] See www.mosus.net for more information.

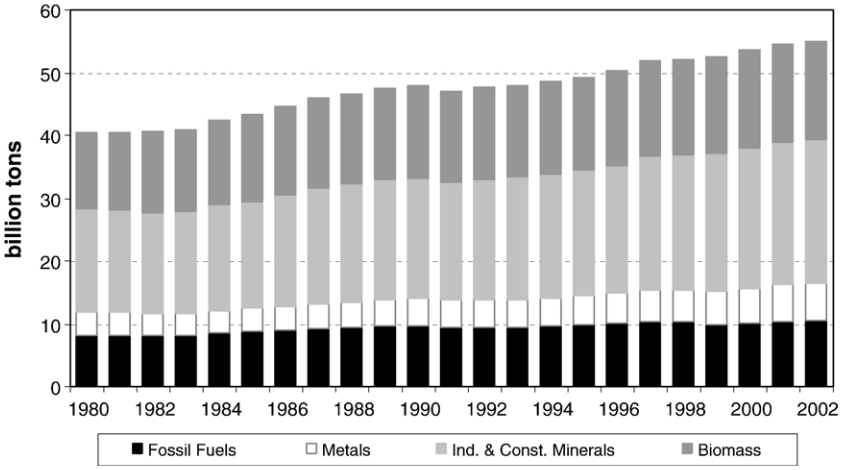

Fig. 1 – Global used resource extraction by material category (in billion tons).

global share of biomass and thus renewable resources decreased from 30% in 1980 to about 28% in 2002.

Adding to global used extraction all materials that were extracted but not actually used to create value in economic processes (i.e. unused extraction or hidden flows), total extraction in 2002 more than doubled to an estimated 113 billion tonnes. Hidden flows thus accounted for about 51% of total extraction as compared to 48% in the early 1980's. Three factors are responsible for this increase: changing factors of unused extraction per used extraction of a certain natural resource over time[3], a relative shift towards materials with larger "ecological rucksacks", and a shift of extraction to regions with larger hidden flows for identical materials. Since, due to data limitations, we had to use constant factors for the whole time period, only the latter two explanations can apply in our case. They are particularly evident in the extraction of biomass and metal ores.

In Fig. 2 global used resource extraction data is disaggregated into world regions illustrating the shares of each region in total used extraction.

The regional analysis reveals that Asia's share in global used resource extraction has increased considerably as a consequence of rapid industrialisation in countries such as China and India. In China, for example, used DE of fossil fuels, metal ores and biomass grew by 130%, 160% and 80%, respectively, between 1980 and 2002. The total increase in used extraction was 123%, as compared to an increase of 70% in India. Increasing DE in China is mainly used domestically to fuel the rapidly growing national economy, with large imports of fossil energy, mineral products and basic raw materials needed to meet domestic demand (National Bureau of Statistics of China, 2004). In contrast to China, a considerable part of Latin American increases in domestic resource extraction results from specialisation in resource-intensive export products such as metal ores (see for instance, Giljum, 2004; Muradian and Martinez-Alier, 2001; Schaper, 1999). Our data supports these findings, showing a 161% increase in regional used extraction of metal ores. The most dramatic decline of used DE can be observed in the group of Transition Countries, which faced deep economic recession at the beginning of the 1990s (e.g. real GDP of the Russian Federation fell by 30% between 1992 and 1998), resulting in a 15% reduction of domestic resource extraction. The share of Western Europe also declined, mainly reflecting a reduction in the extraction of metal ores and fossil fuels. These raw materials are increasingly substituted by imports from other world regions (Schütz et al., 2004).

We now turn to per capita and material intensity indicators associated with used DE, allowing for a better cross-regional comparison. In Fig. 3, we use population as the denominator to show used DE per capita for the seven world regions as well as the global average. The highest per capita resource extraction can be observed in Oceania with 64 tons per capita at the beginning of this decade. This reflects the stark increase in production of fossil fuels (particularly coal) and metal ores in Australia in the time period under consideration, which grew by 192% and almost 200%, respectively. North America ranks second with a per capita extraction of just over 32 tons, due to high amounts of industrial minerals, fossil fuel and biomass extraction. The economic decline in the transition countries is also reflected in this figure, with per capita extraction dropping from levels of about 18 tons in the 1980s to about 13 tons by the beginning of the new millennium. With 5–6 tons, developing regions in Africa and Asia are characterised by the smallest per capita numbers. World average per capita extraction slightly dropped from 9.2 tons in 1980 to 8.8 tons in 2002.

In Fig. 4, intensity of used domestic extraction, calculated as the relation of used resource extraction to GDP at constant prices, is shown for the different world regions. The inverse of this relation is referred to as productivity of used domestic extraction. Due to the fact that imports equal exports on the global level, intensity of used domestic extraction equals the material intensity of the world economy.

Industrialised economies are characterised by the lowest intensities of used DE (or the highest productivities of used DE). Western Europe is in the lead worldwide with about 1 ton

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[3] Some materials (e.g. metals) may become scarcer over time and mining may thus involve the movement of increasing amounts of materials.

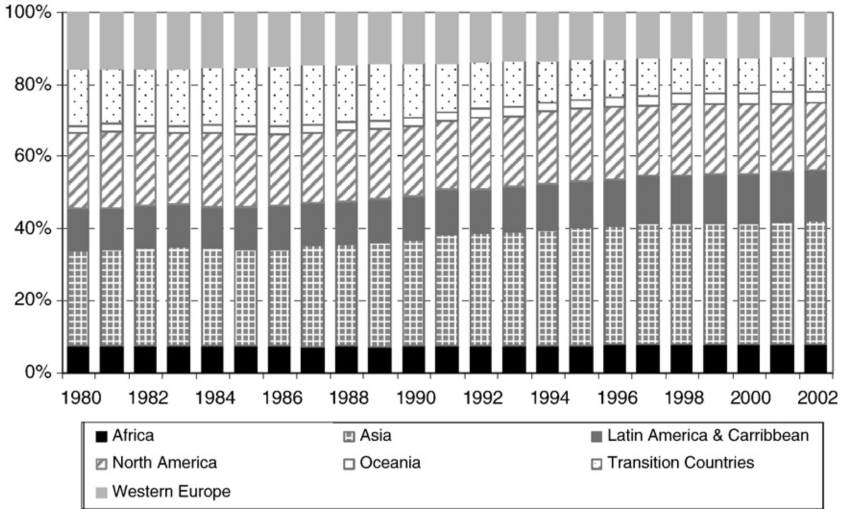

Fig. 2 – Shares of global used resource extraction by world region (in percent).

per 1000 US $ GDP in the 1980s and only 0.6 tons at the beginning of this decade. Although North America has high levels of per capita used DE, intensity of used DE is low and declining (from 1.6 tons in 1980 to just above 1 ton per 1000 US $ in 2002). The two major drivers for this trend in industrialised regions are (1) the use of new technologies with improved material and energy performance per unit of economic output (technology effect), and (2) structural change of economies towards growing service sectors characterised by less material input per unit of output (structural effect). Together with improvements in the intensity of used DE in Asia (from 2.2 tons in 1980 to 1.8 tons per 1000 US $ in 2002), these regions determined the development of material intensity on the global level, which decreased from 2.1 tons in 1980 to 1.6 tons per 1000 US $ in 2002. From this it follows that in 2002 about 25% less material input was needed to produce one unit of real GDP than in the year 1980. Hence, relative decoupling of economic growth from the extraction of natural resources was achieved on the global level. Fig. 4 also reveals the enormous differences between industrialised and developing regions when comparing intensities of used DE (with the exception of Oceania, see above). Although the situation in Transition Countries has significantly improved over the past 10 years, particularly in Eastern European countries, the generation of GDP in these countries is still linked to used DE more than three times higher than world average (5.3 tons per 1000 US $ in 2002).

Material flow data also helps in detecting specificities of the physical structures of economies, since it allows determining the domestic natural resources different countries depend on. Similar intensities of used domestic material extraction in different countries may result from significantly different compositions of DE (see Table 1).

These variations in composition imply different consequences in terms of environmental impacts related to

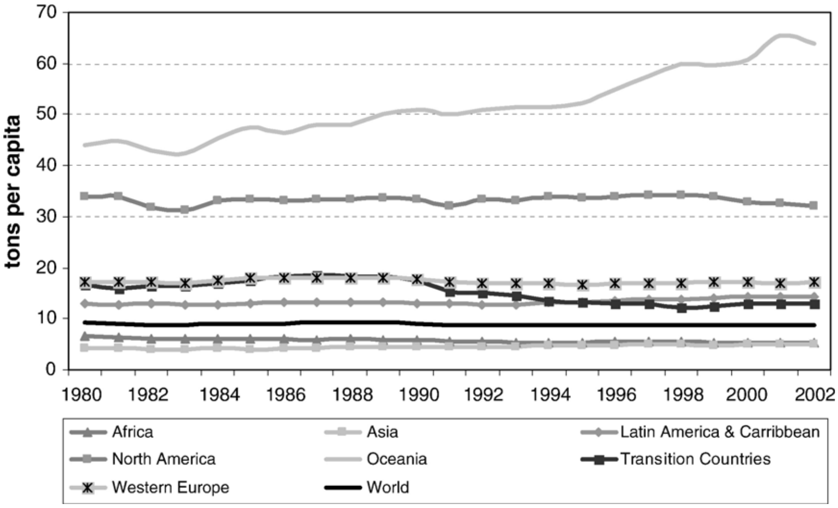

Fig. 3 – Global used resource extraction per capita by world region (in tons per capita).

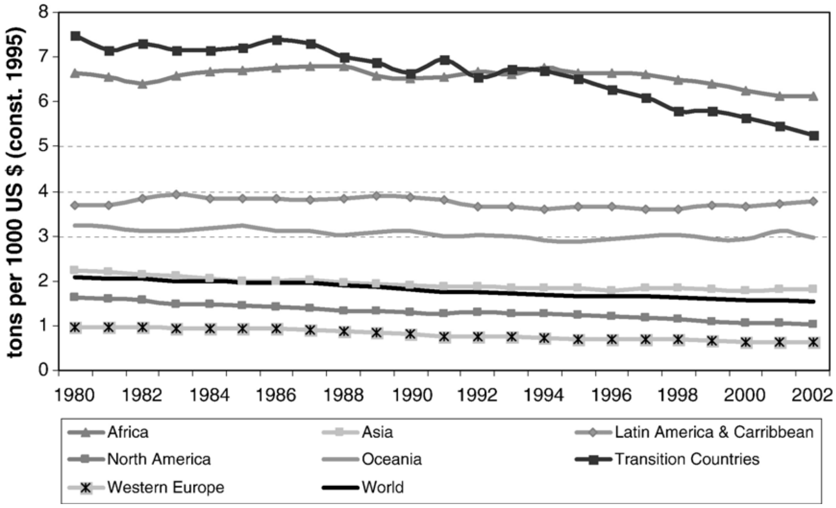

Fig. 4 – Intensity of used domestic resource extraction by world region (in tons per constant 1000 US $).

extraction, processing, and use and thus for the implementation of strategies towards a more sustainable use of domestic natural resources. While agricultural activities constitute the most important category in Argentina (cattle products, soy beans, vegetable oils), other countries are dominated by abiotic resource extraction, such as oil drilling (in the case of Libya) or extraction of industrial and construction minerals (e.g. Philippines or Malaysia). The consideration of different groups of materials used in the most resource-intensive sectors of an economy (such as mining, construction, energy, transport and agriculture) is very important for the design of an appropriate policy mix aimed at absolute dematerialisation (see Giljum et al., 2005; Behrens, 2004 for details).

It should be emphasised once more that the data presented above only reflects domestic extraction of natural resources and does not take into account trade aspects. This allows for robust conclusions concerning the aggregated global level. However, for specific world regions, the values of per capita resource consumption and material intensity can significantly change when international trade flows are considered (see Giljum and Eisenmenger, 2004). For example, per capita numbers of material consumption are likely to increase in regions with high levels of physical imports (such as Western Europe and Japan), while decreasing in regions with high levels of resource-intensive exports (such as oil or metal producing countries) (Schütz et al., 2004).

4. Discussion

Data analysis of the material basis of the global economy reveals two diverging trends. On the one hand, there is broad evidence for decoupling of global material extraction and use of natural resources from economic growth, emphasising that the production of economic output is becoming less material intensive in relative terms. At the same time, however, overall levels of resource extraction are increasing in absolute terms in all regions of the world. This is an indication of the scale effect, caused by the expansion of economic activities around the world, over-compensating potentially positive developments regarding the environment, such as structural change towards the service sector and worldwide diffusion of cleaner technologies and products. This trend is clearly incompatible with sustainable development, considering the fact that global environmental problems such as climate change, loss of biodiversity, and pollution (all closely linked to the material and energy throughput of the global economy) are already putting pressures on the world's ecosystems beyond a sustainable level (Millennium Ecosystem Assessment, 2005; UNEP, 2002).

Furthermore, resource extraction activities are likely to accelerate in view of the fast rise of new consumer classes in emerging countries, where people increasingly aspire to

Table 1 – Composition of used domestic resource extraction of selected countries with similar intensities of used domestic extraction

	Argentina	Libya	Malaysia	Mexico	Philippines
Intensity of used DE (kg/1995 US $)	2.9	3.3	2.8	2.9	3.0
Composition of used DE (in %)					
Fossils	10.2	64.3	24.3	22.6	1.6
Metal ores	6.8	0.0	0.9	9.6	3.6
Industrial and construction minerals	34.8	30.4	44.7	38.8	57.1
Biomass	48.2	5.3	30.1	29.1	37.7

achieve lifestyles comparable to industrialised countries. This new consumer class already amounted to more than 1 billion people in the year 2000 (Myers and Kent, 2003). It is undeniable that new consumers should benefit from their newly acquired wealth. However, it is also in their self-interest and in the interest of the entire world to limit related negative environmental consequences. The example of China, accounting for almost 30% of all new consumers, shows that rapid economic growth can lead to considerable costs. Recent estimates of the costs of pollution to the Chinese economy range from 3% to 13% of GDP (Project Syndicate, 2006). Some estimations are thus of the same dimension as annual economic growth, indicating that the economy is producing little or no net national wealth. However, environmental impacts of China's growth also reach beyond its national borders. With carbon emissions growing by 47% between 1990 and 2003, China now ranks second with a 14% share in global emissions (Worldwatch Institute, 2005). A large part of this increase is due to the new consumers, who possess almost all cars in their country. With an increasing number of new consumers, car ownership in China increased by 445% between 1990 and 2000 (Myers and Kent, 2003).

Considering the increasing domestic extraction as well as the rapidly rising imports of energy (petroleum and petroleum products) and raw materials (in particular, steel and non-ferrous metals; see National Bureau of Statistics of China, 2004), the remarkable expansion of China's physical basis is a good example to show that current development paths and the adoption of western lifestyles and associated environmental consumption by ever more people cannot be generalised on a global level. From this point of view, the key challenge of sustainable development will be to reconcile highly resource-intensive prosperity of industrialised countries and the aspiration of developing countries to copy Northern development models within the environmental limits posed by the biosphere. These findings underline the need for radical changes in production and consumption patterns, particularly in industrialised countries, in order to generate "environmental space" for Southern economic growth.

So far in our analysis, we have barely touched the issue of trade since we only analysed domestic extraction without being able to trace where the extracted materials are actually being used. Trade, however, is a powerful instrument to redistribute the responsibilities associated with environmental degradation caused by the extraction of natural resources. By means of outsourcing extraction and related "ecological rucksacks" to other world regions, many industrialised countries have been successful in maintaining or even increasing their regional and/or national environmental quality (Schütz et al., 2004). As a result, industrialised countries are generally physical net-importers of natural resources from other world regions. For materials such as fossil fuels and basic metal products, their physical import surplus continues to increase (Weisz et al., 2006; Giljum and Eisenmenger, 2004). With only 15% of global population, industrialised countries consume about 50% of global fossil fuel production, over 50% of global primary aluminium production, and almost 65% of global lead production (Wuppertal Institute, 2005). However, in a closed global economy, it is impossible for all countries to be net-importers of raw materials. Rising physical trade surpluses are thus only possible with other countries specialising in the production and export of some of these natural resources.

This specialisation cannot be condemned by itself. First of all, countries differ in their endowment with natural resources and second, some countries may be more environmentally or economically efficient in extracting certain resources than others. An international division of labour of this kind, however, with some world regions specialising in primary sector activities and others in manufacturing and/or service activities leads to an unequal distribution of the benefits of globalisation due to several reasons.

From an environmental point of view, it has repeatedly been suggested that the primary sector is generally characterised by higher environmental loads than other sectors (Fischer-Kowalski and Amann, 2001; UNEP, 1999; Mani and Wheeler, 1998). Mining activities, for example, are associated with large amounts of overburden, water use and energy consumption (Wuppertal Institute, 2005). The use of toxic substances in metal mining, over-fertilisation in agriculture, oil spills on land and water, or land degradation due to strip mining of coal are just some of the many examples of negative environmental impacts associated with the extraction of resources. The end of the value-added chain, on the other hand, is much less polluting and largely located in industrialised countries. The specialisation of developing countries in primary sectors thus tends to lead to an unequal distribution of environmental burden.

The continuous outsourcing of primary commodity activities associated with little added value and large environmental impacts, while adopting "cleaner" processing activities at the end of the value-added chain can explain relative decoupling trends in industrialised countries (Adriaanse et al., 1997). Trade is thus an important aspect to consider in the discussion about the "Environmental Kuznets Curve" (EKC), which suggests a correlation between economic affluence and negative environmental consequences in the shape of an inverted U (Grossman and Krueger, 1995; Kuznets, 1955).

5. Policy implications

Traditional economics studies the interrelation between economy and the environment in terms of value and exchange. From this point of view, a wide variety of policy options is available to support dematerialisation. These commonly include economic measures such as ecological fiscal reforms (e.g. material input and energy taxes), reforms of the subsidy systems (e.g. temporary support for development of new eco-efficient technologies and materials), certificates trading systems, and eco-efficient public procurement (see Behrens, 2004 for more details). With a complementing tax relieve on labour, such measures may contribute to increased employment alongside environmental improvements. Focussing on key sectors that are either directly (e.g. mining, agriculture, fisheries) or indirectly responsible for large amounts of natural resource extraction (e.g. energy, transport, and industry) will benefit the efficiency of the selected mix of instruments.

For developing countries, the prime goal will be to reduce dependence on primary commodity exports and to promote economic activities with higher potential for the creation of added value. This can be achieved by encouraging the domestic processing of natural resources (“vertical diversification”) and by building up other, less resource-intensive sectors (“horizontal diversification”). Another recently proposed measure is the implementation of an environmental tax reform (ETR) for poverty reduction, as advocated by the DAC Network on Environment and Development Co-Operation of the OECD (OECD, 2005). Including extraction levies and material input taxes, an ETR of that kind will address environmental problems associated with extraction activities that often impact the poor. It will also generate or free up resources for critical pro-poor investments (e.g. in water supply, sanitation, education, etc.).

Unlike traditional economics, MFA allows for a shift of focus towards physical flows and physical transformation processes. It thus allows for extending the policy analysis beyond those parts of the economy–environment interface that do not yield to economic methods and thus provides for policies, which are not available from purely economic approaches. Some examples will be given as follows.

5.1. *Assessments of environmental pressures of products and product groups*

Linking economy-wide material flow accounts to economic models, which disaggregate economic sectors and product groups (particularly input–output models), allows for determining the most resource-intensive supply chains as well as the total (direct and indirect) material requirements to produce different products for final demand (Huppes et al., 2006). National environmental input–output models can be linked to form multi-national (or multi-regional) input–output models, capable of tracing production chains and related material flows through different economies (Wiedmann et al., 2006; Giljum, 2005). For example, in an upcoming EU-funded research project[4] the global data set on material extraction presented in this paper will be linked to such a multi-regional input–output model in order to calculate indirect material requirements of traded products.

If analysed in parallel with other important environmental categories (land use, waste generation, greenhouse gas emissions), the environmental impacts related to resource use can be quantified (Moll et al., 2004). In such an assessment framework, the micro, meso and macro levels are systematically and consistently linked. This is essential, as many persistent environmental problems (such as high levels of material use, climate change, etc.) increasingly affect the macro level, while their causes and solutions are located on the meso and micro levels of sectors, technologies, and products.

5.2. *Integrated approaches of waste management*

In addition to an overall growth of natural resource extraction, our analysis suggests an increase of unused material flows during the time period under consideration. These are flows without attached economic value and can thus be regarded as physical market externalities (Hinterberger et al., 1999). However, these flows do have an ecological impact, such as acidification of ground water through overburden at mining sites (e.g. Wisotzky and Obermann, 2001). Quantity and quality of outputs from the economy to the environment (e.g. waste, emissions, sewage, etc.) depend crucially on the inputs. Much of these inputs remain unconsidered, however, if these unused flows are unaccounted for. Assessing unused material flows is thus very relevant from a waste management point of view. It is an important contribution to studying the dynamic and complex interactions between resource extraction and waste production and recovery, indicating the need to define more integrated policies towards sustainability. Dynamic stock models can be used to test scenarios of waste production resulting from different resource productivity trends.

5.3. *Applications for integrated sustainability modelling*

Economic forecast and simulation models can be extended by environmental data in physical units (such as material flow accounts, or accounts of energy or land use) in order to consider environmental aspects in the evaluation of future economic development strategies. The use of integrated environmental–economic models allows for quantification of the implications of economic growth, of structural changes, of technological changes in specific economic sectors, and of changes in consumption behaviour (lifestyles) in terms of extraction and use of natural resources and the production of emissions and waste.

In the MOSUS project (see above), different scenarios towards a more sustainable use of natural resources were simulated. The results illustrated that policy instruments aimed at raising eco-efficiency on the micro and sectoral levels result in significantly increased resource productivities while being conducive to economic growth. These instruments should, however, be accompanied by other policies raising the prices of energy and materials, in order to limit rebound effects on the macro level (for details see Giljum et al., 2007).

6. Conclusions

In this paper, the first comprehensive quantification of the material basis of the global economy was presented for the period from 1980 to 2002. We illustrated that global extraction of natural resources expanded considerably in absolute terms. At the same time, however, we observed relative decoupling between global resource extraction and global GDP. This indicates that the scale effect dominates structural and technology effects and that anthropogenic pressures on the environment associated with resource extraction continue to increase. Taking into account that many developing countries will further expand their physical basis in the future to cover at least basic needs, a change in global production and consumption patterns will be necessary to achieve sustainable global development. Particularly the wealthiest regions of the world are

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[4] EXIOPOL — A New Environmental Accounting Framework Using Externality Data and Input–Output Tools for Policy Analysis. Project in the 6th Framework Programme of the European Union.

challenged to implement policies aimed at dematerialisation, since they are responsible for a disproportionate share of global resource extraction and use in relation to their population.

The data on natural resource extraction presented in this paper has important implications for improving the effectiveness of global environmental and development governance. We presented policy options aimed at achieving absolute dematerialisation in industrialised countries and others facilitating a reduction of the dependence of developing countries on material extraction and primary commodity exports. Similarly, we have pointed out options provided by the application of physical accounting frameworks, such as material flow analysis that are not available from a purely economic point of view. What is needed, however, is the political will to implement such policies and to explore alternatives to currently unsustainable patterns of global natural resource use.

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