social ecology vienna

ALPEN-ADRIA UNIVERSITÄT KLAGENFURT

SOCIAL ECOLOGY WORKING PAPER 115

Marina Fischer-Kowalski • Fridolin Krausmann • Julia K. Steinberger • Robert U. Ayres

Towards a low carbon society: Setting targets for a reduction of global resource use.

ISSN 1726-3816

April 2010

Marina Fischer-Kowalski, Fridolin Krausmann, Julia K. Steinberger, Robert U. Ayres (2010):
Towards a low carbon society: Setting targets for a reduction of global resource use.

Social Ecology Working Paper 115, Vienna

Social Ecology Working Paper 115
Vienna, April 2010

ISSN 1726-3816

Institute of Social Ecology
IFF - Faculty for Interdisciplinary Studies (Klagenfurt, Graz, Vienna)
Klagenfurt University
Schottenfeldgasse 29
A-1070 Vienna
+43-(0)1-522 40 00-403
www.uni-klu.ac.at/socec
iff.socec@uni-klu.ac.at

TOWARDS A LOW CARBON SOCIETY: SETTING TARGETS FOR A REDUCTION OF GLOBAL RESOURCE USE

Authors:
Marina Fischer-Kowalski
Fridolin Krausmann
Julia K. Steinberger
Robert U. Ayres

Contents

List of Tables and Figures

Summary

We focus on three questions: one, what have been the quantitative dynamics and the main drivers of the global use of natural resources (energy and materials) in the past century? Two, how will these trends continue over the next decades, and what would be more sustainable scenarios? In other words, what is the size of the challenge? Three: how can policy interventions into resource use be argued and justified? For the first question, we come up with empirical answers, based upon secondary analysis from recently compiled centennial databases on global primary resource extraction. We interpret our findings of a roughly tenfold increase in human use of energy and materials in terms of an ongoing major transformation from an agrarian, biomass-based to an industrial, fossil fuels based social metabolism. This framework also supports the scenarios created under question two: two thirds of the world population currently only at the beginning or in early stages of this transformation must be expected to undergo the very same changes boosting global resource demands, unless novel forms of structural change occur. Such changes then are presupposed in the additional scenarios that follow *contraction and convergence* assumptions to explore more sustainable futures. Part three explores potential justifications for policies aiming at reduced resource use: by type of resource, we discuss resource scarcity, limited absorption capacities for wastes and emissions (in particular in relation to mitigating climate change), efficient and equitable supply of services to people and to economies. Key insight emerging from our analyses is the intimate interlinkage between resource use levels of energy and materials, based upon technologies, infrastructures and cultural patterns, and, last not least, upon thermodynamics. Thus major change needs to be systemic change, a new, further industrial transformation?

1. Introduction

Material and energy resources are essential for economic activity, even though most economic theory treats physical resources as abstractions that appear like manna from heaven as needed in production and conveniently disappear when products are "consumed". However the laws of physics do not permit such casual appearance and disappearance. Extraction presupposes a source and consumption presupposes a sink. In a human society, neither materials nor energy are created or destroyed. What changes is the utility and/or the quality of the materials and energy (Georgescu-Roegen 1971). Nevertheless, resources have been treated as if they were unlimited, corresponding to the "cowboy economy" vision of Boulding (1966). But as we enter the era of "space-ship earth," the endless frontier vision of resource availability is no longer tenable. In the "cowboy economy" waste disposal was generally free and harmless (with the notable exception of diseases caused by human and animal waste disposal). Today, in "space-ship earth" physical products cause harm long after the end of their useful lives, even, or possibly especially, in the form of that inert and harmless gas carbon dioxide. It follows, both from the perspective of scarcity and the actuality of pollution, that it is increasingly important to improve resource productivity and to stabilize or even reduce society's overall resource demand.

This maxim is winning increasing political recognition. While the European Commission has set up a "Thematic strategy on the sustainable use of natural resources" in 2005, Japan had already in 1998 carved out its "3R – reduce, reuse, recycle!" policy, some of which reflects itself in China's Five Year plan of 2006. Similarly, Germany decided on a National Strategy for Sustainable Development (2002), aiming at a doubling of resource productivity by 2020. In 2007, UNEP set up an International Panel on Sustainable Resource Management and will soon publish reports on "Decoupling" and on "Metals use". Part of the materials in this article originates from the work of the authors for this panel. We focus on three questions: one, what have been the quantitative dynamics of the global use of natural resources (energy and materials) in the past century, and what were its main drivers? Two, how will these trends continue over the next decades, and what would be more sustainable scenarios? In other words, what is the size of the challenge? Three: how can policy interventions into resource use be argued and justified?

In a first section we will quantitatively demonstrate, on a very aggregate level, the global rise of human resource use during the 20th century, for all materials and for energy carriers.[1] We will argue that the explosive rise of human resource use has been triggered by transformative change linking new energy sources, new demographic patterns and a new economic organization (the latter transcending our focus). This transformative change has been gradually spreading globally, thereby determining also future trajectories of resource use. In a next chapter we discuss scenarios of future resource use under different assumptions. Based upon country-level knowledge of underlying dynamics of demography and resource use, we create a business-as-usual scenario for 2050. In relation to this, we generate two "contraction and convergence"-scenarios that would lead to somewhat lower (and therefore more "sustainable") outcomes in terms of primary resource use. Such scenarios of moderation in resource use cannot be expected from market dynamics alone, so we assume, but needs to be achieved by policy intervention (Jackson 2009). Thus in the third part of our paper we open a discussion on the potential legitimacy of policy interventions into resource consumption, and the arguments that deserve consideration.

2. Levels and trends in global resource use during the 20th century

The past century was characterized by an unprecedented growth in human resource extraction and consumption (McNeill 2000) and concomitant transformations of the earth system (Turner et al. 1990). This was linked to a world wide ongoing industrial transformation, the transition from an agrarian to an industrial socio-metabolic regime (Krausmann et al. 2008b). At the core of this process was the transition of the socioeconomic energy system which began in Great Britain in the 18th century and during the subsequent century affected the industrializing nations in Europe and North America. The controlled solar energy system of the agrarian regime, tapping into renewable energy flows (biomass), was rapidly replaced by a fossil fuel based energy system exploiting large stocks which allowed for much higher power density. With the shift from land based and limited biomass flows towards abundant stocks of fossils, the major limitations for physical and economic growth constraining the agrarian regime were abolished (Fischer-Kowalski and Haberl 2007; Grübler 1998; Krausmann et al. 2008a). The energy transition triggered far reaching changes of the overall size and structure of materials use in the industrialized countries. It was associated with a major demographic transition from high birth and death rates, across a phase of very high population growth, to the very low birth rates and high life expectancy enjoyed by current industrialized countries.

[1] As the details of the new data on which our analysis draws have been published elsewhere (Krausmann et al. 2009), we will stay very brief here and just sketch major trends.

As a result, the resource use, or metabolism, of the industrializing nations multiplied. In early periods of the industrial transformation, resource use increase was driven primarily by population growth, later this gave way to growth driven by a surge in per capita resource use. Large parts of the world population were, however, hardly affected by this metabolic transition. Countries of the global South often served as agrarian hinterland for the industrial core and were kept in that state by colonial practices. The metabolic profile of many countries in the so called developing world at the turn of the 21st century resembles rather that of the historic agrarian regime than that of the industrial one[2]. Material and energy use per capita in general, and, in particular, the consumption rates of key resources like fossil fuels, steel or electricity, are low, while the share of renewable biomass in DMC is very high (see Table 1). The metabolic transition thus has to be considered an ongoing process. It spurred growth and changes in the composition of global material and energy use in the past and is likely to drive major changes in the future.

Table 1: Metabolic profiles of (historic European) agrarian societies and of selected developing and industrial nations in the year 2000

		Historic agrarian*	India 2000	China 2000	Ghana 2000	Brazil 2000	Germany 2000	USA 2000
Energy use (DEC) per capita**	[GJ/cap/yr]	40-70	37	55	38	139	225	440
Material use (DMC) per capita***	[t/cap/yr]	3-6	6	7	5	16	20	28
Electricity use per capita	[GJ/cap/yr]	0	2	4	1	8	25	52
Steel consumption per capita	[t/cap/yr]	0	26	108	8	113	510	462
Biomass (share of DEC)	[%]	>95%	64%	42%	84%	73%	17%	19%
Agricultural population	[%]	>80%	54%	67%	56%	16%	3%	2%

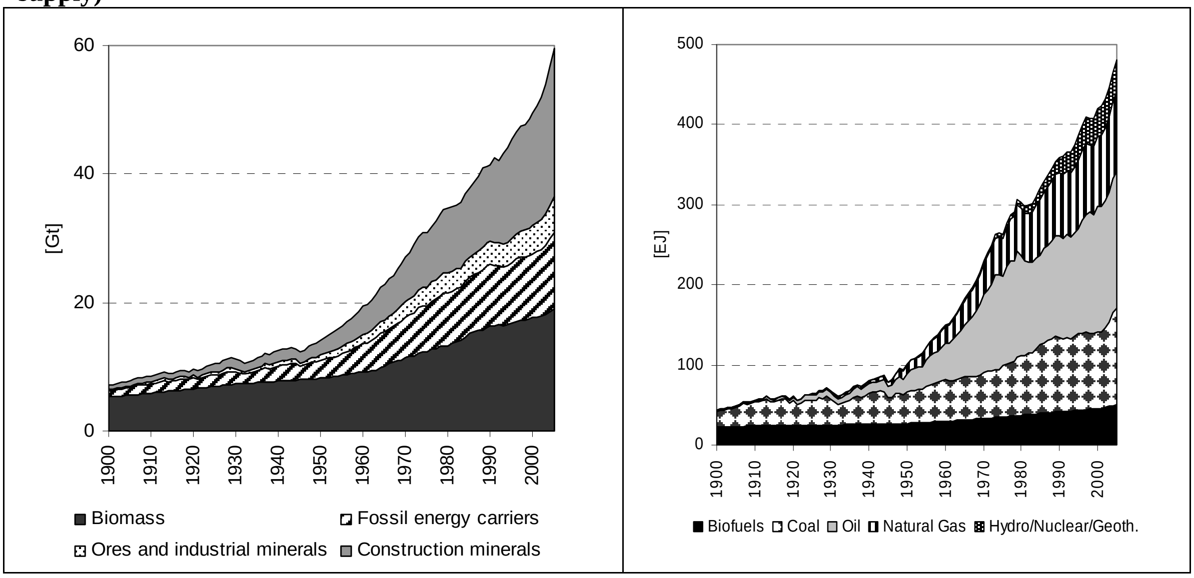
*These are typical values for advanced European agrarian socio-metabolic regimes.
**DEC, domestic energy consumption, is defined as all primary energy input into the society per year (minus exports). In contrast to TPES (total primary energy supply) as it is used in international energy statistics, DEC is a more comprehensive measure and includes food and feed (Haberl 2001).
***DMC, domestic material consumption, is defined as all annual material input into the society minus exports (Eurostat 2007).
Sources: Own calculations based on: SocialEcology dataset version 1.0 (Krausmann et al. 2008a) (DMC and DEC, share of biomass in DEC), FAO (2006a) (agricultural population), IEA (2007a) (electricity), USGS (2008) (steel).

At the global scale, the metabolic transition resulted in a multiplication of material extraction and primary energy supply (see figures 1 and 2). In 1900, when the coal based period of industrialisation had reached its peak in Western industrialized countries and coal had by and large replaced fuel wood as the principal technical energy carrier, fossil fuels accounted for almost 50% of global primary energy supply. With respect to materials, renewable biomass still made up three quarters of the overall resource input into socioeconomic processes. During the 20th century this changed rapidly. Within one hundred years, global primary energy supply and annual material extraction increased by roughly one order of magnitude, and economic output (GDP) by a factor 20. At the beginning of the 21st century, 440 EJ of primary energy and almost 60 Gt of materials (biomass, fossil fuels, ores & industrial minerals, and construction minerals) were used by human society each year (Krausmann et al. 2009). The share of biofuels in energy supply declined to 10% and mineral materials accounted for two thirds of the total material input.

[2] It has to be emphasized, however, that the metabolic profile tells only one part of the story: even a small level of modern energy use (electricity, fuels) makes a huge difference in the way people live.

The transition of the global patterns of resource use was by no means a steady process. After a period in the first half of the 20th century, when material and energy use was rising at a slow pace and was driven primarily by population growth, the dynamic of change markedly sped up after World War II. Rapid growth in that phase was closely linked to the shift towards petroleum and electricity and corresponding technologies, declining energy prices and the establishment of a society of mass production and consumption. This period, which has been termed "the great acceleration" (Steffen et al. 2007), saw a surge in metabolic rates (resource consumption per capita). Global averages of material and energy use per person doubled, a process dominated by development in the industrial world. After the first oil price shock at the beginning of the 1970s, global metabolic rates stagnated, both with energy and materials, despite rising incomes. Material use stabilized globally at about 8 tons / person, and commercial primary energy use more or less stabilized at 60 GJ/person. At the global level, this indicates relative decoupling of economic growth from resource use. However, in the period 2000-2005 global material and energy metabolism regained momentum and re-coupled with economic growth. This appears to result mainly from the increasing economic weight of fast-growing China and other emerging industrializing countries. The 2008/09 economic crisis should certainly have had an impact upon those trends, but data are not yet available.

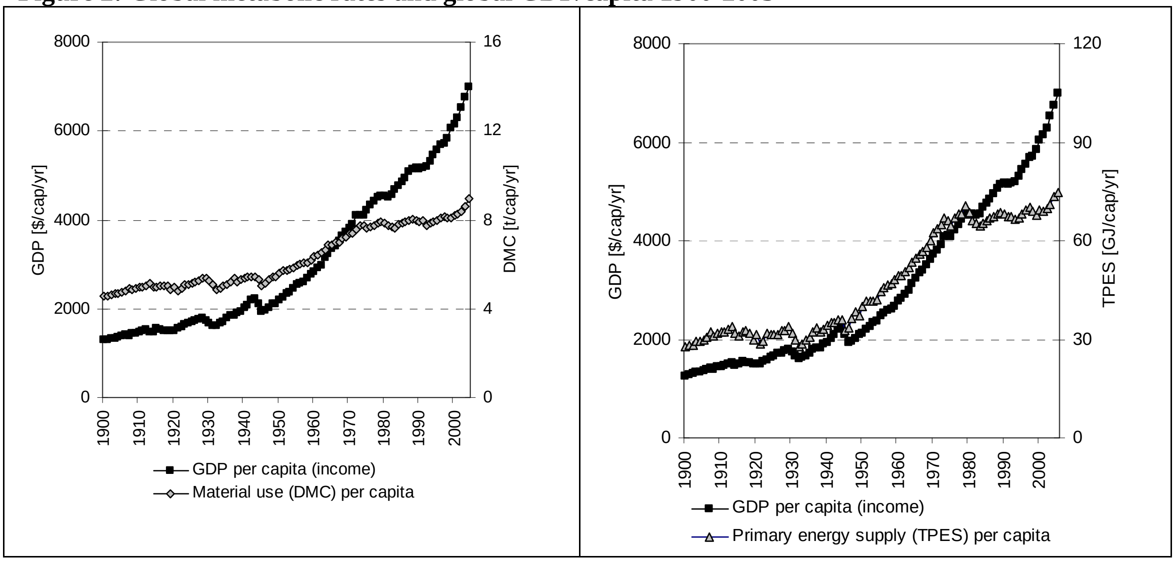
Figure 1: Global resource extraction 1900-2005 (raw materials extraction and total primary energy supply) [3]



Sources: Material flows based on data provided in Krausmann et al. (2009).

[3] On the global level, resource extraction (DE) is equivalent to resource use (DMC), as all trade flows net out. Total primary energy supply (TPES) only refers to so called technical energy. Food and feed, the primary energy sources for human and animal labour, are excluded (see Haberl, 2001).

Figure 2: Global metabolic rates and global GDP/capita 1900-2005



Sources: Based on data provided in Krausmann et al. (2009)

For individual countries as well as at the global averages, we can observe that in the long run the economy (measured in terms of GDP) grows faster than resource use. As a consequence, resource productivity (economic output gained per unit of material/energy use) has increased tremendously in the past century. Industrial countries featured increases in energy and material productivity of 150-250%. At the global level as well, resource productivity increased steadily during the last century, material productivity by 170% and energy productivity doubled.

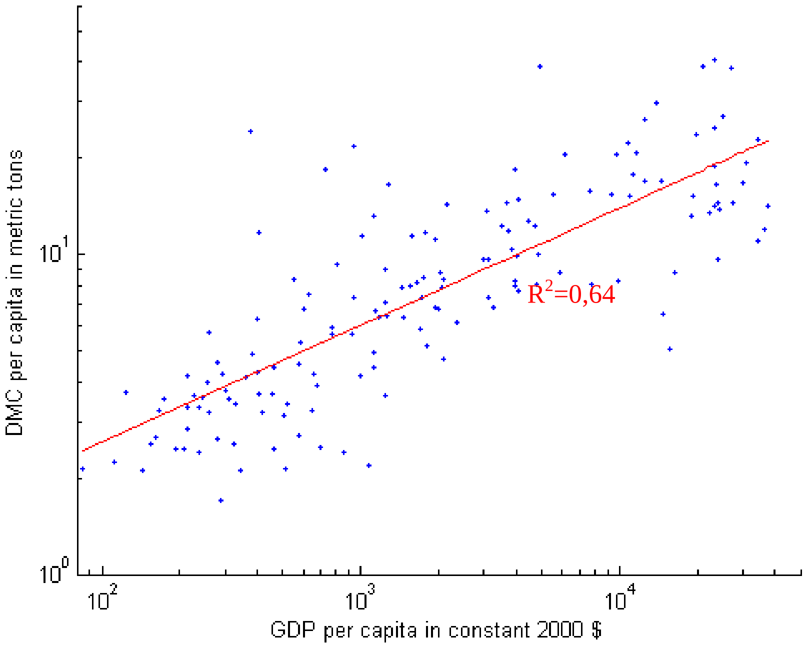
3. Scenarios of future global resource use

In the past century it was mainly the highly industrialized countries (in Europe, North America and in a few Asian countries) that contributed most to the dynamic rise of global resource consumption. However, at present the newly industrialized and the developing countries play an increasing role. The two relevant factors are population and rising metabolic rates.[4] Metabolic rates vary between countries by a factor of ten or more, depending on development status and population density as well as on climate and other factors. The global average per capita metabolic rate is somewhere between 8.0 tons (Behrens et al. 2007; Krausmann et al. 2009; Krausmann et al. 2009), and 10 tons (Krausmann et al. 2008a) of annual material use. However, the average metabolic rate for the industrialized countries (which make up only one fifth of the world population) is twice the global average and four or five times that of the poorest developing countries. Per capita income is strongly correlated with resource consumption, with a goodness-of-fit R2 factor of 0.64, indicating that the variation in income explains 64% of the variation in material use per capita (see Figure 3). The regression represented in figure 3 is performed

[4] We define is the size of the overall annual material (e.g. DMC) or primary energy input (e.g. TPES) of a socio-economic system (according to established standards of MEFA analysis) as *metabolic scale*. The metabolic rate is the metabolic scale of a socio-economic system divided by its population number (annual material or energy use per capita). It represents the biophysical burden associated to an average individual

on logged quantities: in part due to the range of two orders of magnitude in the variables, but also to account for non-linear behaviour. Indeed, material use is not exactly proportional to income, it is economically inelastic: it increases with income, but at a slower rate than income, with no indication of the high income turnover hypothesized by the so-called environmental Kuznets curve (Grossman and Krueger 1995). This means that when a country's income rises, a corresponding rise in resource consumption is to be expected.

Figure 3: Metabolic rates worldwide in the year 2000, by income level

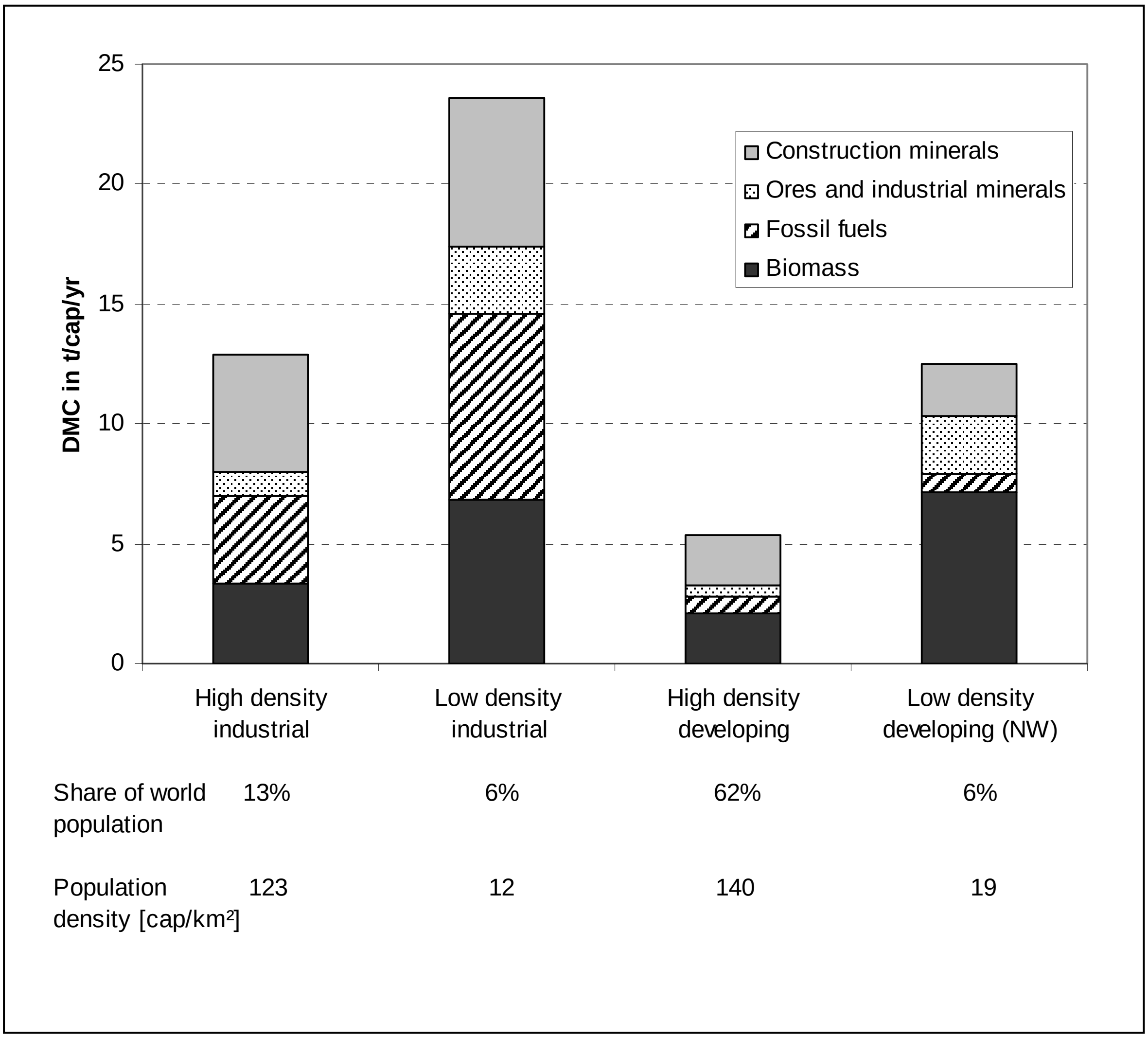


Source: DMC per capita for the year 2000[5] (175 countries) (SocialEcology global material flow dataset version 2b; (Steinberger et al. 2010); GDP per capita in constant USD of the year 2000 (The World Bank Group 2007).

Apart from income (and/or development status), population density seems to play a major role. At one extreme, the low density industrialized countries, most prominently the United States of America, Canada and Australia, are characterized by resource consumption rates between 25 and 40 tons per capita per year, which is twice or more the European or Japanese average. At the other extreme, the metabolic rates of the almost two thirds of the world population living in densely populated developing countries amount to only 5-6 tons of resources per capita per year (see figure 4).

[5] Calculation based on IEA (2007b; 2007c); USGS (2008); FAO (2006a), UN (2004).

Figure 4: Metabolic rates worldwide in the year 2000, by the development status and population density of countries



Source: Calculated on the basis of the SocialEcology global material flow data set 1.0 (Krausmann et al. 2008a). For simplicity, from the altogether 175 countries, the heterogeneous cluster of 41 developing countries with low density from the Old World (representing 13% of the world population and including some of the major oil exporters, but also some of the poorest and most arid countries in the world) has been left out. Classification by UN for development status (industrialized vs. all others) and for population density (High = >50 people / km2).

Other factors remaining the same, and irrespective of development status, it seems likely that densely populated areas and regions need a lower input of physical resources per capita. This holds particularly for the use of biomass, but to a lesser degree also for the other components. The difference in the use of biomass (see figure 4) may be attributed to two reasons. On the one hand, bulky grains, roots, fruits, vegetables and animal feeds are produced in less populated areas, and only the refined (and in sum lighter) products such as meat, dairy products, beans, sugar and tea or coffee are exported to urbanized regions. On the other hand, world regions with a traditionally high population density tend to be culturally adapted to a more vegetarian diet, whereas livestock (associated with large biomass flows) tends to be raised in low density regions.

Similarly, particularly among industrialized countries, there is a density related difference in the per capita use of fossil fuels. In densely populated areas, there is less need for transport fuels (as has often been demonstrated for cities, see (Newman and Kenworthy 1991), and the supply of heat for housing can be provided more efficiently, e.g. by district heating. Industrial facilities with a particularly high energy demand (such as mines, smelters and electric power plants), on the other hand, tend to be located in sparsely populated areas.

That per capita use of metal ores tends to be higher in low density areas is probably due to the fact that they are rather mined in low density countries, though other factors may also be involved. Finally, the per capita use of construction minerals follows a similar pattern: in high density areas space is understandably more valuable; whence saving space (and therefore construction material) and using infrastructure more intensively and thus more efficiently, is characteristic of dense areas.

For future scenarios, it therefore seems justified to assume a continuation of the current patterns: namely, that densely populated regions and countries require only about half the metabolic rate (annual resource use per capita) for the same standard of living as sparsely populated areas.

Based upon these considerations, the following three scenarios for the year 2050 have been constructed and may be compared to the baseline of the year 2000[6]. The first represents one vision of "business as usual", and the two others are increasingly stringent versions of the "contraction & convergence" ideas put forward in the climate debate (GCI 2003).

Forced future scenarios for 2050

All scenarios assume a population change according to UN projections (medium variant), calculated country by country. They assume the ratios of metabolic rates between high and low density countries to remain stable, and they assume that the composition by material components remains the same.

Scenario 1: Business as usual
Freeze (industrial countries) and catching up (developing countries)

Industrial countries maintain their metabolic rates of the year 2000 (**freeze)**, developing countries catch up by 2050 to the same rates (**catching up)**. For developing countries, this implies something more than a doubling of their metabolic rates which, in combination with projected population growth, boosts their material demand. This scenario complies well with the projections on material use derived from economic models (Lutz and Giljum 2009) and trends observed in the past decades ("business as usual"): For industrialized countries, metabolic rates have remained fairly stable since the mid 1970's (Bringezu and Schütz 2001; Eurostat 2002; Rogich et al. 2008; Weisz et al. 2006), while in many developing countries steep increases were observed (Giljum 2002; Gonzalez-Martinez and Schandl 2008; Russi et al. 2008; Xiaoqiu Chen and Lijia Qiao 2001)

[6] We have used the year 2000 as a baseline, as it best reflects a metabolic equilibrium that had dominated the 25 preceding years (see Figure 3) and was mainly shaped by the trends in the industrialized countries. In the years since, a new phase of growth can be observed that we chose to capture in the scenario part of our analysis, as according to more detailed data it is already due to a "catching up"-process by major developing countries (such as China or several Latin American countries).

By 2050, this scenario results in a global metabolic scale of 140 billion tons annually, and an average global metabolic rate of 16 tons / cap. In relation to the year 2000, this would imply more than a tripling of annual global resource extraction, and establish global metabolic rates that correspond to the present European average. Average per capita carbon emissions would triple to 3.2 tons/cap and global emissions would more than quadruple to 28.8 GtC/yr.

This scenario represents an extremely unsustainable future in terms of both resource use and emissions, exceeding all possible measures of environmental limits. Its emissions are higher than the highest scenarios in the IPCC SRES (Nakicenovic and Swart 2000), but since the IPCC scenarios have already been outpaced by the evolution since 2000 (Raupach et al. 2007), it might in fact be closer to the real business-as-usual.

Scenario 2: Moderate contraction and convergence
Reduction by Factor 2 (industrial countries) and catching up (developing countries)

In this scenario, industrial countries reduce their metabolic rates by a factor of 2, while developing countries catch up to these reduced rates by the year 2050. This scenario presupposes substantial structural change, amounting to a new pattern of industrial production and consumption. So far, despite technical efficiency gains in various domains, there are very few industrial countries whose metabolic rates have declined. On the other hand, such metabolic rates correspond roughly to the conditions in Spain or Greece in the early 1970s – a situation many people still remember as comfortable. Given the resource efficiency gains that occurred meanwhile, living by these rates today would be much more comfortable. For developing countries, this scenario implies an increase of metabolic rates by a factor 1.2 to1.3 (depending upon density).
By 2050, this scenario amounts to a global metabolic scale of 70 billion tons, which means about 40% more annual resource extraction than in the year 2000. The average global metabolic rate would stay roughly the same as in 2000, at 8 tons / cap. The average CO_2 emissions per capita would increase by almost 50% to 1.6 tons per capita, and global emissions would more than double to 14.4 GtC.
Taken as a whole, this would be a scenario of friendly moderation: while overall constraints (e.g. food supply) are not transgressed in a severe way beyond what they are now[7], developing countries have the chance for a rising share in global resources, and for some absolute increase in resource use, while industrial countries have to cut on their overconsumption. Its carbon emissions correspond to the middle of the range of IPCC SRES climate scenarios.

Scenario 3: Tough contraction and convergence
Freeze global resource consumption at the 2000 level, and converge (industrial & developing countries)

In this scenario, the level of global consumption of primary resources in 2050 is limited to equal the global resource consumption of the year 2000; industrial and developing countries converge in their metabolic rates. This scenario requires the industrialized countries to reduce their metabolic rate by factor 3-5, and also even requires 10-20%

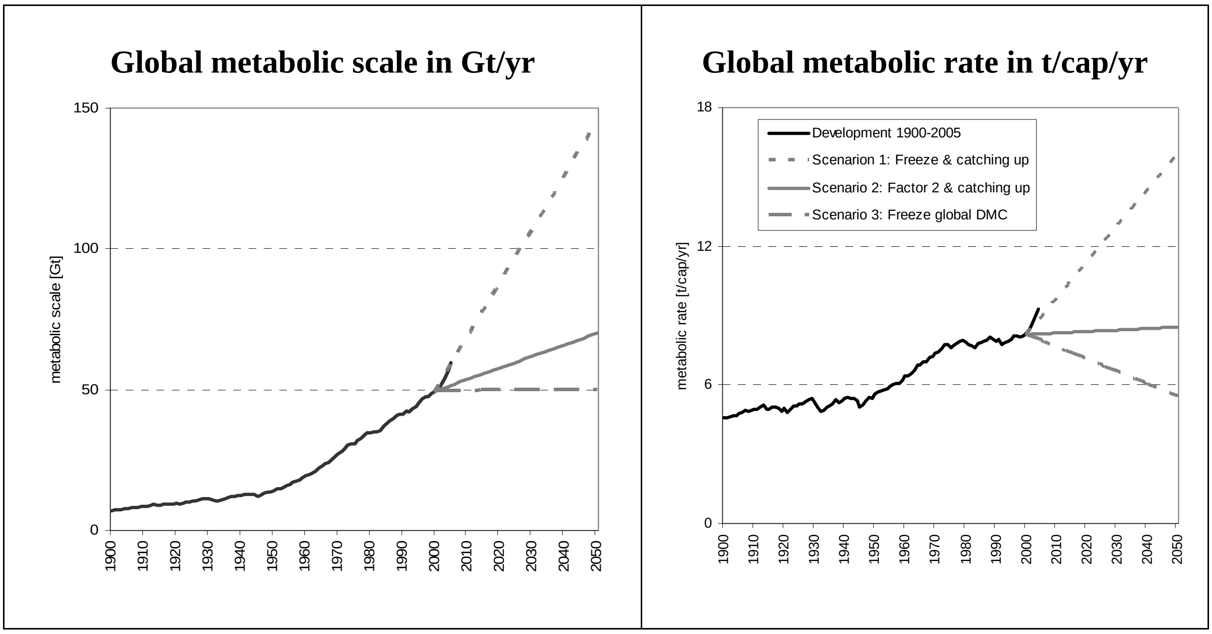
[7] If we think in terms of global footprint, already present resource consumption exceeds earth's carrying capacity, let alone another increase of 40%.

reductions in metabolic rate on the part of the countries that were classified as “developing” in the year 2000.

By 2050, this scenario amounts to a global metabolic scale of 50 billion tons (the same as in the year 2000) and allows for an average global metabolic rate of only 6 tons /cap (equal, for example to that of India in the year 2000). The average per capita carbon emissions would be reduced by roughly 40% to 0.75 tons/cap – global emissions obviously would remain constant at the 2000 level of 6.7 GtC/yr.

Taken as a whole, this would be a scenario of tough restraint. Even in this scenario the global ecological footprint of the human population on earth would exceed global biocapacity (unless substantial efficiency gains and reductions in carbon emissions would make it drop), but the pressure on the environment, despite a larger world population, would be roughly the same as it is now. The carbon emissions correspond approximately to the lowest range of scenario B1 of the IPCC SRES, but are still 20% above the roughly 5.5 GtC/yr advocated by the Global Commons Institute for contraction and convergence in emissions (GCI 2003).

Figure 5: Development of material metabolic scale and rate 1900 to 2005 and projections of three forced future scenarios for 2050



Sources: Krausmann et al. 2009 (development of metabolic scale and rate 1900-2005) and own calculations (see text).

The implications of these scenarios are far reaching. The “freeze and catching up” scenario (***scenario 1: BAU***) implies almost tripling global annual resource extraction and consumption by 2050, as developing countries catch up with the resource consumption patterns of the industrialized countries (see also Lutz and Giljum 2009). In more detail, this means globally more than doubling biomass use, while almost quadrupling fossil fuel use, tripling annual metals use (ores) and the use of construction minerals. This scenario would place an equivalent burden on the planet as if the human population tripled by the year 2050 to 18 billion people, while maintaining the resource consumption patterns of the year 2000. Moreover, this increase would, to a very large extent, take place in countries that were classified as developing countries with a very high population density in the year 2000, such as China and India. Thus, the burden of resource flows *per unit area* would in

2050 be substantially above the European or Japanese levels of today. This BAU scenario is incompatible with IPCC's climate protection targets, even if highly improbable carbon-capture-and-storage (CCS) rates on top of very high rates of (non-biomass-based) renewable energy supplies are assumed.

Scenario 2 (moderate contraction and convergence), although assuming substantial structural change of the dominant industrial production and consumption patterns, still implies a roughly 40% increase in annual global resource use. Practically all of that increase would occur in the countries classified as "developing" in the year 2000. Such a fast increase in resource consumption would render the existing policies of "circular economy" (OECD 2008) very difficult, if only because the potentially re-usable wastes are – and will always be - very much smaller than the required inputs. For the industrialized countries, achieving a factor 2 reduction of metabolic rates would imply resource productivity gains of 1-2% annually (which is within the range of the productivity gains of the past two decades), net of any income-based rebound effects (Greening et al. 2000). More realistically, it would require much higher innovation rates and productivity (efficiency) gains.[8] In either case, this scenario would require substantial economic structural change.

Scenario 3 (tough contraction and convergence), by definition, does not raise global resource consumption above the 2000 levels; thus it would be most compatible with the existing (if unknown) limits to the earth's resource base, and best adjusted for as much circularity in economies as technically feasible. However, it would be quite restrictive in terms of other goals such as reducing poverty and providing for material comfort.

What these scenario calculations demonstrate is that there exist strong drivers for a continued upward trend of annual resource extraction, pertaining to practically all resources – from biomass to fossil fuels to minerals and metals. Not only ever more resources, also ever more diverse resources, across the whole spectre of chemical substances (UNEP 2010), are being extracted and put into use. Such increases of multiple resources also defeat the traditional hopes for mechanisms of substitution: if there is rising consumption of all resources, there is nothing to switch to if we run out of some of them. If, on the contrary, growth in natural resource extraction should be contained, quite drastic reductions in metabolic rates in industrial and newly industrializing countries will be required.

Should this be left to market forces, or does this mean to risk that next generations will be deprived of their life chances? What would be justifications to bring resource use into the policy arena, and how could this be argued? This is the subject of the next section.

[8] One should be aware that achieving a substantial reduction of resource use on an economy-wide per capita level is much more difficult than achieving substantial resource productivity gains within certain areas of production. For an overall "Factor 2"-reduction of metabolic rate, much larger resource productivity gains have to be achieved in some areas (cf. Weizsäcker et al. 1997) "factor 4" or Schmidt-Bleeks "factor 10",(Hinterberger and Schmidt-Bleek 1999), while, for example, food supply can only be reduced by a much smaller margin.

4. Setting sustainability targets for resource use

What are reasonable policy targets for sustainable resource use and decoupling? Such targets need to be related both conceptually, and ethically, to the meaning of long-term sustainability. Secondly, they need the potential to be defined and broken down to various levels, globally, nationally, and possibly on the level of economic sectors, firms and products. Otherwise, they would not be practical.

Conceptually, some principles can be derived from the definition of sustainability – in particular the principle of intergenerational equity. At the same time, international fairness is the necessary political precondition to arrive at global agreements. The most important of these principles that are incorporated implicitly or explicitly in the relevant literature, are the following:

- The capacity of the earth to sustain humans, to produce resources and to absorb residues is not infinite. Even if capacity limits in each case are largely unknown, and even if a potential of learning, of substitution and of capacity expansion is assumed, humanity may soon come to a point where it exceeds that capacity (cf. Meadows et al. 1972; 1992). By some measures, such as the ecological footprint, the capacity of the earth to support human civilization has already been exceeded (cf. Hails et al. 2008). In any case, the earth may now not be too far from such a point.
- In order for global agreements to be conceivable, the benefits of resource use – including the planetary waste absorptive capacity - need to be distributed more equitably in the future than in past or present. There must be room for development of those in need, and there must be a converging trajectory in the future.

These two principles have been incorporated under the heading “equity and precaution” into the UN climate convention (UNFCCC) decided upon in Rio de Janeiro in 1992. Improving the lot of the poorest is the basis of the UN Millennium Development Goals. In the following paragraphs, we discuss policy targets based on these principles when applied to resource use, from four perspectives: (1) the perspective of limitations to the resource base, (2) the perspective of limitations to absorption capacities of the earth’s ecosystems, (3) the perspective of efficient and equitable resource supply for people, and (4) the perspective of efficient and equitable resource supply for economies.

4.1 Policy targets with reference to extraction rates from a limited resource base.

In principle, any policy target that refers to a possibly limited resource base needs to be argued on a global level, and has to relate to quantities of **global primary resource extraction.** By means of world trade, resources can be and are being exchanged across world regions. Equity considerations with respect to the amount of extracted resources do not apply across different countries and regions: resources need to be extracted where they can be found. This refers particularly to resources with localized geological deposits (e.g. copper, petroleum, phosphates), while for more ubiquitous resources (biomass, silica, iron, aluminium) other criteria may be also relevant. These other criteria are particularly important when concerning resources of daily need, such as food and water. For such resources, local and regional security of supply and affordability also come into play.

Equity considerations concerning resource extraction must apply, though, with regard to future generations. The higher the resource extraction from exhaustible stocks today, the less there will be for future extraction (this holds even if stocks are very difficult to quantify). The earlier sustainability discourse used to draw a distinction between “non-renewable resources” which ought to be extracted as little as possible in order to save them for future generations, and “renewable resources”, which should be extracted only at rates not exceeding their regeneration rates (Daly 1990). While these may be wise principles, they have long been overtaken by reality. Depending on definition, one third to half of the over 50 billion tons of primary resources extracted each year globally is “non-renewable”, with this fraction rising (fossil fuels, ores and industrial minerals, and parts of construction minerals, cf. Figure 1a). For a number of these resources, concerns about imminent scarcity have been articulated, and increasing efforts required for their extraction are reported (Gordon et al. 2006; Mudd 2009; Norgate 2009)

At the same time, “renewable resources” like biomass or many bulk minerals used for construction are also extracted in very high and increasing quantities, and there exist no clear standards as to their global regeneration rates. Thus the partial substitution of non-renewables with renewable resources as a strategy may be possible, but a general target of withdrawing from the use of non-renewables is not advocated by anyone and appears unrealistic.

If we discuss global resource extraction by the major clusters of resources, we see the following: Out of the roughly 50 billion metric tons of materials extracted each year, about one fifth (20%) consists of fossil fuels (coal, petroleum, natural gas). It is very clear that there is a scarcity issue. Both “peak oil” and “peak gas” are apparently due to occur in the near future, while global demand (particularly in developing countries) is rapidly rising. At the same time, fossil fuel extraction and use (in particular also the use of coal which is less scarce) needs to be dealt with under the header of climate change (see section 4.2) down below).

Another 30% of global resource extraction consists of biomass, a renewable energy carrier. Global biomass demand is bound to increase significantly during the coming decades due to population growth and income related changes in diet, and the substitution of biomass for fossils (Erb et al. 2009). The relation between biomass and scarcity is complex and there is currently a heated debate as to what the limits on biomass extraction are or ought to be: supplying sufficient biomass for a growing population and changing dietary patterns relate to scarcity of land (competing with wilderness/biodiversity), of water and of energy, and with the threat of soil depletion. The significance of these scarcity issues varies from region to region and over time (due, among other things, to climate change). There is concern that the growing demand of biomass for the provision of food, fibre and fuel will increase the pressure on the few remaining pristine ecosystems as well as increase land use intensity on the managed areas. An aggregate measure for society’s pressures on terrestrial ecosystems is the Human Appropriation of Net Primary production (HANPP). It depicts both the expansion and intensification of land use and biomass extraction by indicating the distance between the amount of natural primary production of plants (serving as nutritional base for all heterotrophic organisms), and the amounts remaining in ecosystems after biomass is extracted or prevented by human activity. It has been argued that there are strong causal relations between HANPP and biodiversity loss (Haberl et al. 2007b). Currently, human appropriation of NPP amounts to 25-30% globally (Haberl et al. 2007a; Rojstaczer et al. 2001; Vitousek et al. 1986) but in some world regions (e.g. India, the

Philippines) it is already as high as 70% or more. Clearly, HANPP can never exceed 100% globally – but anything close to 100% would mean the end of all wildlife. HANPP would lend itself as an adequate “scarcity indicator” for formulating political targets for biomass extraction/prevention, in particular in the context of strategies that aim at allocating large amounts of biomass for energy generation.

A small fraction, roughly 10%, of global resources extracted consists of metal ores and industrial minerals – a mixed bag of the very scarce and precious elements or gems down to the ubiquitous. For some of these materials scarcity issues play a major role, but the scarcity constraints cannot easily be translated into policy targets. One classical argument that applies here is reference to recycling. By accumulating previously extracted primary resources in our infrastructure and our waste deposits, we create potential new sources for extraction (cf. (Brunner 2004). This argument, though, does not apply to all minerals. Recycling is particularly difficult for the often precious “spice” metals (used in very small but crucial quantities, for example in electronic equipment (Hilty 2008) or minerals which are used in a dissipative way such as phosphorous in fertilizers. Additionally, the recycling of dispersed materials requires significant amounts of energy. More generally speaking, as long as overall resource use is continuously rising, remains from the past will always run short of demand. We cannot “recycle ourselves into sustainability” (Hashimoto et al. 2007; UNEP 2010).

Finally, the largest fraction (about 40%) of extracted resources consists of construction minerals. Sand, gravel and stone, and limestone for cement production, may be considered effectively unlimited, if not precisely renewable resources, and do not present a scarcity challenge, except at the regional scale in some localities (EEA 2008; Habert et al. 2010)– and thus do not offer themselves for being targeted under this perspective.

A major advantage of choosing global **primary resource extraction** as a reference point for policy targets is measurability and clear spatial assignment. However, the overall amount of resources extracted does not lend itself easily for targeting, as standards of scarcity and resource preservation strongly vary by type of resource. We are not aware of any one policy case in which decisions were taken to preserve some fraction of known resource reserves for future generations.[9]

4.2 Policy targets with reference to the limited capacity of the Earth of absorbing wastes and providing ecosystem services

In principle, any policy with reference to limited absorption capacities has to refer to **resource use,** and both on a global and on regional and local levels. During past decades, the major focus of what was considered “environmental impacts” has been on the side of wastes and emissions as a consequence of resource use, rather than on the input side. Indeed, most policies have targeted this side of the equation. How can more general policy targets for sustainable resource management be formulated from such a perspective?

The most far-reaching effort along these lines was made by the IPCC: In effect, the IPCC said that to protect the global climate, CO_2 emissions from anthropogenic sources must be

[9] Actually, South Korea has saved its own coal reserves for the time of reunification with North Korea (now it imports coal). That might count as an intergenerational restraint.

curtailed. As long as there is no powerful technology for carbon capture and storage (CCS) in place, this implies reducing the combustion of fossil fuels, and limiting Portland cement production. In the absence of CCS, one ton of fossil fuel use corresponds to roughly three tons of CO_2 emissions. One ton of limestone burned for cement production corresponds to roughly 0.5 tons of CO_2 emissions. If global climate change is to be kept below a dangerous threshold, an atmospheric CO_2 concentration above 450 ppm needs to be avoided and annual fossil fuel combustion must be reduced from the current levels of 10 billion tons of fossil fuels globally, or about 1.7 tons per capita (corresponding to 5 tons of CO_2) roughly by a factor 4. Similar reductions would be required for cement production. Thus, climate considerations legitimize a target of reducing fossil fuel use and the use of (certain) construction materials to much lower levels than today. How this correspondence can be established, must be elaborated in more detail.

Climate considerations also apply to certain aspects of biomass use. As has been shown recently (Canadell et al. 2007; Crutzen et al. 2007), IPCC's assumed "carbon-neutrality" of biomass use does not hold in all, or even many cases. For instance, it is very clear that cutting primary tropical rainforests not only removes aboveground carbon storage capacity, but also leads to the release of substantial amounts of soil organic carbon. More generally, the substitution of forest cover by cultivated land leads to net emissions of CO_2 to the atmosphere (Houghton 2003). Thus, insofar as the increase of biomass use implies an extension of agricultural land, it also has negative climate implications.

Similarly, the increase in grazing animal livestock leads to an increase in greenhouse gas emissions in the form of methane from bacterial action in the stomachs of ruminants. Methane is 21 times more effective than CO_2, per unit mass, in trapping heat. The contribution of the livestock sector to global greenhouse gas emissions (18%, measured in CO_2 equivalents) is larger than that of transport (FAO 2006b). From this perspective, one might even consider a policy target of global stabilization of livestock numbers, as these numbers both drive deforestation and greenhouse gas emissions. (McMichael et al. 2007; see also Voet et al. 2005).

As far as the use of metal ores and industrial minerals is concerned, some of them (e.g. arsenic, lead, cadmium, mercury) are among the most dangerous toxic wastes industrial societies need to deal with. There, again, it is very hard to formulate general targets except at the level of specific elements or industrially produced compounds. There are huge differences in environmental impact between the various substances and chemical compounds which are in use. But, the scarce metals are most often mined and used in conjunction with one another. Thus, it does make sense to have very specific policy targets limiting specific types of uses of certain resources (e.g. lead in gasoline or paint). But a sustainable resource management perspective can probably best be directed at the recovery and recycling (and avoidance of dissipative uses) of dangerous materials. If policy targets were formulated, not relative to waste output (i.e., recovery rates), but rather relative to primary resource input (perhaps by limiting the virgin fraction of materials use), this would also have beneficial implications in curbing raw material extraction (see considerations above).

Finally, how should the use of construction materials be treated within this perspective? Major environmental impacts of the use of construction materials include land-use associated with resource extraction and construction activities (e.g. the paving of farmland or the destruction of habitats), the GHG emissions associated with the production of

Portland cement, and fossil fuel use in quarrying and transport of large quantities of construction materials. In addition, and maybe most importantly, the use of construction materials creates legacies for future resource use as their maintenance and operation directly and indirectly influences the use of energy, materials and water (EEA 2008). The main considerations to guide policy in this domain should therefore be functional, i.e. to encourage future savings. But the lifetime resource use associated with the built environment is not directly related to the amount of construction materials used, but primarily to urban design and architecture.

In general, the use of construction materials *per se* is closely linked to fossil fuel use (Steinberger et al. 2010). If the use of fossil fuels is constrained, the use of construction materials will, at least to some degree, be constrained, too. Thus, from the perspective of end-of-life and use-related environmental consequences of resource use, policy targets formulated from a climate protection angle will have some bearing on sustainable resource management.[10] These implications ought to be elaborated in more detail. For some selected resources, policy targets of recovery and recycling may best be formulated as minimal proportion of recycled materials in certain production processes. For example, it might be reasonable to require that concrete for certain applications should incorporate a minimum percentage of recycled construction minerals and slag or fly ash recovered from coal-burning power plants.

In all cases, orienting policy targets at the **environmental impacts of resource use** will always face certain ambiguities that are hard, if not impossible, to overcome:

- System boundaries are much harder to define. While the point of extraction of a raw material, and the amounts extracted, can often be clearly identified and monitored, the full life cycle of resources extends over many functions and many areas and countries. The spatial and temporal distance between cause and effect may in some cases be very large.

- The selection of which environmental impacts to consider and how to quantify them will always remain somewhat arbitrary and subject to historically varying concerns.

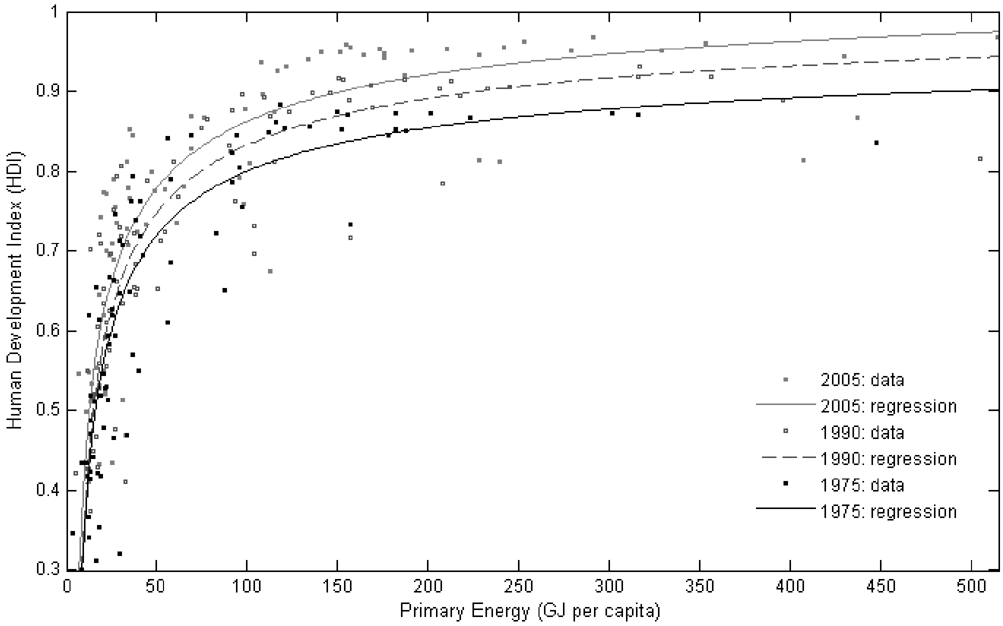
4.3 Policy targets from the angle of an efficient and equitable supply of services to people

In principle, any policy with reference to efficient resource supply to people has to relate **per capita resource use** (as an input) to some desired **outcome per capita**, such as (healthy) life expectancy, opportunity for education, sufficient and healthy nutrition or a certain level of material comfort (housing, water and electricity supply etc.). Basically, this is about **resource productivity** in the sense of providing a maximum benefit for people at the expense of a minimum of resources. The relation between primary energy supply of countries and the level of HDI achieved is such that an increase in primary energy supply (measured as GJ TPES) from very little to 100 GJ/cap/yr increases the Human Development Index (HDI) from minimum up to above 0.8 (which is the threshold value for

[10] A major concern here, though, has to be that competing sustainability goals related to fossil fuel use and biomass use are taken into consideration when strategies to meet the climate related emission targets are formulated!

"high human development"), while further increases do not generate significant improvements. Thus, this function implies an extreme reduction of returns upon resource investment in the higher ranges. Beyond this already well known result (Suarez 1995), Steinberger and Roberts (2009) have demonstrated that in the past three decades the amount of energy needed for a threshold of 0.8 HDI has decreased by 50%. As could be expected, this relation is almost identical for carbon emissions and HDI, and similar results can be seen with material consumption data.

Figure 6: The changing relation between per capita energy use (Total Primary Energy Supply) and the Human Development Index for the years 1975, 1990 and 2005



(adapted from *(Steinberger and Roberts 2009)*

The main implication of this result is that human needs can well be met at lower and lower resource use levels, and thus that reductions in resource use do not have to come at a cost of lower living standards, if their implementation is done correctly. For instance, an equitable society will be able to provide its population with decent basic services, such as food, water and shelter, at lower levels than an inequitable society where an elite consumes a large share of the resources.

The food system can serve as an example for the potential to increase resource use efficiency: A number of recent studies have analysed the wastefulness of the human food system in industrial countries. It has been shown that currently up to 40% of all produced food is not used but thrown away (Griffin et al. 2009; Hall et al. 2009; Lackner 2008): A large fraction of this waste is up to private households that buy more than they can eat, to restaurants that serve too large portions, to retailers that calculate their storage too generously, and to producers. While some of this waste is obviously inevitable, there sure is some savings potential. Considerable potential for reduction is related to the fact that people in industrial countries eat (or drink) in excess of their metabolic needs – food overconsumption can be estimated to roughly 1/6 of the food consumed, and contributes to adverse health outcomes and obesity. Finally, a reduction of the animal based food share (meat and other animal based products) could lead to another reduction, both of biomass use and even more so of environmental impact (McMichael et al. 2007; Smil 2002).

The latter two opportunities for savings could be exploited via a synergistic effort between health and environmental policies. In effect, one quarter to one third of resource use in food production could be saved, without necessarily appearing in (economic) resource productivity statistics. Nevertheless, to achieve the benefit of feeding one person (more healthily than before), less resources would be required – it would be a “double dividend” in that an increase of resource productivity in a broader sense would also be achieved. Such an achievement would take a certain time, of course, as the change of cultural habits is involved – but as the example of smoking bans has shown, success is possible. Other examples to increase resource productivity (service per unit of primary resource input) are strategies increasing recycling rates (Japan Ministry of the Environment 2008); policies aiming at energy/heat efficient housing units or increasing passengers per car or mileage per fuel input.

As analyses have shown (Fischer-Kowalski and Haberl 2007; see Krausmann et al. 2008a) metabolic rates in given contexts tend to be rather stable, unless structural change occurs. There is good reason for this: the use of various resources is strongly interlinked, especially mineral resources (Steinberger et al. 2010). The use of various materials depends on the use of others, and requires specific amounts of energy and water, based upon technologies and infrastructure. Moreover, a certain material standard of living becomes habitual within societies. As technical efficiency and incomes rise, they seemingly balance each other out to maintain a relatively constant metabolic rate. As a consequence, under structurally stable conditions, the total amount of resource use of a country strongly corresponds to population numbers.

In terms of absolute resource consumption, there is a trade-off between population dynamics and metabolic rates: there is an equivalent environmental impact if the population grows (while metabolic rates remain the same) or if population stays stable but metabolic rates rise. This is highly relevant in developing countries facing structural change. For instance, China has been fairly successful in curbing population growth, but is now confronted with rapidly rising metabolic rates. The impact on the environment is equivalent to further population growth. Thus, focusing on metabolic rates implies addressing consumption and lifestyles.

An advantage of basing policy targets on **population numbers and metabolic rates** is reasonably good measurability and fairly reliable projections over longer time spans. What is difficult to determine and to agree upon is the **outcomes** that should be referred to (such as life expectancy, HDI, or other indicators for quality of life). This could be alleviated by a multi-criteria approach (Munda 1995).

4.4 Policy targets for efficient and equitable resource supply to economies

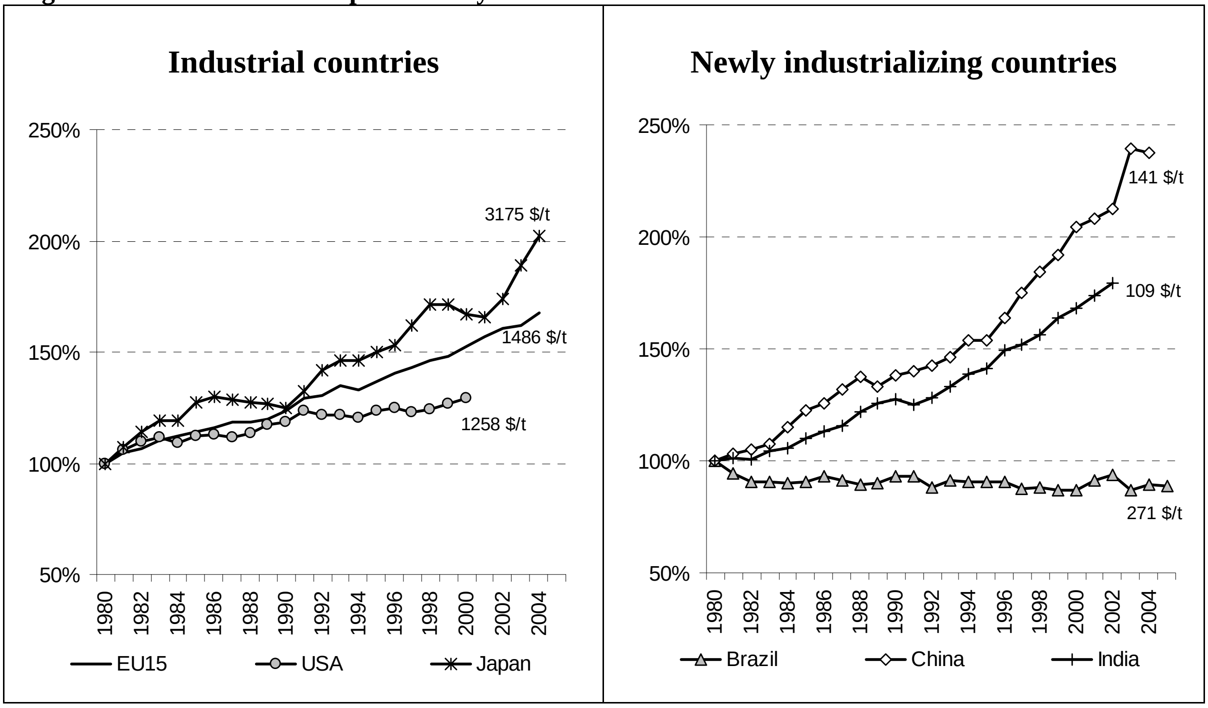
In principle, any policy for an economic system (whether a nation, a region, sector, a firm or a production process) needs to refer to **overall resource inputs** and relate them to **economic output**, usually value-added. The goal then would be to raise **economic resource productivity,** which means to achieve a higher value added per unit resources used. Technological progress can and does raise resource productivity. But for larger systems under conditions of economic growth and stable (or even declining) resource prices usually rebound effects occur that (out)balance those productivity gains – thus the resource use of the larger system, despite resource productivity gains, remains the same or even rises. (Alcott 2005; Ayres et al. 2007; Binswanger 2001; Holm and Englund 2009; see: Jevon' s paradox: Polimeni and Alcott 2008).

Another inherent problem in measuring and comparing (economic) resource productivity was already spelled out in the seminal work of Ayres and Kneese (1969) While the economic value of a product, or a commodity, due to labour input increases in the life cycle from raw material extraction to consumption, and finally disappears or even turns negative after consumption, when disposed as waste, its material mass is highest in the phase of extraction (if all materials that will ever be incorporated in the final commodity are counted, the so-called raw material equivalents, RME), this mass is gradually decreased through the stages of production, with the final commodity weighing no more than, say, ten percent of all the materials that had been mobilized to produce it, with the remaining ninety percent having occurred as extraction and production wastes before consumption. In the last stage, waste after consumption, the mass of the product does not, like its value, "disappear", but remains constant.[11]

If an indicator like resource productivity relates the value of a product to its weight, there is bound to be a bias depending on the phase in life cycle: in the early phases of resource extraction, resource productivity (that is: economic value per unit of mass) systematically is lower than in the late phases. It is, therefore, difficult and often inconclusive to compare resource productivities between different systems (such as economic sectors, firms, or even countries) that have a different position on the life cycle axis. Even with comparisons for the same system across time, this problem may occur: If a country, for example, gives up resource extraction or production in some areas in favour of importing manufactured products and specializing in services, its resource productivity is likely to increase – while the resource productivity of the larger system, that is, this country plus the countries it imports from, may remain unchanged or even decline (if the exporting countries have a less advanced technology than the importing country).

[11] This paradox can be illustrated for a very common commodity, a passenger car with the mass of 1 ton. At the beginning of the life cycle (or rather: of all the life cycles that converge in a car), there is a large amount of iron, copper and aluminium ore, ores of spice metals that will go into the car's electronics; there will be a fibre harvest to end up in upholstering; there will be timber and recycling paper to go into all the paperwork associated with the car; there will be silica sands for all the glass, and finally there will be crude petroleum to be transformed into plastics, lubricants, and oils, as well as for providing energy in the extraction, production and transportation processes. Most of this will be gradually removed, burned and transformed into wastes much before the car reaches its climax value at the point of sale. During the consumption phase, then, the car will maintain its weight but gradually loose its value, until this, finally, becomes zero, while the weight still is one ton. It is pretty evident then, that resource productivity, as the quotient of value/mass, will be lowest for the systems of resource extraction and highest for the systems where the car is only sold (and maybe occasionally repaired). A direct comparison of the resource productivity of the two systems tells more about the amount of labour invested up to the respective phase in the life cycle, than about the technological efficiency of the respective system.

Figure 7: Trends in material productivity 1980 to 2005 of selected countries



Material productivity in tons of DMC per $ GDP (constant 2000 prices); indexed 1980=1. Source: calculated from SocialEcology Database (USA, Brazil, China, India), (Eurostat 2007) (EU15), Ministry of the Environment 2008 (Japan), The World Bank Group 2007 (GDP).

Figure 7 illustrates, for a number of large economies, the huge gap (factor 10 or more) in resource productivity between fully developed and newly industrializing economies. This has much less to do with lacking technological efficiency than with the bias due to different positions in the extraction-consumption cycle and the also with the size of the GDP. Across 175 countries (for the year 2000), Steinberger et al. (2010) found a very strong correlation between income (GDP/cap/yr) and the material resource productivity indicator GDP/DMC, with a goodness-of-fit R^2 of 0.84.

Despite these precautions, using **economic material productivity** as a basis for political targets makes sense, particularly if this is one among other targets (as it is, for example, in the Japanese “3R: reduce, reuse, recycle” policy, (Krausmann et al. 2009). Increases in productivity are a precondition for saving resources without reducing the standard of living of people. The big challenge is to have substantial productivity increases but small rebound effects, or else savings are (over)compensated by growth of consumption: effectively, to push economic productivity beyond the business-as-usual levels. **Economic resource productivity** can be reliably measured on various system levels. It cannot always be so easily interpreted, though.

5. Conclusions

Carbon emissions cannot be separated from the rest of the physical infrastructure of the economy, and are in many ways linked to other types of resource use. The transition from a biomass based to a fossil fuel based economy allowed industrial societies to mobilize and handle a huge amount of resources. This transition is still ongoing, and countries with very large populations have entered that track, some of them only fairly recently. In combination with global population growth still ongoing, this would, according to a business-as-usual scenario, lead to a tripling of global primary resource extraction, including a quadrupling of fossil fuel extraction, by the year 2050.

For these reasons, it cannot be assumed that emission and resource use targets can be set independently: they necessarily have implications for each other. In fact, we would argue that a low carbon society is per necessity a low overall resource use society.[12] Such a society could be using the latest and most efficient technologies to produce the highest level of benefits and services from these resources, and living standards worldwide may even improve, but the current pattern of industrial development would certainly have to be altered. As a policy measure, rationing of resource inputs into the economy might be a necessary step towards truly curbing carbon emissions. From our discussion of the potential justifications for such policy measures, there arises a fairly diverse picture. Scarcity considerations – pertaining to ethical sustainability issues concerning future generations – can arguably be applied only to some resources, most prominently petroleum and natural gas, to a number of minerals (e.g. phosphorus) and metals, and to biomass (with reference to declining biodiversity and soil depletion). They suffer from the fact that carrying capacity and reserves tend to be ill defined.

Considerations referring to the environmental impact of resource use often suffer from weak knowledge on the interrelation of resources use and impact during the full life cycle. The strongest case here is made by climate impacts, as CO_2 emissions necessarily arise from fossil fuel use unless CCS is successfully implemented. The third line of argument claims as criteria that resources should be optimally used to satisfy human needs and wellbeing. It became apparent that not only for energy, but also for material use it holds that, at the lower levels, a small increase already provides substantial benefits of human life chances, while in higher scale levels additional resource use does not make so much of a difference. Finally, targeting resource use with the goal of gaining maximum income with as few resources as possible (in effect boosting resource productivity beyond economic growth rates) was demonstrated as potentially useful or even indispensable but tricky in terms of the interpretation of indicators. Finally, we conclude that the challenge of make-do with the Earth's resources in the face of a still rising world population and substantially rising demand per capita is so great that it will not be met by incremental means. It requires (and will, if not voluntarily dealt with, enforce) another socio-economic transformation of at least the same scale as the industrial revolution.

[12] This conclusion is in line with a recent attempt at modelling the potential to achieve a 50% cut in global industrial carbon emissions by 2050 (Allwood et al. 2010)

6. Acknowledgements

We wish to credit the UNEP panel on Sustainable Resource Management, in particular the chair of the Decoupling Working Group, Ernst Ulrich von Weizsäcker, and Mark Swilling, lead author, with eliciting many of these analyses from us. Equally, we need to thank our fellow experts Wendy Crane, Paty Romero Lancao, Anna Bella Siriban Manalang, Yong Ren, Yuichi Moriguchi and the UNEP secretariat, in particular Bas de Leeuw and Janet Salem, for critical discussions and support. Financial resources were contributed by the Austrian Ministry of agriculture, forestry, environment and water management, Division environmental economics, energy policy, and core data as well as their statistical analysis could be provided thanks to support by the Austrian Science Fund, project number P21012-G11.

7. References

Alcott B. Jevons' paradox. Ecological Economics 2005; 54 (1) p.9-21

Allwood JM, Cullen JM, and Milford RL. Options for Achieving a 50% Cut in Industrial Carbon Emissions by 2050. Environmental Science & Technology 2010;

Ayres RU and Kneese AV. Production, Consumption and Externalities. American Economic Review 1969; 59 (3) p.282-297

Ayres RU, Turton H, and Casten T. Energy efficiency, sustainability and economic growth. Energy 2007; 32 (5) p.634-648

Behrens A, Giljum S, Kovanda J, and Niza S. The material basis of the global economy: Worldwide patterns of natural resource extraction and their implications for sustainable resource use policies. Ecological Economics 2007; 64 (2) p.444-453

Binswanger M. Technological progress and sustainable development: what about the rebound effect? Ecological Economics 2001; 36 (1) p.119-132

Boulding KE. The Economics of the Coming Spaceship Earth. In: Jarrett, H. Environmental Quality in a Growing Economy. Essays from the Sixth RFF Forum. Baltimore: John Hopkins Press; 1966. p. 3-14

Bringezu S and Schütz H. Material use indicators for the European Union, 1980-1997. Economy-wide material flow accounts and balances and derived indicators of resource use. Luxembourg: Eurostat; Eurostat Working Papers 2/2001/B/2. 2001.

Brunner PH. Materials Flow Analysis and the Ultimate Sink. Industrial Ecology 2004; 8 (3) p.4-7

Canadell JG, Pataki DE, and Pitelka LE. Terrestrial Ecosystems in a Changing World, Berlin, Heidelberg: Springer; 2007.

Crutzen PJ, Mosier AR, Smith KA, and Winiwarter W. N2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels. Atmospheric Chemistry and Physics Discussion 2007; 7 (4) p.11191-11205

Daly HE. Toward some operational principles of sustainable development. Ecological Economics 1990; 2 p.1-6

EEA. Effectiveness of environmental taxes and charges for managing sand, gravel and rock extraction in selected EU countries. EEA Report 2/2008, Copenhagen: European Environment Agency (EEA); 2008.

Erb K-H, Haberl H, Krausmann F, Lauk C, Plutzar C, Steinberger JK, Müller C, Bondeau A, Waha K, and Pollack G. Eating the planet: Feeding and fuelling the world sustainably, fairly and humanely - a scoping study. Vienna, Potsdam: Institute of Social Ecology and PIK Potsdam. Report commissioned by Compassion in World Farming and Friends of the Earth, UK; Social Ecology Working Paper 116. 2009. p. 1-133

Eurostat . Material use in the European Union 1980-2000. Indicators and Analysis. Luxembourg: Eurostat, Office for Official Publications of the European Communities, prepared by Weisz, H., Fischer-Kowalski, M., Amann, C., Eisenmenger, N., Hubacek, K., and Krausmann, F.; Working papers and Studies. 2002.

Eurostat. Economy-wide Material Flow Accounting. A Compilation Guide, Luxembourg: European Statistical Office; 2007.

FAO . FAOSTAT 2006, FAO Statistical Databases: Agriculture, Fisheries, Forestry, Nutrition. Rome: Food and Agriculture Organization of the United Nations (FAO); 2006a.

FAO . Livestock's long shadow - environmental issues and options. Rome: Food and Agriculture Organisation of the United Nations; 2006b. p. 1-408

Fischer-Kowalski M and Haberl H. Socioecological transitions and global change: Trajectories of Social Metabolism and Land Use, Cheltenham, UK: Edward Elgar; 2007.

GCI . GCI Briefing "Contraction & convergence". Global Commons Institute; 2003.

Georgescu-Roegen N. The Entropy Law and the Economic Process, Cambridge, MA: Harvard University Press; 1971.

Giljum S . Trade, Material Flows and Economic Development in the South: the Example of Chile. Paper presented at the 7th Biennial Conference of the International Society for Ecological Economics, Sousse, Tunisia: 2002.

Gonzalez-Martinez AC and Schandl H. The biophysical perspective of a middle income economy: Material flows in Mexico. Ecological Economics 2008; 68 (1-2) p.317-327

Gordon RB, Bertram M, and Graedel TE. Metal stocks and sustainability. Proceedings of the National Academy of Sciences of the United States of America 2006; 103 (5) p.1209-1214

Greening LA, Greene DL, and Difiglio C. Energy efficiency and consumption - the rebound effect - a survey. Energy Policy 2000; 28 (6-7) p.389-402

Griffin M, Sobal J, and Lyson TA. An analysis of a community food waste stream. Agriculture and Human Values 2009; 26 p.67-81

Grossman GM and Krueger AB. Economic Growth and the Environment. Quarterly Journal of Economics 1995; CX (2) p.353-379

Grübler A. Technology and Global Change, Cambridge: Cambridge University Press; 1998.

Haberl H. The Energetic Metabolism of Societies, Part I: Accounting Concepts. Journal of Industrial Ecology 2001; 5 (1) p.11-33

Haberl H, Erb K-H, Krausmann F, Gaube V, Bondeau A, Plutzar C, Gingrich S, Lucht W, and Fischer-Kowalski M. Quantifying and mapping the human appropriation of net primary production in earth's terrestrial ecosystems. Proceedings of the National Academy of Sciences of the United States of America 2007a; 104 (31) p.12942-12947

Haberl H, Erb K-H, Plutzar C, Fischer-Kowalski M, and Krausmann F. Human appropriation of net primary production (HANPP) as indicator for pressures on biodiversity. In: Hak, T, Moldan, B, and Dahl, AL. Sustainability Indicators. A Scientific Assessment. Washington, D.C., Covelo, London: SCOPE, Island Press; 2007b. p. 271-288

Habert G, Bouzidi Y, Chen C, and Jullien A. 2010, Development of a depletion indicator for natural resources used in concrete. Resources, Conservation and Recycling 54(6), 364-376

Hails C, Humphrey S, Loh J, and Goldfinger S. Living Planet Report 2008, Gland, Switzerland: WWF International; 2008.

Hall KD, Guo J, Dore M, and Chow CC. The Progressive Increase of Food Waste in America and its Environmental Impact. PLoS ONE 2009; 4 (11) p.e7940

Hashimoto S, Tanikawa H, and Moriguchi Y. Where will large amounts of materials accumulated within the economy go? - A material flow analysis of construction minerals for Japan. Waste Management 2007; 27 (12) p.1725-1738

Hilty LM. Information Technology and Sustainability. Essays on the Relationship between Information Technology and Sustainable Development., Norderstedt: Books on Demand; 2008.

Hinterberger F and Schmidt-Bleek F. Dematerialization, MIPS and Factor 10, Physical sustainability indicators as a social device. Ecological Economics 1999; 29 p.53-56

Holm SO and Englund Gr. Increased ecoefficiency and gross rebound effect: Evidence from USA and six European countries 1960-2002. Ecological Economics 2009; 68 (3) p.879-887

Houghton RA. Revised estimates of the annual net flux of carbon to the atmosphere from changes in land use and land management 1850-2000. Tellus B 2003; 55 (2) p.378-390

IEA . Energy Balances of Non-OECD Countries, 2004-2005 -- 2007 Edition. International Energy Agency (IEA), Organisation of Economic Co-Operation and Development (OECD); 2007a.

IEA . Energy Statistics of Non-OECD Countries, 2004-2005 -- 2007 Edition. International Energy Agency (IEA), Organisation of Economic Co-Operation and Development (OECD); 2007b.

IEA . Energy Statistics of OECD Countries, 2004-2005 -- 2007 Edition. Paris: International Energy Agency (IEA), Organisation of Economic Co-Operation and Development (OECD); 2007c.

Jackson T . Prosperity without growth? The transition to a sustainable economy. Sustainable Development Commission; 2009. p. 1-133

Krausmann F, Fischer-Kowalski M, Schandl H, and Eisenmenger N. The global socio-metabolic transition: past and present metabolic profiles and their future trajectories. Journal of Industrial Ecology 2008a; 12 (5/6) p.637-656

Krausmann F, Gingrich S, Eisenmenger N, Erb K-H, Haberl H, and Fischer-Kowalski M. Growth in global materials use, GDP and population during the 20th century. Ecological Economics 2009; 68 (10) p.2696-2705

Krausmann F, Schandl H, and Sieferle RP. Socio-ecological regime transitions in Austria and the United Kingdom. Ecological Economics 2008b; 65 (1) p.187-201

Lackner M . Sozialökologische Dimensionen der österreichischen Ernährung. Eine Szenarienanalyse. Vienna: IFF Social Ecology; Social Ecology Working Paper. 2008. p. 1-59

Lutz C and Giljum S. Global resource use in a business-as-usual world up to 2030: updated results from the GINFORS model. In: Bleischwitz, R, Welfens, PJJ, and Zhang, Z. Sustainable growth and resource productivity. Economic and global policy issues. Sheffield: Greenleaf; 2009. p. 30-42

McMichael AJ, Powles JW, Butler CD, and Uauy R. Food, livestock production, energy, climate change, and health. The Lancet 2007; 370 (9594) p.1253-1263

McNeill JR. Something new under the sun. An environmental history of the twentieth century, London: Allen Lane; 2000.

Meadows DL, Meadows DH, and Randers J. The Limits to Growth, New York: Universe Books; 1972.

Meadows DL, Meadows DH, and Randers J. Beyond the Limits: Global Collapse or a Sustainable Future, London: Earthscan; 1992.

Ministry of the Environment GoJ . Annual Report on the Environment and the Sound Material-Cycle Society in Japan. Tokyo: 2008.

Mudd GM. The Sustainability of Mining in Australia - Key Production Trends and Their Environmental Implications for the Future (updated version): Department of Civil Engineering, Monash University and the Mineral Policy Institute.; 2009.

Munda G. Multicriteria evaluation in a fuzzy environment. Theory and application in ecological economics, Heidelberg: Physica Verlag; 1995.

Nakicenovic N and Swart R. Special Report on Emission Scenarios, Cambridge: Intergovernmental Panel on Climate Change (IPCC), Cambridge University Press; 2000.

Newman P and Kenworthy J. Cities and Automobile Dependence: An international source book, Aldershot, UK: Avebury; 1991.

Norgate TE. Deteriorating Ore Resources. Energy and Water Impacts. In: Graedel, TE and van der Voet, E. Linkages of Sustainability. Cambridge, MA: MIT Press; 2009. p. 131-148

OECD. Measuring Material Flows and Resource Productivity. Volume III. Inventory of Country Activities., Paris: OECD; 2008.

Polimeni JMMKGM and Alcott B. The Myth of Resource Efficiency. The Jevons Paradox., London: Earthscan; 2008.

Raupach MR, Marland G, Ciais P, Le Quere C, Canadell JG, Klepper G, and Field CB. Global and regional drivers of accelerating CO2 emissions. Proceedings of the National Academy of Sciences of the United States of America 2007; 104 (24) p.10288-10293

Rogich D, Cassara A, Wernick I, and Miranda M. Material Flows in the United States: A Physical Accounting of the U.S. Industrial Economy. WRI Report.: 2008.

Rojstaczer S, Sterling SM, and Moore N. Human Appropriation of Photosynthesis Products. Science 2001; 294 (5551) p.2549-2552

Russi D, Gonzalez-Martinez AC, Silva-Macher JC, Giljum S, Martinez-Alier J, and Vallejo MC. Material flows in latin america: a comparative analysis of Chile, Ecuador, Mexico and Peru (1980-2000). Journal of Industrial Ecology 2008; 12 (5-6) p.704-720

Smil V. Eating Meat: Evolution, Patterns, and Consequences. Population and Development Review 2002; 28 (4) p.599-639

Steffen W, Crutzen PJ, and McNeill JR. The Anthropocene: Are Humans Now Overwhelming the Great Forces of Nature. Ambio 2007; 36 (8) p.614-621

Steinberger JK, Krausmann F, and Eisenmenger N. Global patterns of material use: a socioeconomic and geophysical analysis. Ecological Economics 2010; 69 (5) p.1148-1158

Steinberger JK and Roberts JT. Across a Moving Threshold: energy, carbon and the efficiency of meeting global human development needs. Vienna: IFF Social Ecology; Social Ecology Working Paper. 2009.

Suarez CE. Energy Needs for Sustainable Human Development. In: Goldemberg, J and Johansson, TB. Energy As An Instrument for Socio-Economic Development. New York: United Nations Development Programme; 1995.

The World Bank Group . World Development Indicators 2007. the World Bank; 2007.

Turner BLI, Clark WC, Kates RW, Richards JF, Mathews JT, and Meyer WB. The Earth as Transformed by Human Action: Global and Regional Changes in the Biosphere over the Past 300 Years, Cambridge: Cambridge University Press; 1990.

UN. Energy Statistics Yearbook 2001, New York: United Nations, Department of Economic and Social Affairs; 2004.

UNEP . The Recycling of metals: A status report. United Nations Environment Programme; 2010.

USGS . Minerals Information. USGS; 2008.

Vitousek PM, Ehrlich PR, Ehrlich AH, and Matson PA. Human Appropriation of the Products of Photosynthesis. BioScience 1986; 36 (6) p.363-373

Voet Evd, Oers Lv, and Nikolic I. Dematerialization. Not Just a Matter of Weight. Journal of Industrial Ecology 2005; 8 (4) p.121-137

Weisz H, Krausmann F, Amann C, Eisenmenger N, Erb K-H, Hubacek K, and Fischer-Kowalski M. The physical economy of the European Union: Cross-country comparison and determinants of material consumption. Ecological Economics 2006; 58 (4) p.676-698

Weizsäcker EUv, Lovins AB, and Lovins HL. Factor four doubling wealth - halving resource use. The new report to the Club of Rome, London: Earthscan; 1997.

Xiaoqiu Chen and Lijia Qiao. A Preliminary Material Input Analysis of China. Population and Environment 2001; 23 (1) p.117-126

Band 1
Umweltbelastungen in Österreich als Folge menschlichen Handelns. Forschungsbericht gem. m. dem Österreichischen Ökologie-Institut. Fischer-Kowalski, M., Hg. (1987)

Band 2
Environmental Policy as an Interplay of Professionals and Movements - the Case of Austria. Paper to the ISA Conference on Environmental Constraints and Opportunities in the Social Organisation of Space, Udine 1989. Fischer-Kowalski, M. (1989)

Band 3
Umwelt &Öffentlichkeit. Dokumentation der gleichnamigen Tagung, veranstaltet vom IFF und dem Österreichischen Ökologie-Institut in Wien, (1990)

Band 4
Umweltpolitik auf Gemeindeebene. Politikbezogene Weiterbildung für Umweltgemeinderäte. Lackner, C. (1990)

Band 5
Verursacher von Umweltbelastungen. Grundsätzliche Überlegungen zu einem mit der VGR verknüpfbaren Emittenteninformationssystem. Fischer-Kowalski, M., Kisser, M., Payer, H., Steurer A. (1990)

Band 6
Umweltbildung in Österreich, Teil I: Volkshochschulen. Fischer-Kowalski, M., Fröhlich, U.; Harauer, R., Vymazal R. (1990)

Band 7
Amtliche Umweltberichterstattung in Österreich. Fischer-Kowalski, M., Lackner, C., Steurer, A. (1990)

Band 8
Verursacherbezogene Umweltinformationen. Bausteine für ein Satellitensystem zur österr. VGR. Dokumentation des gleichnamigen Workshop, veranstaltet vom IFF und dem Österreichischen Ökologie-Institut, Wien (1991)

Band 9
A Model for the Linkage between Economy and Environment. Paper to the Special IARIW Conference on Environmental Accounting, Baden 1991. Dell'Mour, R., Fleissner, P. , Hofkirchner, W.,; Steurer A. (1991)

Band 10
Verursacherbezogene Umweltindikatoren - Kurzfassung. Forschungsbericht gem. mit dem Österreichischen Ökologie-Institut. Fischer-Kowalski, M., Haberl, H., Payer, H.; Steurer, A., Zangerl-Weisz, H. (1991)

Band 11
Gezielte Eingriffe in Lebensprozesse. Vorschlag für verursacherbezogene Umweltindikatoren. Forschungsbericht gem. m. dem Österreichischen Ökologie-Institut. Haberl, H. (1991)

Band 12
Gentechnik als gezielter Eingriff in Lebensprozesse. Vorüberlegungen für verursacherbezogene Umweltindikatoren. Forschungsbericht gem. m. dem Österr. Ökologie-Institut. Wenzl, P.; Zangerl-Weisz, H. (1991)

Band 13
Transportintensität und Emissionen. Beschreibung österr. Wirtschaftssektoren mittels Input-Output-Modellierung. Forschungsbericht gem. m. dem Österr. Ökologie-Institut. Dell'Mour, R.; Fleissner, P.; Hofkirchner, W.; Steurer, A. (1991)

Band 14
Indikatoren für die Materialintensität der österreichischen Wirtschaft. Forschungsbericht gem. m. dem Österreichischen Ökologie-Institut. Payer, H. unter Mitarbeit von K. Turetschek (1991)

Band 15
Die Emissionen der österreichischen Wirtschaft. Systematik und Ermittelbarkeit. Forschungsbericht gem. m. dem Österr. Ökologie-Institut. Payer, H.; Zangerl-Weisz, H. unter Mitarbeit von R.Fellinger (1991)

Band 16
Umwelt als Thema der allgemeinen und politischen Erwachsenenbildung in Österreich. Fischer-Kowalski M., Fröhlich, U.; Harauer, R.; Vymazal, R. (1991)

Band 17
Causer related environmental indicators - A contribution to the environmental satellite-system of the Austrian SNA. Paper for the Special IARIW Conference on Environmental Accounting, Baden 1991. Fischer-Kowalski, M., Haberl, H., Payer, H., Steurer, A. (1991)

Band 18
Emissions and Purposive Interventions into Life Processes - Indicators for the Austrian Environmental Accounting System. Paper to the ÖGBPT Workshop on Ecologic Bioprocessing, Graz 1991. Fischer-Kowalski M., Haberl, H., Wenzl, P., Zangerl-Weisz, H. (1991)

Band 19
Defensivkosten zugunsten des Waldes in Österreich. Forschungsbericht gem. m. dem Österreichischen Institut für Wirtschaftsforschung. Fischer-Kowalski et al. (1991)

Band 20*
Basisdaten für ein Input/Output-Modell zur Kopplung ökonomischer Daten mit Emissionsdaten für den Bereich des Straßenverkehrs. Steurer, A. (1991)

Band 22
A Paradise for Paradigms - Outlining an Information System on Physical Exchanges between the Economy and Nature. Fischer-Kowalski, M., Haberl, H., Payer, H. (1992)

Band 23
Purposive Interventions into Life-Processes - An Attempt to Describe the Structural Dimensions of the Man-Animal-Relationship. Paper to the Internat. Conference on "Science and the Human-Animal-Relationship", Amsterdam 1992. Fischer-Kowalski, M., Haberl, H. (1992)

Band 24
Purposive Interventions into Life Processes: A Neglected "Environmental" Dimension of the Society-Nature Relationship. Paper to the 1. Europ. Conference of Sociology, Vienna 1992. Fischer-Kowalski, M., Haberl, H. (1992)

Band 25
Informationsgrundlagen struktureller Ökologisierung. Beitrag zur Tagung "Strategien der Kreislaufwirtschaft: Ganzheitl. Umweltschutz/Integrated Environmental Protection", Graz 1992. Steurer, A., Fischer-Kowalski, M. (1992)

Band 26
Stoffstrombilanz Österreich 1988. Steurer, A. (1992)

Band 28
Naturschutzaufwendungen in Österreich. Gutachten für den WWF Österreich. Payer, H. (1992)

Band 29
Indikatoren der Nachhaltigkeit für die Volkswirtschaftliche Gesamtrechnung - angewandt auf die Region. Payer, H. (1992). In: KudlMudl SonderNr. 1992:Tagungsbericht über das Dorfsymposium "Zukunft der Region - Region der Zukunft?"

Band 31
***Leerzeichen.* Neuere Texte zur Anthropologie**. Macho, T. (1993)

Band 32
Metabolism and Colonisation. Modes of Production and the Physical Exchange between Societies and Nature. Fischer-Kowalski, M., Haberl, H. (1993)

Band 33
Theoretische Überlegungen zur ökologischen Bedeutung der menschlichen Aneignung von Nettoprimärproduktion. Haberl, H. (1993)

Band 34
Stoffstrombilanz Österreich 1970-1990 - Inputseite. Steurer, A. (1994)

Band 35
Der Gesamtenergieinput des Sozio-ökonomischen Systems in Österreich 1960-1991. Zur Erweiterung des Begriffes "Energieverbrauch". Haberl, H. (1994)

Band 36
Ökologie und Sozialpolitik. Fischer-Kowalski, M. (1994)

Band 37
Stoffströme der Chemieproduktion 1970-1990. Payer, H., unter Mitarbeit von Zangerl-Weisz, H. und Fellinger, R. (1994)

Band 38
Wasser und Wirtschaftswachstum. Untersuchung von Abhängigkeiten und Entkoppelungen, Wasserbilanz Österreich 1991. Hüttler, W., Payer, H. unter Mitarbeit von H. Schandl (1994)

Band 39
Politische Jahreszeiten. 12 Beiträge zur politischen Wende 1989 in Ostmitteleuropa. Macho, T. (1994)

Band 40
On the Cultural Evolution of Social Metabolism with Nature. Sustainability Problems Quantified. Fischer-Kowalski, M., Haberl, H. (1994)

Band 41
Weiterbildungslehrgänge für das Berufsfeld ökologischer Beratung. Erhebung u. Einschätzung der Angebote in Österreich sowie von ausgewählten Beispielen in Deutschland, der Schweiz, Frankreich, England und europaweiten Lehrgängen. Rauch, F. (1994)

Band 42
Soziale Anforderungen an eine nachhaltige Entwicklung. Fischer-Kowalski, M., Madlener, R., Payer, H., Pfeffer, T., Schandl, H. (1995)

Band 43
Menschliche Eingriffe in den natürlichen Energiefluß von Ökosystemen. Sozio-ökonomische Aneignung von Nettoprimärproduktion in den Bezirken Österreichs. Haberl, H. (1995)

Band 44
Materialfluß Österreich 1990. Hüttler, W., Payer, H.; Schandl, H. (1996)

Band 45
National Material Flow Analysis for Austria 1992. Society's Metabolism and Sustainable Development. Hüttler, W. Payer, H., Schandl, H. (1997)

Band 46
Society's Metabolism. On the Development of Concepts and Methodology of Material Flow Analysis. A Review of the Literature. Fischer-Kowalski, M. (1997)

Band 47
Materialbilanz Chemie-Methodik sektoraler Materialbilanzen. Schandl, H., Weisz, H. Wien (1997)

Band 48
Physical Flows and Moral Positions. An Essay in Memory of Wildavsky. A. Thompson, M. (1997)

Band 49
Stoffwechsel in einem indischen Dorf. Fallstudie Merkar. Mehta, L., Winiwarter, V. (1997)

Band 50+
Materialfluß Österreich- die materielle Basis der Österreichischen Gesellschaft im Zeitraum 1960-1995. Schandl, H. (1998)

Band 51+
Bodenfruchtbarkeit und Schädlinge im Kontext von Agrargesellschaften. Dirlinger, H., Fliegenschnee, M., Krausmann, F., Liska, G., Schmid, M. A. (1997)

Band 52+
Der Naturbegriff und das Gesellschaft-Natur-Verhältnis in der frühen Soziologie. Lutz, J. Wien (1998)

Band 53+
NEMO: Entwicklungsprogramm für ein Nationales Emissionsmonitoring. Bruckner, W., Fischer-Kowalski, M., Jorde, T. (1998)

Band 54+
Was ist Umweltgeschichte? Winiwarter, V. (1998)

Mit + gekennzeichnete Bände sind unter
http://www.uni-klu.ac.at/socec/inhalt/1818.htm
Im PDF-Format downloadbar.

Band 55+
Agrarische Produktion als Interaktion von Natur und Gesellschaft: Fallstudie SangSaeng. Grünbühel, C. M., Schandl, H., Winiwarter, V. (1999)

Band 57+
Colonizing Landscapes: Human Appropriation of Net Primary Production and its Influence on Standing Crop and Biomass Turnover in Austria. Haberl, H., Erb, K.H., Krausmann, F., Loibl, W., Schulz, N. B., Weisz, H. (1999)

Band 58+
Die Beeinflussung des oberirdischen Standing Crop und Turnover in Österreich durch die menschliche Gesellschaft. Erb, K. H. (1999)

Band 59+
Das Leitbild "Nachhaltige Stadt". Astleithner, F. (1999)

Band 60+
Materialflüsse im Krankenhaus, Entwicklung einer Input-Output Methodik. Weisz, B. U. (2001)

Band 61+
Metabolismus der Privathaushalte am Beispiel Österreichs. Hutter, D. (2001)

Band 62+
Der ökologische Fußabdruck des österreichischen Außenhandels. Erb, K.H., Krausmann, F., Schulz, N. B. (2002)

Band 63+
Material Flow Accounting in Amazonia: A Tool for Sustainable Development. Amann, C., Bruckner, W., Fischer-Kowalski, M., Grünbühel, C. M. (2002)

Band 64+
Energieflüsse im österreichischen Landwirtschaftssektor 1950-1995, Eine humanökologische Untersuchung. Darge, E. (2002)

Band 65+
Biomasseeinsatz und Landnutzung Österreich 1995-2020. Haberl, H.; Krausmann, F.; Erb, K.H.;Schulz, N. B.; Adensam, H. (2002)

Band 66+
Der Einfluss des Menschen auf die Artenvielfalt. Gesellschaftliche Aneignung von Nettoprimärproduktion als Pressure-Indikator für den Verlust von Biodiversität. Haberl, H., Fischer-Kowalski, M., Schulz, N. B., Plutzar, C., Erb, K.H., Krausmann, F., Loibl, W., Weisz, H.; Sauberer, N., Pollheimer, M. (2002)

Band 67+
Materialflussrechnung London. Bongardt, B. (2002)

Band 68+
Gesellschaftliche Stickstoffflüsse des österreichischen Landwirtschaftssektors 1950-1995, Eine humanökologische Untersuchung. Gaube, V. (2002)

Band 69+
The transformation of society's natural relations: from the agrarian to the industrial system. Research strategy for an empirically informed approach towards a European Environmental History. Fischer-Kowalski, M., Krausmann, F., Schandl, H. (2003)

Band 70+
Long Term Industrial Transformation: A Comparative Study on the Development of Social Metabolism and Land Use in Austria and the United Kingdom 1830-2000. Krausmann, F., Schandl, H., Schulz, N. B. (2003)

Band 72+
Land Use and Socio-economic Metabolism in Pre-industrial Agricultural Systems: Four Nineteenth-century Austrain Villages in Comparison. Krausmann, F. (2008)

Band 73+
Handbook of Physical Accounting Measuring bio-physical dimensions of socio-economic activities MFA – EFA – HANPP. Schandl, H., Grünbühel, C. M., Haberl, H., Weisz, H. (2004)

Band 74+
Materialflüsse in den USA, Saudi Arabien und der Schweiz. Eisenmenger, N.; Kratochvil, R.; Krausmann, F.; Baart, I.; Colard, A.; Ehgartner, Ch.; Eichinger, M.; Hempel, G.; Lehrner, A.; Müllauer, R.; Nourbakhch-Sabet, R.; Paler, M.; Patsch, B.; Rieder, F.; Schembera, E.; Schieder, W.; Schmiedl, C.; Schwarzlmüller, E.; Stadler, W.; Wirl, C.; Zandl, S.; Zika, M. (2005)

Band 75+
Towards a model predicting freight transport from material flows. Fischer-Kowalski, M. (2004)

Band 76+
The physical economy of the European Union: Cross-country comparison and determinants of material consumption. Weisz, H., Krausmann, F., Amann, Ch., Eisenmenger, N., Erb, K.H., Hubacek, K., Fischer-Kowalski, M. (2005)

Band 77+
Arbeitszeit und Nachhaltige Entwicklung in Europa: Ausgleich von Produktivitätsgewinn in Zeit statt Geld? Proinger, J. (2005)

Band 78+
Sozial-Ökologische Charakteristika von Agrarsystemen. Ein globaler Überblick und Vergleich. Lauk, C. (2005)

Band 79+
Verbrauchsorientierte Abrechnung von Wasser als Water-Demand-Management-Strategie. Eine Analyse anhand eines Vergleichs zwischen Wien und Barcelona. Machold, P. (2005)

Band 80+
Ecology, Rituals and System-Dynamics. An attempt to model the Socio-Ecological System of Trinket Island. Wildenberg, M. (2005)

Band 81+
Southeast Asia in Transition. Socio-economic transitions, environmental impact and sustainable development. Fischer-Kowalski, M., Schandl, H., Grünbühel, C., Haas, W., Erb, K-H., Weisz, H., Haberl, H. (2004) Helmut Haberl

Band 83+
HANPP-relevante Charakteristika von Wanderfeldbau und anderen Langbrachesystemen. Lauk, C. (2006)

Band 84+
Management unternehmerischer Nachhaltigkeit mit Hilfe der Sustainability Balanced Scorecard. Zeitlhofer, M. (2006)

Band 85+
Nicht-nachhaltige Trends in Österreich: Maßnahmenvorschläge zum Ressourceneinsatz. Haberl, H., Jasch, C., Adensam, H., Gaube, V. (2006)

Band 87+
Accounting for raw material equivalents of traded goods. A comparison of input-output approaches in physical, monetary, and mixed units. Weisz, H. (2006)

Band 88+
Vom Materialfluss zum Gütertransport. Eine Analyse anhand der EU15 – Länder (1970-2000).
Rainer, G. (2006)

Band 89+
Nutzen der MFA für das Treibhausgas-Monitoring im Rahmen eines Full Carbon Accounting-Ansatzes; Feasibilitystudie; Endbericht zum Projekt BMLFUW-UW.1.4.18/0046-V/10/2005. Erb, K.-H., Kastner, T., Zandl, S., Weisz, H., Haberl, H., Jonas, M., (2006)

Band 90+
Local Material Flow Analysis in Social Context in Tat Hamelt, Northern Mountain Region, Vietnam. Hobbes, M.; Kleijn, R. (2006)

Band 91+
Auswirkungen des thailändischen logging ban auf die Wälder von Laos. Hirsch, H. (2006)

Band 92+
Human appropriation of net primary produktion (HANPP) in the Philippines 1910-2003: a socio-ecological analysis.
Kastner, T. (2007)

Band 93+
Landnutzung und landwirtschaftliche Entscheidungsstrukturen. Partizipative Entwicklung von Szenarien für das Traisental mit Hilfe eines agentenbasierten Modells.
Adensam, H., V. Gaube, H. Haberl, J. Lutz, H. Reisinger, J. Breinesberger, A. Colard, B. Aigner, R. Maier, Punz, W. (2007)

Band 94+
The Work of Konstantin G. Gofman and colleagues: An early example of Material Flow Analysis from the Soviet Union. Fischer-Kowalski, M.; Wien (2007)

Band 95+
Partizipative Modellbildung, Akteurs- und Ökosystemanalyse in Agrarintensivregionen; Schlußbericht des deutsch-österreichischen Verbundprojektes. Newig, J., Gaube, V., Berkhoff, K., Kaldrack, K., Kastens, B., Lutz, J., Schlußmeier B., Adensam, H., Haberl, H., Pahl-Wostl, C., Colard, A., Aigner, B., Maier, R., Punz, W.; Wien (2007)

Band 96+
Rekonstruktion der Arbeitszeit in der Landwirtschaft im 19. Jahrhundert am Beispiel von Theyern in Niederösterreich. Schaschl, E.; Wien (2007)

Band 98+
Local Material Flow Analysis in Social Context at the forest fringe in the Sierra Madre, the Philippines. Hobbes, M., Kleijn, R. (Hrsg); Wien (2007)

Band 99+
Human Appropriation of Net Primary Production (HANPP) in Spain, 1955-2003: A socio-ecological analysis. Schwarzlmüller, E.; Wien (2008)

Band 100+
Scaling issues in long-term socio-ecological biodiversity research: A review of European cases. Dirnböck, T., Bezák, P., Dullinger S., Haberl, H., Lotze-Campen, H., Mirtl, M., Peterseil, J., Redpath, S., Singh, S., Travis, J., Wijdeven, S.M.J.; Wien (2008)

Band 101+
Human Appropriation of Net Primary Production (HANPP) in the United Kingdom, 1800-2000: A socio-ecological analysis. Musel, A.; Wien (2008)

Band 102 +
Wie kann Wissenschaft gesellschaftliche Veränderung bewirken? Eine Hommage an Alvin Gouldner, und ein Versuch, mit seinen Mitteln heutige Klimapolitik zu verstehen. Fischer-Kowalski, M.; Wien (2008)

Band 103+
Sozialökologische Dimensionen der österreichischen Ernährung – Eine Szenarienanalyse. Lackner, M.; Wien (2008)

Band 104+
Fundamentals of Complex Evolving Systems: A Primer.
Weis, E.; Wien (2008)

Band 105+
Umweltpolitische Prozesse aus diskurstheoretischer Perspektive: Eine Analyse des Südtiroler Feinstaubproblems von der Problemkonstruktion bis zur Umsetzung von Regulierungsmaßnahmen. Paler, M.; Wien (2008)

Band 106+
Ein integriertes Modell für Reichraming. Partizipative Entwicklung von Szenarien für die Gemeinde Reichraming (Eisenwurzen) mit Hilfe eines agentenbasierten Landnutzungsmodells. Gaube, V., Kaiser, C., Widenberg, M., Adensam, H., Fleissner, P., Kobler, J., Lutz, J., Smetschka, B., Wolf, A., Richter, A., Haberl, H.; Wien (2008)

Band 107+
Der soziale Metabolismus lokaler Produktionssysteme: Reichraming in der oberösterreichischen Eisenwurzen 1830-2000. Gingrich, S., Krausmann, F.; Wien (2008)

Band 108+
Akteursanalyse zum besseren Verständnis der Entwicklungsoptionen von Bioenergie in Reichraming. Eine sozialökologische Studie. Vrzak, E.; Wien (2008)

Band 109+
Direktvermarktung in Reichraming aus sozial-ökologischer Perspektive. Zeitlhofer, M.; Wien (2008)

Band 110+
CO_2-Bilanz der Tomatenproduktion: Analyse acht verschiedener Produktionssysteme in Österreich, Spanien und Italien. Theurl, M.; Wien (2008)

Band 111+
Die Rolle von Arbeitszeit und Einkommen bei Rebound-Effekten in Dematerialisierungs- und Dekarbonisierungsstrategien. Eine Literaturstudie. Bruckner, M.; Wien (2008)

Band 112+
Von Kommunikation zu materiellen Effekten - Ansatzpunkte für eine sozial-ökologische Lesart von Luhmanns Theorie Sozialer Systeme. Rieder, F.; Wien (2008)

Band 113+
(in Vorbereitung)

Band 114+
Across a Moving Threshold: energy, carbon and the efficiency of meeting global human development needs.
Steinberger, J. K., Roberts, .J.T.; Wien (2008)

Band 115
Towards a low carbon society: Setting targets for a reduction of global resource use. Krausmann, F., Fischer-Kowalski, M., Steinberger, J.K., Ayres, R.U.; Wien (2010)

Band 116+
Eating the Planet: Feeding and fuelling the world sustainably, fairly and humanely - a scoping study. Erb, K-H., Haberl, H., Krausmann, F., Lauk, C., Plutzar, C., Steinberger, J.K., Müller, C., Bondeau, A., Waha, K., Pollack, G.; Wien (2009)

Band 117+
Gesellschaftliche Naturverhältnisse: Energiequellen und die globale Transformation des gesellschaftlichen Stoffwechsels. Krausmann, F., Fischer-Kowalski, M.; Wien (2010)

Band 118
(in Vorbereitung)

Band 119
Das nachhaltige Krankenhaus: Erprobungsphase. Weisz, U., Haas, W., Pelikan, J.M., Schmied, H., Himpelmann, M., Purzner, K., Hartl, S., David, H.; Wien (2009)

Band 120+
LOCAL STUDIES MANUAL
A researcher's guide for investigating the social metabolism of local rural systems. Singh, S.J., Ringhofer, L., Haas, W., Krausmann, F., Fischer-Kowalski, M.; Wien (2010)

Band 121+
Sociometabolic regimes in indigenous communities and the crucial role of working time: A comparison of case studies. Fischer-Kowalski, M., Singh, S.J., Ringhofer, L., Grünbühel C.M., Lauk, C., Remesch., A.; Wien (2010)

Band 122
Klimapolitik im Bereich Gebäude und Raumwärme. Entwicklung, Problemfelder und Instrumente der Länder Österreich, Deutschland und Schweiz. Jöbstl, R.; Wien (2010)

Band 126
Masterstudium "Sozial- und Humanökologie": Selbstevaluation 2005-2010. Schmid, M., Mayer A., Miechtner, G.; Wien (2010)