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Trends and Developments of the Use of Natural Resources in the European Union

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Trends and Developments of the Use of Natural Resources in the European Union

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1.1 What are natural resources?

The core meaning of „resource“ is something that can be used for producing something. In this broad meaning everything may be a resource: the song of a bird inspiring a composer, the shine of a star used by a captain to find his way, and a stone in the field to start building a wall. What characterizes a resource is a particular quality, or rather a number of qualities, that render it practical for certain uses. Once this quality is lost, the potential usefulness of the resource disappears.

A first distinction that needs to be drawn is the distinction between material and immaterial resources. This distinction is very basic: with immaterial resources, actual use does not change the qualities that make them useful. The same song of the bird may be used by still another composer, the same starlight has information for hundreds of captains, and the same genetic sequence for millions of productive cows. The useful qualities of immaterial resources cannot be "used up" by making use of them. However, immaterial resources can be eradicated by extinguishing them from memory, which is most likely done by extinguishing the "hardware" to which they are coupled.

With material resources, making use of them eliminates at least some of the qualities that make them useful for the purpose at hand – they can be "used up". In a recent JRC study (Nielsen et al., 2005) some of them have therefore been termed "stock resources". This does not mean that they materially disappear (basic physics does not allow for the disappearance of energy/matter), but that their potential usefulness for the same purpose declines. How much it declines depends on how much the resource is modified through use.

Finally, there is a class of material resources where the source is so abundant that making use of it cannot possibly "use it up". Examples of this are wind, sunshine, geothermal or tidal energy – resources that have been termed "flow resources" (Nielsen et al. 2005). Another example may be air: the use of air for cooling or drying, but even its use for providing oxygen to combustion processes (for abundance see Smil, 2008).

With such a wide definition, everything in the material world may be a material resource. No clear distinction can be drawn. And everything may be put to a principally infinite number of uses. This wide definition was adopted by the Commission of the European Communities (2003) in preparation of its sustainable resource strategy, and also used by the Technical Report on the Environmental Impact of the Use of Natural Resources (Nielsen et al. 2005, p.11) and led to a classification of resources into

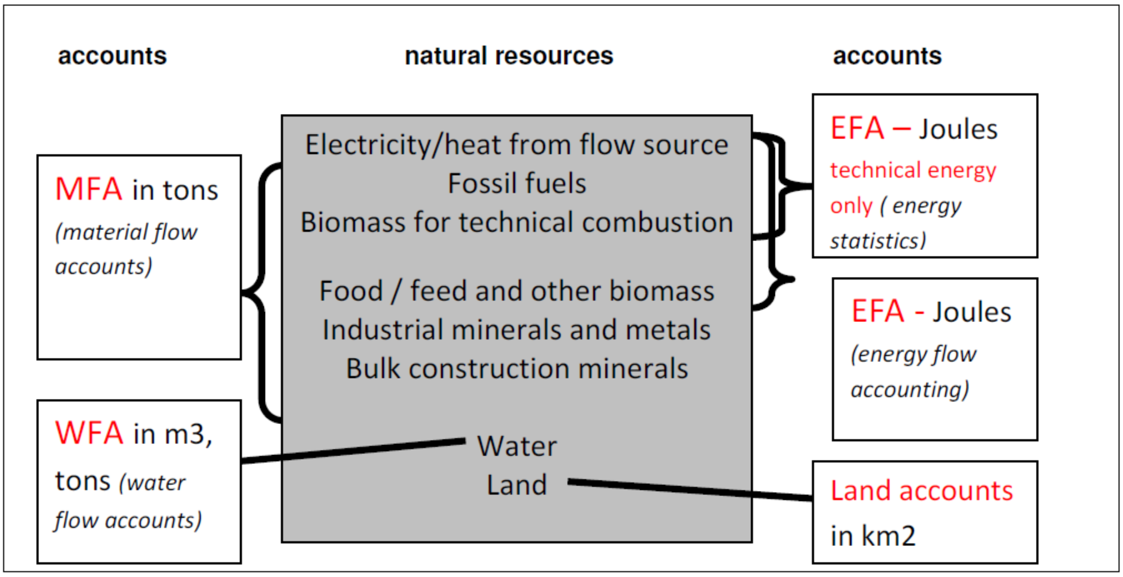
- raw materials
- environmental media
- flow resources, and
- space.

As resources and resource use conceptually serve as one of the most important links between the environment and economic activities, we suggest choosing a somewhat narrower notion of resources that better complies to the use of this term in economics.

We suggest defining resources in the following way: *Resources are natural assets deliberately extracted and/or modified by human activity for their utility to create economic value. They can be* *measured both in physical units (such as tons, joules or area), and in monetary terms expressing their economic value.*

Such a narrower definition allows an exhausting and fully quantifiable classification of natural resources as presented below.

Figure 1: Classification of natural resources and corresponding accounting frameworks (highest aggregation level)



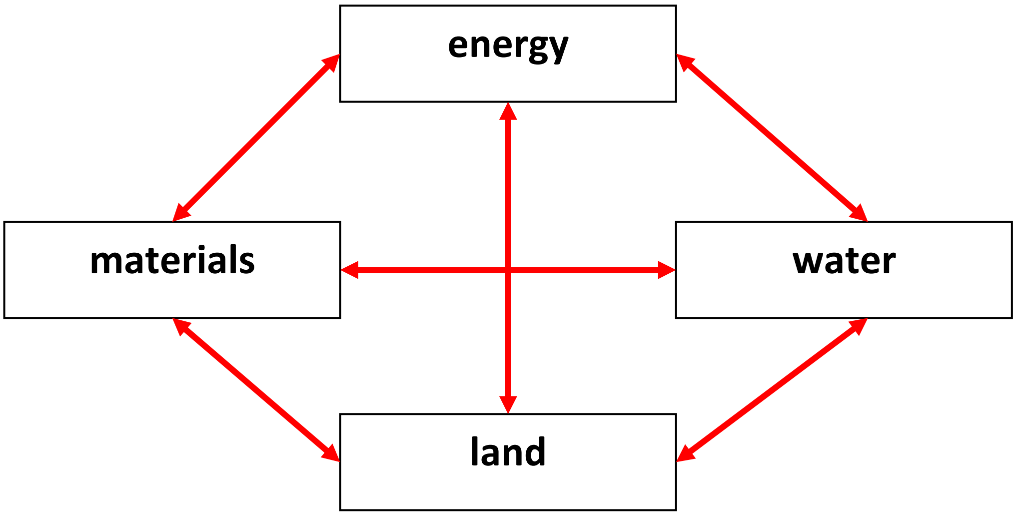
This classification already refers to fully operational standard measures, as far as materials and energy are concerned. For materials, this complies to the standard indicators of MFA, material flow analysis (Eurostat 2001 and 2007). For energy resources, either indicators well established in energy statistics such as total primary energy supply (TPES) can be used, or the somewhat more encompassing indicators constructed in analogue to MFA (Haberl, 2001) are available.

For the use of water as a resource, comprehensive accounting frameworks and indicator standardization has not yet been developed that far, though it is well under way and follows a similar logic and similar system boundaries as have been established for MFA. (Gleick, 2003, Hoekstra and Chapagain, 2008). While indicators for materials use can be presented both in disaggregated form and also be added up to comprehensive aggregates, water resources have to be accounted for separately as they are used in one or two orders greater magnitude and would virtually “drown” all other information.

For used land resources, a number of quantified indicators have been established. One very simple indicator is the respective system’s territory or some subdivision, such as inhabitable territory. On more detailed levels, productive land or land used for specific purposes (such as for example built up land) are relatively well defined and can be expressed in square kilometres. Bringezu et al., 2009b) for instance have developed a more complex accounting framework that also considers global land use associated with the consumption of biomass based products. For most purposes, it does make sense to talk about “land” and not about “space” (as e.g. in Nielsen et al. 2005), because terrestrial area (in contrast to water or even ocean surfaces) is much more clearly linked to exclusive economic use, and because it seems more adequate to look upon it as a two-dimensional rather than a three-dimensional resource.[1]

For many purposes, it is important to note that the ties between resources and their use are anything but linear. As illustrated in figure 2, the use of materials always has implications and is linked with energy use. Similarly, the use of energy resources are almost invariably connected to water use – be it for biomass production, or for cooling of industrial aggregates. The use of many materials is linked to additional use of water (for example, in construction, with biomass and, for example, in metals extraction). Equally, a certain though highly variable amount of land use is always associated to each materials use. Thus it cannot be assumed that single resources can be manipulated on their own – there always will be a substantial halo effect in many other resources.

Figure 2: Interdependencies of resource use



The amounts of resources used can be looked upon as the most important physical representation of socio-economic activity. Socio-economic activities that do not result in resource use are environmentally irrelevant. Like in economic accounting where GDP refers both to production and to consumption (and presupposes an equilibrium between production and consumption), accounting for material resource use refers equally to production and consumption, and – at least for materials in the narrower sense – an equilibrium must be presupposed between input flows and outflows in the form of wastes and emissions. As with the economy, upon closer scrutiny this is somewhat more complex (with stocks to be accounted for, time delays and interregional exchange), but nevertheless material resources accounting is a homologue of economic accounting. This is most apparent for material resources, because for them the outflows can be and are measured (and must equal the input flows), while energy outflows (dissipative heat) usually do not attract much interest. While it is clear that resource use causes effects "from cradle to grave", the amount of resources put to use can be most easily accounted for and measured at the point of entry into the economic system, that is at the input side of the use chain. While the flow of resources through the economy can be portrayed by Sankey diagrams (as often employed in energy accounting)[2] and followed in a top down direction, it is more difficult – but not impossible

[1] In the future, this might of course change. Already now coastal areas belong to specific territories, and there may be a time when the "global commons" of oceans will be consigned for specific purposes and governance. But for the time being, for simplicity "land" may suffice.
[2] See e.g. http://www.sankey-diagrams.com/

– to reconstruct resource inputs from down the chain, i.e. for example from the products in a basket of consumption (as Life Cycle Assessment (LCA) usually practices).

Resources, environmental media and earth systems

Environmental media, environmental compartments and earth systems[3] closely resemble resources insofar as they provide certain services indispensable for socioeconomic activities. They also resemble resources insofar as their overuse may render them unable to further deliver those services. In two respects though, environmental media/compartments and earth systems are very different: first, they are not traded within the economy, and if they are (such as, for example as water) they do become resources. Second, they provide a principally innumerable assembly of services. While some services can be singled out and have a value attached to them (for example by willingness-to-pay approaches), or other services may be preserved through deliberate investment (such as restoring the water quality of a lake), the totality of services any one media/environmental system provides cannot be quantified, neither in economic nor in biophysical terms.

While Nielsen et al. (2005) consider only the environmental media air, water and soil, seeing them as sustaining life and producing biological resources, we would suggest make this list longer and address its elements as systems. Doing so implies attributing a higher degree of complexity to them, up to the point of looking at them as self-organizing systems that reproduce themselves and provide certain services depending upon this self-reproduction. These systems cannot be "steered" by human activity ("cleaning the air" is a much too simple metaphor, for example), but they can be irritated to change their behaviour in welcome or less welcome (or simply unpredictable) ways. We suggest to distinguish the following relevant systems.

- atmosphere
- aquatic systems
- soil
- lithosphere
- live systems (ecosystems/organisms/genes)
- human health

Our reasons for this proposal are not only of a systematic nature, but also strategic: the conceptual framework should be as inclusive as possible and as open as possible for fruitful recent approaches such as earth systems theory (Schellnhuber et al., 2005) and theories of ecosystem services (Daily et al., 1997). The inclusion of the lithosphere is important, as deposition / erosion are key mechanisms to reproduce soil nutrients and contribute to global bio-geospherical cycles. Live systems need to be explicitly addressed as they are an important source of (ecosystem)

[3] The choice of terms here is a strategic issue, as it creates the arena for the meeting of various discourses. Each term has a certain disciplinary origin and refers to some discourse. Choosing a term, therefore, expresses a willingness to join or invite a certain discourse. On the other hand, terms have functional features related to their theoretical background: what you can do with a term depends on what the theory allows and implicates. The term "environmental media" with its main origin in environmental chemistry relies upon a distinction between complex systems (such as organisms, or a factory) and their environments; in this relation, the environments are merely distinguishable assemblies of loosely coupled elements (like, for example, water molecules, or the specific mix of molecules in the air). The term "environmental compartments" in contrast originates from system ecology and refers to more complex units (systems?) that are much more tightly coupled and considered as interacting with each other. The terms "ecosystems" and, more generally, "earth systems", are the most recent terminological innovations in the environmental debate (mainly rooted in system ecology and climate sciences) and portray the natural environment of human activities as highly complex systems of their own, systems that reproduce themselves by specific mechanisms that can be irritated by human activity. (See von Foerster, 1960, Maturana and Varela, 1975).

services. It also seems reasonable to address the human organism (health) on its own, as this is a key source of services for human activities and an issue where the arena can be shared with the important debate on health promotion.

Separating environmental media / systems from resources allows analyzing their interaction. And within this interaction, it is possible to give the term "environmental impacts" a more specific meaning and link them into more complex theoretical concerns.

In the traditional (DPSIR) meaning, (negative) "environmental impacts" are unwanted changes in states of the environment that are triggered by (socio-economic) pressures on this environment. Why some changes are unwanted, or not welcome, remains arbitrary. In the mental model we propose here, we suggest a systematic link between impacts and ecosystem/earthsystem services: *negative environmental impacts of resource use would, by this logic, be an effect of resource use on one or several environmental systems that puts their services at risk.* (see table 1)

Table 1: Resource use, environmental media/systems, impacts and system services

Media (j) / Resource use (i)	Atmo-sphere	Aquatic systems	Soil	Litho-sphere	Life systems	Human health	aggregated impacts by resource use
Use of energy from flow resources		I_{ij}		I_{ij}			Sum of Imp_i
Use of energy materials	I_{ij}		I_{ij}		I_{ij}	I_{ij}	e.g. EMC_i
Use of non-energy materials		I_{ij}	I_{ij}	I_{ij}		I_{ij}	e.g. EMC_i
Water use		I_{ij}			I_{ij}	I_{ij}	e.g. water footprint
Land use	I_{ij}	I_{ij}	I_{ij}		I_{ij}		e.g. HANPP
aggregated impacts on earth/eco system services	Sum of Imp_j	Imp of all resources use on aquatic systems	Sum of Imp_j	Sum of Imp_j	Imp of all resource use on ecosystem health and biodiv	Sum of Imp_j	e.g. ecological footprint Sum of Imp_{ij}

It is very clear though that each and every impact will have to be selected and estimated by criteria that derive from the policy concerns of the time (be it acidification in periods of concern about forest dieback, be it greenhouse gas emissions in times of threatening climate change) and evade comparability among each other. It will always remain a policy issue which criteria to choose, how to weigh them and therefore, how to finally generate indicators of resource use weighed by selected impacts, such as attempted by various indicators like EMC or ecological footprint. All this and its implications will be further discussed in chapter 3.6.

1.2 Concepts, methods and data sources

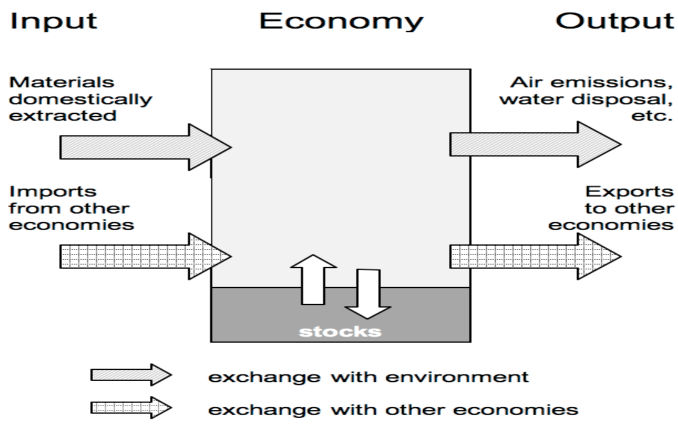
This report focuses on trends and patterns of materials use and establishes links between material use and land use. The most important source of data on material consumption in the European Union are material flow accounts. During the last years, material flow accounting (MFA) has emerged as an important tool in monitoring socio-economic resource use. This section briefly introduces MFA and discusses the availability and quality of data and also their potential and limitations for the purpose of this study. It provides important background information for the sections discussing trends and patterns of material use in the EU.

Economy wide material flow accounts

In the past years the physical dimension of economic processes, in particular the socio-economic use of materials, was increasingly recognized internationally as a focal issue in sustainable development. The 6th environmental action programme (European Parliament and Council, 2002) specifies the sustainable use of resources as one of six priority fields for the period 2002 to 2012. A thematic strategy on a sustainable use of resources was published by Commission of the European Communities (2005) and an OECD (2004) council recommendation on material flows and resources productivity in April 2004 fostered the establishment of an OECD work program on this topic by the working group on environmental information and outlook and lead to an OECD-UNEP conference on resource efficiency in 2008.[4] Finally, in 2007, UNEP initiated the foundation of an international expert panel on a sustainable use of resources[5] which is about to publish a series of reports on global resource use and its environmental impacts (e.g. UNEP, 2009).

These policy processes substantially increased the need for economy-wide, reliable and comparable time-series data and indicators for material use. The backbone of an environmental reporting system which provides such information is economy-wide material flow accounting (MFA). Economy wide material flow accounts provide consistent information of the overall material inputs into national economies, changes in material stock within the economic system and the material outputs to other economies and to the domestic environment of the observed economy (Figure 3). Flows within the economic system are not considered. Economy-wide MFAs cover all solid, gaseous, and liquid materials, except for bulk water and air; the unit of measurement is tonnes (i.e. metric tonnes) per year. Similar to the system of national accounts, material flow accounts serve two major purposes. The detailed accounts provide a rich empirical database for numerous analytical studies. The aggregate accounts are also used to compile different extensive and intensive material flow indicators for national economies at various levels of aggregation. Economy-wide MFA thereby is to be seen as a satellite system to the system of national accounts (Eurostat, 2009a, OECD, 2008c).

Figure 3: Scope of economy-wide Material Flow Accounting (MFA)



Source: Eurostat, 2009a

Since the publication of an initial guide for economy wide MFA by Eurostat in 2001, the methodology and accounting principles of MFA reached a certain level of standardization: In 2007,

4 http://www.oecd.org/environment/resourceefficiency, see OECD, 2008a.
5 http://www.unepie.org/scp/rpanel/.

Eurostat (2007b) issued a hands on guide for material flow accounting (MFA) which was revised in 2009 and also OECD launched a process to standardise MFA methodology. OECD published a series of methodological reports in 2008 (OECD, 2008b and 2008c). Based on these agreed upon methodological standards Eurostat began collecting material flow data from national statistical offices in 2007. For the European Union and its member states several MFA datasets exist: A dataset commissioned by Eurostat covering the EU-15 member states and for the period 1970 to 2004. MFA data from Eurostat's 2007 data collection have been published for the EU-27 member states plus Switzerland and Norway for the period 2000 to 2005; the data of the 2009 data collection, covering the period 2000 to 2007 have been published by Eurostat in late June 2010, to late to be considered in the data analysis for this report. Additionally, a number of national MFA studies and datasets for European countries have been published by researchers or statistical offices (see OECD, 2008d). The existing national studies however differ with respect to the methods and estimation procedures, the flows covered and the level of aggregation by which materials are reported or discussed.

Unused extraction and indirect flows

Material flow analysis differentiates between used or direct material flows and indirect or hidden flows. Indirect or hidden material flows are resource flows associated with used material extraction which do not enter the economy[6]. Examples for hidden flows are overburden from mining operations, eroded soil or earthen materials displaced during construction activities. Hidden flows can be large and are associated with considerable environmental pressures. Several attempts to quantify these flows in MFA accounts exist. They are used to calculate material flow indicators like total material requirement (TMR) and total material input (TMI) (Eurostat, 2001, Bringezu et al., 2009c). While accounting principles and estimation procedures for used flows are widely standardized, this is not yet the case for indirect or hidden flows and data on these flows are currently not collected by Eurostat.

Indirect flows or upstream resource requirements associated with traded materials are a specific case which needs to be mentioned. It has been recognized that limiting MFA accounts to (direct) traded flows is not sufficient to detect shifts in resource use due to changing trade patterns (Eisenmenger et al., 2007). Particularly industrialized countries tend to import large amounts of semi-manufactured materials and products. The production of these commodities can be associated with huge material flows in the exporting countries that are not reflected in direct import/export flow accounts. This makes it difficult to interpret material input and use indicators only including direct trade flows. The quantification of upstream flows[7], however, is a difficult task; currently methods for their inclusion into MFA accounts are being developed.[8] Up to date, no agreed upon method allowing for standardized application producing comparable results over time and countries is available. A few case studies indicating the general size of upstream resource requirements and the distortion of DMC or DMI caused by trade exist (Weinzettel and Kovanda, 2009, Bringezu et al., 2009b). They illustrate the dimension of the distortions caused by the exclusion of upstream resource flows associated with trade flows.

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[6] The OECD glossary defines hidden and indirect flows as "the displacement of environmental assets without absorption into the economic sphere; example: overburden from mining operations". http://stats.oecd.org/glossary/detail.asp?ID=6472. In contrast, direct flows refer to flows of materials that physically cross the boundary of the economic system (*at the level for which the accounts are made, i.e. the national economy in the case of national economy-wide material flow accounts)* either as an input or as an output. Direct flows refer to the actual mass (weight) of the material or product that enters or leaves the system and do not take into account the life-cycle dimension of the production chain (Eurostat 2001, OECD 2008).

[7] To denote the upstream requirements of used extraction associated with imports or exports the concept of "raw material equivalents" has been developed (OECD, 2008b; Eurostat, 2001)

[8] The most promising methods include the application of LCA derived coefficients and coefficients derived from Input-Output tables or a combination of both approaches.

Material flow data used in this study

For the purpose of this study we mostly restrict ourselves to the use of the two official economy wide MFA datasets available from Eurostat:

In 2007, Eurostat commissioned the compilation of MFA data in time series for the EU-15. This data set provides MFA data for the EU-15 and 14 member states (Belgium and Luxembourg are aggregated). It covers the flows of used extraction, exports and imports, and distinguishes 11 different material groups (Eurostat, 2007a). Data are available for the period 1970 to 2004. These are the only publicly available data covering a longer time series for Europe.

In 2009, Eurostat published the results of its first MFA survey conducted in 2007 (Eurostat, 2009b).[9] An MFA questionnaire distinguishing approximately 50 different material groups was sent out to member states. Roughly half of all member states returned data for DE, imports and exports; flows for countries not reporting data were estimated by Eurostat. Data on used extraction, imports, exports were published only for three highly aggregate material groups (biomass, fossil energy carriers and mineral materials) but are available in more detail from Eurostat. Data on changes in stocks and direct processed outputs are only available for a very limited number of countries.

It has to be noted that the MFA data available from these two datasets are not fully consistent. Due to methodological changes, data on material consumption in the EU-15 for the period 2000 to 2004 derived from Eurostat (2009b) are 3-8% above the data reported in Eurostat (2007).

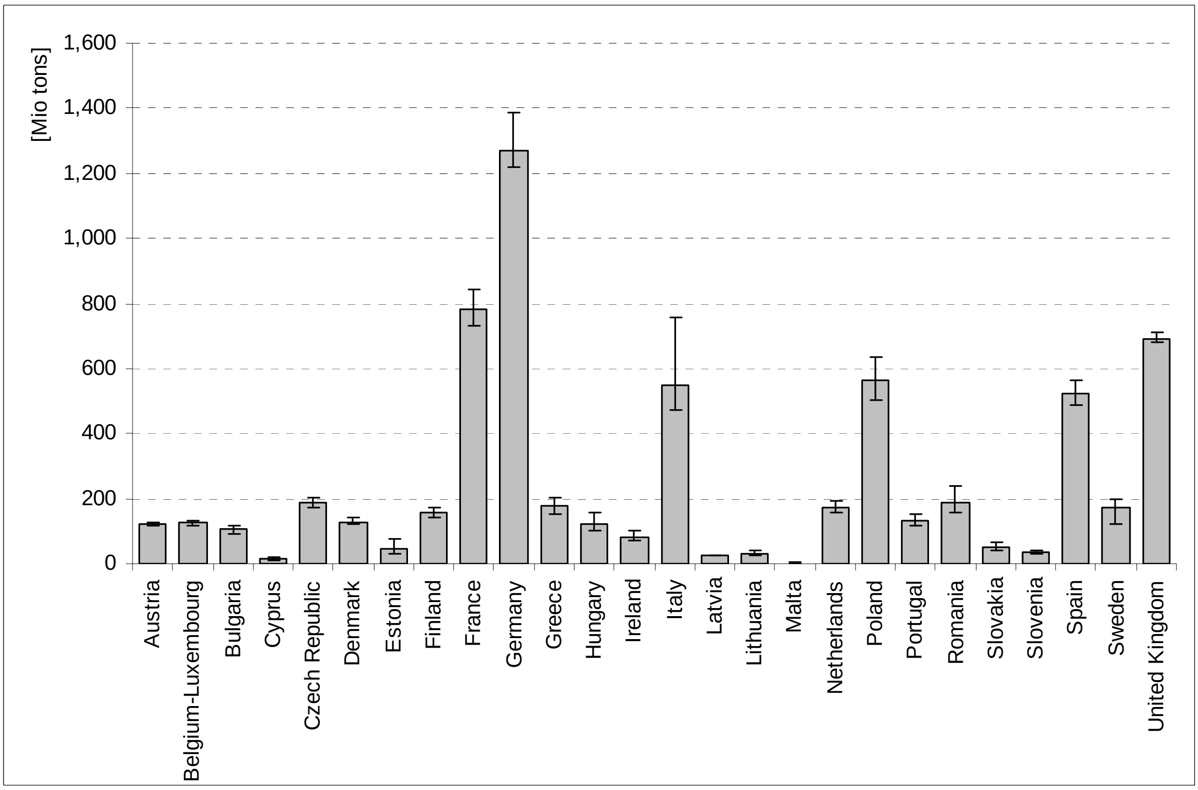
Data for 2004 and 2005 are, unfortunately, the most recent MFA data available for the European Union and its member states. In 2009 Eurostat started its second collection of MFA data covering the years 2000 to 2007. These data have been published by Eurostat in June 2010. This was unfortunately to late to include the data into the analysis for this report, except for the trends in material use shown in Figure 24, which refer include to the new dataset (Eurostat 2010). The most recent MFA data are, therefore not considered in this report.

[9] http://epp.eurostat.ec.europa.eu/portal/page/portal/environment/data/main_tables.

Quality of MFA data

In order to provide a rough indication of the reliability of indicators derived from material flow accounts we have compared data on domestic material extraction for the year 2000 from five different studies. Figure 4 shows that for most countries the deviations from the mean are comparatively small. Existing differences are mostly due to the development of different estimation procedures for flows not covered by statistical sources. Due to the strong efforts at standardizing accounting principles and estimation methods, and the high quality of primary data available for European Union member states, uncertainties of MFA data and derived indicators have been significantly reduced. MFA data can be considered to be of reasonable quality sufficient for cross country comparison and the interpretation of development over time.

Figure 4: Comparison of existing estimates of domestic material extraction in EU27 countries (average and range across studies)



Source: Own calculation on the basis of the following material flow accounts: Schandl and Eisenmenger, 2006, Krausmann et al., 2008b, Eurostat, 2007a, Eurostat 2009, SERI, 2009.

2 Extraction, Trade and Consumption of Materials in the EU

2.1 Summary

The most recent MFA data available for the European Union show that material use (Domestic Material Consumption, DMC) of the EU-27 amounted to 7.7 billion tones in 2005. Non renewable minerals (including fossil energy carriers) account for nearly four fifths of total material use in the EU. At the global scale, the 85% of world population living in the EU consume roughly 13% of all extracted materials – not counting upstream material use associated with the production of imported commodities. These data show that the EU has an over proportionally high share in global material use, which is also reflected in an annual per capita material consumption more than 50% above the global average (15.8 tons in 2005). Japan, having adopted a rigorous resource saving policy, has a significantly lower per capita material use (12 t/cap/yr) than the EU. On the other hand, material consumption in the USA (27 t/cap/yr) is more than 70% above the European level. Across the EU member states, DMC ranges between 10 and 39 t/cap/yr. In general, material use is lowest in countries with low GDP per capita and/or high population density. It is noteworthy that countries with a low rate of material use per capita may be characterized by a high rate of material use per unit of area nevertheless, indicating a high level of overall environmental pressure.

Data on the long term development of material use in the EU are only available for the EU-15: After a period of increasing material use in the 1970s and 80s, growth in DMC of the EU-15 (and in most countries) has decelerated markedly and per capita material consumption has stabilized at a comparatively high level. For the 12 new member states data are available only for the period 2000 to 2005. In this period, material use has increased by 24% and material use per capita grew from 12 to 15 t/cap/yr, almost reaching the level of the EU-15. Overall, material use in the EU-27 increased only slightly in this period from 7.4 to 7.7 billion tons.

In combination with high economic growth rates in the past, the slow growth of material use resulted in considerable growth in overall resource productivity (measured as DMC or DMI per unit of GDP) and, hence, in relative dematerialization: While the physical economy of the EU (both EU-15 and EU-27) has been growing at a slower pace than GDP, absolute decline of material use only occurred during very short periods, always linked to phases of recession or very low economic growth. Absolute decoupling of material use and economic growth, as it has been observed for Japan, has not been achieved in the European Union. At the member state level different trends can be observed: While most countries show comparatively stable DMC and relative dematerialization, a few member states were characterized by absolute dematerialization, even in the long run, for example Germany and the United Kingdom. Absolute dematerialization in most cases was a result of deindustrialization and fading out of material intensive heavy industries or mining activities. A number of countries are characterized by a DMC which grows faster than GDP. Typically, these are countries with a low level of per capita income but high economic growth (e.g. Spain, Hungary). In these countries, in particular, the development of built infrastructures contributed to the high increase of overall material use.

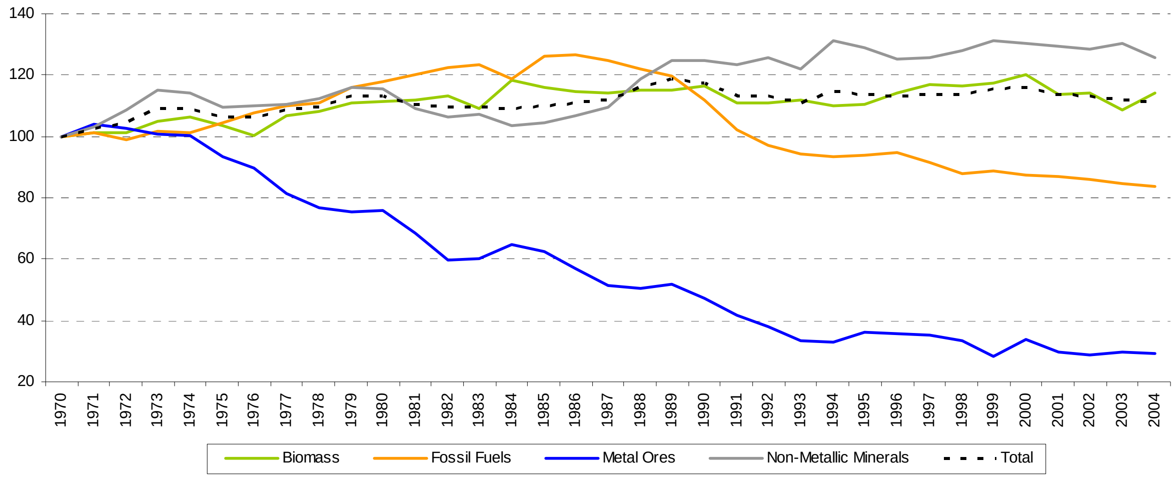
The overall trend of stabilization of material consumption rests upon trends of stable or even decreasing domestic material extraction of all four main material groups. Domestic extraction (DE) of materials in the EU has in particular declined with respect to ores and fossil energy carriers, while DE of biomass and non-metallic minerals have stabilized at high levels. In contrast, the significance of physical trade for meeting the EU's material demands, both in terms of direct material input (DMI) and domestic material consumption (DMC) is rapidly increasing. Like other industrial economies such as Japan, the European Union is characterized by a very high import dependency, in particular with respect to strategically important materials such as ores, fossil energy carriers and specific non-metallic minerals. For the EU-15 countries, the contribution of imports to DMI for metals has increased to almost 90% and for fossil energy carriers to 60%. Since the year 2000, net-imports of materials into the EU-27 have increased by 20% to more than 1.2 billion tones per year. The growing significance of trade not only means a growing dependence of the EU on imports of key raw materials, but it also calls for caution with respect to the interpretation of the observed trend of stabilization of material use as indicated by MFA data: Current material flow accounts only consider direct material flows, but neglect upstream material flows associated with the production of traded commodities in exporting countries. Pilot studies which quantified these upstream flows indicate that for highly industrialized countries the so called

raw material equivalents (RME) of imports are three to six times larger than direct import flows. Even when raw material equivalents of exports are included in the calculation, this results in raw material equivalents of domestic consumption roughly 30% above DMC. Although the methods used to calculate raw material flows are not yet fully developed and need standardization, they clearly show that the inclusion of upstream flows may change the overall picture of trends and patterns considerably. These results indicate that the EU by importing material intensive commodities might increasingly shift environmental burdens to the producing countries in the global south.

2.2 Domestic extraction of materials

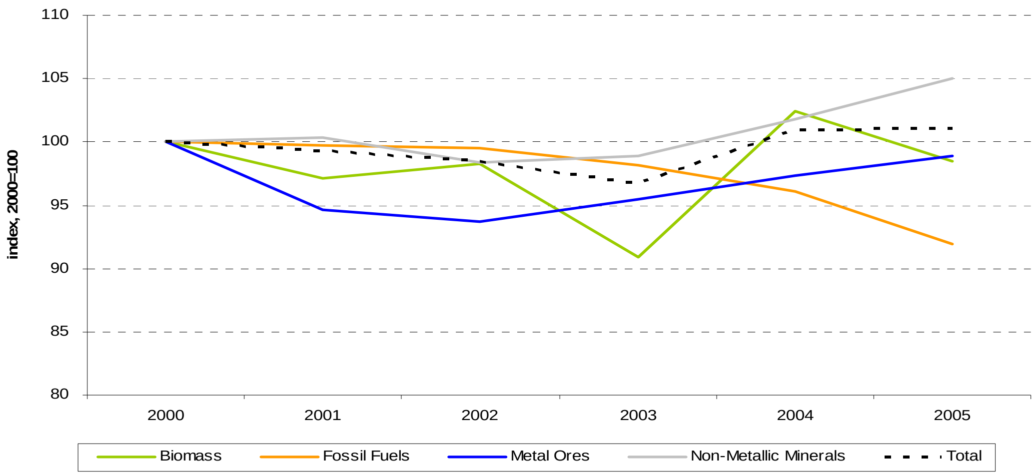
Figure 5 shows the development of domestic material extraction (DE) in the EU-15 in an indexed form (the value for 1970 corresponds to 100). Overall DE has stabilized since the early 1990s at a level of slightly below 5 billion tons. For two material groups, fossil energy carriers and metal ores, domestic extraction even declined – in the case of metals it was continuously reduced to a level of only 30% of the value of the early 1970s. This relates to declining ore grades and increasing production costs in the EU and the subsequent shift of mining to regions outside Europe. Another remarkable trend is the sharp decline in domestic extraction of fossil energy carriers beginning in the late 1980's. In the EU-15, coal was (and is) the dominant form of fossil fuel extracted – contributing almost 90% to DE of fossil fuels in 1970 and still approximately 50% in 2004. Coal is also the fossil energy carrier for which DE has decreased most significantly in absolute terms from a peak of about 717 Mio t extracted in 1986 to less than half of that value (333 Mio t) in 2004. DE of biomass and non-metallic minerals on the other hand has increased 15% (biomass) and 20% (minerals) over the course of this 35 year period – but also for these material groups extraction has stabilized since the 1990s. The total DE of the EU-15 was 4.3 bio tons in 1970, peaked at just over 5 billion t in 1989 and was at 4.7 bio t in 2004.

Figure 5: Domestic Extraction by Material Categories for the EU-15 1970-2004 (indexed 1970=100).



Source: derived from Eurostat 2007a.

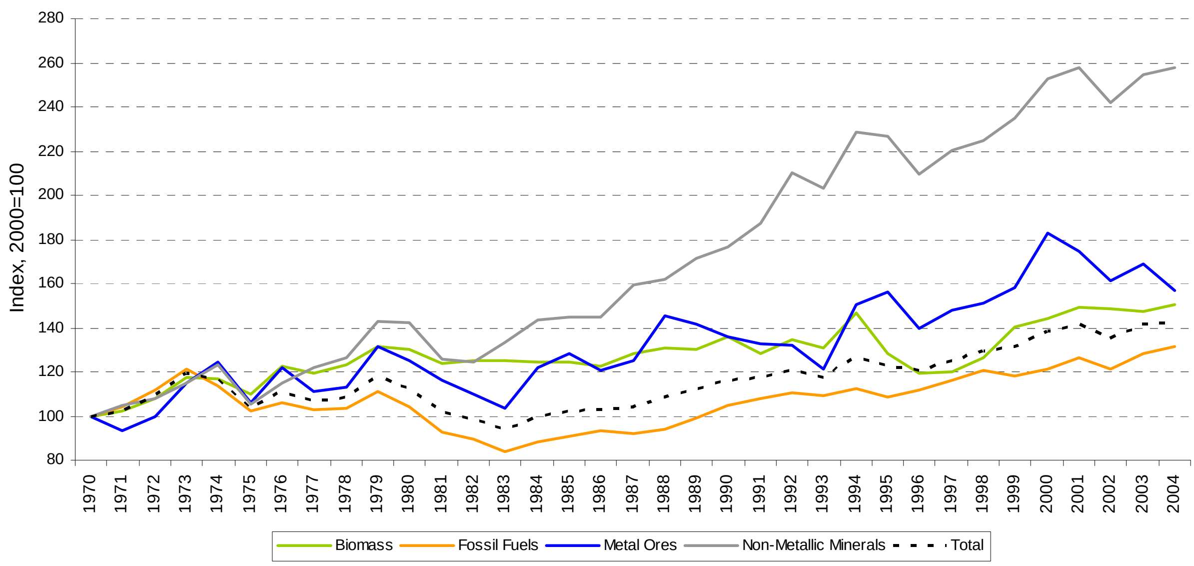
Figure 6: Domestic extraction by Material Categories for the EU-27 2000-2005 (indexed 2000=100).



Source: derived from Eurostat 2007a.

A similar trend of stable domestic materials extraction can be observed for the EU-27 – however due to the short time periods for which data are available (2000 to 2005) annual fluctuations are larger than trends. Only the extraction of fossil energy carriers exhibits a pronounced trend of decline. (Figure 6). Biomass extraction fluctuates somewhat across this six-year period and DE of non metallic minerals even increases slightly.

Figure 7: Imports by Material Categories for the EU-15 1970-2004 (indexed 1970=100).

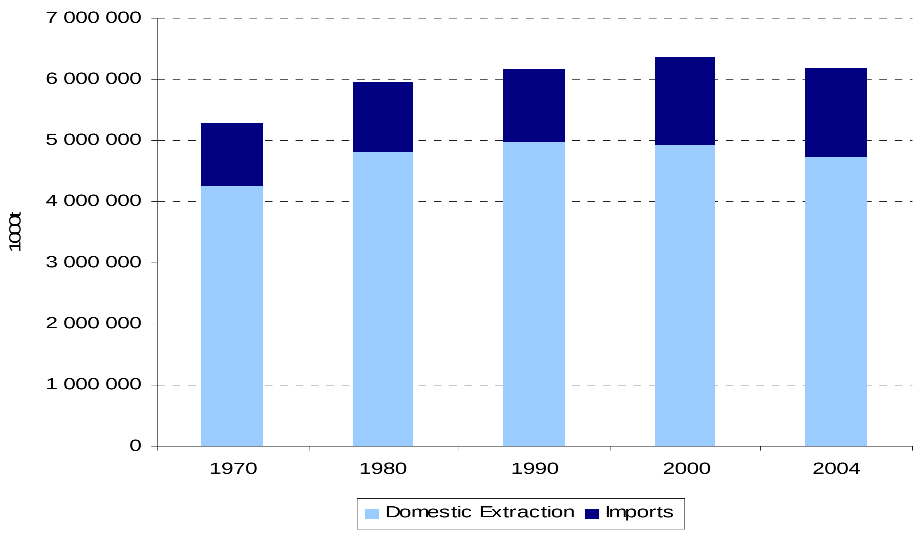


Source: derived from Eurostat 2007a

2.3 Trade and its physical contribution to resource use in the EU

While domestic extraction in the EU-15 is declining and is currently at a level only slightly above the level of 1970, physical trade flows show a pronounced dynamic of growth. Imports for all material groups have been increasing strongly since the 1970s (see Figure 7). Imports of raw materials and commodities from non metallic minerals were about 160% larger in 2004 than they were in 1970 and those for metals by 60%. Imports of biomass increased by over 50% and of fossil fuels by 31%. In absolute terms, 432 Mio t more were imported into the EU-15 in 2004 than in 1970. Growth of physical imports by far exceeded that of population growth and consequently also per capita imports grew: While 3.0 t per capita and year were imported in 1970, this figure reached 3.8 t/cap/yr in 2004.

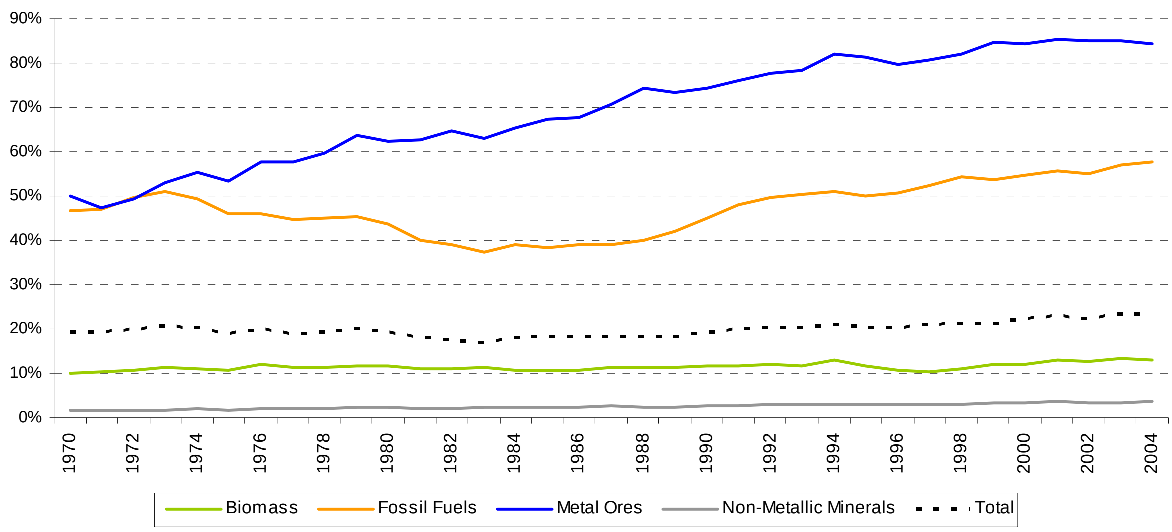
Figure 8: Composition of DMI in Domestic Extraction and Imports, EU-15 1970-2004.



Source: derived from Eurostat 2007a.

Figures 8 and 9 illustrate that overall the contribution of imports to the direct material input (DMI) of the EU-15 economy has increased slightly since 1970 when imports made up 19% of DMI to 2004 when their contribution was at 23%. For the EU-27, this contribution was at 14% in 2000 and 16% in 2005.

Figure 9: Imports per DMI in % and by Material Categories for the EU-15 1970-2004.

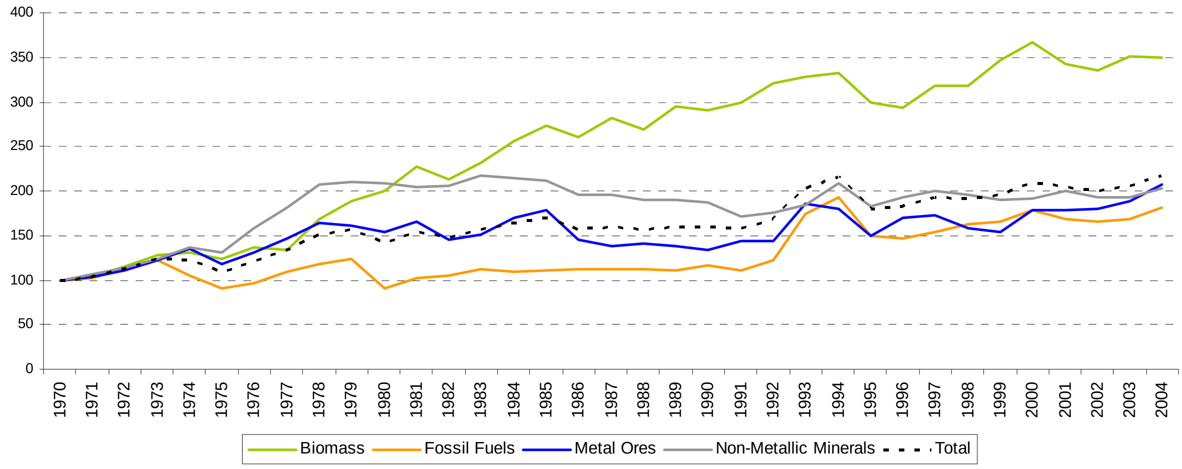


Source: derived from Eurostat 2007a.

The role that imports play in the EU-15 DMI differs by material categories (see Figure 9) – for metals the contribution of imports to DMI was 85% and for fossil fuels almost 60% in 2004. For biomass and non metallic minerals it was much lower (13% and 4% respectively). This means, that for key resources the European economy is highly dependent on imports from outside the EU. The high level of imports in DMI and the upward trend of physical imports also has strong implications for the interpretation of resource use and input indicators derived from MFA: Imports (and exports) can be associated with significant upstream resource flows and the gross material requirement of the European economy is likely to be much larger than DMI and DMC indicate. The shift from DE to imports may also indicate a shift in environmental burden from the EU towards the countries providing exports (see below).

Exports show an even more pronounced growth trend in the EU-15 but are still considerably smaller in total mass than imports: In absolute terms, total exports increased from 197 Mio t in 1970 to 430 Mio t in 2004. Figure 10 illustrates that, in relative terms, the strongest increase in exports occurred for biomass based commodities (factor 3.5) between 1970 and 2004. Exports of (products made of) metallic and non metallic minerals doubled over the same period of time and export of fossil fuels increased by a factor of 1.8. Despite the high growth rates, the mass of physical exports still is significantly smaller than that of imports: Imports increased from 1021 Mio t to 1452 Mio t between 1970 and 2004, exports increased from 197 Mio t to 430 Mio t.

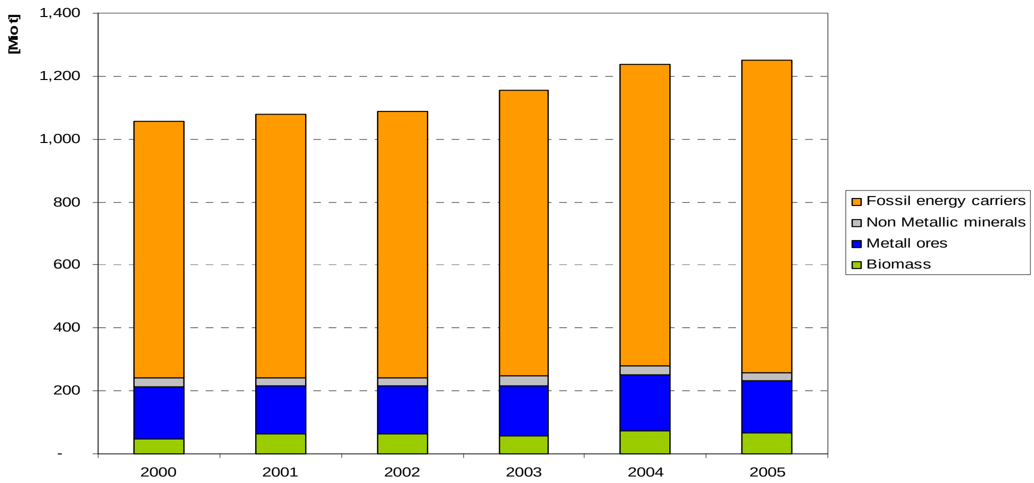
Figure 10: Exports by Material Categories for the EU-15 1970-2004 (indexed 1970=100).



Source: derived from Eurostat 2007a.

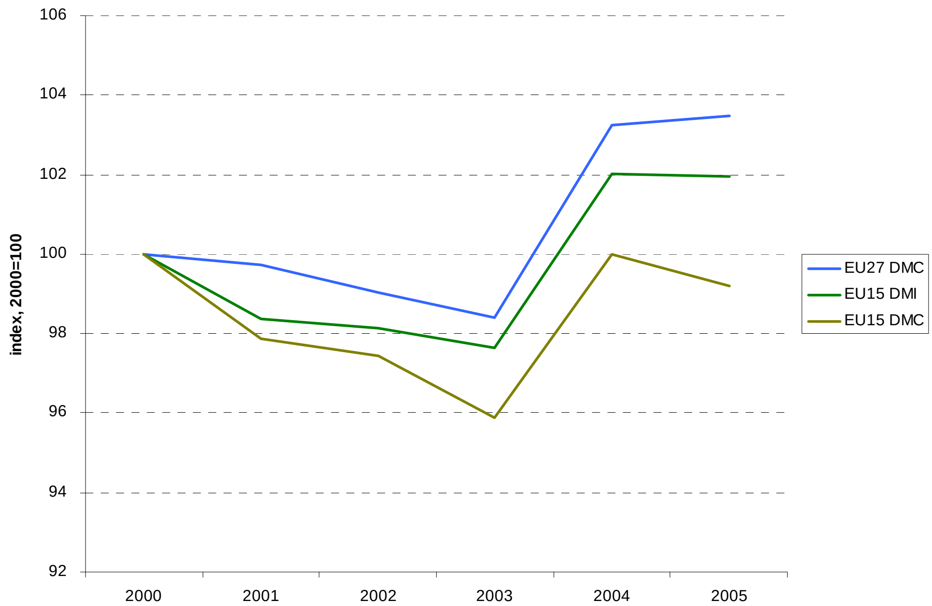
For the EU-27 physical trade data exist only for the individual member states but no import or export data for the EU-27 as an economic entity has yet been compiled. Therefore only data concerning the physical trade balance (PTB) can be shown (Figure 11). From these data it is obvious, that the EU-27 (just like the EU-15) is a net importer with respect to all major material groups and also on this level imports are growing: In only five years from 2000 to 2005 net imports have increased by 18% from 1.1 billion tons to 1.25 billion tons. Net imports are largest for fossil energy carriers and metals.

Figure 11: Physical trade balance (imports minus exports) for the EU-27, 2000 to 2005.



Source: derived from Eurostat 2007a.

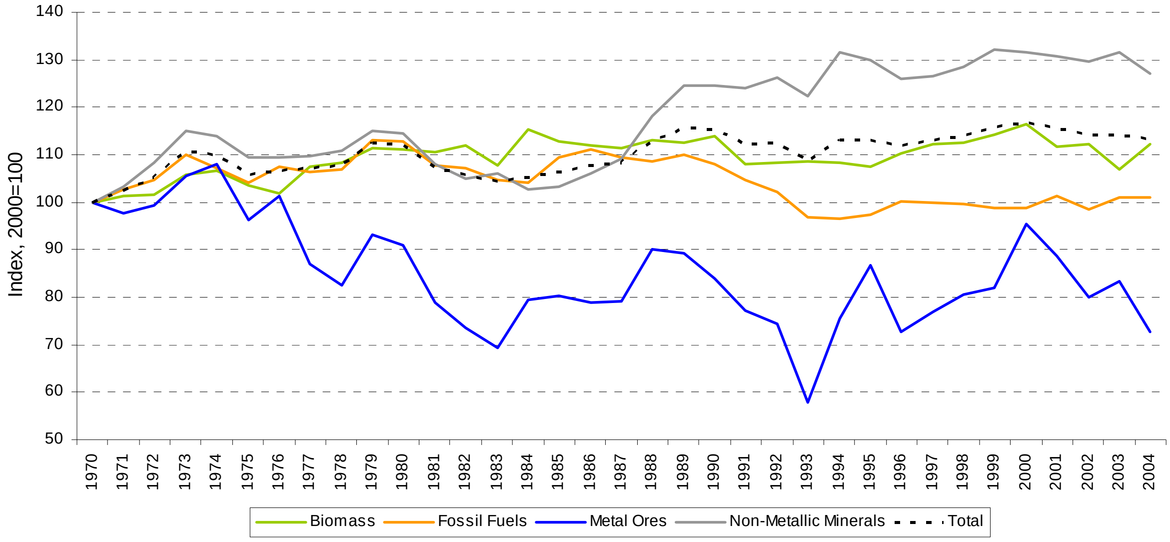
Figure 12: Development of DMI and DMC for EU-15 and EU-27 2000-2005 (indexed 2000=100).



Source: derived from Eurostat 2009b

The development of DMC of the EU-15 for a longer period of time (1970-2004) is shown in Figure 13: After periods of growth in the 1970s and 80s material consumption in the EU has more or less stabilized since the beginning of the 1990s for most material groups. The observed periods of growth and contraction of DMC can be explained by economic developments. In particular the oil price peaks in 1973 and 1979 are followed by years of declining material use, indicating the strong relation of energy and overall material consumption.

Figure 13: Indexed Development of DMC by Material Categories for the EU-15, 1970-2004.

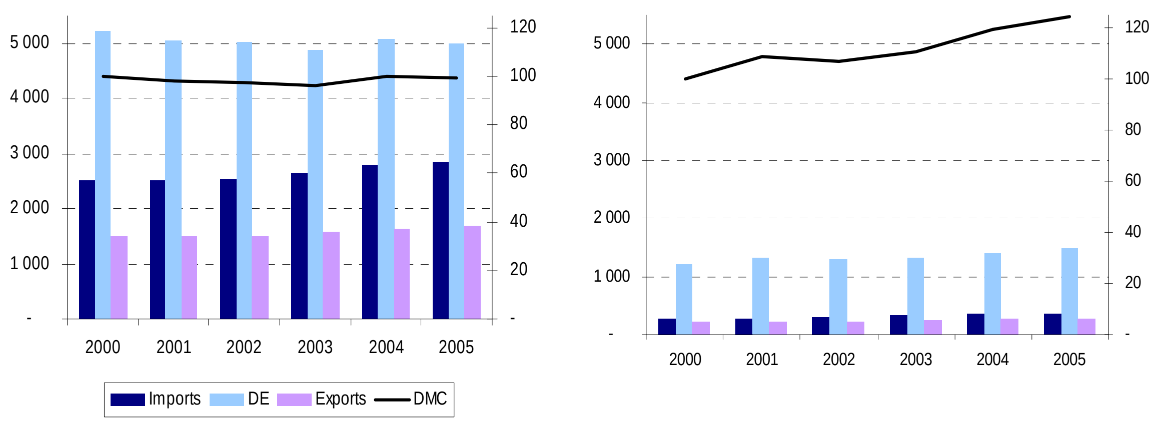


Source: derived from Eurostat 2007a.

Domestic material consumption (DMC) in the EU-27 amounted to 7.7 billion tons in 2005. More than half (54%) of all used materials were minerals (including metallic ores and non metallic minerals for industrial use and construction). With a share of 25%, fossil energy carriers were the second largest fraction of total DMC, while renewable biomass accounted for only 21%. Total DMC showed a slightly declining trend between 2000 and 2003 but increased considerably since. Over the whole period, the EU-27 experienced a slight growth in overall material consumption from 7.5 to 7.7 billion tons.

Material demand in the EU-15 currently dominates the EU-27's rate of resource use. Figure 14 shows that in 2005, only about 20% of the EU-27's domestic extraction occurred in the 12 new member states (NMS). The disparity is even greater for trade with the 12 NMS' imports contributing only 11% to the EU-27 volume and their exports accounting for 14% of the total exports.

Figure 14: Import, DE, and Exports and indexed DMC for the EU-15 (Left Figure) and the 12 NMS (Right Figure), 2000-2005.



Source: derived from Eurostat 2009b

However, while the EU-15 DMC is more or less stable in the period 2000-2005 and at a very high level, the DMC in the new member states has experienced a period of considerable growth (20% in five years).

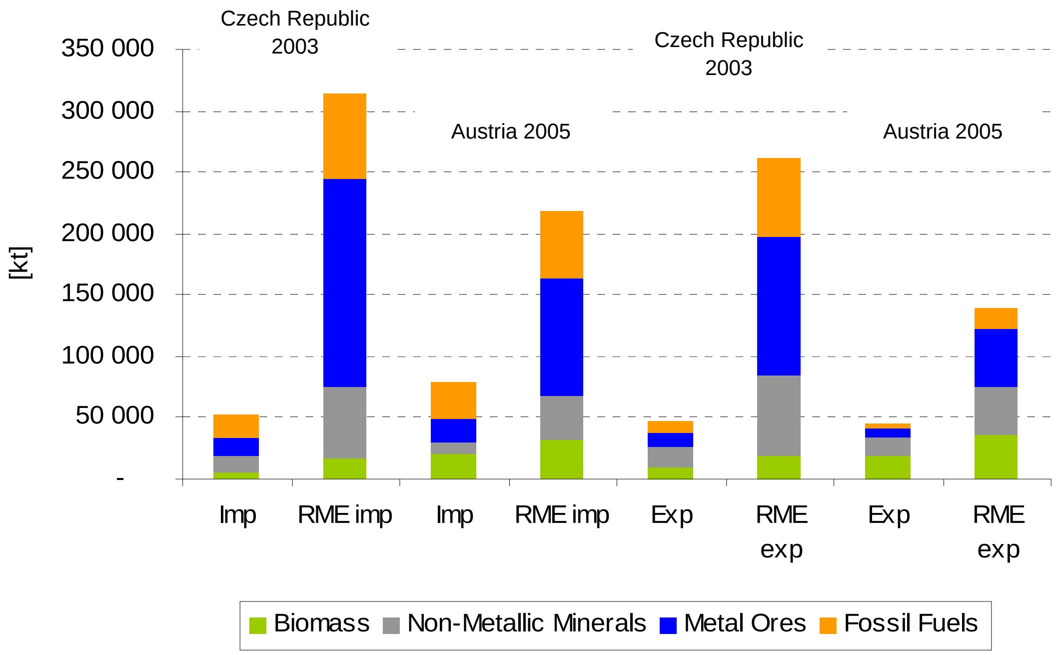
2.4 Raw Material Equivalents of Traded Goods

It has been shown that imports play an important and further increasing role in providing the material inputs required by the European economy. Current material MFA accounts only provide data on direct trade flows (see section 3.1.2). No information concerning materials required to produce these imports are reported. This has been recognized as an important limitation for the interpretation of MFA derived headline indicators and Eurostat and several research groups (e.g. in Austria, Germany and Czech Republic) currently develop methods for the quantification of raw material equivalents (RME) of imports and exports. RME are defined as the direct trade flow (import or export) plus the associated indirect flows, i.e. "the 'cradle to border' inputs necessary to make a product (i.e., a good or a service) available at the border for import or export, excluding the mass of the product itself" (Eurostat, 2001, 19).

In two recently completed studies, the RME of Austrian (Schaffartzik et al., 2010) and of Czech (Weinzettel and Kovanda, 2009) trade flows were calculated using a similar method which is based on monetary input-output data for each economy paired with coefficients based on life cycle analysis (LCA) for select resource flows. The logic behind this hybrid approach is to calculate the intermediate material inputs for those traded goods which are also produced in the domestic economy using domestic input-output data and to calculate the intermediate inputs for those goods not produced or those raw materials not extracted in the domestic economy using LCA coefficients.

The Austrian and the Czech economy are of comparable orders of magnitude. While the Czech Republic imported 53 Mio t of commodities in 2003, the import flow amounted to 79 Mio t in Austria (2005). Applying the RME method and adding the intermediate material inputs required for the extraction and production of imported resources and goods, the RME of these imports (RMEimp) can be calculated. Figure 15 illustrates that in the Czech Republic, the RME of imports were 261 Mio t or approximately six times larger than the direct imports in 2003 while the Austrian RMEimp were estimated at 138 Mio t, that is three times larger than the direct imports in 2005.

Figure 15: Direct Imports (Imp) and Imports Expressed in RME (RME imp) for Austria and the Czech Republic

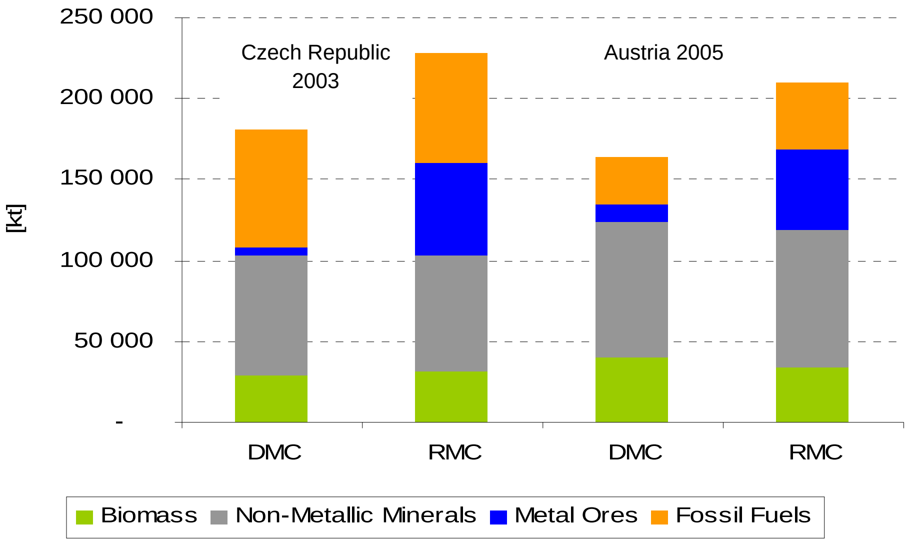


Source of Data: Schaffartzik et al., 2010

In the Czech Republic, the RME of exports amounted to 47.3 Mio t and were thus approximately six times larger than the direct exports in 2003. The Austrian RMEimp were estimated at 139 Mio t and were three times larger than the direct exports in 2005.

While the RMEimp adds to the apparent material consumption of the importing countries, the RME of exports (RMEexp) must be deducted to arrive at a measure of raw material use associated with domestic consumption. It is possible to calculate the raw material consumption (RMC) of an economy - that is, to express domestic material consumption (DMC) in raw material equivalents. Figure 16 compares DMC and RMC for the Czech Republic in 2003 and Austria in 2005.

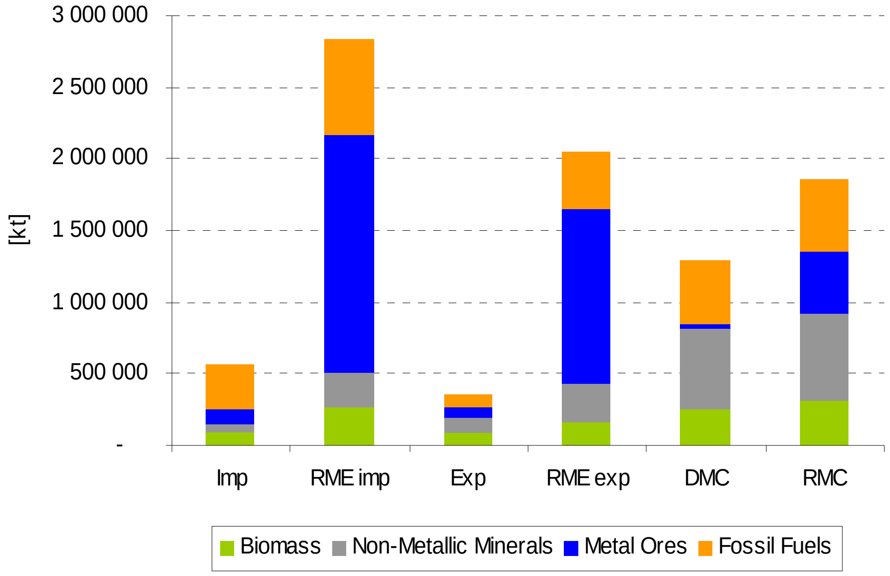
Figure 16: DMC and Its Equivalent as Expressed in RME (RMC) for the Czech Republic (2003) and Austria (2005)



Data Sources: Weinzettel and Kovanda (2009) and Schaffartzik et al. 2010

In both countries, the RMC is about 30% larger than the DMC. This similarity in the ratio between RMC and DMC despite the significant differences in the ratio of direct imports and RMEimp and direct exports and RMEexp is partially due to the differences in the composition of traded goods in the two economies and the size of physical import and export flows: In 2003, the volume of goods exported from the Czech Republic corresponded to approximately 90% of the volume of imported goods, in Austria, this figure was only 57% in 2005.

Figure 17: Overview of Direct Imports and Exports (Imp and Exp), RME of Imports and Exports (RME imp and RME exp), DMC, and RMC for Germany in 2005



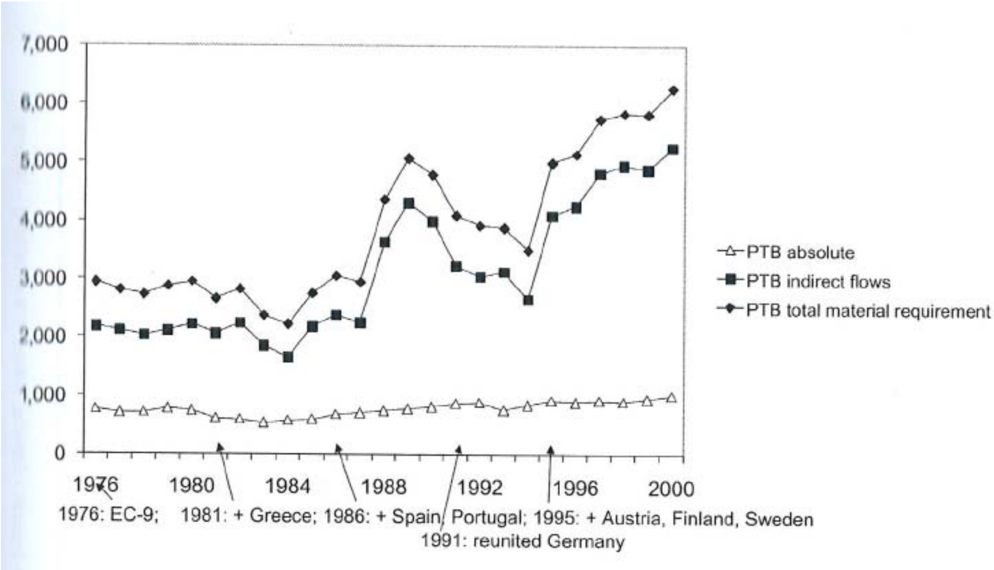
Source: based on data from Buyny et al., 2009

Data on upstream resource requirements of imports and RME are also available for Germany. Figure 17 illustrates that the German RMEimp were 2831 Mio t in 2005 and thus approximately five times larger than the direct imports. The German RMC is 1.4 times larger than the DMC (as compared to a factor of 1.3 for Austria and the Czech Republic).

Another attempt to take the material flows associated with the production of traded goods into consideration is based on the calculation of so-called total material requirement (TMR) (Eurostat 2001). In contrast to the RME approach, TMR of imports includes hidden flows (e.g. overburden from mining, soil moved during construction processes) but does not include all indirect flows (e.g. energy inputs into production processes or auxiliary material not included in the traded product itself).

Figure 18 shows results from a study by Schütz et al. 2003 who calculated the physical trade balance of the EU (or the EC, respectively) in the period 1976 and 2000 including indirect flows and TMR. Over the whole period, net imports (direct flows) into the EU slowly increased from 0.6 towards 1 billion tons. According to this estimate, the total material requirements associated with these imports are much greater than the direct trade flows and increased at a faster pace. In 2000, indirect and hidden flows which were considered amounted to more than 6 billion tons. These results also indicate that the importance of considering burden-shifting effects in analyzing the material inputs and use of the European Union.

Figure 18: European Physical Trade Balance (PTB), Absolute and Total Material Requirements in Mio. t



Source: Bringezu et al., 2009b (Quoted from Schütz et al., 2003).

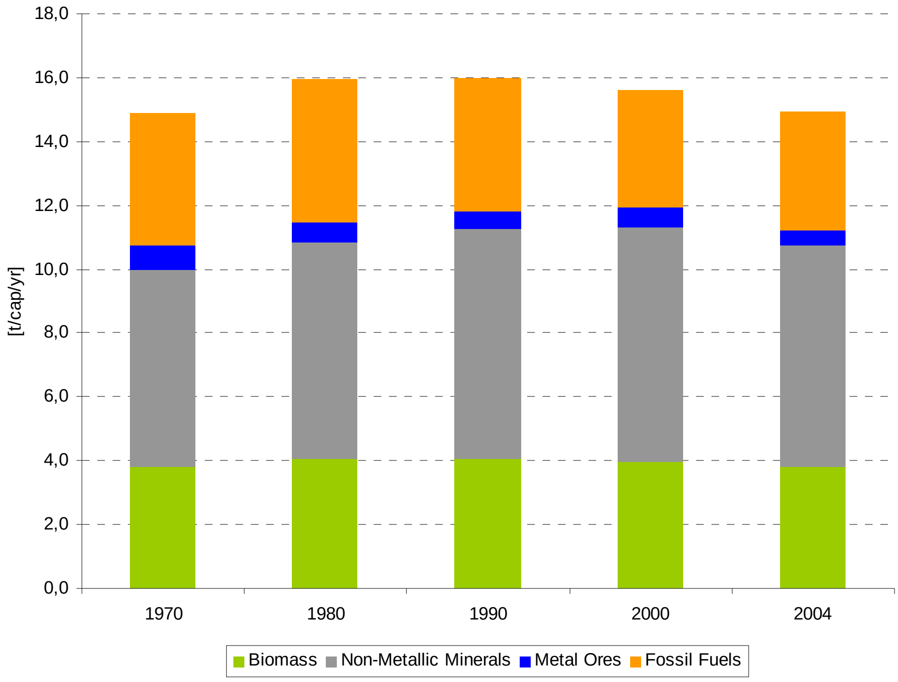
In differentiating between the information provided by the TMR calculation and the RME application, it is important to consider that exports are not deducted from TMR (but are deducted from RME). The reasoning behind this decision in the development of TMR methodology is that even though the materials contained in the exports are ultimately transferred to another economy, they are nonetheless extremely relevant for the economy's performance and must therefore be considered to be part of the material requirements.

Although the methods available to calculate upstream resource requirements of imports and exports are not yet fully developed and standardized, the existing case studies show that the upstream flows of European net trade are of a considerable size and their inclusion provides a better picture of overall material use. In a situation where domestic extraction of many materials in the EU is declining, both imports and exports are rapidly increasing and imports are considerably larger than exports this has to be kept in mind when MFA derived indicators like DMC and DMI are interpreted. The observed stabilization of material use in the EU might not be true if RME or TMR indicators are applied.

3.2.5 Material use per capita in the EU and across member states

From 1970 through 2004, the per capita resource consumption (DMC/cap/yr) in the EU-15 was comparatively stable. It increased from 14.9 tons in 1970 to 16 tons/cap and year in 1990 and than began to slowly decline. In 2004, per capita material use was at about the same level as in 1970 (see Figure 19).

Figure 19: Per Capita Domestic Material Consumption (DMC) in the EU-15, selected years 1970 to 2004.



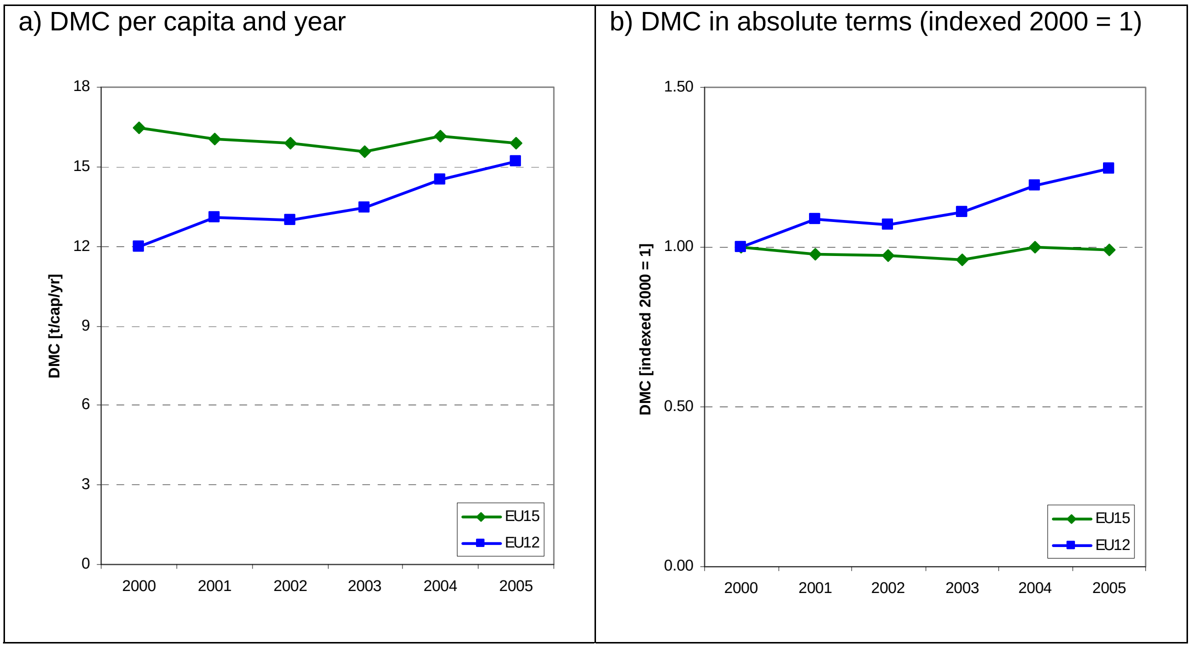
Source: based on data from Eurostat 2007a.

The contribution of the individual material fractions also remained relatively stable. Metal ores make up the smallest share and account for 3-5% of material use. Biomass contributes constantly 4t/cap and year or roughly one quarter to total DMC and is in a similar range as fossil energy carriers (24 and 29%). Non metallic minerals are the largest fraction and amount to 6-7 t/cap/yr corresponding to between 40 and 48% of total DMC.

Data from Eurostat 2009 show that per capita material consumption in the 12 new member states amounted to only 12t/cap/yr in 2000 and was 27% below the level in the EU-15 (Figure 20a). While DMC in the EU-15 remained more or less stable in the period 2000 to 2005 (Figure 20b) it increased in the EU-12 (which were also characterized by much higher economic growth) by 24%. As a consequence, also per capita DMC grew in the new member states and almost reached the level of the EU-15 in 2005.[10]

[10] Note that data from Eurostat 2007a and Eurostat 2009 are not fully consistent due to methodological differences. DMC reported in Eurostat 2009 is 3-8% above the values reported in Eurostat 2007a.

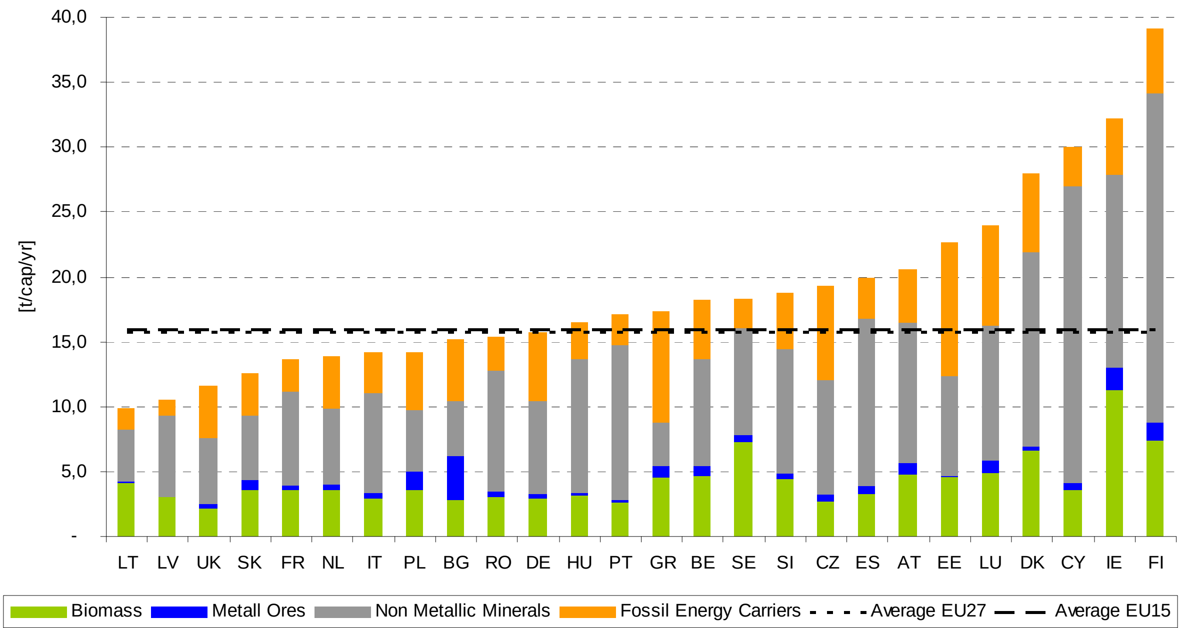
Figure 20: Material consumption in the EU-15 and the 12 new member states (EU-12) from 2000 to 2005



Source: based on data from Eurostat 2009b

The current level of per capita material consumption varies quite strongly across the EU-27 (Figure 21). In 2005, per capita apparent material consumption in the EU-27 and the EU-15 was relatively similar and amounted to 15.8 t/cap/yr and 15.9 t/cap/yr respectively. 11 of the 27 EU MS had a DMC/cap/yr which was below average and only 27% of the EU-27 population lived in a country in which material consumption was higher than the average of 15.8 t/cap/yr. DMC/cap ranged from just under 10 t/cap/yr in Latvia to almost 40 t/cap/yr in Finland.

Figure 21: Per capita DMC across the EU-27 (except Malta) in 2005



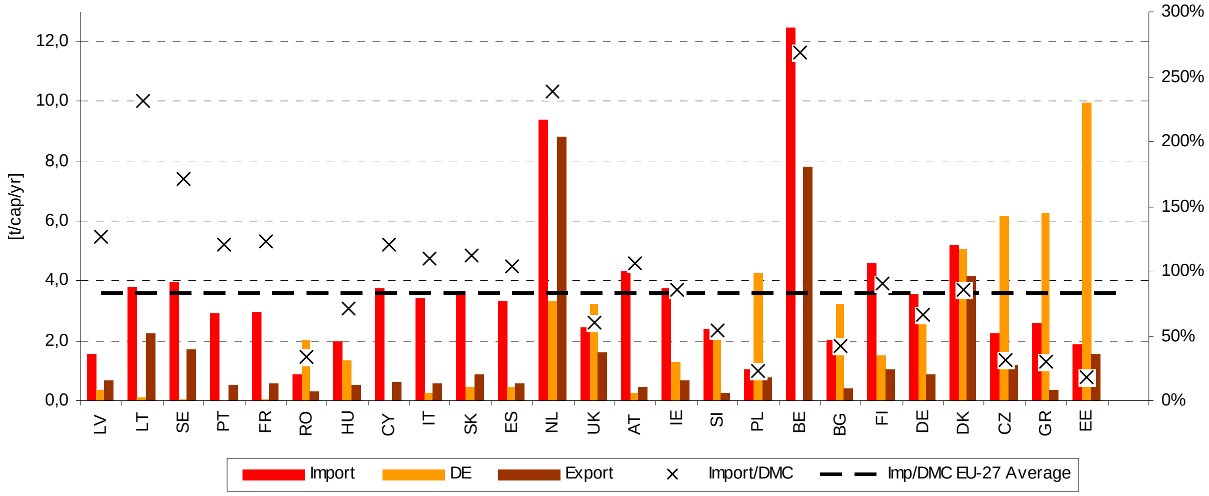
Source: based on data from Eurostat 2009b

Not only the level of per capita material use but also its composition shows strong variation across the EU-27 MS. The share of biomass in DMC ranges from 40% in Sweden and 42% in Lithuania to 12% in Cyprus, 14% in the Czech Republic, and 15% in Portugal. Metal ores contribute 23% to Bulgaria's DMC while their contribution to per capita DMC is only about 1% in Lithuania and Hungary. In most of the EU-27 MS, non-metallic minerals make up the major fraction of DMC/cap. This contribution is as high as 70% in Portugal and 76% in Cyprus and as low as 27% in Bulgaria and 19% in Greece. The share of fossil fuels is highest in Greece (49%) and Estonia (45%) and lowest in Cyprus (10%) and Latvia (12%).

The size of per capita material use and its composition depend on broad range of bio-geographical and economic factors. It has been shown that next to economic development and the sectoral structure of the economy also climate, population density and resource endowment have significant influence on patterns of resource use across countries factors (Weisz et al., 2006, Steinberger et al., 2010). Also the openness of the economy and the significance of international trade play have an impact on differences in per capita materials use (see also section 3.2.3). Among the countries with the lowest DMC per capita are on the one hand countries with a low per capita GDP (Latvia, Lithuania or Slovakia) and on the other hand high income countries with high population density or high dependency on imports (UK, the Netherlands, France, Italy). In contrast, the countries with the highest DMC per capita in the EU are those with high income and low population density (Finland, Ireland, Denmark) and countries with specific resource endowment (Estonia).

Next to Cyprus, Estonia is one of the few new EU member states which have a per capita DMC that lies significantly above the EU-27 average (see Figure 21). At the same time, the contribution of fossil fuels to DMC is among the highest in the EU-27. Like the other European economies, Estonia is highly dependent on fossil fuels in meeting its energy requirements. However, it covers only a small share of its DMC through imports: While on the EU-27 average, imports account for 83% of DMC, this fraction is only 18% for Estonia. This is possible due to its endowment with oil shale the combustion of which is main manner in which the economy secures its energy supply.

Figure 22: Imports, Domestic Extraction, and Exports of Fossil Energy Carriers as per capita Values for the EU-27 in 2005



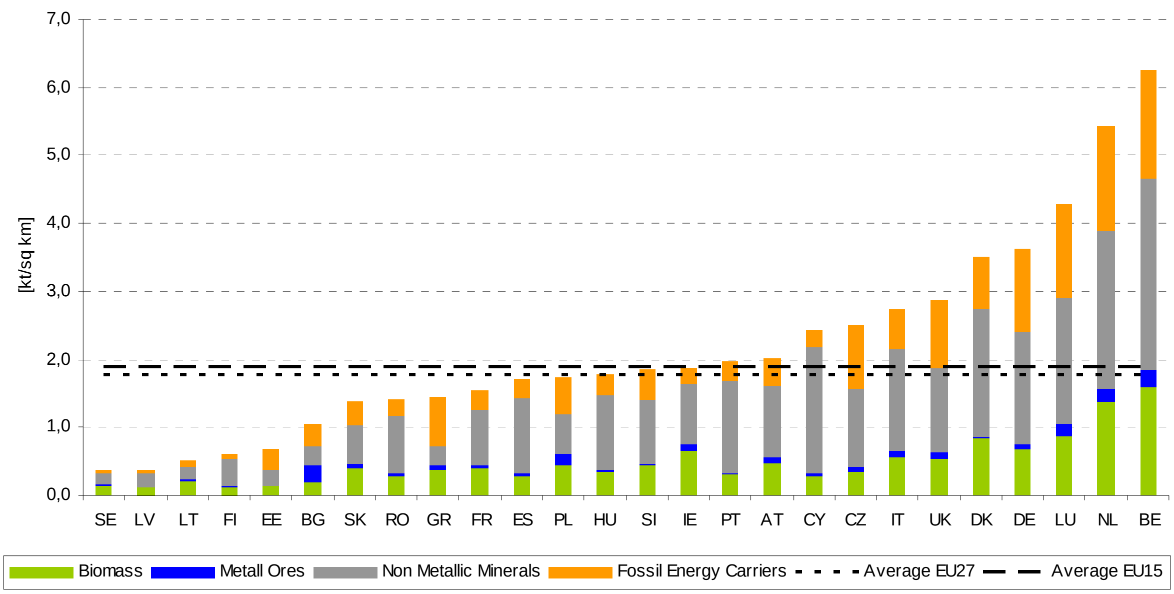
Source: based on data from Eurostat 2009b

Estonia (EE) exhibits a high level of domestic extraction of fossil energy carriers and relatively low import and export volumes (see Figure 22). In contrast, the Netherlands (NL) and Belgium (BE) have the highest trade flows in the EU-27 which in this case especially highlights their function as ports of entry into and exit out of the EU for traded goods. For both these countries, imports play a dominant role in covering DMC requirements: Imports account for 239% (NL) and 268% (BE) of

DMC respectively. These data indicate that while trade is playing an increasingly important role in meeting the EU's demand for fossil energy carriers on an aggregate level, this trend is even more pronounced for a number of countries. From left to right in Figure 22, those countries for which imports make up less than 100% of their fossil energy carriers DMC are Romania, Hungary, the United Kingdom, Ireland, Slovenia, Poland, Bulgaria, Finland, Germany, Denmark, the Czech Republic, Greece, and Estonia.

While expressing the indicator DMC per capita of population indicates the metabolic rates, i.e. the average "cost" of each inhabitant in terms of resources used (size of the physical economy in relation to its social reference system), relating DMC to the territory of the economic system gives an indication of the burden upon the natural environment (Figure 23). Therefore, the indicator DMC per unit of land area is regarded a proxy for potential environmental pressures on domestic ecosystems related to a countries material use (Eisenmenger et al., 2007).

Figure 23: Per Area DMC across the EU-27 (except Malta) in 2005



Source: based on data from Eurostat 2009b

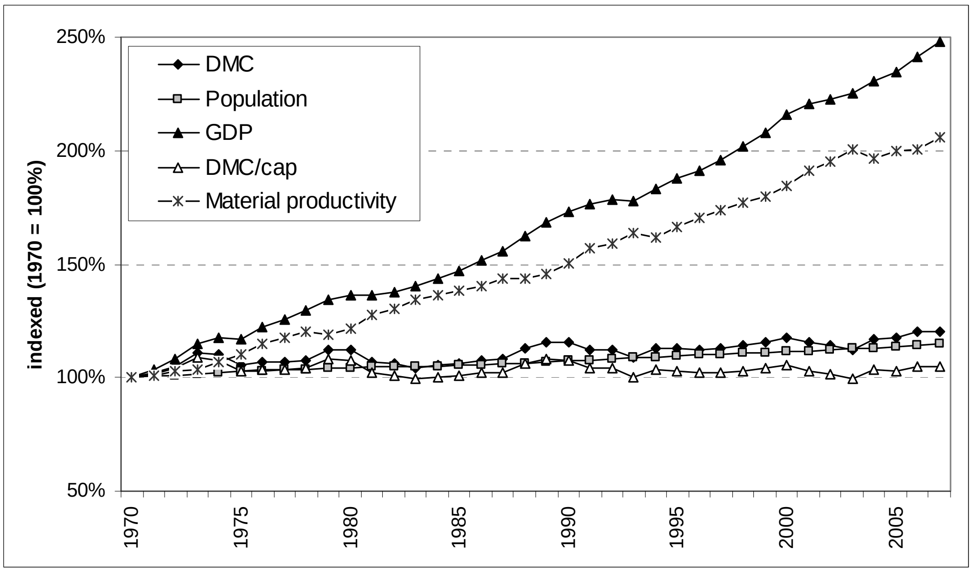
Variations of DMC per unit of area are larger than variations of DMC per capita (Figure 23): The EU-27's DMC per area ranges from 0.4 kt per square kilometre in Sweden (SE) to 6.2 kt/km^2 in Belgium (BE) in 2005. The average DMC/area of the EU-15 and the EU-27 are relatively similar and amount to 1.9 kt/km^2 and 1.8 kt/km^2 respectively. In general there is an indirect proportionality between per capita material use and material use per unit of area. The countries with the highest level of material use per unit of area tend to have low per capita consumption and vice versa. Those countries with a DMC/area that lies well above the EU average have some characteristics in common in terms of material flows: On the one hand, these are countries with a high level of domestic extraction (Germany, the United Kingdom, Italy). On the other hand, countries with low resource endowment and high population density (Belgium, the Netherlands, Luxemburg). Belgium and the Netherlands are points of entry into Europe in terms of trade so that transit trade plays an important role and trade volume is generally high. While the DMC/area per se is no indicator for environmental impacts, it does provide a proxy for the relationship between material consumption and the area available either as a source of this material (domestic extraction) or to absorb the waste which all material consumption (which can also be interpreted as domestic waste potential) inevitably leads to.

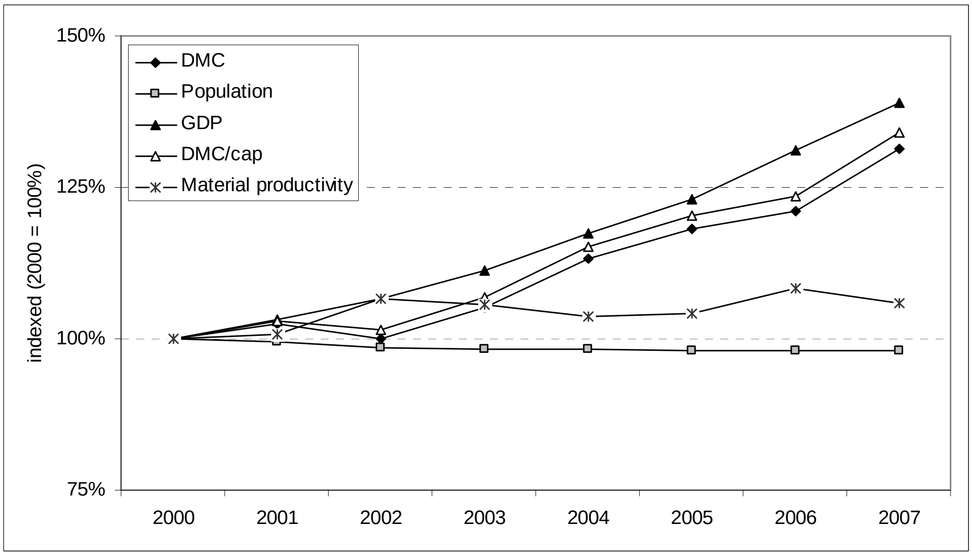
Due to the fact that total DMC in the EU-15 has been stagnating since 1970, the DMC per area has also remained relatively constant and increased only very slightly from 1.6 kt/km^2 in 1970 to 1.8 kt/km^2 in 2004.

2.6 Decoupling of material use and economic development in the EU and its member states

Data on the long term development of material use and GDP for the EU-15 reveal a trend of continuously increasing resource productivity (see section 3.5) which resulted in relative but not absolute dematerialisation (Figure 24a). Overall DMC grew by about 20% between 1970 and 2007. Population and DMC grew at a similar rate between 1970 and 2007 and per capita DMC remained roughly constant. GDP grew much faster and material productivity increased continuously, it approximately doubled between 1970 and 2007. Figure 24 also shows the linkage between the development of DMC and economic growth: In general, periods of declining DMC (1973-1975; 1979-1983; 1990-1993; 2000-2004) occurred only in conjunction with recession or very slow economic growth. For the new member sates, data are only available for the period 2000 to 2007. During this period, material use has increased by 31% and material use per capita grew from 13 to 17.5 t/cap/yr, even surpassing the level of the EU-15. Overall, material use in the EU-27 increased moderately during this period from 7.6 to 8.2 bn tonnes.

Figure 24: Development of GDP, Population, DMC, Material Productivity, and DMC per cap and year in the EU-15 (24a) and the EU-12 (24b)





Source: Source: Based on Eurostat 2007a and Eurostat 2010

Patters across countries are different from the long term EU-15 trend. While in most countries DMC per capita remained stable or even showed slight decline with growing income, in a number of countries per capita DMC showed a significant increase: The countries with the steepest increase in the period 1970 to 2004 were the countries with the lowest per capita GDP in 1970 that is Portugal, Greece, Spain and Ireland. In these countries DMC grew faster than GDP (see section 3.5).

Also for the EU-27 as a whole and in the period 2000 to 2005, relative dematerialization was observed. During this period, material use in the EU-27 declined modestly by 3.5% while the economy grew by 9%. Across individual countries diverging patterns concerning the development of DMC, GDP and material productivity can be observed (Table 2) Opposite to the EU-27 trend, several countries experienced absolute dematerialization: In six of the 26 countries listed in Table 2, DMC declined in absolute terms while GDP grew. Among the countries with the strongest decline in DMC were the large economies of Italy and Germany, where DMC declined by more than 10%. Other countries where absolute dematerialization has been observed were Portugal, France, Belgium and the United Kingdom. In all other Member States listed in Table 2, as well as in Switzerland and Norway, DMC increased in the period 2000 to 2005. The largest increases in DMC have been observed for Romania (+94%), Hungary (49%) and Sweden (39%). In these and six other countries, DMC grew at an even faster pace than GDP; that is, the material productivity of the economy declined. In eleven countries DMC grew at a slower rate than the economy and relative dematerialization was observed.

Table 2: Dematerialization: Relative change of GDP, DMC and Material Productivity in the period 2000 to 2005 by country

Country	Change in GDP	Change in DMC	Material Productivity
Absolute Dematerialization: Declining DMC			
UK	13%	-0%	+13%
BE	8%	-1%	+10%
FR	9%	-3%	+12%
PT	4%	-4%	+9%
DE	3%	-11%	+16%
IT	4%	-14%	+22%
No Dematerialization: DMC grows faster than GDP			
RO	32%	94%	-32%
HU	23%	49%	-17%
SE	13%	39%	-18%
SK	27%	30%	-2%
ES	17%	25%	-6%
CY	17%	24%	-5%
FI	13%	15%	-2%
DK	6%	12%	-5%
AT	9%	11%	-2%
Relative dematerialization: DMC grows slower than GDP			
LV	48%	26%	+17%
BG	29%	17%	+10%
LT	46%	17%	+24%
IE	31%	12%	+17%
SI	20%	11%	+8%
GR	23%	9%	+12%
PL	16%	7%	+9%
NO	12%	4%	+7%
CH	7%	3%	+4%
CZ	20%	3%	+17%
EE	46%	2%	+43%

Source: based on data from Eurostat 2009b. Country names: see list of abbreviations

3 Land use and biomass extraction in the European Union

3.1 Summary

The EU-27 covers a territory of 4.3 mio km². Of this roughly 44% are currently used by agriculture and 36% are covered with forests. As in many other industrialized regions, the EU is experiencing a long term trend of declining agricultural areas. During the last ten years, an annual average of 10,700 km² was taken out of production and either reforested or taken by urban or infrastructure land. As a consequence of declining agricultural areas, forests grew by roughly 7,100 km² per year. Data on land take by urban settlements and infrastructure are less comprehensive and difficult to interpret, but for the period 1990 to 2000 it was estimated that a minimum of 1000 km² have been converted into infrastructure each year.

Despite of the substantial decline of agricultural area, biomass production from agriculture has been growing for many years. Since the 1980s, growth in harvest from cropland and grassland has slowed down or even stabilized at a high level. While the shift from intensively used agricultural land towards forest land can be interpreted as a release of environmental pressures, land use intensity on agricultural areas has been increasing until the late 1980s. Since then, agricultural inputs like artificial fertilizers and pesticides have decreased markedly while yields remained high. Nevertheless, land use intensity is very high in the European Union and in many regions human appropriation of net primary production (HANPP) is at a very high level above 40 or 50%. The growth in forest land and the decline in agricultural inputs can be interpreted as a certain overall decoupling of land use intensity from economic development.

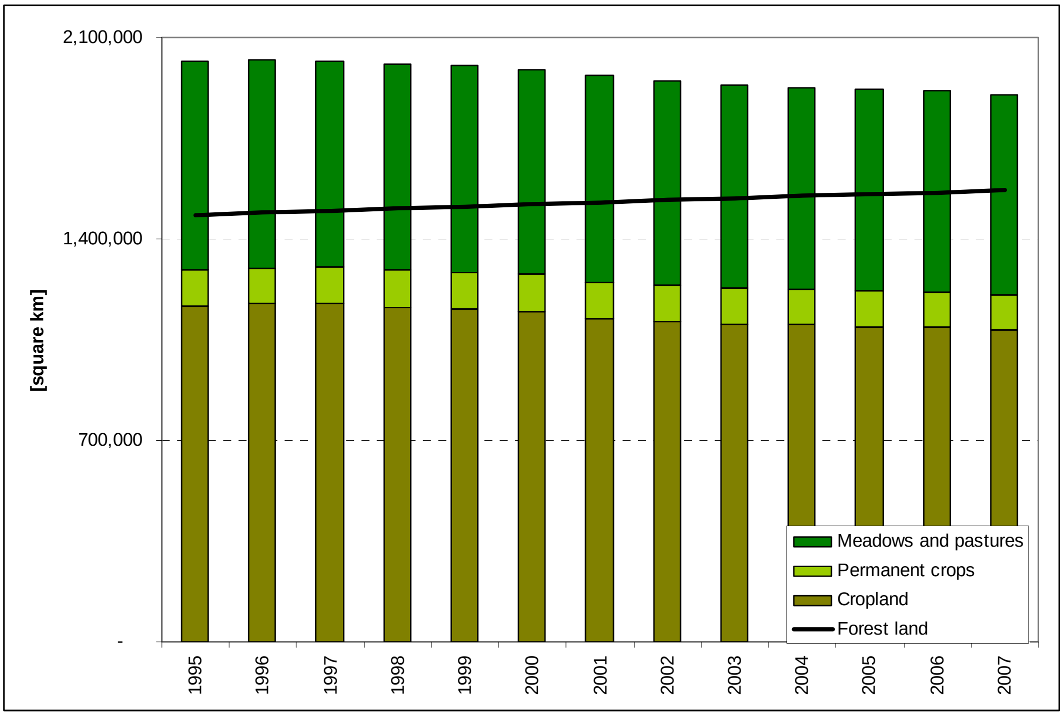
In contrast to domestic biomass extraction, trade with biomass products is very dynamic, both imports and exports of biomass are growing rapidly. Overall, the European Union is a net importer of biomass products. It Imports large amounts of feed and animal products as well as wood and wood products. In net terms therefore, European biomass consumption is based on land use abroad. European imports of soybeans and soybean cake used in intensive European livestock production as protein feed are equivalent to an area of over 20 million ha of cropland, an area larger than the total area used for soybean production in Brazil. A recent study has estimated that the net imports of agricultural biomass of the EU-15 in the 1990s were equivalent to 25 to 33 mio ha of land. The implementation of the European biofuel strategy (10% share of transport fuels in 2020) will increase biofuel demand from currently 10 to 35 mtoe and is likely to further increase Europe's draw on global land resources.

3.2 Land use trends in Europe

Land is a key resource and the use of land is closely interrelated with socio-economic material flows. The availability of biologically productive land is the basis for the production of biomass and the provision of food for humans, feed for domesticated livestock, raw materials for manufacturing and industry and, increasingly, also for renewable energy carriers. Statistical data on the development of land use and land cover is available from Eurostat. However, these datasets cover only selected years and show considerable data gaps for some EU-27 member states. We therefore refer to data from the United Nations Food and Agricultural Organizations database (FAOSTAT)[11] to investigate the long term trends in land use in the European Union and its member states.

[11] http://faostat.fao.org/default.aspx.

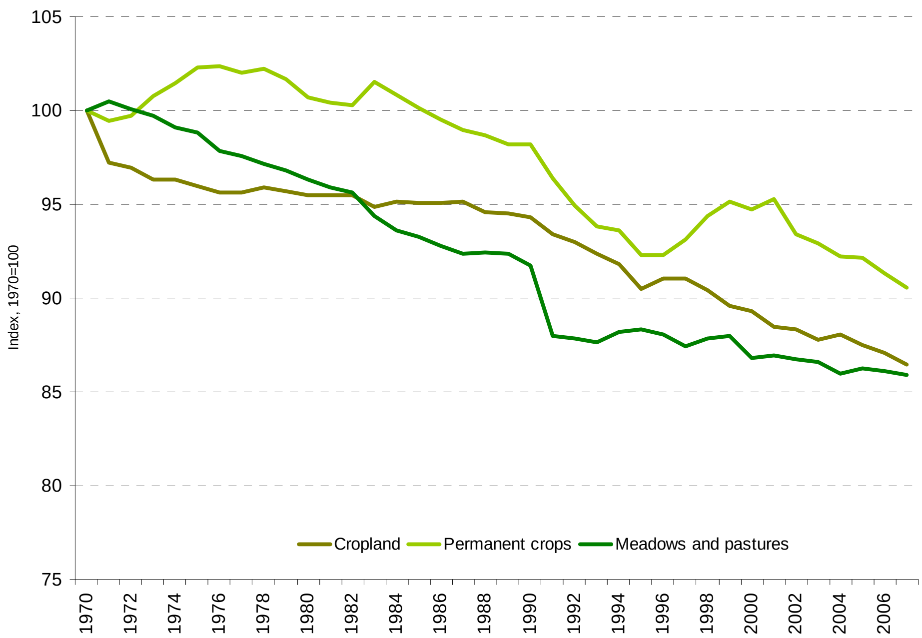
Figure 25: Development of agricultural and forest land in the EU-27 from 1995 to 2007



Source: FAOSTAT 2010

The 27 member states of the European Union cover a territory of 4.3 mio km² of which 44% are used as agricultural land and 36% as forests (FAOSTAT, 2010). Figure 25 shows the development of agricultural land and forest land in the EU-27 in the period 1995 to 2007. As in many industrialized countries, agricultural areas are slowly declining. In the observed 12 year period the total extent of land used for agriculture shrank by roughly 6% from 2.0 to 1.9 million km². The declining trend was strongest for cropland which was reduced by 8%, but also permanent crops and grassland were shrinking (by 3 and 4%, respectively).

Figure 26: Development of Agricultural Land in the EU15, 1970-2007 (indexed 1970=100)



Source: FAOSTAT 2010

For the EU-15 data is available for a longer time span. Figure 26 indicates that the trend of a reduction of agricultural area is prevailing since several decades: While a total of 1.6 Mio km^2 of land was classified as agricultural area for the EU-15 countries in 1970, this area had decreased by 16% to 1.4 Mio km^2 by the year 2007. The decline was strongest for permanent meadows and pastures as well as for cropland which decreased by 14% and 12%, respectively. Permanent crops shrank by 8% between 1970 and 2005. This trend seems to continue, there is no indication of slowdown.

Data on the development of forest area are less reliable than those for agriculturally used land. FAOSTAT data indicate that in the period from 1995 to 2007 forest area in the EU-27 countries expanded by 6% from 1.48 to 1.57 Mio km², corresponding to an annual forest growth of 7000 km². A comparison of the net growth of forest area in the EU-27 countries in the period 1995 to 2007 (+85,000 km²) with the decline in agricultural area in the same period (-117,000 km²) reveals that only three quarters of the lost agricultural areas have been turned into forest land.
Next to erosion, contamination, and compaction, the EEA's State of the Environment report (EEA, 2005d) identifies sealing as one of the important contributors to soil degradation. There is no fully consistent European data set on the extent and expansion of built-up land available, but Eurostat provides some data on land covered by buildings and infrastructures for selected countries and years (Table 3). These data and the abovementioned difference between total loss of agricultural area and growth in forest area indicate that the extension of built up land is progressing at a high rate and that significant amounts of highly productive agricultural land continue to be converted into land used for infrastructure and settlements.

Table 3: Development of Built-Up and Agricultural Land Across the Designated Time Period for Select EU15 MS,

Country	Time Period	Built-Up Land	Agricultural Land
Belgium	1985 – 2000	+ 21%	± 0%
Denmark	1985 – 2000	+ 44%	- 7%
France	1985 – 2000	+ 30%	- 6%
Germany*	1970 – 2000	+ 81%	- 10%
Netherlands	1970 – 2000	+ 75%	- 11%

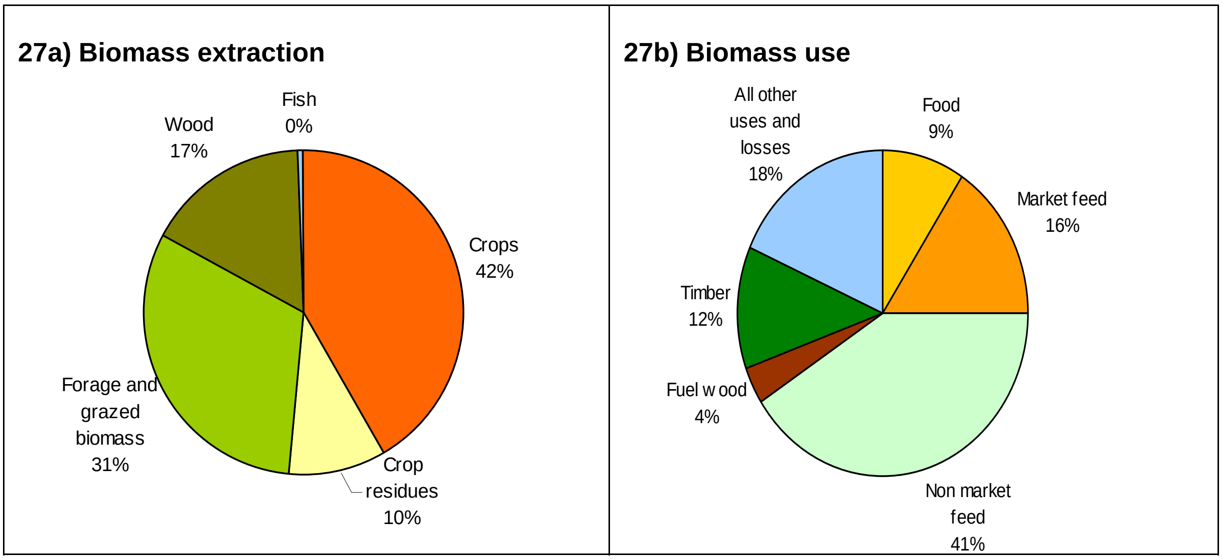
*Calculations based on: Eurostat 2010, *refers to the sum of values for East and West Germany before 1989*

An EEA assessment of land take (EEA, 2005a) reported, that land uptake by urban areas and other artificial surfaces in 23 European countries covered by Corine Land Cover 2000 amounted to 9200 km² in the 10 years from 1990 to 2000. Total land take in these countries represented 0.3% of their total territory. This value may seem low, but spatial differences are very important and urban sprawl in many regions is very intense. In the period 1990 to 2000 artificial land uptake was fastest in Ireland (3.1% increase in urban area per year), Portugal (2.8%), Spain (1.9%) and the Netherlands (1.6%).

3.3 Extraction and use of biomass and land use

The European Union has a highly productive land use system. Biomass extraction (Figure 27a) in the EU-27 amounted to 1.6 billion tons in 2005, which corresponds to roughly 8% of total global biomass extraction. Crop harvest accounted for the largest share of total extraction (42%), followed by forage and grazed biomass (31%). The share of timber and fuel wood was 17% and that of crop residues 10%. The use of (plant) biomass in the EU-27 is clearly dominated by feeding domesticated livestock (Figure 27b). Data for biomass use in the year 2000 indicates that 57% of all biomass domestically consumed in the EU-27 countries was used to feed animals (market feed and non market feed including grazed biomass). Timber and fuel wood accounted for roughly 16% of used biomass, and only 9% of all plant based biomass was used for human nutrition.

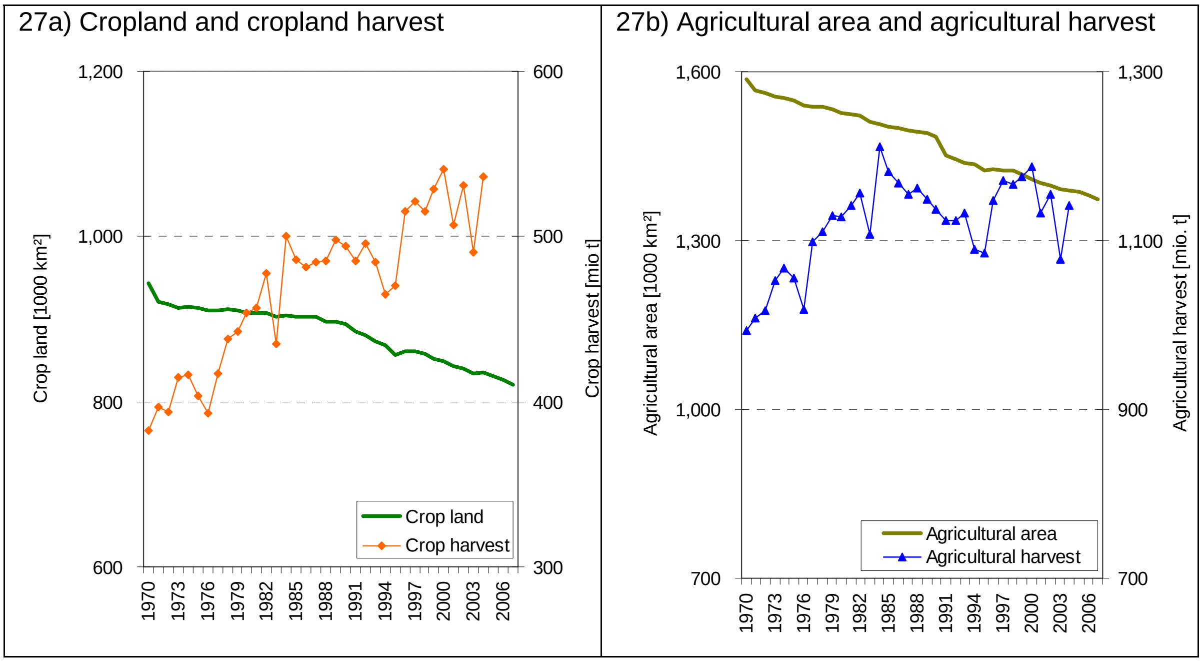
Figure 27: Biomass extraction and use in the EU-27. Extraction data for 2005, use data for 2000.



Sources: Extraction based on Eurostat 2009, biomass use based on Krausmann et al., 2008a

While agricultural land shows a declining trend in the European Union, biomass extraction has been increasing considerably. Figure 28 highlights these opposite trends for the EU-15: Despite of a 13% reduction of both total agricultural area and cropland since 1970, biomass extraction from these areas has surged – and in particular did so in the period from 1970 to 1985. Over the whole period extraction of agricultural biomass grew by 15% and crop production by even 40%. While crop production continued to grow in the 1980s and 1990s, peak production of agricultural biomass was already reached in the mid 1980s.

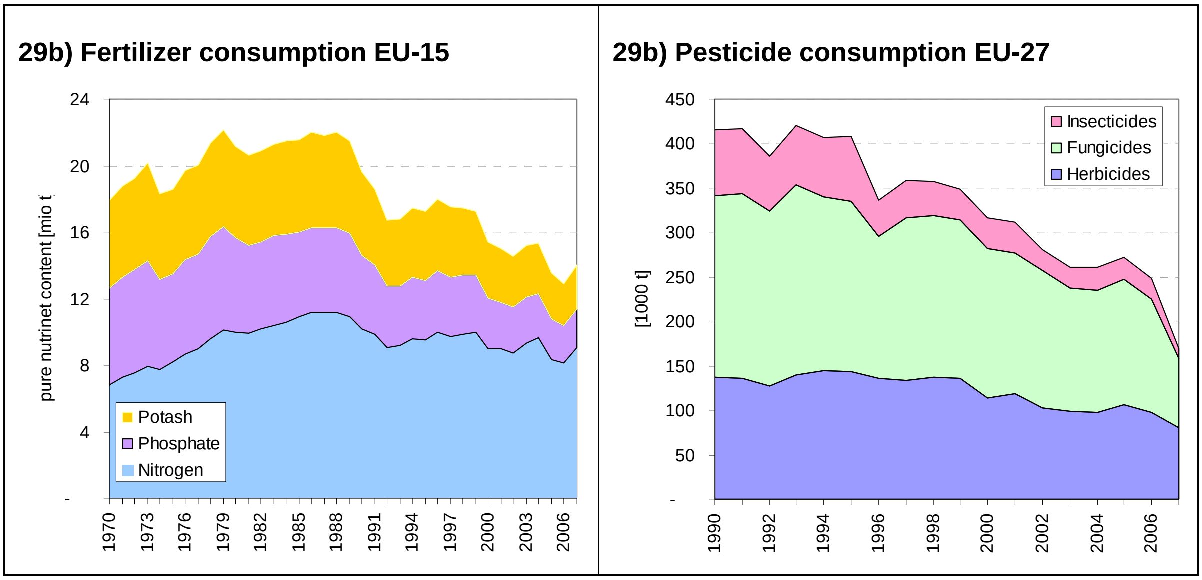
Figure 28: Development of land use and harvest: a) Cropland and crop harvest; b) Agricultural area and agricultural harvest



Source: FAOSTAT 2010 (area) and Eurostat, 2007a (harvest)

The observed decoupling of the extent of agriculturally used areas and increases in biomass harvest was associated with significant increases in land use intensity and environmental pressures. The surge in output and yields was based on increasing inputs of agro-chemicals, fossil fuel use in agriculture and agricultural water use; It was associated with increased field size and loss of landscape structures; biodiversity loss, ground water pollution. However, since the early 1990s efficiency of agricultural inputs is increasing and pressures have been reduced. Figure 29 shows that the development of fertilizer consumption in the EU-15 peaked in the late 1980s and since has been declining markedly. A similar development has been observed for pesticide inputs (Figure 29): According to FAO data, pesticide input declined in the EU-27 since 1993.

Figure 29: Consumption of fertilizer in the EU-15, 1970 to 2007 and pesticide consumption EU-27, 1990 to 2007.



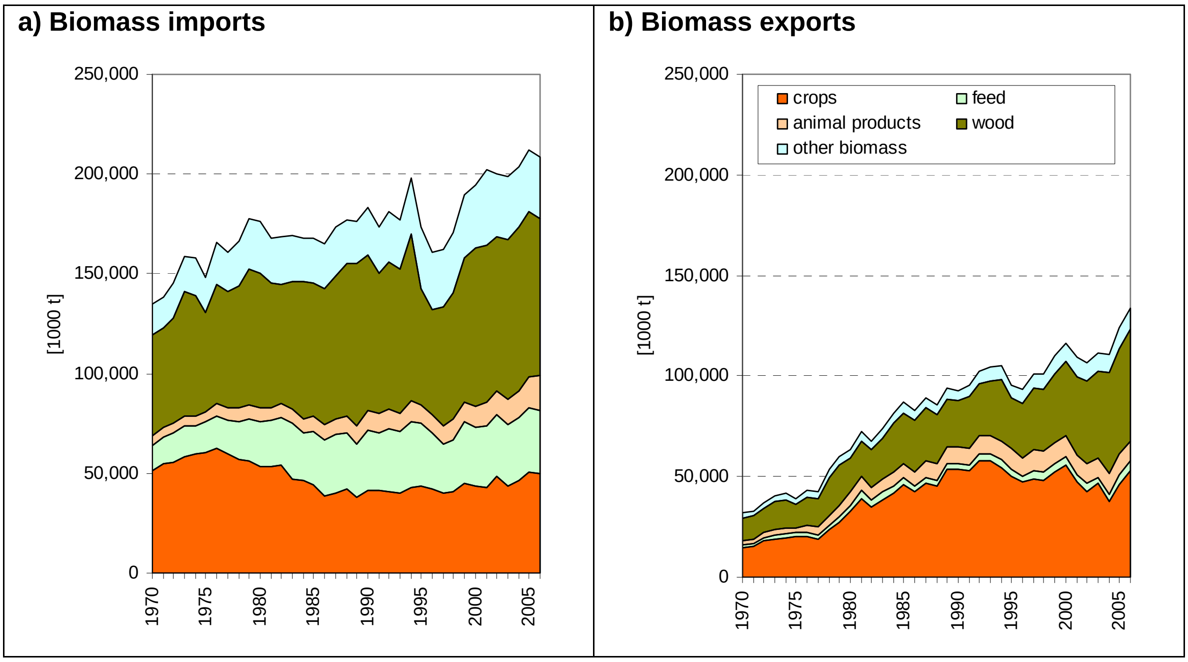
Source: FAOSTAT 2010

3.4 Biomass trade

While biomass extraction in the European Union is stabilizing at a high level, trade with biomass and biomass products is growing dynamically. Figure 30 shows the trends of biomass trade (net imports and exports, see also section 3.2.3) of the EU-15 from 1970 to 2006.[12] In that period, biomass imports have increased by 54% and grew from 135 to 208 mio t. Exports grew at an even faster pace (over 300%) but are still considerably lower than imports (133 mio t in 2006).

[12] EU-15 trade data refer to extra EU-15 trade only. Trade within the EU between its member states is excluded.

Figure 30: Biomass imports and exports, EU15



Source: Eurostat 2007

3.5 Land use intensity: Human appropriation of net primary production

The intensification of land use has helped to increase production while the extent of land used for this production is declining. Overall, terrestrial ecosystems in the European Union are used very intensively. This is reflected in patterns of human appropriation of net primary production (HANPP).[13] Net primary production (NPP) is the biomass produced by green plants through photosynthesis. It is the basis for all food chains, the ultimate food resource in all ecosystems. Two types of processes contribute the human appropriation of NPP: (1) Land use alters the productivity (NPP per unit area and year) of ecosystems (e.g., through replacement of natural ecosystems with agro-ecosystems or build-up land) and (2) used and unused harvest of biomass in ecosystems reduces the amount of biomass available for food chains in ecosystems. From a socioeconomic perspective, HANPP represents a composite measure of the impacts of biomass harvest and land-use induced productivity changes on biomass energy flows in terrestrial ecosystems. From an ecological perspective, HANPP measures the land-use induced changes in the annual availability of biomass energy for all heterotrophic organisms.[14] It has been argued that HANPP and its components are indicative of the quality of land management as well as of pressures on biodiversity (Wright, 1990, Haberl et al., 2005), biogeochemical cycles (Steffen et al., 2004) and on the water cycle (Gerten et al., 2008).

From a global estimate of HANPP (Haberl et al., 2007) spatially explicit information on land use intensity in Europe can be derived. Figure 31 presents maps of harvested NPP (31a) and of HANPP for as percent of potential productivity of terrestrial ecosystems (31b) for the year 2000.[15] The spatially explicit information in the maps is complemented by data for each country in Table 4. According to these data, several regions in Europe show exceptionally high levels of human appropriation of NPP. In the EU-27, HANPP averages at 46% which amounts to twice the reported global value (23%). Several countries in Europe have HANPP levels of 50% or more. The group of countries with high HANPP is dominated by the most densely populated countries (e.g.,

[13] HANPP has been proposed as an indicator of human domination of ecosystems two decades ago as an (Vitousek et al., 1986, Vitousek et al., 1997)

[14] i.e. food energy-consuming organisms, as opposed to autotrophic organisms that are capable of photosynthesis.

[15] It is important to note, that in contrast to material flow accounts, HANPP accounts also include unused biomass extraction in harvested NPP.

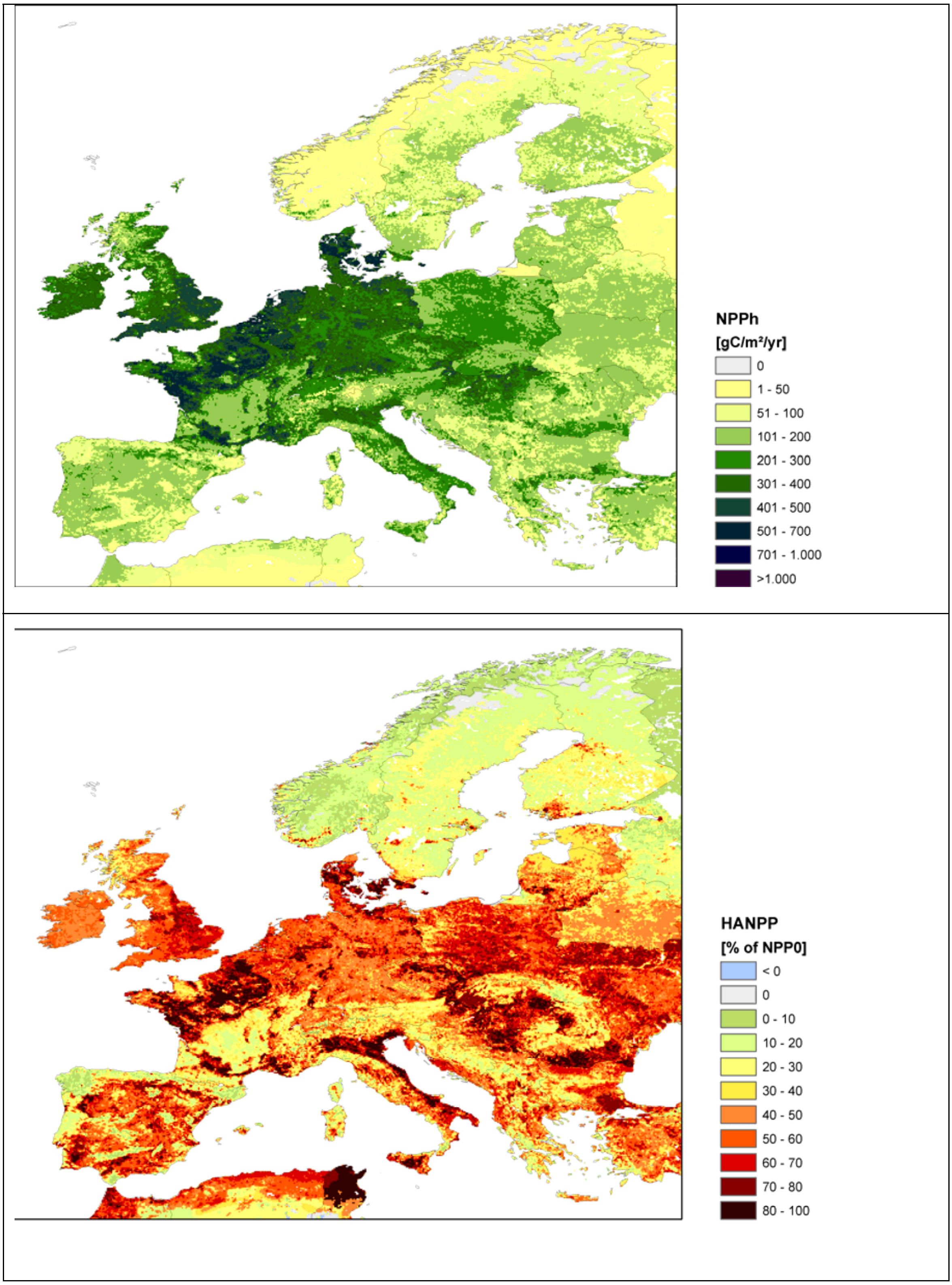
Netherlands, Belgium) and countries with a high share of agricultural area of their total area (e.g., Hungary, Denmark). In contrast, HANPP is lowest in countries which are sparsely populated and/or have a high share of their land in forests (e.g. Sweden, Finland, Slovenia). Across the EU-27 member states, the rate of biomass extraction per unit of land area varies by one order of magnitude. It is as low as 69 t of dry matter per ha in Cyprus and reaches values above 700 t/ha in Belgium and the Netherlands. Relating the amount of used biomass extraction (consistent with domestic biomass extraction in MFA accounts) to the amount of appropriated NPP (both in tons dry matter) reveals that significant differences with respect to the HANPP efficiency of biomass harvest occur (factor 3). This suggests that in some regions efficiency gains might be possible, which would allow to increase biomass extraction without increasing HANPP, might be possible. Although there are no time series data of HANPP available in the European Union, existing case studies for Hungary, Spain and the United Kingdom indicate, that HANPP in Europe has stabilized in the second half of the 20th century (Erb et al., 2009b). In terms of HANPP, the growth in forest area is likely to counterbalance increases in harvest and soil sealing.

Table 4: Human appropriation of net primary production in EU-27 member states

	Human appropriation of net primary production (HANPP)	**Population density**	**Share of cropland in total land area**	**Biomass extraction per km²**	**HANPP per ton used biomass extraction**
	[% of NPP of potential vegetation]	[cap/km²]	[%]	[t/km²]	[t dry matter]
Sweden	21%	20	6%	108	2.0
Finland	23%	15	7%	119	2.0
Cyprus	26%	85	14%	69	3.2
Slovenia	32%	98	10%	218	2.0
Greece	38%	80	30%	175	2.0
Latvia	39%	37	29%	136	3.5
Estonia	40%	31	23%	151	3.0
Austria	41%	96	18%	311	1.7
Spain	41%	79	36%	162	2.8
Bulgaria	45%	72	41%	167	3.0
Portugal	46%	109	29%	192	2.7
Ireland	47%	54	15%	518	1.1
Slovakia	48%	110	32%	262	2.4
France	50%	107	36%	435	1.5
Italy	51%	191	37%	283	2.0
Lithuania	51%	57	46%	178	3.5
Romania	52%	94	42%	209	2.7
Germany	53%	230	34%	485	1.4
United Kingdom	53%	245	24%	475	1.2
Belgium-Luxembourg	56%	323	26%	704	1.0
Poland	58%	123	46%	281	2.6
Czech Republic	59%	130	42%	354	2.1
Hungary	63%	107	53%	415	1.9
Denmark	65%	123	54%	588	1.4
Netherlands	68%	382	27%	811	1.0
EU15	43%	104	27%	301	1.6
EU12	52%	102	42%	247	2.5
EU27	46%	103	30%	287	1.8

Source: Calculations based on Haberl et al., 2007, Krausmann et al., 2008a, Haberl et al., 2009.

Figure 31: Harvested net primary production (NPPh) and human appropriation of NPP (HANPP) in Europe in the year 2000



Source: Haberl et al. 2007; NPPh is given in grams carbon per m² and year, HANPP as percentage of the NPP of potentially prevailing vegetation.

3.6 The impact of biomass use in the EU on global land use

During the last decades, technological progress in agriculture has triggered tremendous increases in area productivity and the production of agricultural biomass was increasing faster than demand in the European Union. On the one hand, this is reflected in rapidly increasing biomass exports, on the other hand, gains in area productivity allowed for the observed decline in agricultural areas. A significant part of the agricultural areas which have been taken out of production have been reforested. Another part has been consumed by the expansion of built up land. But European farmers were also paid for not growing crops. This so called set aside land became fallow land or it was used to grow so called non food crops. These trends and in particular the efforts to reduce agricultural production by taking land out of production lead to the widespread communication that the EU has spare agricultural land which could be used for the substitution of biomass for mineral materials and fossil fuels. Considering the growing imports of biomass, however, changes the picture: Soybeans and soybean cake may serve as an example here: The European Union has a large livestock sector and produces roughly 43 million tones of meat per year which equals 15-18% of global meat production. Most of this meat is consumed within the EU, the share of net exports is very small. To maintain this level of highly intensive livestock production system, large amounts of high quality protein feed are required. The largest share of this protein feed is based on soybeans and soybean cake and is imported from countries like Brazil or the United States. Figure 32 shows that the European Union is only producing minor quantities of soybeans domestically, but imports roughly 15 mio tons of soybeans and 23 mio tons of soybean cake. These imports correspond to an area of more than 20 mio ha of cropland (based on average yields obtained in Brazil) – an area actually larger than that used for soybean cultivation in Brazil. What this example shows, is that while European agricultural areas are declining, European imports are demanding large areas of fertile cropland in distant regions of the world and European consumption patterns are contributing to deforestation and land use change elsewhere.

Figure 32: Development of soybean production in the EU-27 and net-imports of soybean(cake) (32a) and Area-equivalent of net-imports of soybean(cake) in comparison with soybean area of Brazil (32b)

Fig.32a: Production and net-imports of soybeans

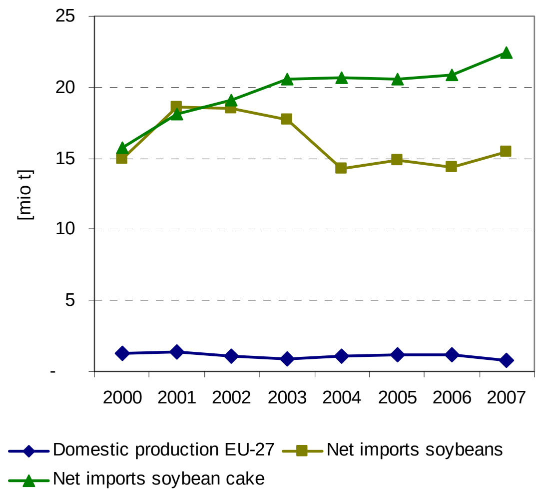
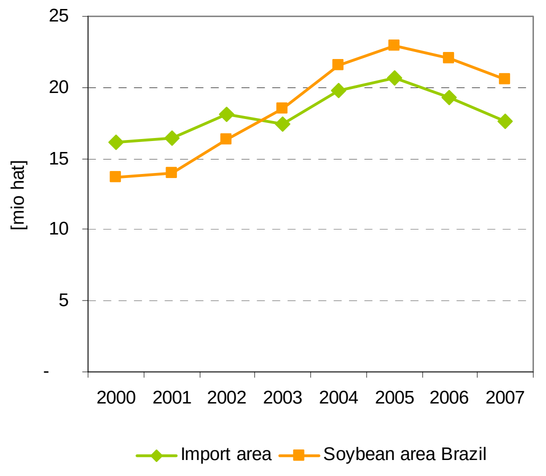


Fig.32b Area-equivalent of net imports and Brazilian soybean area



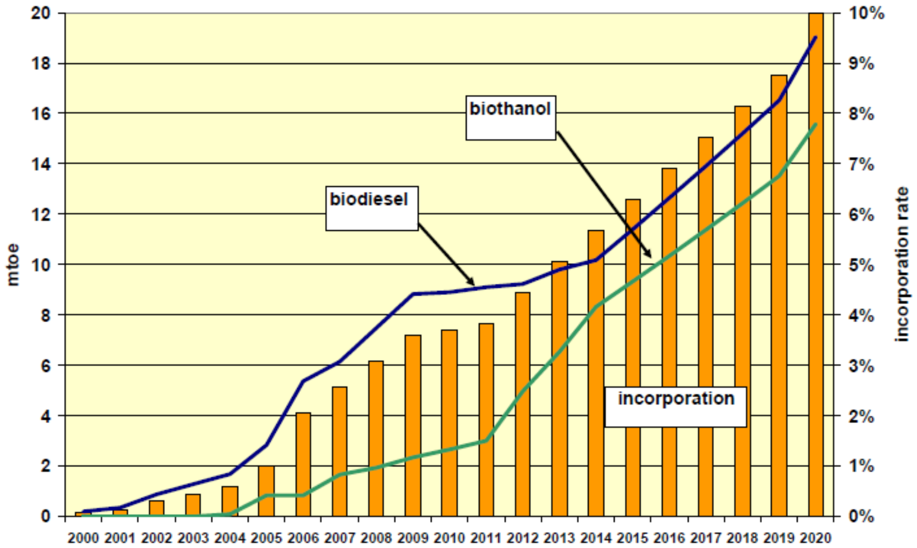
Source: calculations on the basis of FAOSTAT 2010

Hardly any comprehensive studies exist which provide quantitative data on European land imports. The best available material is a study by Bringezu and colleagues (Steger, 2005, Bringezu et al., 2009b) who have quantified the global land use that is related to domestic biomass use in the

European Union, taking into account that the European Union is a net importer of agricultural biomass.

According to this study global land used for the imports of agricultural biomass into the EU-15 countries in the period 1990 to 2000 by far exceeded the land used for exports. The net trade balance in terms of land in that period had a surplus of between 25 and 33 million ha with a slightly declining tendency – which reflects that exports were growing at a faster pace than imports. The study lists oil cakes, soybeans, sunflower coffee and cocoa as the major contributors to global land use of EU imports. In 2000 the global land use for agricultural goods consumption in the EU-15 was 4310 m^2/cap.This area was 18% larger than the domestic agricultural area used. A more recent study on the EUs virtual land use abroad by ven der Sleen (2009) concludes, that "for every hectare of agricultural land use in the EU one hectare is used outside of the EU only for the production of the raw imported agricultural products." Assessments of global HANPP embodied in imported biomass products corroborate these results and indicate that the European Union is drawing considerably on the global land system. According to data derived from Erb et al. (2009c), net imports of biomass to the EU-27 are associated with a HANPP equivalent to 45% of domestic EU-27 HANPP in 2000.
European efforts to increase the use of biofuel might enhance pressures on European and global land use systems: During the last decade, biofuel consumption in the EU-27 has been growing rapidly. In 2008 roughly 10 mio tons of oil equivalents (mtoe) of biofuels (mostly biodiesel) have been consumed, equal to roughly 3% of the energy currently used in road transport (EurObserv'ER, 2009, Fischer et al., 2010). The implementation of the goals formulated in the European biofuels directive might lead to an increase of biofuel consumption towards 35 mtoe (Figure 33). A quantification of the agricultural area required to produce the feedstock for the production of these fuels is difficult, as it depends on the development of crop yields, assumptions on which crops are used and where they are produced and the share of 1st and 2nd generation biofuels in production. A study by the European Commission (2007) estimates that an area of 17.5 mio hectares would be required by 2020 if the 10% incorporation goal is fulfilled, others estimate up to 30 mio ha (Eickhout et al . 2008). A recent study concluded, that the European biofuel target can only be met by producing additional biofuel outside the European Community (Bringezu et al. 2009, Eickhout et al., 2008)

Figure 33: Development and projections of biodiesel and bioethanol demand and the incorporation rate until 2020 in the EU-27



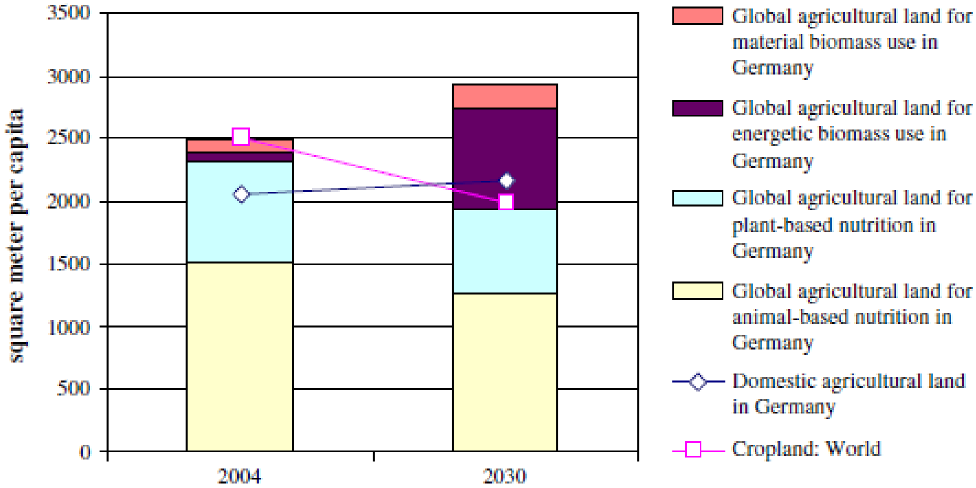
Source: European Comission 2007 (http://ec.europa.eu/agriculture/analysis/markets/biofuel/impact042007/text_en.pdf)

A detailed estimate of the impact of n a scenario analysis for Germany, Bringezu et al. (2009a) showed, that if Germany was to fulfil biofuel demands of current policy targets, this would considerably expand its global cropland demand. The study estimates that roughly 32% to 42% of

Germany's biofuel demand in 2030 would have to be imported and that four fifths of the total land required for biofuels would have to be claimed abroad, for biodiese the share would be as high as 94-99%. Figure 34 from Bringezu et al (2009) show that Germany's global land requirement in 2004 was in line with the worldwide per capita availability, but exceeded its domestically available agricultural land of 2063 m2 per person by around 21%. Since domestic land could only meet about one-fifth (19–22%) of the demand for biofuels in 2030, increased imports would be necessary. In 2030, 43–44% of Germany's global land requirement would be for animal based nutrition, 23% for plant based nutrition, 27% for energetic biomass, and 6–7% for nonenergetic biomass. In this scenario Germany's global land requirement in 2030 would exceed its domestically available agricultural land of 2160 m2 per person by 30–36%, under BAU development for non-food biomass and given unchanged nutrition habits. Overall, the German biofuel scenarios for 2030 result in an additional net requirement of land between to 2.5 to 3.4 million hectares, causing significant CO_2 emissions due to direct and indirect land use changes in tropical regions.

Figure 34: Global agricultural land use of Germany compared with domestically available agricultural land in Germany and cropland in the World (square meters per capita in 2004 and 2030).

On the basis of net consumption land, 2.800 m2 per Person would be available under BAU I in 2030 and 2930 m2 per Person under BAU II in 2030.



Source: Bringezu et al. 2009

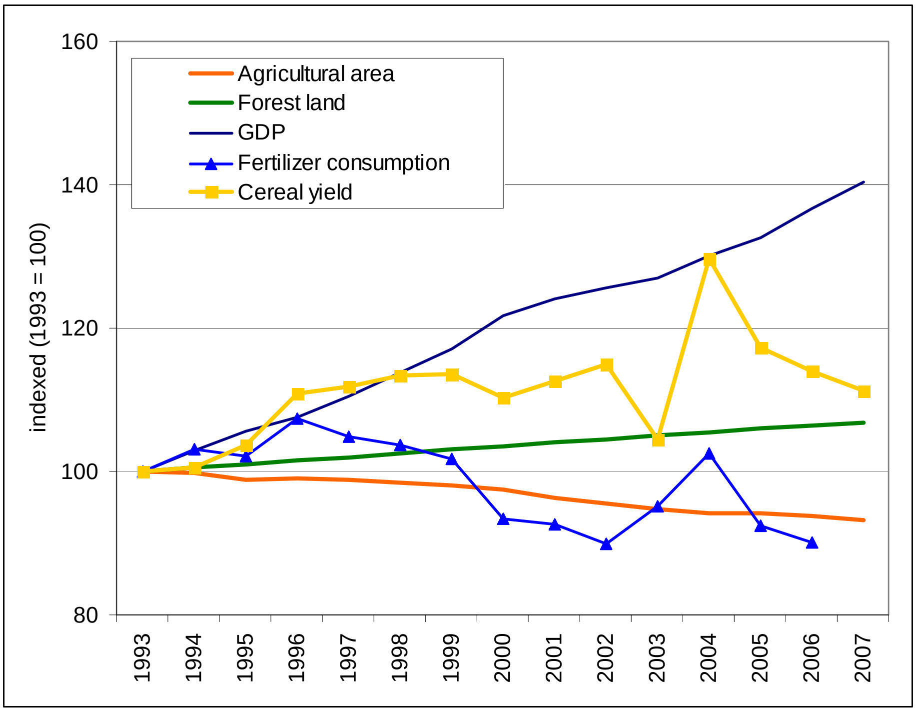
These studies indicate that despite declining agricultural areas and a stabilization of HANPP there is little room for a shift towards an increased use of agricultural biomass and in particular crop products as a substitute for mineral materials and energy carriers. These attempts are likely to contribute to the existing tendency of shifting pressures from Europe to the land system in the rest of the world. Eickhout et al (2009), therefore argue that "this additional pressure on land, globally, asks for sustainability criteria. Criteria that can also be applied outside the EU. Even when most of the biofuels are grown within the EU (as concluded in the Commission's Impact Assessment), criteria need to address the displacement effect: food and feed will be grown elsewhere outside the EU because productive land will be occupied by biofuel crops."

3.7. Decoupling of land use and economic development

The relation between land use and economic development is complex. Land is not a flow resource like materials or energy and it can not be consumed or "used up" in economic processes. Economic development is rather related to shifts from one land use type to another and with changes in land use intensity. Data on the long term development of land use, land use intensity and economic development in the EU-27 reveal different trends: Figure 35 shows that in the European Union, like in many other industrialized countries a shift from intensively used agricultural land towards extensively used woodlands can be observed. This process, which has been termed forest transition (Kauppi et al., 2006), is common in almost all member states of the European Union: The largest reductions in agricultural area were observed in the new member states, above all in the Baltic States, Poland and Bulgaria, while the least decline occurred in the UK and Belgium/Luxembourg. (see Table 5). In addition to a shift from intensively used agricultural land towards forest land also a trend towards more efficient use of agricultural inputs with economic development is visible: While for example fertilizer application (and also pesticide use – Figure 29 above) is decreasing in the EU-27, yields are still on the rise. Also these trends occur in most of the EU-27 member states.

With respect to the loss of productive land to urban and infrastructure land, however, there is no decoupling from economic development observable. Even though comprehensive data are lacking, all available evidence suggests, that increase in built up land are progressing in all member states and are closely linked to economic development. In the period 1990 to 2000 roughly 1000 km² of productive land were converted into built up land per year in 23 European countries and conversion rates were highest in countries with high growth rates of GDP such as Spain, Portugal or Ireland (EEA, 2005a).

Figure 35: Trends of land use, fertilizer consumption, cereal yields and GDP, EU-27 1993 to 2007



Source: based on data from FAOSTAT 2010

Table 5: Changes in GDP, Agricultural area and forest land in the EU-27 member states in the period 1993 to 2007

	GDP (constant prices)	Agricultural area	Forest area
Estonia	130%	-38%	5%
Malta	60%	-28%	0%
Latvia	138%	-27%	6%
Slovakia	105%	-21%	1%
Lithuania	101%	-19%	8%
Bulgaria	48%	-16%	11%
Poland	93%	-14%	3%
Italy	25%	-13%	17%
Portugal	39%	-12%	19%
Slovenia	84%	-11%	6%
Greece	65%	-10%	12%
Romania	58%	-8%	0%
Sweden	54%	-7%	1%
Austria	41%	-6%	2%
Hungary	65%	-5%	9%
Spain	63%	-5%	29%
Finland	69%	-4%	1%
Netherlands	48%	-4%	5%
Ireland	169%	-3%	41%
Denmark	40%	-3%	11%
France	36%	-3%	6%
Cyprus	79%	-1%	6%
Germany	26%	-1%	2%
Czech Republic	58%	-1%	1%
United Kingdom	52%	1%	8%
Belgium-Luxembourg	42%	1%	-1%

Source: United Nations 2010 (GDP) and FAOSTAT 2010 (land use)

4 Material Use of the European Union in a Global Context

4.1 Summary

In 2005 the European Union directly used 13% of all resources extracted globally. EU's global share was highest for materials of strategic importance, such as fossil energy carriers and metals (16% each). On top of this, the EU in physical terms is a large net importer of commodities that are associated with substantial upstream resource requirements in the exporting countries that do not reflect themselves in the MFA indicators. Thus, the European draw on global resource base is likely to be even pronounced than the data presented suggest. The European pattern of material use is typical for highly industrialized countries with. a high share of non renewable mineral materials in DMC, in particular of fossil energy carriers. The per capita rate of material use is more than 50% above the global average of 9-10 tonnes per year. In comparison with other industrialized regions, European material consumption per capita is average: DMC in the EU-27 is roughly 30% above the level of Japan and 40% below the level of the United States. However, while Japan has significantly reduced its DMC, material use in the EU-15 and the USA has only remained stable. In the EU-27, however, DMC is still growing, but at a lower rate than GDP.

At the global scale, material use is growing at a rapid pace. While industrialized countries still contribute an over proportionally high share to direct material use, their relative contribution is declining. Further growth in material extraction at the global scale is increasingly driven by newly industrializing countries such as China, Brazil or India. It is important to keep in mind, though, that a substantial portion of this material use in newly industrializing countries is due to the production of commodities for consumption in the industrial core.

There exist very few projections of material use over the coming decades, neither for the European Union nor at the global scale. Only recently the data base and the knowledge about patterns and drivers of material use surpassed the critical threshold required to make reasonable projections and scenario calculations. Up to date only two comprehensive scenario studies dealing with overall material flows in the European Union have been published (EEA 2005 and Lutz and Giljum 2009). These studies are, however, basically limited to forecasts of material extraction without covering trade and material consumption. The baseline scenarios of both studies assume overall material extraction in the European Union to rise during the next decades (up to 2020 and 2030, respectively). Lutz and Giljum (2009), for example, assume that material extraction in the EU-27 will increase by 16% during the next 20 years. Most of this growth is expected for construction minerals and forest biomass. The reasons for assuming these long term trends of material extraction are not clear, however. They run counter the trends observed in the past years in which material extraction in the European Union has been declining (fossil energy carriers and ores) or has stabilized (biomass and non metallic minerals). Also DMC has stabilized in the European Union during the last years: Average per capita DMC of the EU-15 countries is constant at xy t/cap/yr and has been growing in the 12 new member states to almost the level of the EU-15. Based on these trends the plausibility of the scenarios which predict further growth in materials use ought to be questioned.

At the global scale, the two existing projections (Lutz and Giljum 2009 and Fischer-Kowalski et al. 2010) expect a substantial increase in material extraction and consumption. Lutz and Giljum (2009) estimate that global DE will increase from currently 60 billion tons to 115 billion tons in 2030 and Fischer-Kowalski et al. (2010) create a very similar business-as-usual trajectory (material use in the developing countries reaching the stable levels typical for mature industrial economies) in which overall material use would climb towards 150 billion tons in 2050. Scenarios for a more sustainable development of global material use all rely upon a significant reductions in the material consumption in industrialized countries.

4.2 Share of the EU in Global Material Extraction and Use

The economy of the European Union contributes considerably to global material use (see Table 6). With respect to non-metallic minerals and fossil energy carriers, EU's share of global extraction and use was even higher (at 16%). As a consequence, per capita material use in the European Union (15.8 tons) is above global average (depending on the source between 9 and 10t).

Still the EUs overall material demand is likely to be underestimated in these figures due to a high reliance on net imports of materials (and in particular of metals): Considering indirect flows associated with net imports would considerably increase the share of Europe in global material consumption.

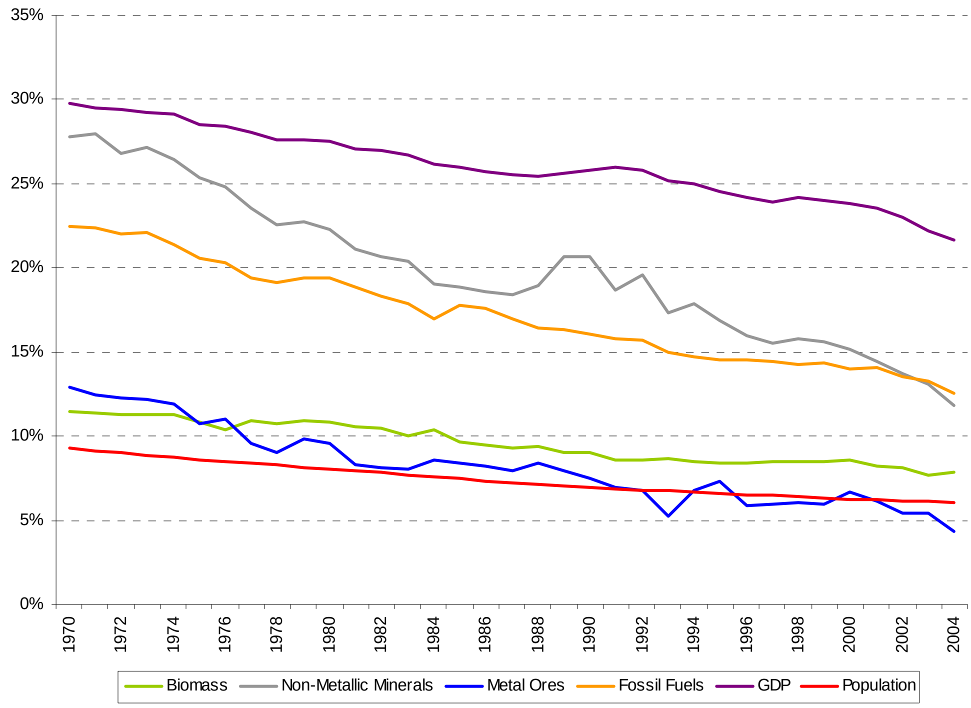
Table 6: Share of the EU-27 in Global DE, DMC, Population, and GDP, 2005

	% of Global DE	% of Global DMC	% of Global Population	% of Global GDP
Total	11%	13%	8%	22%
Biomass	8%	9%		
Non-Metallic Minerals	16%	16%		
Metal Ores	3%	6%		
Fossil Fuels	8%	16%		

Source: based on Eurostat 2009

The dominant role which the EU-15 play for the EU-27's level of resource use also means that the contribution of the EU-15 economies is significant at the global level. Due to the fact that material use in the EU-15 has stabilized while global material use is growing at high rates (Krausmann et al., 2009, SERI, 2009) the share of the EU-15 in global material use is declining (Figure 36). Non-metallic minerals made up 28% of global DMC in 1970, fossil fuels made up 22%, metal ores 13%, and biomass 11%. In the same year, the EU-15 had 9% of the global population and accounted for 30% of global GDP. Despite this relative decline, in 2004, the EU-15 still accounted for 13% of global fossil fuel DMC, 12% of non-metallic minerals DMC, 8% of biomass DMC, and 4% of metal ores DMC while at the same time having 6% of global population and 22% of global GDP.

Figure 36: Share of EU-15 DMC in Total Global DMC by Material Categories in Percent. 1970-2004



Source: based on Eurostat 2007

4.3 Comparison of material use patterns in the EU, Japan and the USA

In this section we compare the development and size of material use in the European Union with that in Japan and the USA, two of most important global economies and global trends. Data for Japan are derived from official Japanese statistics (Ministry of the Environment, 2008); Data for the USA are based on the SocialEcology database (see also Rogich, 2005) and global data from Krausmann et al. (2009).

In 2004 all three industrialized economies had a per capita material use above the global average. With a DMC of roughly 16 t/cap/yr per capita in 2004, resource us in the EU-27 is 31% above the Japanese level and 42% below the level in the USA (Figure 37). Per capita DMC in the USA is roughly three times the global average. Together, EU-27, Japan and the USA occupy approximately 14% of global population and they contribute 30% to global material use (Figure 38). Compared to the EU-27 and Japan the share of the USA in global material use is over proportionally high: The USA inhabit only 5% of the global population but use 14% of global resources.

Figure 37: Per capita DMC in 2004: Global Average, Japan, EU-15 and EU-27 and the USA

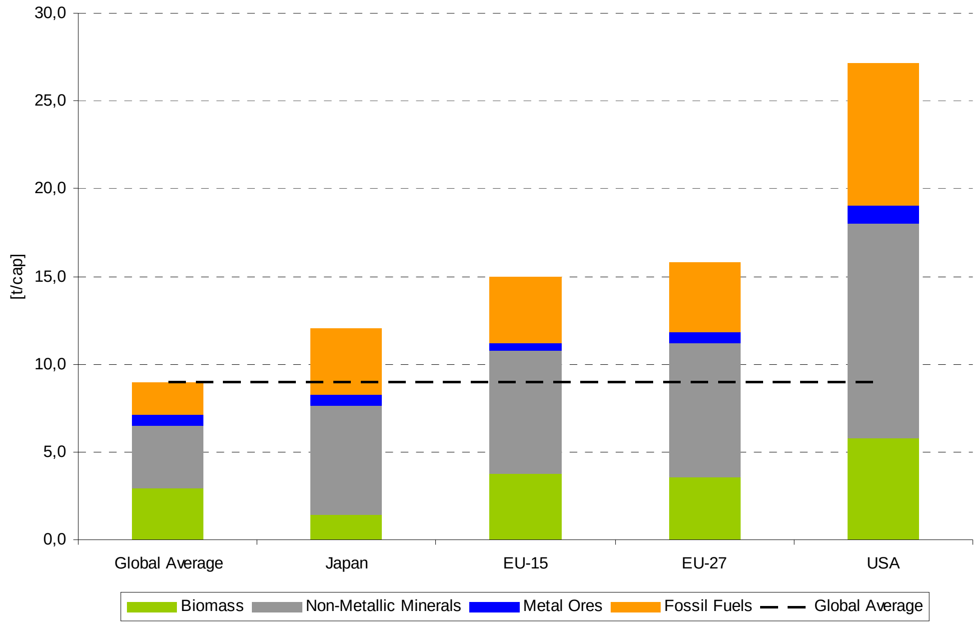
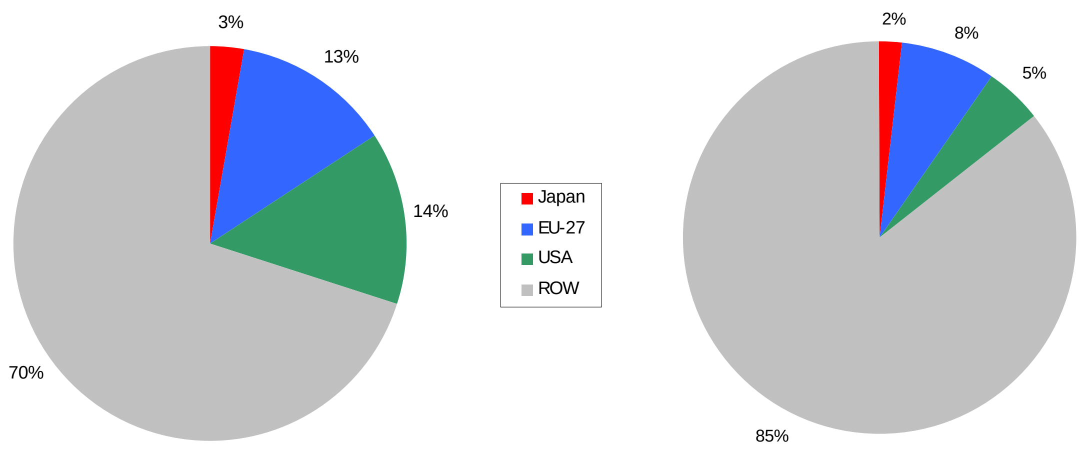


Figure 38: Share of Japan, EU-27 and USA in global DMC and population

38a) Share in Global DMC

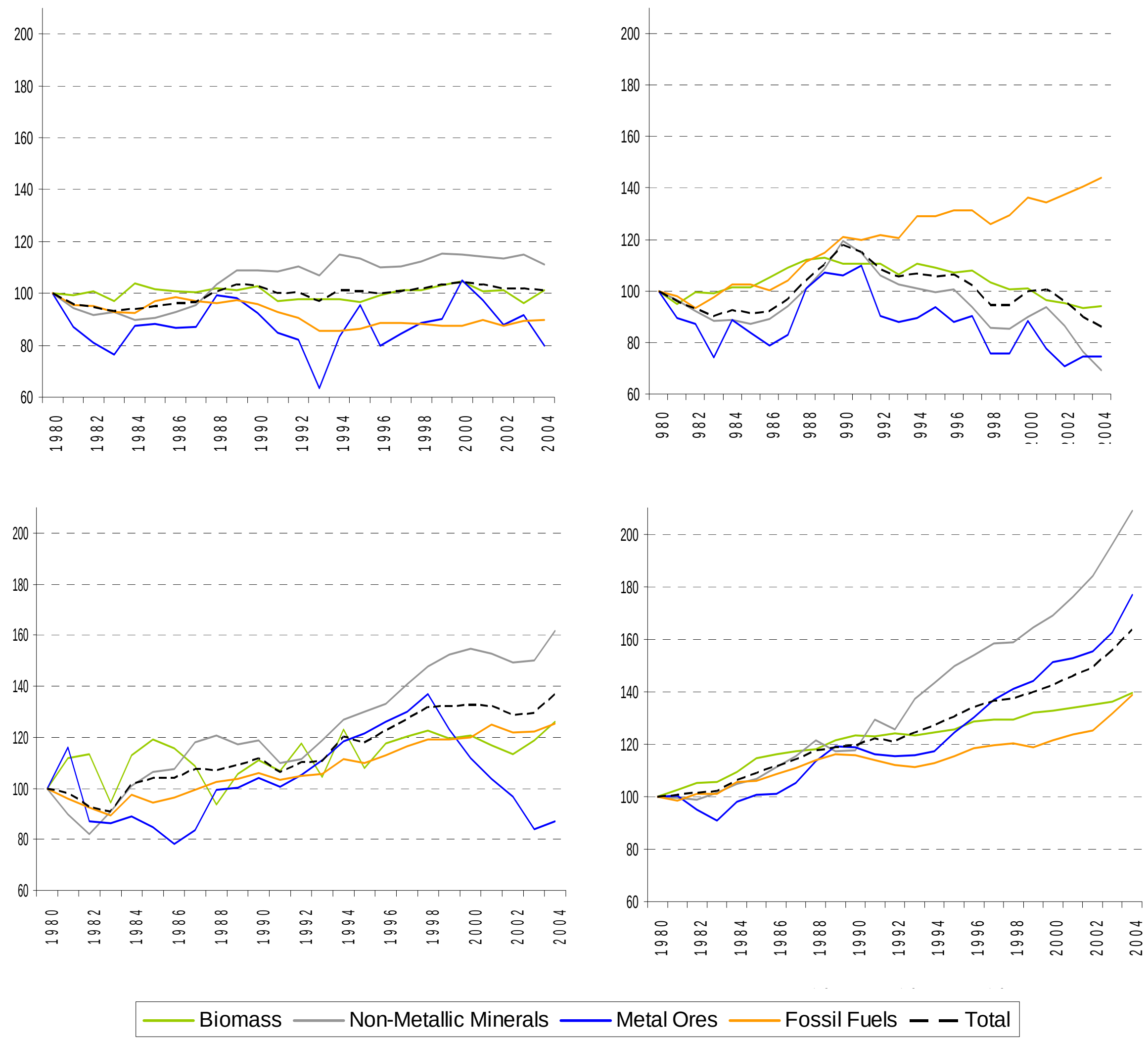
38b) Share in Global Population



Source: based on Eurostat 2009, Rogich et al. 2005, Ministry of the Environment 2008

Also the development over time differs between the three economies and the global pattern (Figure 39). While DMC has stabilized in the EU-15 and did not increase since 1980, material consumption at the global level is characterized by rapid growth. Overall, global DMC has surged by 64% between 1980 and 2004 (see Figure 39d). The physical economy of the USA also has been growing considerably in this period. With the exception of metals, all material groups have increased by 20-62%, overall DMC grew by 37%. In contrast, Japan is one of the few industrialized economies which managed absolute dematerialization: With the exception of fossil fuels (which grew by 44%), the DMC of all material groups significantly declined resulting in an overall reduction of material use between 1980 and 2004 by 14%. In Japan the turning point from physical growth to absolute dematerialisation occurred in 1990 and relates to economic crises and certain saturation effects and massive political efforts to establish sound material flow cycles (reduce, reuse and recycle strategy) (see e.g. Hashimoto et al., 2008).

Figure 39: DMC of the EU-15 (32a), Japan (32b), the USA (32c) and Global (32d) (indexed 1980=100)



Source: Eurostat 2007 (EU-15); Ministry of the environment (Japan); Social Ecology database and Rogich et al., 2005(USA) and Krausmann et al. 2009 (global).

4.4 Projections of European and global material use

While a significant body of literature is available assessing past developments of material use, only little is available with respect to projections or scenarios of future materials use. This section provides an overview of the few existing scenarios of future development of aggregate material use in the European Union and at the global level. We briefly review three scenario studies: Projections published by the European Environmental Agency in 2005 for materials extraction and use in the European Union in 2020 (EEA, 2005b). A recent study (Giljum et al. (2008), Lutz and Giljum (2009)) developed scenarios for future materials use in the European Union and world wide for 2020 and 2030. A study by Fischer-Kowalski et al. (2010) presents scenarios for global resource use for the year 2050.

4.4.1 Projections for European material flows by EEA 2005

The study "Outlook for waste and material flows. Baseline and alternative scenarios" was conducted by the European Topic Center on Resource and Waste Management (EEA, 2005b) and contributed to the EEA report "State and outlook of the European environment" (EEA, 2005d). The main objective of the study was *"to provide an assessment of the likely future trends of waste quantities and material flows" (*EEA, 2005b: p.5). It gives projections for so called "aggregate material flows" (95% of DMC components)[16] and for the DEU (=domestic material extraction used) of minerals and biomass. The development of the DMC has been forecasted only in the case of fossil fuels. Thus, the scenarios on European material use and their results have their limitations: The comparability of the results is problematic because of the inadequate definition of "aggregate materials". The study only takes the European DE (domestic extraction of materials) into account and neglects the global context (except the exception of fossil fuels).

The selected material flows (aggregate material flows, minerals, biomass and fossil fuels) were modelled using two, in the case of fossil fuels three different scenarios: A **business as usual scenario (baseline)**, a **Low growth scenario** and a **Sustainable Emission Pathway scenario (SEP)**. All scenarios were calculated separately for the EU-15 and EU-10 (new accession) countries. The key assumptions on socio-economic variables are based on the LREM[17] baseline scenario: Annual economic growth rates of 2.3% (EU-15) and 3.6-3.8% (EU-10), for the Low growth scenario economic growth rates of 1.6-1.7% (EU-15) and 3.4% (EU-10) were assumed. The SEP "is based on the assumption of certain energy and climate policy measures influencing particularly the energy mix. These changes relate e.g. to increased shares of renewable energies and switches from carbon-intensive coal towards less carbon-intensive crude oil and gas fuels." (EEA, 2005b: p.15). The study arrives at the following projections for material use:

Development of aggregate material extraction along with GDP for Europe

The Baseline as well as the low growth scenarios show that the aggregated material extraction increases, albeit more slowly than GDP (depending on countries and scenario). That is relative decoupling of materials use and economic growth is occurring, however no decrease of material use in absolute terms is predicted. According to the projections, resource productivity in the EU-10 will grow faster (51% in the baseline and 46% in the low growth) than in the EU-15 (35% and 31%, respectively) (Figure 40). The study concludes that according to a "business-as usual" development, technological progress (resource productivity) is not improving enough to achieve an absolute decoupling and furthermore, that in order to achieve a stagnating material input, as a minimum resource productivity has to grow at the same growth rate as the GDP (EEA, 2005b: p.67).

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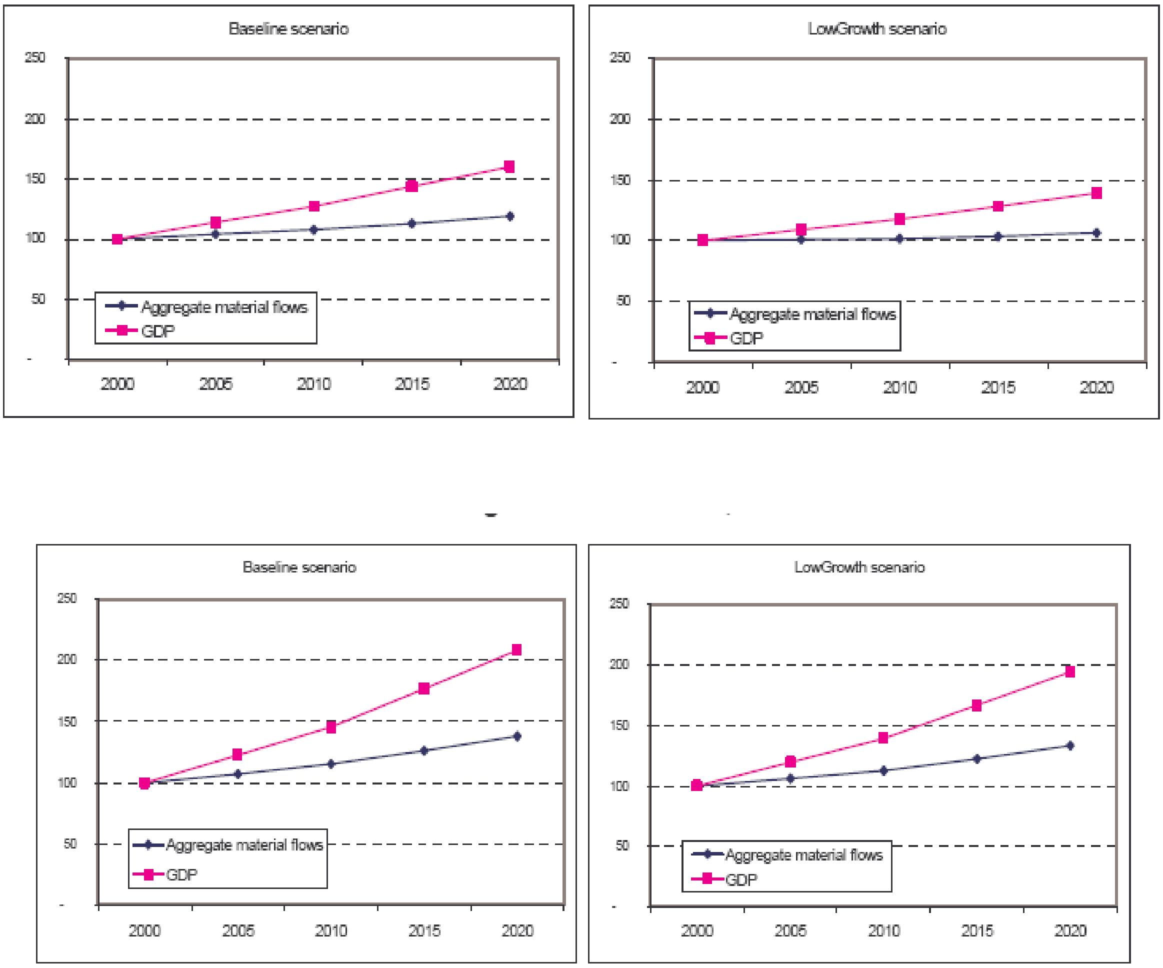
[16] „The projections for material flows comprise main components of the Domestic Material Consumption (DMC), a composite indicator showing how much materials are consumed by a national economy. Not all components of the DMC are included, but the components which have been projected represent about 95% of composite DMC and is therefore a good proxy for it." (EEA, 2005 p. 8 and p. 18).

[17] "The LREM baseline scenario presents a projection of the EU energy and transport outlook to 2030 on the basis of current market trends and existing polices. The LREM baseline scenario is based on a quantitative analysis, with the use of PRIMES and ACE mathematical models, and in a consultation process with energy experts and organisations." (EEA, 2005 p.5)

Figure 40: Development of GDP and aggregate materials extraction in the EU15 (34a) and the EU10 (new accession countries) (34b)



Source: EEA 2005a

Development of the DMC of fossil fuels along with imports

All three scenarios show that the share of domestically extracted fossil fuels in total consumption will decrease. This development goes along with a net increase of imports of fossil from outside the EU and the energy dependency (share of imports) of the EU will increase significantly. In the SEP the energy dependency is even higher due to a changing energy mix from coal to oil and gas.

EU-15 countries: In the business as usual scenario fossil fuels consumption increases slightly (from 1.49 billion tons in the year 2000 to 1.62 billion tons in 2020). The Low growth scenario shows a more or less constant level, even a slight decrease (from 1.49 to 1.44 billion tons) between 2000 and 2020. The SEP forecasts an absolute decrease in fossil fuel material consumption to 1.40 billion tons in 2020.

EU-10 countries.[18] In the business as usual scenario fossil fuel materials consumption decrease slightly from 329 million tonnes in the year 2000 to 314 million tonnes in 2020. This is driven mainly by reductions in the Czech Republic and Estonia. The Low growth scenario shows almost the same results. In the Sustainable Emission Pathway scenario, the fossil fuel materials

[18] “The historical data time series is limited to a relative short period of 8 years (1992-1999). For the historical period 1992-1999, only the Direct Material Input (DMI = domestic extraction + imports) is available for fossil fuel materials, whereas the DMC (= domestic extraction + imports – exports) is projected for the years 2000-2030.” (EEA, 2005: p. 97)

consumption shows a clear and steady decrease from 329 million tonnes in 2000 to 272 million tonnes in 2020.

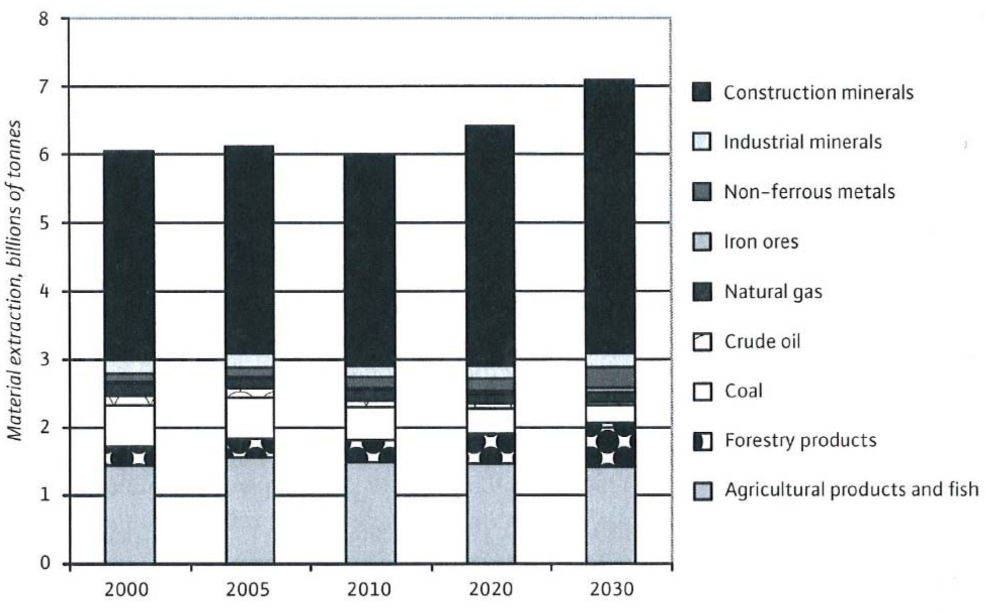
4.4.2 Scenarios of future European and global material extraction by Giljum et al. (2008) and Lutz and Giljum (2009).

This group of scenarios is based on the GINFORS[19] model, a multi sector, multi country, macro-econometric model with global coverage. This economy-energy-environment model combines econometric-statistical analysis with input-output analysis and is extended by a worldwide database on material input. The scenarios are based on assumptions concerning population development, economic growth, energy consumptions and emission development according to national and international projections. Resource supply restrictions were considered only in the case of fossil fuels. Physical flows are presented only for resource extraction in the published material. A first set of scenarios was published in 2008 (Giljum et al., 2008) and an updated version by Lutz and Giljum (2009). Scenarios are provided for a business as usual case; Giljum et al. (2008) also provide scenarios for more sustainable materials use. They assume EU environmental policies (policy goals and measures) and investigate their effect on European and worldwide material use. Here we focus on the updated version of Lutz and Giljum (2009).

<u>Business as usual up to 2030 - used material extraction (domestic material extraction)</u>

According to the business as usual scenario the total used domestic extraction in the EU-25 will increase moderately from 6 to slightly above 7 billion tons (Figure 41). Also according to this model, the stabilization of resource extraction in the EU observed during the last decade ends and a new dynamic of growth sets in.

Figure 41: Used domestic extraction in the business as usual case in EU-25, BASE



Source: Lutz and Giljum, 2009

Extraction of forestry products, non-ferrous metals and construction metals show major increases in the projections for the EU-25, whereas the extraction of fossil fuels declines, which is mostly due to the assumed supply restrictions (see Figure 41).

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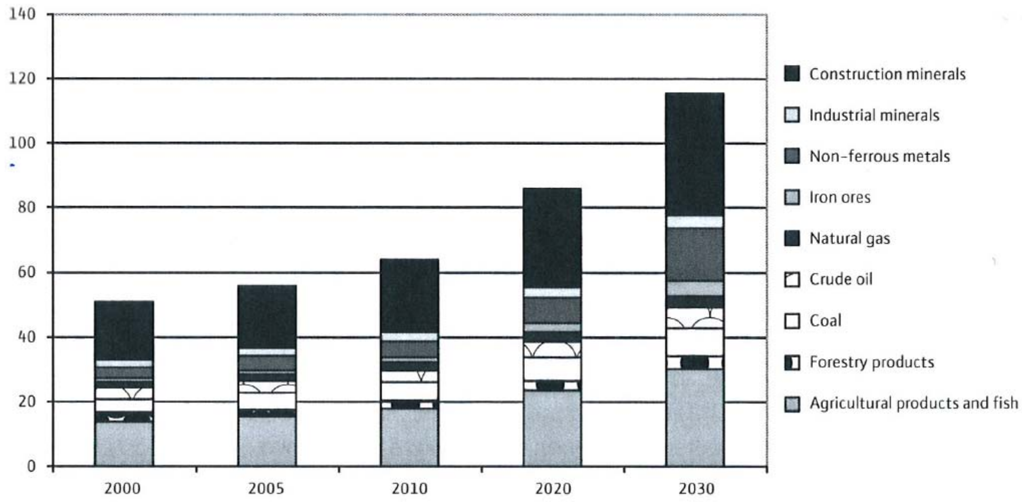
[19] GINFORS (Global INterindustry FORecasting System model).

In contrast to the European projection, the development at the global level (see Figure 42) is characterized by drastic increase. Very high growth rates are forecasted for metals (with high production growth in emerging economies and high extraction growth in other parts of the world) and for the material extraction for agriculture and construction, which are forecasted with annual growth rates of about 2.6%. Overall, global materials extraction is projected to more than double between 2000 and 2030 to 115 billion tons.

Figure 42: Global used material extraction in the business-as-usual case (billions of tonnes)

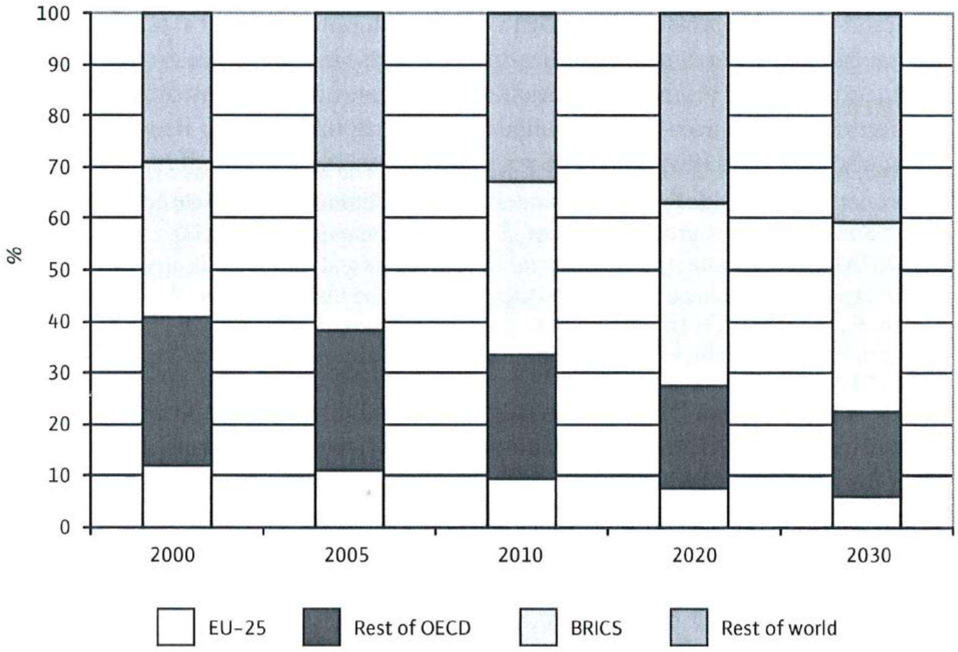


Source: Lutz and Giljum, 2009

According to the business as usual scenario the share of the EU-25 of worldwide material extraction will decline by roughly 50% in the period 2000 to 2030. The same is foreseen for the OECD countries. In contrast to the high industrialised countries, the BRICS[20] countries and the "rest of the world" will increase their share from almost 40% in 2000 up to almost 80% in 2030 (see Figure 43). This indicates, that the significance of material imports into the EU and its draw on global resources compared to domestic resources will continue to increase in this scenario.

[20] BRICS countries = Brazil, India, China, Russia and South Africa.

Figure 43: Global used material extraction for country groups in the business-as-usual case



Source: Lutz and Giljum, 2009

<u>Business as usual up to 2020 by Giljum et. al. (2008) – extraction rates</u>

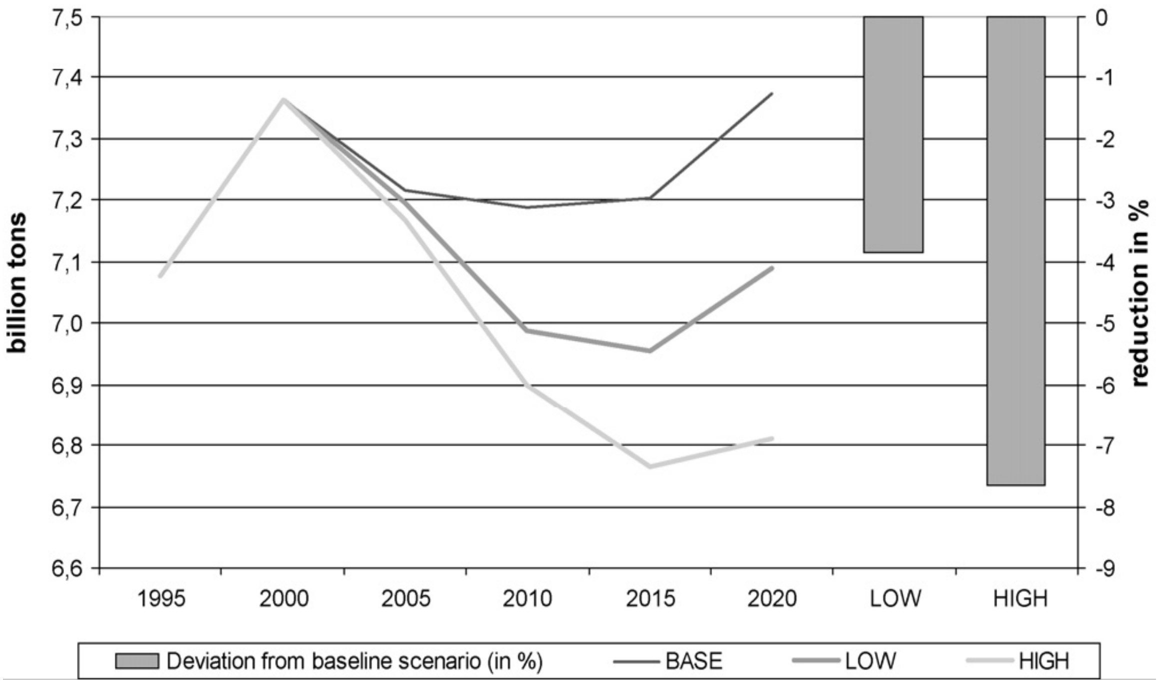
In an earlier version of scenario runs with the GINFORS model, Giljum and colleagues (2008) arrive at similar results: Global extraction rises to more than 80 billion tons in 2020. Metal ores are expected to show the highest grow rates. Extraction rates (DE/capita)[21] are forecasted to increase up to 32 tonnes in the group "other industrialised countries" (from around 28 tons in 1995) due to high extraction rates in Australia, Canada and the US. The highest grow rates – about 60% -are projected for the group Anchor countries due to rapid economic growth and less population growth compared with other developing countries). Europe shows stable rates (10 tons/capita/yr), the country group "rest of the world" show increases from around 8 tons in 1995 to 10 tons in 2010.

<u>LOW and HIGH sustainability scenarios up to 2020 (Giljum et. al 2008)</u>

The results of both the LOW and HIGH sustainability scenario show, that European policy measures might have positive effects on European material use in terms of reduction of the DE (see Figure 44). They do not have strong (positive) effects on global material use: 1% reduction is forecasted in the LOW scenario, 2.1% in the HIGH scenario compared to 1995. The study concludes that these moderate effects results from negative effects by the policy measures on trade volumes.

[21] The global average per capita metabolic rate in the year 2000 is somewhere between 8.0 tons Behrens et al., 2007, Krausmann et al., 2009 and 10 tons Krausmann et al., 2008b of annual resource use.

Figure 44: Used domestic extraction in the EU-25, three scenarios, 1995–2020



Source: Giljum et al., 2008

The authors point out, that both sustainability scenarios indicate positive effects on economic performance with increasing real GDP per capita in the EU-25. Economic growth is strongest between 2015 and 2020, with direct consequences for material extraction, in particular of construction minerals. This result is mainly driven by strong positive effects on growth through productivity gains.

4.4.3 Scenarios of future global material use by Fischer-Kowalski et al. 2010

Based on detailed material extraction data for the year 2000, three scenarios for global materials extraction in 2050 have been calculated (Figure 45)[22]. The scenarios are forced future scenarios assuming different trends of contraction (industrialized countries) and convergence (developing countries) for per capita material use (so called metabolic rates) and population development. In addition to a business as usual scenario two scenarios with a more sustainable resource use based on the idea of "contraction & convergence" put forward in the climate debate (GCI, 2003) have been developed.

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

[22] The year 2000 was used as a baseline, as it best reflects a metabolic equilibrium that had dominated the 25 preceding years (see section 3.2) 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).

Table 7: Overview of 3 scenarios of future global material use compared to 2000

	Baseline 2000	Freeze and caching up	Moderate contraction and convergence	Tough contraction and convergence
Global metabolic use [billlion t/year]	50	140 (more than tripling)	70 (about 40% increase)	50 (constant)
Global metabolic rate [t/cap/yr]	8	16	8	6
CO_2 [tons/capita /yr]		3.2	1.6	0.75
Global emissions [GtC/yr]		28.8	14.4	6.7
Implications for industrialized countries		maintaining the resource consumption patterns	substantial structural change	reduction of metabolic rate by factor 3-5
Implications Developing countries		an increase of metabolic rates by a factor 1.2 to1.3	doubling of metabolic rates	10-20% reductions of metabolic rate

Source: based on Fischer-Kowalski et al. (2010)

<u>Scenario 1: Business as usual - Freeze (industrial countries) and catching up (developing countries)</u>

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 global material use described above (see Figure 43 “Global used material extraction in the business-as-usual case”) and trends observed in the past decades (Krausmann et al. 2009):

Results:

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[23], 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)

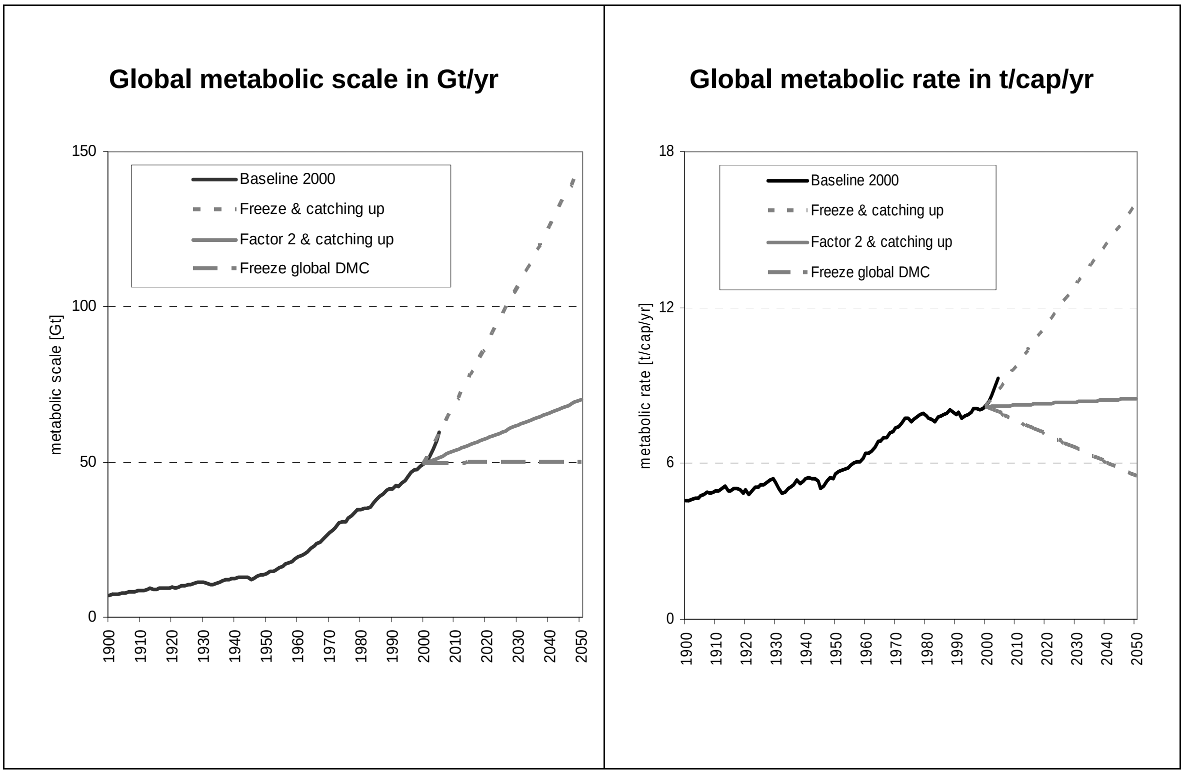
In this scenario, the level of global consumption of primary resources in 2050 is limited to equal the global resource consumption of the year 2000; industrial and developing countries converge in their metabolic rates. This scenario requires the industrialized countries to reduce their metabolic rate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

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

Figure 45: Projections of resource use up to 2050: three forced future scenarios



Source: Fischer-Kowalski et al. 2010

Scenario interpretation:

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 (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, 2008d) 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.[24] In either case, this scenario would require substantial economic structural change.

[24] 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

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.

5 Resource productivity

5.1 Summary: Resource Productivity

Resource productivity (RP) is a ratio measuring the economic output per resource input: the higher the RP, the more economic wealth is produced per unit of resource use. RP is an indicator of *relative decoupling*. A high level of RP can be achieved at high levels of resource use, and progress in RP can accompany increases in resource use. It is thus meaningless to discuss progress in RP without corresponding information on economic growth: absolute dematerialization happens only when RP growth is larger than economic growth. Accordingly, since the EU Lisbon strategy calls for 3% annual economic growth, RP growth needs to be at or above that level simply to stabilize resource use levels.

Individual countries in the EU-27 have experienced growth in RP larger than their GDP growth, leading to absolute dematerialization – but in the vast majority of cases, this was for economic growth rates below 2%. In general, in Europe, high economic growth is still correlated with increases in resource use. Absolute decoupling will thus require actions beyond business as usual, and beyond the "best performance" of most countries.

There is an ongoing debate on whether higher RP is correlated to income or to competitiveness in the EU. We find that material productivity in the EU-27 is significantly correlated to income, but only weakly to competitiveness (and the correlation with competitiveness disappears when both income and competitiveness are considered). Thus countries with larger RP may simply benefit from richer economies rather than being more environmentally efficient.

At the global level, RP is strongly correlated to income. This can be explained by the "inelasticity" of resource use: the more inelastic a resource, the stronger the correlation of RP with income. The challenge of maintaining RP growth at or above economic growth rates can also be expressed in terms of the income elasticity of resource use. The resource elasticity should drop and eventually become negative at higher incomes (as in an Environmental Kuznets Curve), in contradiction with past evidence and present trends.

The conclusion of this analysis is that aggressive and ambitious measures far beyond the usual promotion of technical efficiency need to be pursued in order for reductions or even stabilization in resource use levels to be achieved.

The goal of increases in productivity which are on par or above economic growth is certainly laudable. However, it constitutes a departure from the business-as-usual of EU economies: a more

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.

significant departure than has perhaps been acknowledged to date. Increases in resource efficiency are generally translated into further economic growth through macro-economic rebound effects: effectively, increases in resource productivity constitute increases in factors of production in the economy. New sustainability measures will have to be wide-ranging indeed to overcome this normal phenomenon of market economies.

What is thus required is sweeping changes in the operation of EU economies:

- The most resource-efficient technology must be systematically implemented (and non-efficient technologies need to be phased out faster than their normal lifetime);
- Long-lasting infrastructure choices, such as urban and regional planning, transportation networks and grid/distribution infrastructure, need to be made explicitly in such a way as to reduce future resource use (denser cities, freight by rail rather than road, public transit rather than private, and so on);
- The very structure of economic transactions should be reoriented to favour resource savings. The type of economy where profits are made from resource savings rather than resource throughput is known as a "performance economy" and it requires fundamental changes in financing, insurance, legal and other regulatory and contractual frameworks for its implementation;
- Beyond these measures promoting more resource efficient technologies, infrastructure investments and economic transactions, significant reductions in resource use will likely require further measures, such as carbon taxes and quotas (possibly extended to other key resources).

5.2 Resource productivity as a sustainability metric

Resource productivity (shortened here as **RP**) is defined as the ratio of economic output (usually Gross Domestic Product, GDP) and resource input (usually materials or energy in tons /joules).

(Eq. 1) $$\mathrm{RP} = \frac{\text{Economic output (GDP)}}{\text{Resource input}}$$

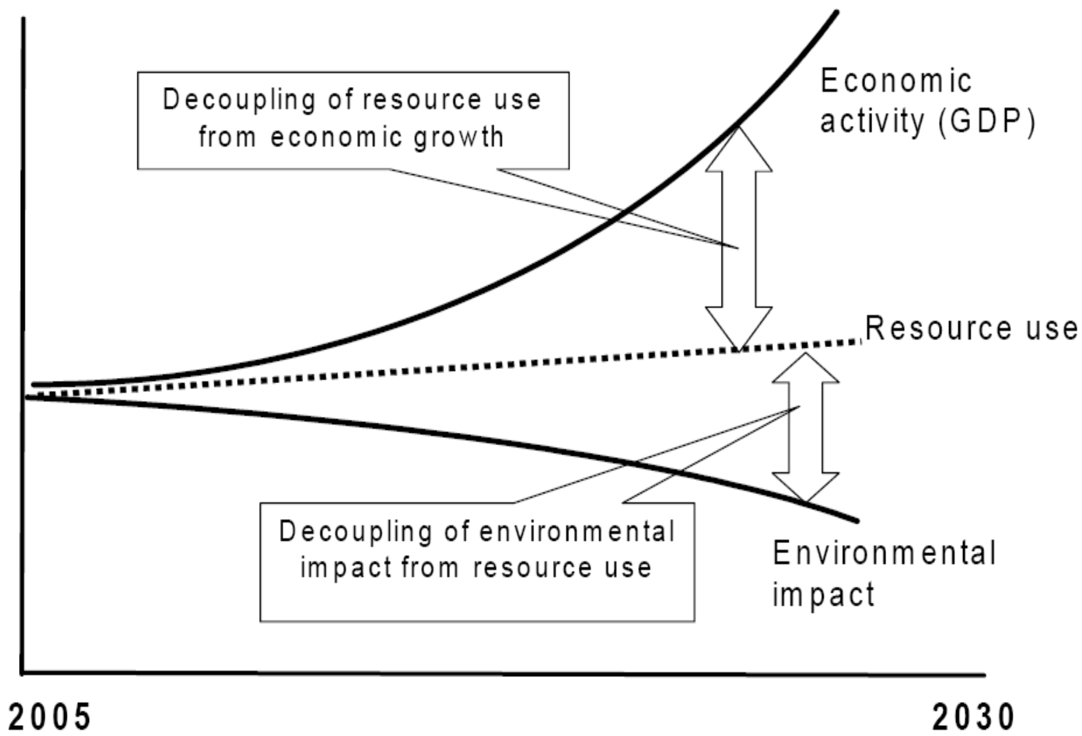
and its units are typically €/kg or €/MJ. RP is the inverse of resource intensity (resource/GDP), which is measured in kg/€ or MJ/€. Resource intensity is also sometimes called "resource efficiency." All of these terms (resource productivity, intensity and efficiency) are used in the literature and policy documents. In this report, we present our findings in terms of resource productivity.

RP can be estimated for various types of resources, at various levels of the economy (product, firm, industry, economic sector, whole economy). RP studies often also consider energy productivity and carbon or greenhouse gas emissions productivity. In general, we do not expect all resources to exhibit the same behaviour with the economy, and one should be cautious in attempting to extrapolate the results from one type of RP to another. In this report, we address the macroeconomic level (whole economy GDP) and focus on material productivity: the ratio of economic output to material use.

RP combines two of the three traditional "pillars of sustainability": economic and environmental (the third pillar is concerned with social aspects) (World Commission on Environment and Development, 1987), and can thus be seen as a comprehensive sustainability measure. In the European Environmental Agency's DPSIR framework (EEA, 2000; EEA, 2002), which divides environment-society interactions into Drivers, Pressures, State, Impacts and Response, resource use is seen as a Pressure, whereas economic activity is a Driver (Stanners et al., 2007). In the context of the DPSIR framework, RP can be seen as an indicator of the balance between a society's economy and its pressures on the environment, and can measure the progress towards decoupling economic growth from negative environmental effects. It is thus understandable that RP is often considered a key indicator of sustainable development. In this interpretation, an increase in RP would be interpreted as "more sustainable," or progress towards decoupling.

RP is central to the EU's main policy document on resource use, the "Thematic Strategy on the Sustainable Use of Resources." (Commission of the European Communities, 2005). According to the Thematic Strategy, "The overall objective is therefore to **reduce the negative environmental impacts generated by the use of natural resources in a growing economy** – a concept referred to as decoupling. In practical terms, this means reducing the environmental impact of resource use while at the same time improving resource productivity overall across the EU economy." The Thematic Strategy is based on the concept of "double decoupling": decoupling resource use from economic growth, and decoupling environmental impacts from resource use (see Figure 46). As described in Section 3.6 of this report, the decoupling of resource use from environmental impacts is far from evident, making the decoupling of resource use from the economy all the more crucial.

Figure 46: Schematic of the double decoupling concept proposed by the EU Thematic Strategy on sustainable use of resources

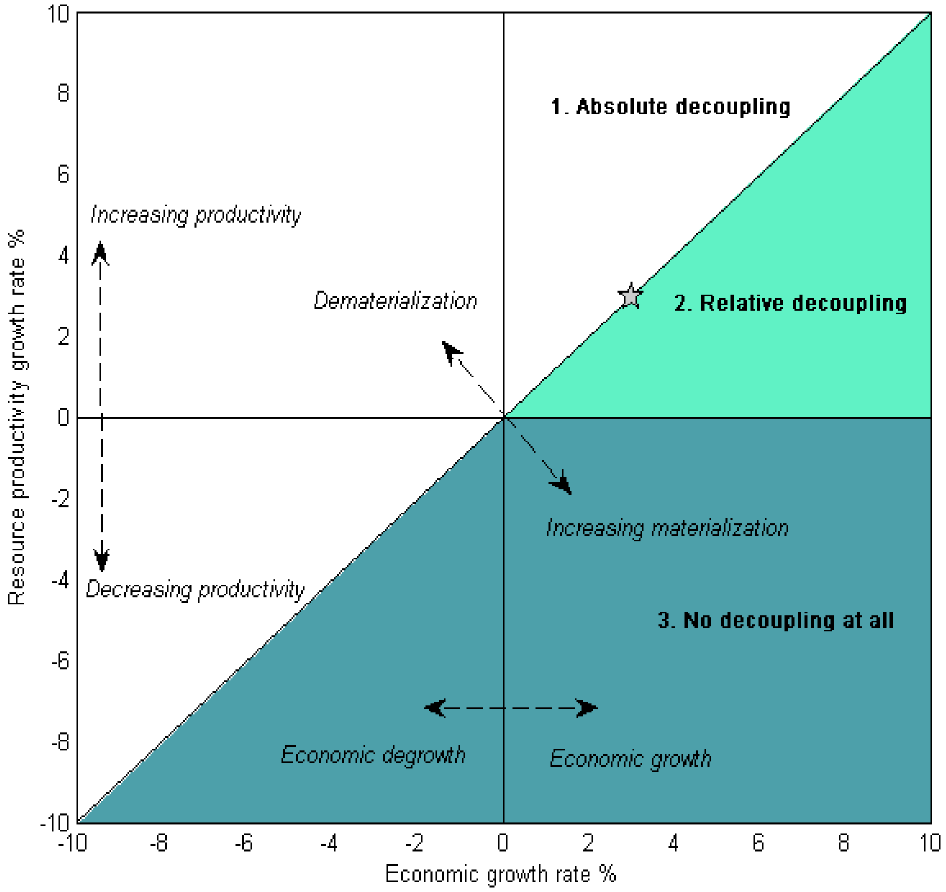


Source: Commission of the European Communities, 2005b

RP is indeed an indicator of decoupling of resource use from the economy. However, as many critics have pointed out, considering RP alone provides an incomplete picture. RP effectively measures the average resource use required for an increment of economic activity. When it increases, it is a sign of *relative* decoupling of the economy from the environment: not absolute. This can be easily understood from Eq. 1. If the GDP growth rate is x% a year, and the RP growth rate is y%, the condition on total resource use decreasing is that y% > x%: that the growth rate of RP is larger than economic growth. The policy goal described in the annexes of the Thematic Strategy on the sustainable use of natural resources is of 3% economic growth and 3% productivity growth, resulting in a constant level of resource use. These growth rates are shown schematically in Figure 47, where it is clear that increases in productivity are compatible with increases in resource use – and that decreases in productivity are possible with decreasing resource use, depending on the level of economic growth they are associated with.

Figure 47: Economic growth (horizontal) and resource productivity growth (vertical) and their effect on decoupling.

If there is positive economic growth, there is only absolute decoupling in the white area (1), otherwise relative decouple in the light green area (2) or no decoupling in the dark blue area (3). The 2005 policy goal of the EU is shown as a star: 3% economic growth (Lisbon Strategy) and 3% resource productivity growth (Thematic Strategy on the sustainable use of natural resources)



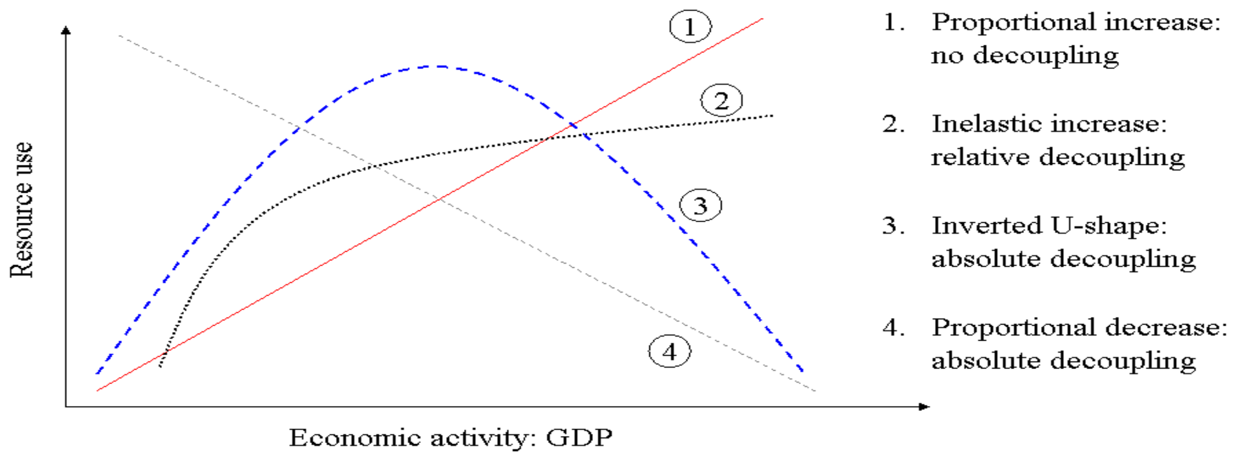
In this sense, we can see that RP growth is merely a measure of *relative decoupling*, or *weak sustainability*, if it is lagging behind economic growth. RP is an indicator of *absolute decoupling*, or *strong sustainability*, only when its growth dominates that of the economy. This distinction between absolute and relative decoupling was already made by the OECD in 2003. Mathematically, the relation between economic growth, RP and absolute vs. relative decoupling can be written as:

$$
\text{(Eq. 2)} \quad \begin{aligned} &\text{growth(Resource use)} \approx \text{growth(GDP)} - \text{growth(RP)} \\ &\Rightarrow \text{Relative decoupling: growth(GDP)} > \text{growth(RP)} > 0 \\ &\Rightarrow \text{Absolute decoupling: growth(GDP)} < \text{growth(RP)} \end{aligned}
$$

These correspond to the different regions shown in Figure 47.

In fact, RP can only be a measure of absolute decoupling if the economy is somehow in a regime where economic growth and resource use decrease go together. Figure 48 shows some of the most basic functional relations between resource use and economic activities. Curve 1 has a constant RP and no decoupling at all: resource use is simply proportional to economic growth. Curve 2 has an RP which grows with the economy, but corresponds to relative decoupling only, whereas curve 4 demonstrates absolute decoupling. Curve 3 is an Environmental Kuznets Curve (EKC): absolute decoupling occurs only above a certain economic level.

Figure 48: Basic functional relations connecting resource use and economic activity



Source: After Wilkinson et al., 2007

In fact, proportional resource decrease with economic growth (curve 4) typically corresponds to a resource which is abandoned at higher incomes (for instance dried animal dung for heating and cooking), but is replaced by a higher quality resource, like kerosene or electricity (curves 1 or 2). Thus curve 4 type behavior should be viewed with caution: it may simply correspond to the substitution of a lower quality resource by a higher one (also known as "transmaterialization" (Labys, 2002)). Moreover, curves 2, 3 and 4 can all be evidence of resource use displacement: often richer economies have apparently lower resource use and associated environmental impacts simply because the resource-intensive industries have been displaced to lower income economies.

This has recently been shown to be the case for CO2 emissions of Annex B countries of the Kyoto Protocol (Peters and Hertwich, 2008).

From this brief introduction to the concept of RP, we conclude that this indicator cannot be interpreted in isolation from other information. High resource productivity coupled with a high GDP may well result in more resource consumption than lower resource productivity at a lower level of economic activity. In the following sections, we thus combine RP and other information to gain a more complete picture of the relevance and limitations of this sustainability indicator.

5.3 Past studies relevant to material productivity

In this section, we review the recent literature on RP, focusing on the European debate. Material productivity has been defined as an indicator of (relative) decoupling of the economy from the environment by Eurostat (Bringezu and Schütz, 2001; Eurostat et al., 2002) and the OECD (OECD, 2008a). The EU-wide application of Material Flow Analysis having only been achieved in the last decade, the interpretation and true meaning of material productivity are still open questions.

Initial cross-national EU studies compared the values in RP of different EU countries (mainly the EU-15), and described the changes in material use, GDP and RP between 1980-1997 and 1980 respectively (Bringezu and Schütz, 2001; Eurostat et al., 2002). They noted the distinction between RP improvements and actual decrease in material use (Bringezu and Schütz, 2001) and investigated whether material use per capita followed an Environmental Kuznets Curve (Eurostat et al., 2002). The conclusion of the EKC investigation was that some EU countries had experienced decreases in material use per capita with increases in income, whereas others had increased their material consumption with economic growth. The EU as a whole did not exhibit any EKC behaviour. A follow-up report covering the EU-15 countries for the period 1970-2001 noted large fluctuations in RP over time, with an overall improvement for the EU-15 as whole – which, however, did not translate into absolute material decoupling (Weisz et al., 2005).

The best shape to fit the relation between material input per capita and GDP per capita was investigated for many EU countries by Bringezu et al. (2004). They did not find conclusive evidence of a particular functional shape. Perhaps this is not surprising, since it has been suggested that industrialized countries will tend to undergo phases of dematerializing and rematerializing over time (De Bruyn, 2002).

5.4 The current debate: resource productivity, income and economic competitiveness

A more systematic investigation of the links between RP and socioeconomic factors was conducted by van der Voet et al. (2005b). They found that there were great disparities between European countries in RP, if the GDP was taken in Market Exchange Rate (MER) euros, with the eastern European and Baltic states having very low RP, but that using Purchasing Power Parity (PPP) euros reflected more comparable values of RP. As they point out, resource use should be compared to the consuming power of the economy, which is reflected by PPP rather than MER monetary values. Accordingly, we use PPP economic values throughout this report.

van der Voet et al. (2005b) then proceed to investigate the socioeconomic factors underlying the variations in RP at the EU level. They find that "around half the variation in resource efficiency can be attributed to the structure of the economy and per capita GDP levels (measured in purchasing power parities)." This has significant implications for the policy relevance of RP: wealthier economies, and those with a smaller share of agriculture, extraction and industry, have higher resource productivities. Does this mean these economies are necessarily more sustainable? Many of the high RP performance countries are only demonstrating relative decoupling. Van der Voet and colleagues suggest that countries should be compared on the basis of "benchmarked" RP values, which are corrected for the influence of income and economic structure, to remove the bias favoring rich and service-dominated economies.

Recently, two significant additions to the RP literature were published. The first is an edited volume entitled "Sustainable growth and resource productivity" (Bleischwitz et al., 2009b). The chapter "Decoupling GDP from resource use, resource productivity and competitiveness: a cross-country comparison" (Steger and Bleischwitz, 2009) is of particular interest here (it is partly based on a longer report: Bleischwitz et al. (2009a). Taking data for the EU-15, EU-25, Japan, Turkey and the USA, they contrast Domestic Material Consumption (DMC) per capita in 2000, and changes in material RP (GDP/DMC) between 1980-2004 and 1992-2000. The choice of different time spans is due to insufficient data for various countries. Overall, most countries in their sample experienced growth in RP, with the exceptions of Greece, Lithuania, Portugal (for 1980-2004, not 1992-2000) and the Slovak Republic. They note that, within the EU, the higher RP of the EU-15 goes hand in hand with higher material consumption, but they still conclude that "Despite the higher consumption in the EU-15, energy and raw materials are used more efficiently in the new EU member states [...]." In this chapter, RP is thus interpreted as an indicator of the economic efficiency of material use, and higher RP to a higher efficiency which the new member states should aspire to ("potential for increasing the resource productivity"). They also point out "the need for addressing the absolute level of resource use," but without facing the apparent contradiction of attaining a high RP without the increase in material consumption. They note that that some countries achieve a high RP with lower material consumption, whereas others have high material consumption but still higher GDP.

Steger and Bleischwitz (2009) then contrast RP values with national measures of economic competitiveness according to the World Economic Forum, and note that these are positively correlated: in general, high RP is accompanied by higher competitiveness. However, they do not consider the correlation of RP with income or economic structure as measured by van der Voet et al. (2005b), which is a considerable oversight. In the longer report (Bleischwitz et al., 2009a), Bleischwitz and colleagues investigate drivers of RP, and come up with a mix of sectoral and other variables which explain differences in RP in the EU-15 from 1980 to 2000 (8 variables) and EU-27 from 1992 to 2000 (7 variables). It is not clear if they consider income as an initial variable in their model, and also unclear how this analysis ties in with either the competitiveness metric or income.

The second report is "Resource productivity, competitiveness and environmental policies" by De Bruyn et al. (2009). They first discuss the concept of resource efficiency and competitiveness at the firm level, which is known as the "Porter hypothesis": the idea that a resource efficient firm will tend to gain a competitive advantage. This hypothesis is extrapolated to the national level by De Bruyn and colleagues, but it is far from clear that the Porter hypothesis withstands the leap in scale from the firm level to the national level.

At the national level, resource use is influenced by larger and more complex forces than for a single firm. For instance, the macroeconomic "rebound effect" explains how resource efficiency improvements at the firm level may in fact translate to cheaper goods and increased aggregate demand (hence more resource throughput overall) (Hertwich, 2005; Herring and Roy, 2007). Moreover, technical efficiency improvements are a factor of economic growth (Warr et al., 2010; Ayres et al., 2007; Ayres et al., 2003): efficiency improvements overall drive economic growth (and hence a larger scale of economy-driven resource use). In this understanding, national increases in resource productivity would tend to lead to growing economies: not reduced resource use. Superficially, the economies may be more "efficient" in terms of higher RP – at a larger level of resource use.

De Bruyn and colleagues then criticize the relation between competitiveness and RP observed by Steger and Bleischwitz (2009). They use energy productivity (GDP/primary energy) to show that a simultaneous regression taking into account both income and competitiveness finds only income to be significant. Although it is helpful to have such a direct comparison between these two hypothesized drivers of RP, it is not clear that energy productivity will behave in the same way as material productivity in this respect. Moreover, it is not clear which countries are used in comparing energy productivity, income and competitiveness.

To summarize, there is an ongoing, decade-old research effort focused on first consistently measuring material flows of European countries, and then on systematically understanding the links between the physical economy. However, there is some confusion regarding the potential links between RP and economic activity: is higher RP a competitive advantage, or simply linked to higher income levels? We will attempt to settle this question, at least for the EU-27, further on in this report.

5.5 Description of the data used in this study

Our productivity overview takes into account diverse datasets, which are summarized in Table 8.

Table 8: Description and sources of the datasets

Geographical area	Source	Time coverage	Material categories
EU-15	Eurostat	1970-2004	1. Total 2. Biomass 3. Fossil fuels 4. Minerals
Global *	SEVI global material flow data v2.0b http://www.uni-klu.ac.at/socec/inhalt/1088.htm	2000	
EU-27 + Norway and Switzerland	Eurostat	2000-2005	1. Total 2. Biomass 3. Fossil fuels 4. Construction minerals 5. Ores/Industrial minerals

* Note: the global dataset used here is derived purely from biophysical data and estimations (without derivations based on economic status, for instance). It is internally consistent, but not directly comparable to the other datasets. In particular, for the global dataset, construction minerals are a conservative estimate and around 30% smaller than the value measured by other methods (Steinberger et al., 2010).

Since the datasets have different geographical, temporal and material flow coverage, we will use each one of them for a specific purpose.

<u>EU-27 + Norway and Switzerland</u>

This dataset is the most interesting from a geographical coverage perspective for the EU, but it has very little time coverage. It will thus be used mostly to showcase cross-country differences and short-term trends.

<u>EU-15</u>

The EU-15 Eurostat dataset has the best time coverage, and can thus be utilized to investigate the evolution of material use, material productivity and economic performance of the EU-15 over several decades. We will also single out a few individual countries with outstanding performance in terms of their productivity growth, decline, materialization or dematerialization.

Global

The global dataset allows us to understand EU productivity in an international context.

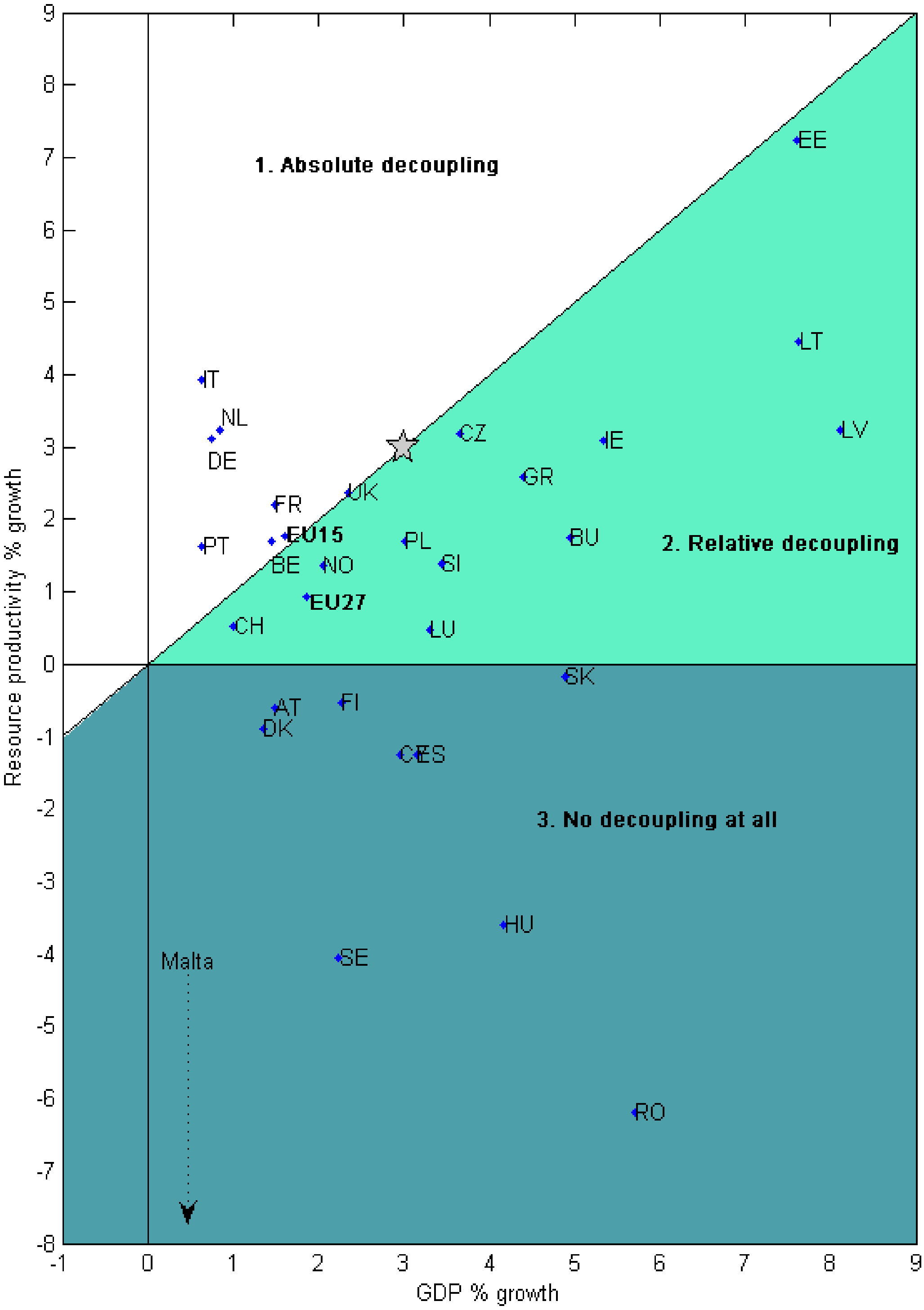
5.6 Material productivity in the EU-27 + Norway and Switzerland

The data for the EU-27, Norway and Switzerland is only available for 2000-2005. In Table 9, we summarize some of the most important parameters. We show both total (extensive) and ratio (intensive) values, and their average yearly growth. As we explained above, for reasonable growth values (i.e. excluding Malta and Romania), growth in productivity is approximately economic growth minus DMC growth.

Economic and productivity growth factors are compared in Figure 49, which also shows the areas of increasing and decreasing material productivity, and absolute dematerialization. In the period 2000-2005, 6 countries demonstrated absolute dematerialization: Belgium, France, Germany, Italy, the Netherlands, and Portugal. The EU-15 countries as a whole experienced slight dematerialization. In contrast, 11 countries of the EU-27, the EU-27 as a whole, and Norway and Switzerland only demonstrate relative decoupling (material growth), and 10 of the EU-27 countries showed no decoupling at all, with double digit material growth seen by Romania and Malta (although Malta is so small that large fluctuations are expected simply due to scale effects).

Perhaps more troubling, there is quite a good systematic trend between economic growth and material growth (R2 = 0.49), implying that economic growth and material growth are NOT decoupled or in the process of decoupling in the EU. The dematerializing countries are also those with the smallest economic growth. This raises important, critical questions for the "double decoupling" concept on which the EU thematic strategy for sustainable resources is based (see Figure 40 above).

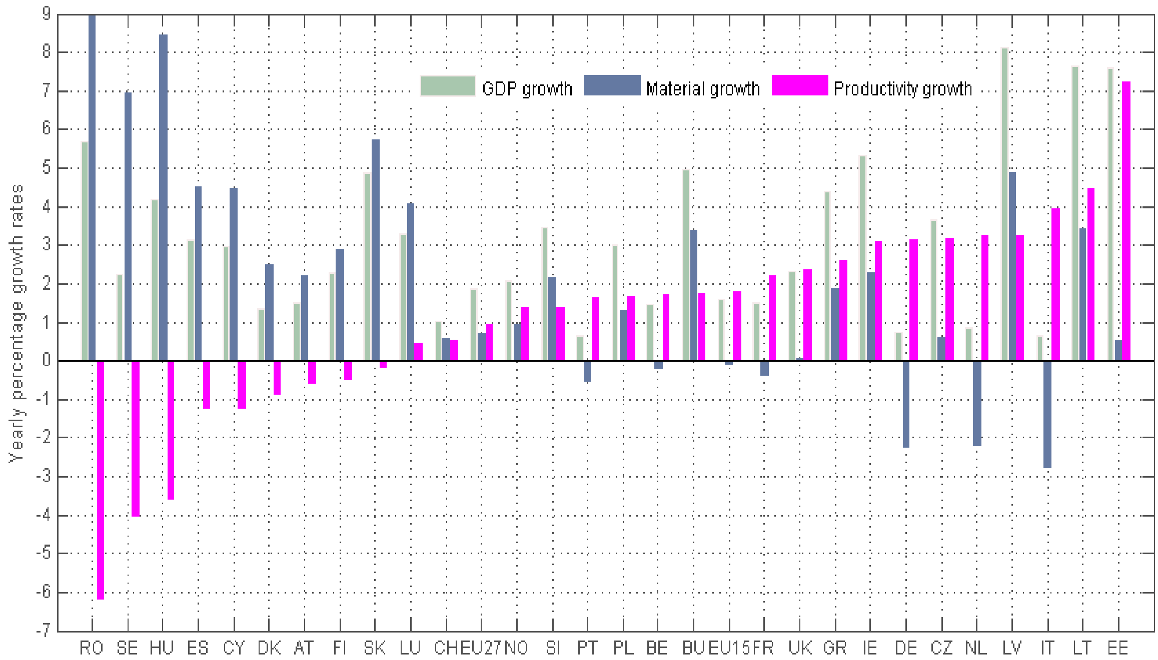
Figure 49: Productivity vs. economic growth in the EU-27 (yearly growth averages 2000-2005)



The combined economic growth and resource productivity policy goal of the EU is shown as a grey star. See Table 9 for the data and list of country codes and names.

The EU-27 countries and their GDP, material and productivity growth rates are shown as a bar chart in Figure 50, ranked by the magnitude of their productivity growth. It is clear that (1) productivity growth is just economic growth minus material growth, and that (2) the productivity growth is seldom associated with negative material growth, and that when it is, economic growth tends to be moderate.

Figure 50: EU-27 countries plus Norway and Switzerland, ranked by productivity percentage growth rates (averages 2000-2005). Romania's material growth is 16.6%, and Malta is not shown.



5.7 Settling the RP, competitiveness and income debate for the EU-27

The recent debate between Steger and Bleischwitz (2009), on one hand, and de Bruyn and colleagues (2009) on the other, is a crucial one for understanding the implications of RP as a sustainability metric for Europe. Is RP linked to income, competitiveness, or both? Do material and energy productivity behave similarly in this respect? In order to bring some clarity to the discussion, we have reproduced their analysis with a set of consistent data, for the year 2005, and the countries of the EU-27 plus Switzerland and Norway, and both energy and material resource use. We have consistent time, geographical and data source coverage, and can conduct a rigorous and comparative analysis.

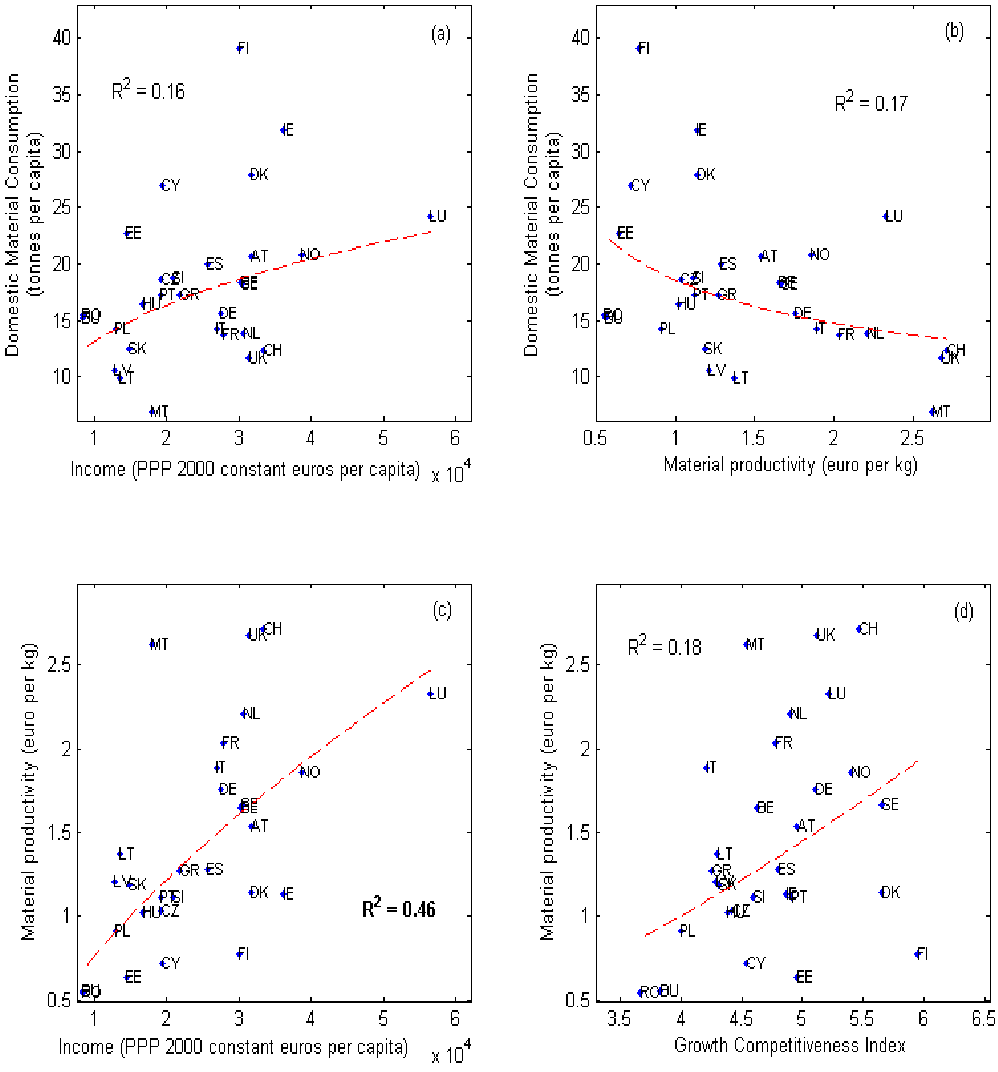
Our data sources are the following:

- Domestic Material Consumption (Eurostat)
- Total Primary Energy Supply (International Energy Agency)
- Purchasing Power Parity GDP (World Bank World Development Indicators)
- Growth Competitiveness Index (World Economic Forum).

Our results for materials are shown in Figures 51 (materials) and 52 (energy). For materials, there is a weak relation between productivity and competitiveness (fig. 51 (d)), but a very strong relation between productivity and income (fig. 51 (c)), which confirms the result of Van de Voet et al.

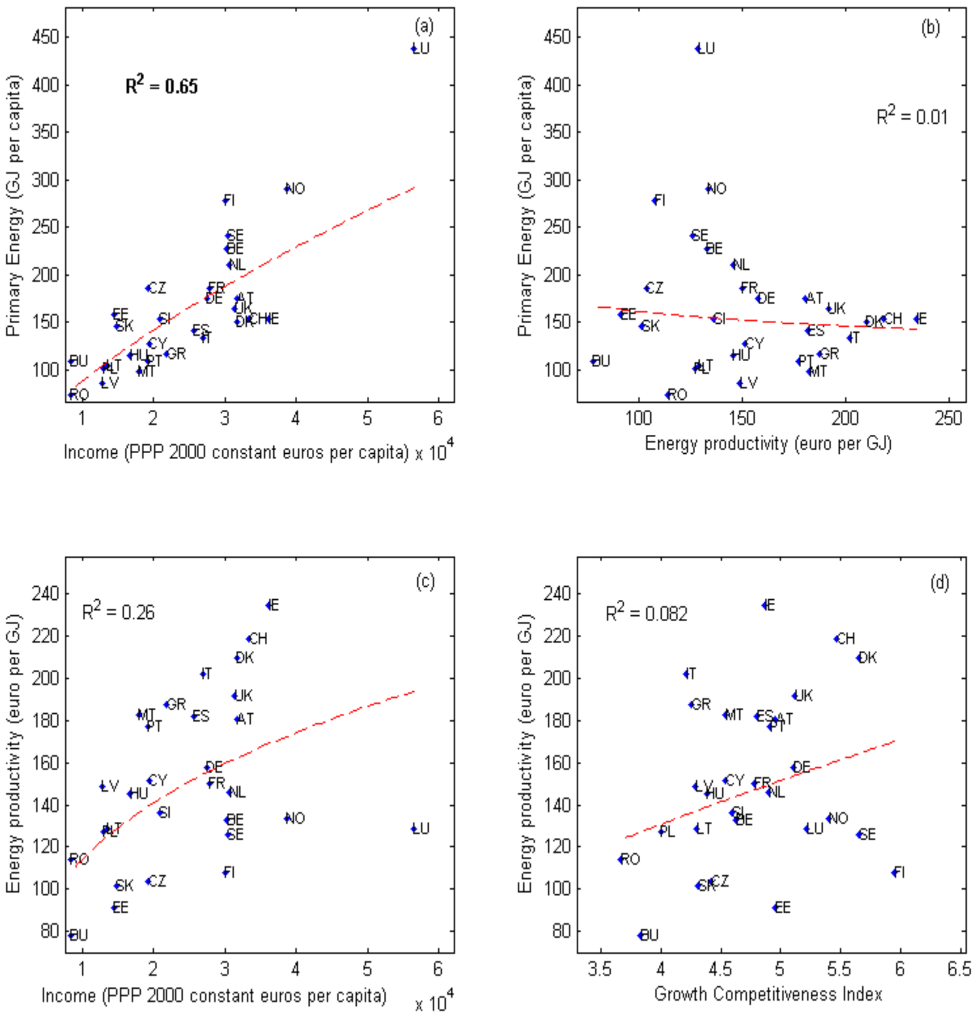
Material consumption per capita is only weakly linked to income or material productivity (fig. 51 (a) and (b)). For energy, the link between productivity and competitiveness is even weaker than for materials, which could be one source of the difference between Steger & Bleischwitz and de Bruyn et al (fig. 52 (d)). Energy productivity is weakly but significantly linked to income (fig. 52 (c)), an effect seen by de Bruyn et al for a larger sample of countries. The strongest correlation for energy is between per capita energy consumption and income (fig. 52 (a)), which is a result often seen in international and time-series studies.

Figure 51: Economic dependence of material use in the EU-27, year 2005: (a) material consumption vs. income; (b) material consumption vs. material productivity; (c) material productivity vs. income; and (d) material productivity vs. competitiveness.



The country name codes are listed in Table 9.

Figure 52: Economic dependence of energy use in the EU-27, year 2005: (a) energy consumption vs. income; (b) energy consumption vs. energy productivity; (c) energy productivity vs. income; and (d) energy productivity vs. competitiveness.



The country name codes are listed in Table 9.

Overall, the findings shown in figures 45 and 46 support the results of Van der Voet and her colleagues: the variation in material productivity among European countries can be largely explained (46% according to our regression) by income alone. These findings also support the conclusion of de Bruyn et al, despite the significant differences between material and energy productivities. Indeed, when we conduct a multivariate regression on the productivity indicator, with income and GCI as independent variables, the only significant variable is income, and GCI is insignificant (has little or no explanatory power), for both energy and material productivity.

The links we find for Europe between material and energy consumption, productivity and income, (figures 45 and 46, (a) and (c)) are in fact consistent with the results of a recent global study on material flows (Steinberger et al., 2010), which showed that fossil fuel consumption had a stronger link to the economy than material consumption as whole, and that material productivity was strongly correlated with income, but that fossil fuel productivity was not. Thus regarding the economic links of material and energy use, and material and energy productivity, the EU-27 countries, with Norway and Switzerland, are consistent with the global trends.

Table 9: Key parameters relevant to material productivity in the EU-27

	Time span	2005			2005			2000-20005			2000-20005		
		Extensive variables			Intensive			Average yearly growth: Extensive			Average yearly growth: Intensive		
		Total DMC *	Population	GDP	DMC per capita	Productivity	Income	Total DMC *	Population	GDP	DMC per capita	Productivity	Income
	Units	*1000 t*	*1000 persons*	*Million 1990 PPP €*	*t per cap*	*€ per kg*	*€ per cap*	*%*	*%*	*%*	*%*	*%*	*%*
AT	Austria	169,189	8,189	259,835	20.7	1.54	31,728	2.20	0.23	1.49	1.97	-0.61	1.26
BE	Belgium	190,772	10,398	315,185	18.3	1.65	30,312	-0.22	0.40	1.46	-0.62	1.71	1.06
DK	Denmark	151,309	5,431	172,308	27.9	1.14	31,729	2.48	0.34	1.36	2.13	-0.88	1.02
FI	Finland	205,135	5,249	157,962	39.1	0.77	30,093	2.88	0.28	2.27	2.59	-0.52	1.99
FR	France	852,441	62,312	1,732,177	13.7	2.03	27,798	-0.42	0.43	1.49	-0.85	2.21	1.06
DE	Germany	1,297,491	82,689	2,275,315	15.7	1.75	27,516	-2.26	0.08	0.74	-2.35	3.12	0.66
GR	Greece	191,799	11,120	243,130	17.2	1.27	21,864	1.87	0.26	4.40	1.60	2.59	4.13
IE	Ireland	132,393	4,148	149,973	31.9	1.13	36,156	2.28	1.76	5.34	0.51	3.09	3.52
IT	Italy	828,531	58,093	1,565,801	14.3	1.89	26,953	-2.80	0.13	0.64	-2.93	3.93	0.51
NL	Netherlands	226,002	16,299	499,523	13.9	2.21	30,647	-2.23	0.50	0.84	-2.72	3.24	0.34
LU	Luxembourg	11,067	457	25,760	24.2	2.33	56,415	4.08	0.89	3.30	3.16	0.47	2.38
PT	Portugal	180,901	10,495	201,642	17.2	1.11	19,214	-0.58	0.52	0.64	-1.10	1.62	0.12
ES	Spain	860,466	43,064	1,104,197	20.0	1.28	25,641	4.52	1.13	3.15	3.36	-1.26	2.00
SE	Sweden	165,080	9,041	274,867	18.3	1.67	30,401	6.95	0.37	2.24	6.56	-4.05	1.87
UK	United Kingdom	699,862	59,668	1,874,667	11.7	2.68	31,418	0.05	0.34	2.34	-0.29	2.38	1.99
BU	Bulgaria	118,070	7,745	65,470	15.2	0.55	8,454	3.38	-0.65	4.94	4.06	1.74	5.63
CY	Cyprus	22,511	836	16,190	26.9	0.72	19,358	4.48	1.24	2.95	3.20	-1.25	1.69
CZ	Czech Republic	190,331	10,192	196,842	18.7	1.03	19,314	0.61	-0.06	3.65	0.67	3.18	3.71
EE	Estonia	30,516	1,344	19,511	22.7	0.64	14,514	0.54	-0.38	7.60	0.92	7.24	8.00
HU	Hungary	165,980	10,086	168,964	16.5	1.02	16,752	8.45	-0.25	4.17	8.73	-3.59	4.44
LV	Latvia	24,290	2,302	29,399	10.6	1.21	12,772	4.86	-0.66	8.12	5.55	3.24	8.83
LT	Lithuania	33,864	3,425	46,345	9.9	1.37	13,531	3.43	-0.45	7.63	3.89	4.46	8.11
MT	Malta	2,764	403	7,251	6.9	2.62	18,010	40.70	0.70	0.06	39.74	-17.57	-0.63
PL	Poland	543,607	38,196	494,903	14.2	0.91	12,957	1.32	-0.12	3.01	1.45	1.69	3.14
RO	Romania	334,459	21,628	183,555	15.5	0.55	8,487	16.04	-0.47	5.70	16.58	-6.19	6.19
SK	Slovak Republic	67,558	5,387	80,068	12.5	1.19	14,863	5.73	0.00	4.88	5.73	-0.18	4.88
SI	Slovenia	37,540	1,999	41,726	18.8	1.11	20,869	2.16	0.16	3.44	2.00	1.38	3.28
NO	Norway	96,672	4,639	179,333	20.8	1.86	38,659	0.94	0.66	2.06	0.28	1.37	1.39
CH	Switzerland	91,451	7,424	248,175	12.3	2.71	33,427	0.58	0.44	1.01	0.14	0.52	0.57
	EU15	6,162,439	386,653	10,852,340	15.9	1.76	28,067	-0.13	0.38	1.60	-0.51	1.78	1.22
	EU27	7,733,929	490,195	12,202,563	20.0	1.40	24,893	0.71	0.24	1.86	0.33	0.92	1.61

*Note: DMC = Domestic Material Consumption = Extraction + Imports – Exports

5.8 Productivity trends in the EU-15

Material consumption data is available for a longer time for the EU-15 than the EU-27 (since 1970 instead of 2000). We use this data to complement our EU-27 analysis with a longer time perspective. As discussed in 3.2, the EU-15 as a whole shows stagnating material consumption, with some of the larger economies decreasing their material use over the past decades (Germany, the UK, France) and some of the others drastically increasing their material use (Greece, Spain, Portugal, Ireland).

The macro-level trends for the EU-15 and EU-27 relevant to material productivity are shown in Fig. 53 for extensive variables: total DMC, GDP and population, and in Fig. 54 for intensive variables: DMC per capita, income and material productivity.

Figure 53: Macro-trends in the EU-15 and EU-27 for extensive parameters: DMC, population and GDP. The GDP is measured in 2000 constant PPP euros.

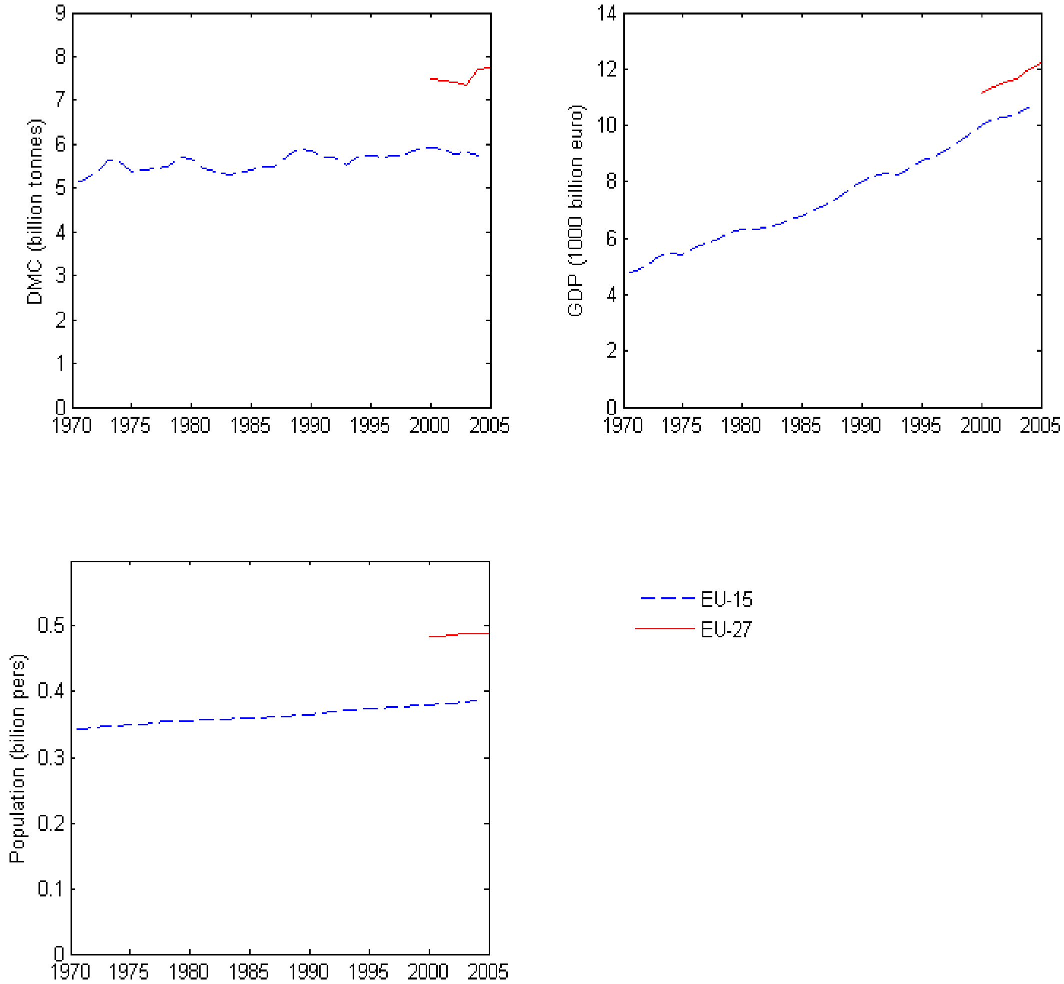
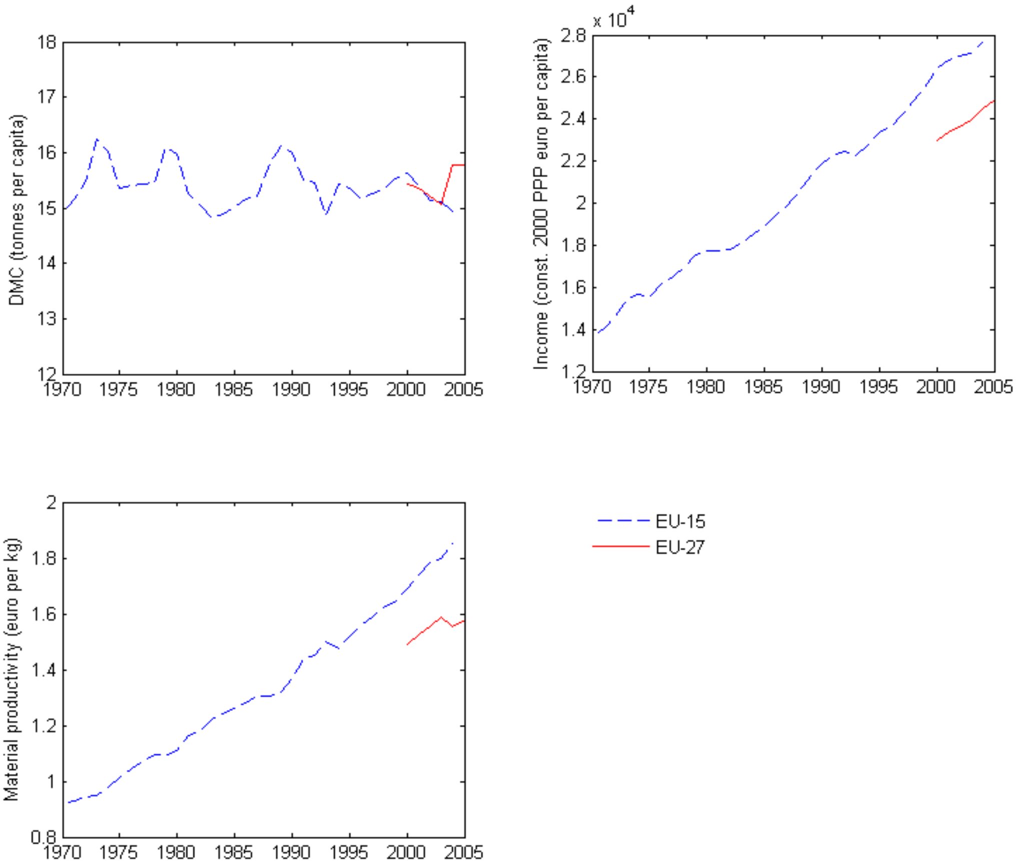


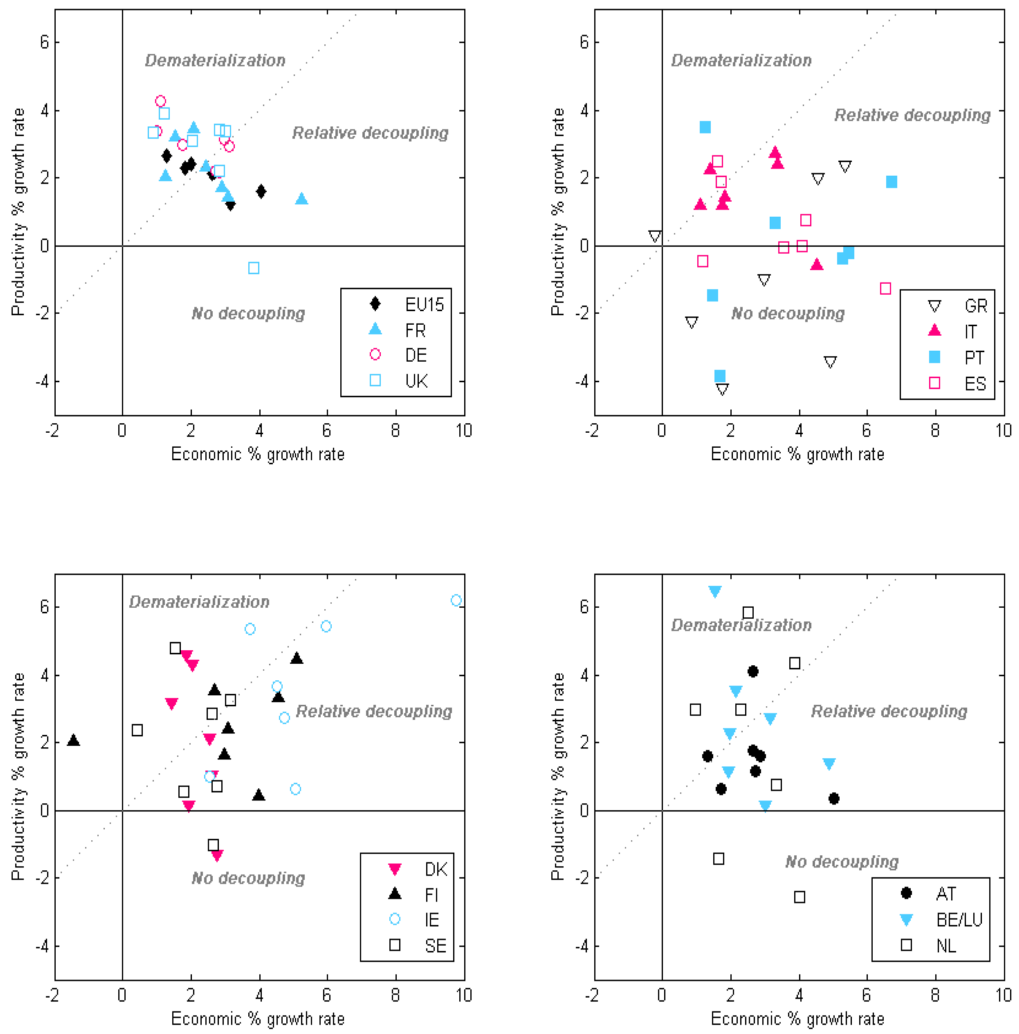
Figure 54: Macro-trends the EU-15 and EU-27 for intensive parameters: DMC per capita, income and material productivity. The GDP is measured in 2000 constant PPP euros.



As can be seen in fig. 54, the level of per capita material use in the EU-15 and EU-27 is remarkably constant, leading to increases in material productivity simply due to economic growth. In sustainability terms, the EU is exhibiting relative decoupling, not absolute dematerialization.

At the country level, the EU-15 have widely differing behaviour. As explained above, changes in RP are best understood when shown in combination with economic growth. In figure 49, we use 5-year averaged growth rates (1970-1974, ..., 2000-2004) to examine productivity and economic growth of the EU-15. Fig 55 is analogue to Figure 49 for the EU-27 and the time span 2000-2005.

Figure 55: Productivity and economic growth rates for the EU-15 (each point represents a 5 year average: 1970-1974, ..., 2000-2004)



The largest countries, France, Germany and the UK, are often in the dematerializing upper right triangle, consistent with their overall dematerialization – but not for the periods of their largest economic growth. The Sourthern European countries, Greece, Italy, Portugal and Spain, are mostly materializing (either demonstrating relative decoupling, as is often the case for Italy, or no decoupling at all, as is most often the case for Greece and Portugal). Interestingly, Portugal was one of the few EU-27 countries showing absolute decoupling in Fig 49, marking the importance of considering longer term trends. The Northern European countries, Denmark, Finland, Ireland and Sweden, are mostly in the relative decoupling area, as are the Netherlands, Belgium/Luxembourg and Austria.

Perhaps the most interesting feature of Fig. 55 is that countries only experience absolute dematerialization when they are at the lower end of their economic growth. Apart from the Netherlands and Ireland, no country experienced economic growth rates of 3% or more while reducing material consumption – and even these two countries did not durably dematerialize. Moreover, the countries which did experience large and consistent dematerialization (France, Germany and the UK) did so by a combination of fuel shifts (moving from coal to oil and gas, or nuclear), and de-industrialization. The fuel shifts may not be available to all in a world where coal is more plentiful than either oil or gas, and the process of de-industrialization generally means that manufacturing activities are displaced overseas – not rendered more efficient. In general, the countries which were dematerializing also had economic grow rates of 2% or below. And the two countries with a period of negative economic growth, Finland and Greece, did dematerialize during that time. It appears from this analysis that resource use and economic activities are still coupled in an absolute sense in the EU-15, even though many countries and the region as a whole has been experiencing relative decoupling for decades.

5.9 International productivity

In this section, we show some results from an international material flow data set for the year 2000, which was constructed based solely on biophysical data and estimations, without economically-derived estimations. The data set and the analysis summarized here are described in more detail in Steinberger et al., 2010. Since the material flows are independent from economic assumptions, they can be correlated with economic parameters. In particular, this data set was used to measure the international economic elasticity of material consumption: the exponent *B* in Eq. 3 (*A* is just a scaling constant).

(Eq. 3) $$\frac{DMC}{capita} = A \cdot \left(\frac{GDP}{capita} \right)^{B}$$

The economic elasticity *B* has the following interpretation:

- if *B* = 1, DMC is *proportional* to income: when income increases by 10%, so does DMC/cap.
- if *B* >1, DMC is *elastic* with income: when income increases by 10%, DMC/cap increases by a larger amount.
- if *B* <1, DMC is *inelastic* with income: when income increases by 10%, DMC/cap increases, but by a smaller amount.
- if *B* = 0, DMC is constant with income.
- if *B* < 0, DMC decreases when income increases.

It can thus readily be seen that *B* corresponds to the slope of resource use in Fig. 48 (curve 1: *B* =1; curve 2: *B* decreasing with income, but positive; curve 3: *B* changing from positive to negative at higher incomes; curve 4: *B* = -1). Indeed, the elasticity does not have to remain constant, but can change at different income levels. However, for international material use, no strong changes in elasticity are seen as a function of income. We can thus measure a single material elasticity for each type of material use. The results are shown in Table 10. The material categories have a large range in elasticities, from very inelastic biomass (0.19) to elastic fossil fuels (1.35).

Table 10: Elasticity coefficients of international material use

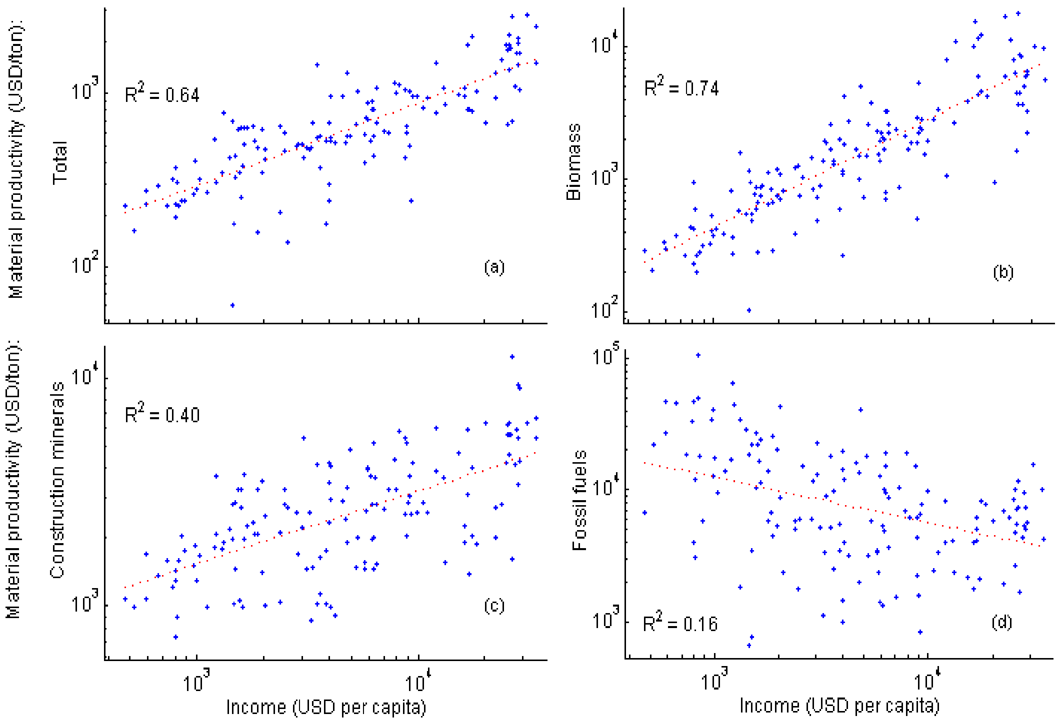
Domestic Material Consumption per capita:	B	Standard error of B
Total	0.52	0.03
Biomass	0.19	0.04
Fossil fuels	1.35	0.07
Construction Minerals	0.69	0.03
Ores/Industrial Minerals	1.01	0.10

The economic elasticity of resource use in fact has profound implications for its productivity, as can be seen from the following simple mathematical relationship (which uses Eq. 3):

(Eq. 4) $$Material\ \ Productivity = \frac{DMC}{GDP} = \left(\frac{DMC}{capita}\right)\cdot\left(\frac{GDP}{capita}\right)^{-1} = A\cdot\left(\frac{GDP}{capita}\right)^{B-1}$$

From Eq. 4, we see that material productivity will be systematically correlated with income unless the material elasticity exponent is 1. In fact, from this analysis, it is *only* in the case of material use which is proportional to income that we expect there to be no correlation of material productivity with income: from Table 10, this would be for ores/industrial minerals and possibly fossil fuels. In figure 56, we show the correlation of international material productivity with income for 4 material categories, and indeed they behave as one would expect from Eq. 4 and the elasticities measured in Table 10.

Figure 56: International correlation of material productivity and income for different material categories



Source : from Steinberger et al., 2010

From this international perspective, the challenge of increasing RP faster than economic growth appears all the more daunting. In order for RP to grow faster than economic growth, the elasticity of material consumption would have to drop from 0.5 to 0 and below, at least for EU countries. It is hard to imagine that this large drop in income elasticity of material use could be achieved without dramatic changes in the very structures and operations of EU economies: it is certainly not going to be attained by simply promoting incremental and small increases in efficient technologies.

5.10 Policy implications regarding material productivity

As a conclusion to this discussion of material productivity as an indicator of sustainable economic development, we can state that the goal of increases in productivity which are on par or above economic growth is certainly laudable. However, it constitutes a departure from the business-as-usual of EU economies: a more significant departure than has perhaps been acknowledged to date.

What is required is fundamental change in the operation of EU economies:

- the most resource-efficient technology must be systematically implemented (and non-efficient technologies need to be phased out faster than their normal lifetime);

- long-lasting infrastructure choices, such as urban and regional planning, transportation networks and grid/distribution infrastructure, need to be made explicitly in such a way as to reduce future resource use (denser cities, freight by rail rather than road, public transit rather than private, and so on, as described in Jaccard et al. (1997);

- the very structure of economic transactions should be reoriented to favor resource savings. The type of economy where profits are made from resource savings rather than resource throughput is known as a "performance economy" (Stahel, 2006) and it requires fundamental changes in financing, insurance, legal and other regulatory and contractual frameworks for its implementation (Steinberger et al., 2009).

6 Resource use and environmental impacts

6.1 Summary

In this chapter, we continue the attempt of reframing the notion of “environmental impacts” started in the introduction. We seek to establish two key links. One link is to earth system and ecosystem services. We feel the conceptualization of the environment in terms of “media” is under-complex and leaves the legitimation of “negative impacts” to policy concerns only. We suggest instead conceiving of the environment in terms of systems that provide human societies with certain services. These services can be put at risk by socio-economic activities (such as resource use), and exactly this may be conceptualized as negative environmental impact. The idea links up to the concept of “ecosystem services” that plays an important role in the Millennium Assessment, for example, and to the “earth systems” that play an important role in climate modelling and policy. We think that much of the more traditional functional references for environmental impacts (toxicity, acidification etc.) can be fairly easily translated into earth system or ecosystem services put at risk by certain socio-economic activities. Such a functional reference would provide with a legitimation for being concerned about the environmental side effects of an activity. The second link should be with resource use (“from cradle to grave”) as a key quantifiable representation of socio-economic activities.

Thus we define (negative) **environmental impacts** *as side effects causally linked to socio-economic activity that put certain earth system / ecosystem services at risk.*

Our next argument builds upon past research experience that environmental impacts can well be identified for specific activities and with reference to specific functionalities (“climate change”, for example), but that it is chronically difficult to aggregate them to plausible and consistently measurable aggregates on higher levels. We therefore suggest making use of the methodological strength of impact identification on lower levels of aggregation to create a strong link to resource use. This should, for each social system (such as a country) of concern, result in impact coefficients that link one unit of resource use (from cradle to grave) to a specific ecosystem service, coefficients for Impacts $_{ij}$, where i refers to a certain resource and j to a certain ecosystem service potentially put at risk. In a next step, we suggest modelling an aggregate environmental impact across all the various resource uses on the system level according to the classical IPAT-formula in a slightly different interpretation.

We see the advantage of this procedure in the potential of delivering reliable aggregate information in time series without the need to monitor impacts in continuous time series (which is chronically difficult, if not impossible. It would nevertheless allow to reflect major environmental policy achievements (such as, for example, the elimination of lead from transport fuels, or the introduction of effective sewage systems, or the shift away from fluorchlorocarbons, or the introduction of CSS) in changes of impact coefficients for certain resource use aggregates. In turn, this would show up, depending on the size of the change, in the aggregate impacts.

In a next step, we review the existing literature linking environmental impacts to resource use. We come up with fairly disappointing results. So far, no comprehensive impact coefficients per unit resource use have been calculated. To our knowledge, no quantitative time series data for environmental impacts exists, not even for specific countries or specific impacts. And finally, the few aggregate impact indicators that have been constructed (EMC, ecological footprint) are criticised for a number of methodological weaknesses.

The final section reviews efforts at targeting resource use and environmental impacts politically. It becomes fairly clear that employing quantifiable targets for overall environmental impacts or for

overall resource use does not look very promising and would be hard to justify. We review one existing effort at reflecting and justifying reasons for a more differentiated targeting of resource use. It could be an interesting exercise to compare this with the efforts of IPCC to manage a targetting process with reference to a specific impact. It would be a separate intellectual effort to compare these two principal strategies (i.e. targeting resource use or targeting impacts, or may be a combination of both), but this effort is beyond the scope of our report.

6.2 What is an environmental impact?

In the past decades, a broad literature on environmental impacts and impact assessment has evolved. Environmental impacts are usually described as impacts on environmental media and impacts on human health. An assessment of environmental impacts is mainly operationalised on the product level in Life Cycle Assessments (LCA) and a definition is found in ISO 14.040 standards where the following seven impact categories are differentiated (Nielsen et al., 2005): acidification, climate change and global warming, ecotoxicity, human toxicity, eutrophication / nutrient enrichment, photochemical ozone formation (summer smog), and stratospheric ozone depletion. From the list we see that environmental impacts considered are “those which are known, well explored and operationalised, and for which statistical information is available.” (Moll et al., 2004, p. 4f) This literature did not, however, converge in a shared understanding of what environmental impacts actually are, how they should be conceived and classified. On the most general level, the notion is shared that environmental impacts are **undesirable changes in the natural environment (or one of its compartments)** that can be **causally linked to some socio-economic activity.** Often this is placed within the traditional DPISR or DPSIR model: driving force – pressure – state – impact - response (EEA, 2000, EEA, 2002).

As the term “undesirable” suggests, there is inevitably some value judgement involved in drawing a distinction between causal effects of socio-economic activities that ought to be considered as relevant (negative) impacts, and other causal effects that need not be considered. And this value judgement, as many authors before have noted (Althaus, 2005, Nielsen et al., 2004, p35f), is historically variable, depending on the prominent environmental problems perceived and policy issues of the time. CFC emissions for example were not considered an environmental problem before the ozone depletion became well-known. Also, environmental problems 40 years ago were quite different compared to current problems. Environmental impacts may occur with considerable time delay which leads to high uncertainty about the effects of substances released to the environment which may occur in 50 to 100 years. Even new impacts can appear that were previously unknown. (EEA, 2005d, p. 59f) Impacts also vary across regions. For very densely populated countries like Japan, wastes and emissions and impacts from these are highly relevant, whereas countries in arid areas may suffer from water shortages, or countries with intensive agriculture observe impacts from eutrophication. In the end, as reviewers of the relevant literature do not fail to note (e.g. Nielsen et al., 2005, p. 25, Hertwich et al., 2009), hardly ever do two different studies select the same environmental impact categories for their lists. Depending on disciplinary background and policy focus, impacts tend to have a strong health/epidemiology inclination, may be dominated by environmental chemistry issues, biodiversity concerns or climate change – to name but a few. With time progressing, lists have a tendency to get longer, but not necessarily more consistent or consensual. A certain pragmatic stability is provided by the key LCA (life cycle assessment) databases that build upon sets of criteria (e.g. ISO 14.040), but they do not necessarily provide the criteria that would be chosen from the point of view of a most recent state of the art. And even when the appearance of comprehensiveness is created, the information behind is rarely as comprehensive as one would like it to be.

The “undesirability” of an environmental impact of a socioeconomic activity always needs to be legitimized, as the socioeconomic activity as such usually pursues desired goals and environmental impacts occur as trade-offs, as unintended side-effects, of in reaching these goals. This legitimacy can be most easily established for cases where there are two or more functional equivalents for pursuing the goal (products, production processes, materials…) that can be compared in terms of their environmental trade-offs. It is indeed broadly accepted that the choice between alternatives should take into account negative side effects. Classical examples of this kind were the choice between plastic or paper bags, and between chloride or ozone bleaching in paper production. If the outcomes of impact assessments are contested, they can be debated impact by impact on this level of complexity.

On higher levels of aggregation, overall impact assessments become increasingly indeterminate. It is no surprise that only few solid conventions could be established in this field despite substantial efforts. Among the difficulties encountered are

- problems of impact selection: which environmental concerns need to be accounted for, on which spatial and temporal level, on which level of causal proximity (e.g. habitat loss or threat for biodiversity)…?
- problems of impact weighting and composing aggregates
- problems of system completeness (potential omissions) and double counting.

Even the few existing high quality studies that made serious attempts at comprehensive solutions (such as van der Voet et al., 2005b, EEA, 2005c) did not come up with fully satisfactory results that would help to establish solid conventions for the field.

On higher system levels and higher levels of aggregation, the purpose of impact assessments changes. It is no more about a choice between two functionally equivalent alternatives, but more about system descriptions. It does not really seem possible, for example, to advise an economy to reduce its agricultural activities and instead focus on, for example, medical and health business, because the latter have fewer environmental impacts.

Could it be a step ahead to accept the qualitative selectiveness of environmental impacts and functionally relate them to the – equally problem-oriented and selective – concept of ecosystem/earthsystem services, as proposed in the introduction?

The notion of ecosystem services came of age conceptually (Daily et al., 1997; Mooney et al., 2009) and policy-wise (Millennium Ecosystem Assessment, 2005) in the past decade, despite sometimes being fairly weakly defined and despite difficulties of quantification. This development may be owed to a change in perspective: seeing the environment not as something potentially threatened by human activity, as something that ought to be protected at least partly on its own account, but as a source of often indispensable benefits to humans. By that change of perspective, the legitimacy of caretaking and preserving future services is implicitly incorporated, and positive thinking about demands on nature is stimulated.

Functionally interrelating environmental impacts and ecosystem services would make use of and harvest the qualitative richness of both concepts. It would free environmental impacts of their historical links with certain policy issues and re-link them to a new and creative research field. Applying this idea to the definition of environmental impacts would lead in the direction sketched below:

(Negative) **environmental impacts** are side effects **causally linked to socio-economic activity** which put **certain earth system/ecosystem services at risk.**

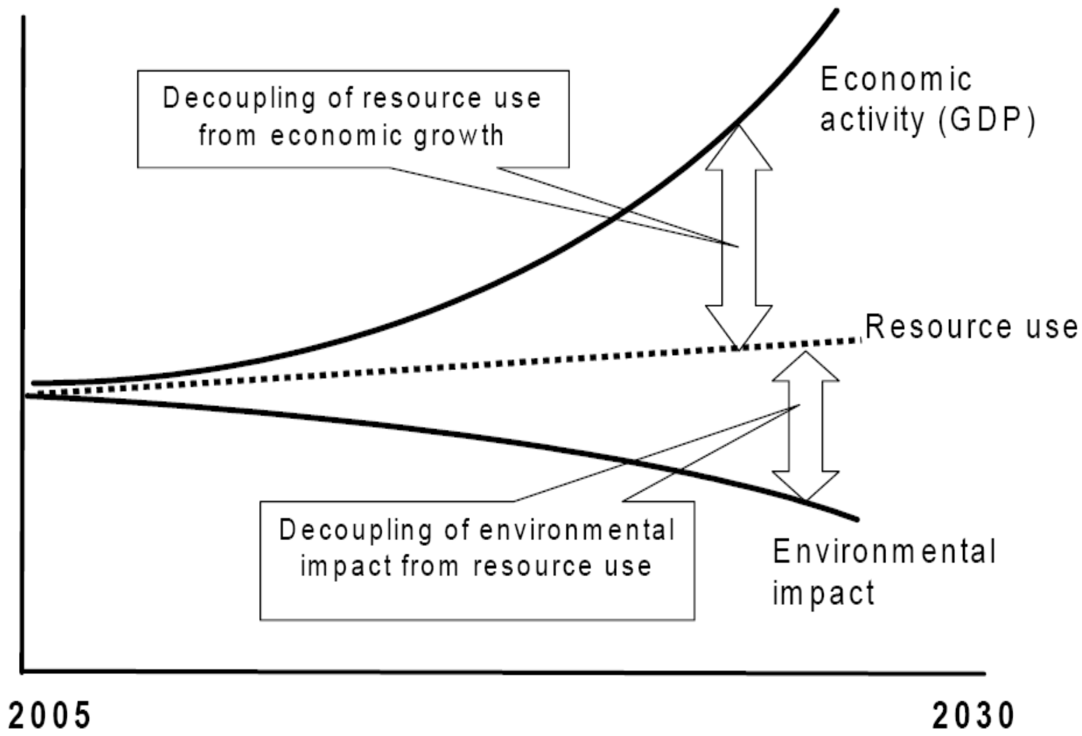
Such a conceptualization would allow for the re-introduction of the somewhat antiquated notion of environmental media / compartments by reframing them in system language as a classification scheme linking socioeconomic activities, environmental impacts, and earthsystem/ecosystem services.

This re-framing would of course not allow resolving all the problems of impact measurement and aggregation mentioned above. We rather tend to believe that many of those problems can be overcome only partially, for concrete system services (such as an acceptable climate system) and concrete policy goals, but not on a generic level. Maybe the weakness can also be turned into a strength: in communication, one does not always succeed with aggregate numbers, but often by a plausible and rich qualitative storyline.

6.3 How does resource use relate to environmental impacts?

Behind the question of the relation between resource use and environmental impacts there lingers an attractive policy model: the model of "double decoupling". It is possible, as has been repeatedly demonstrated and recently been argued by UNEP's Panel for Sustainable Resource Management (Swilling and Fischer-Kowalski, 2010) to "decouple" resource use from economic activity. This, for highly industrialized countries, is the most common outcome of technological innovation (see chapter 3.5). This decoupling, though, is rarely strong enough to create a situation of declining resource use. As long as environmental impacts grow proportionally to resource use and resource use grows along with GDP, this leads to GDP growth causing a growing environmental burden. But if, as suggested in Figure 57, environmental policy can contribute to an additional decoupling of impacts from resource use, the possibility arises to reach a situation in which, in the face of a growing economy, the state of the environment is improving.

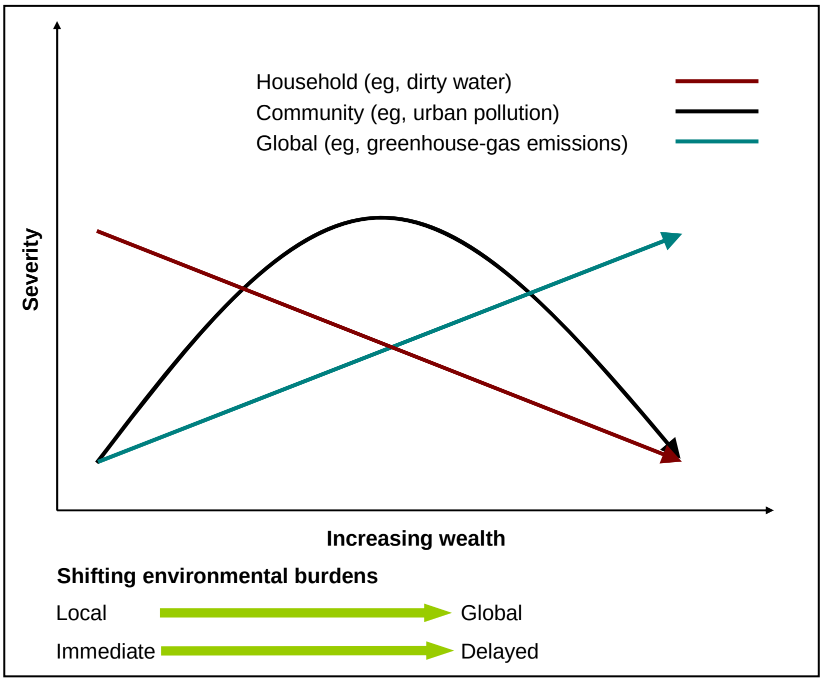
Figure 57: Policy model of "double decoupling" as proposed by the EU Thematic Strategy on sustainable use of resources



Source: Commission of the European Communities, 2005b

Wilkinson et al. (2007) add another dimension to the issue: the authors built on a hypothesis formulated by Holdren et al. (2000) which identifies a relation between the scale level of environmental impact and its relation to economic activity and increasing wealth. They assume that household level environmental burdens (such as dirty water, or indoor pollution) decline with a rise in wealth, community-level burdens (such as urban air pollution) display a hump-shaped, typical environmental Kuznets function, while finally global environmental burdens (such as greenhouse gas emissions) rise.

Figure 58: Environmental risk transition framework



Source: Wilkinson et al., 2007

This hypothesis has not yet been empirically corroborated. However, the argument holds potential for a more sophisticated understanding of the complex relations between pressures and impacts. The authors of the UNEP report share the assumption that "short term and local environmental impacts of resource use across the life cycle have been and can be mitigated in a way that allows for "impact decoupling" to be larger than "resource decoupling". With global and far reaching environmental impacts, this is less likely to be the case." (Swilling and Fischer-Kowalski, 2010, p. 23)

Before exploring the empirical relation between resource use and environmental impacts, it is required to clarify their interrelation on the conceptual level. In the chapter 3.1, we claimed that resources and resource use conceptually serve as the most important links between the environment and socioeconomic activities; even more strongly, we claimed that socio-economic activities that do not translate into resource use are environmentally irrelevant. Thinking in terms of the DPSIR model, economic activity (in monetary terms) serves as a driver for resource use[25], and resource use represents pressure that translates into environmental impacts.

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[25] Economic activity in monetary terms is not the only driver for resource use. Demographic change (in particular, but not only, change in population numbers) has to be looked upon, according to recent findings (Krausmann et al., 2009, Steinberger et al., 2010), as an even stronger driver. More people does not only mean more food demand (which, particularly in subsistence economies, need not reflect itself in economic growth), but also more demand for all material and energy commodities common in a certain society. In contrast to the relation with GDP, there is no "relative decoupling" between resource use and population numbers.

This relationship can more clearly be expressed with the help of a slight extension of the classical Ehrlich I=PAT formula (Ehrlich and Holdren, 1971), where I = environmental impact, P = population, A = affluence/population, T = technology/affluence.

The extension would read as follows:

I(t) = P * A/P * R/A * I/R, where:

I(t) = (total) environmental impact

P = population numbers

A = affluence (GDP), A/P income per capita

R = Resources used, R/A resource productivity

T = I/R = technology, impact per resource unit (environmental efficiency)

The interpretation would be the following:

The environmental impacts of a social system (e.g. a nation state) would

1. equal its population,
2. weighted by the per capita income, times the
3. amount of resources used per unit of income, times
4. the environmental impact per unit of resource use (depending on technology)

On this plain level the policy implications would be that component 1. is subject to demographic politics, 2. would be subject (among others) to economic policies, 3. would be mainly a function of technological and organizational innovation leading to resources savings, and 4. would be mainly influenced by environmental policies taking care of an environmentally friendly (composition and) use of resources across their life cycle.

This of course is a very simplistic model assuming homogeneity and linearity, but it is good enough to sketch the overall mental picture.

For all these considerations, it is important not to conceive of the impact of “resources” and “resource use” in terms of impact of specific materials. The environmental impact potential (see Moll et al., 2004) of resource use is **not mainly a function of the material (chemical, physical) qualities** of a resource, but a **function of the ways it is used across a life-cycle** from extraction through production/manufacture to consumption and the end-of-life-phase. The ways a resource is used does not directly reflect itself in the quantities (tonnes, Joules) it is used. But the standard uses of resources are not so extremely different between societies: nobody feeds coal to cows, uses spice metals for fertilizing gardens or wood for constructing roads. This is to say that the amounts and structure of resources used is not a bad approximation to a society’s production and consumption patterns.

Nevertheless, local and regional environmental impacts of the same level of use of one resource can be influenced, as we try to illustrate in Figure 59 for sand and gravel (bulk minerals used for construction), a particularly “harmless” resource. If we look at the potential impacts from the use of sand and gravel across their life cycle from extraction to deposition, they can clearly be lessened by wise use and specific environmental measures: How much dust is released during extraction, the risk of groundwater contamination due to extraction activites, how the soil removed is taken care of (and possibly replaced after the active phase of the mine), and the noise that is created in the process, can be improved. In the production phase, the key question will be how high a proportion of this resource is transformed into concrete – this may be variable. Similarly, in the use phase impacts will clearly depend on the purposes for which these minerals are being used. If it is mainly for renovating houses, most impacts will be smaller than if it is for large scale construction of highways or dams, for example. Finally, in the end-of-life phase the recycling rates will matter. Nevertheless, some impacts will relate in a fairly linear way to the amount of material used: resource depletion, for example; or the indirect impacts via the associated use of fossil fuels for transportation. Some of the impacts might have a tendency to become worse instead of better: when mines in close proximity of settlements have been exhausted, there is a need to accept further distances and increased transportation.

In effect, major changes in the use of the same resource category (such as a shift from road construction to the renovation of buildings) or major changes in technology (resulting, for example, in a substantial reduction of CO_2 emissions per ton of cement produced) would reflect themselves in the change of impact coefficients, and would also influence total environmental impacts via the IPAT formula. It would not necessarily require continuous monitoring of impacts to estimate such changes of coefficients.

Figure 59: Describing the resource use of "bulk construction minerals" across their life cycle in terms of environmental impacts (illustration)

Ecosystems / Use of sand and gravel	Atmo-sphere	Aquatic systems	Soil	Litho-sphere	Live systems	Human health
Extraction phase	Dust particles	ground-water pollution	Soil loss	Resource depletion	Habitat loss	noise
Production and delivery phase	CO_2(con-crete pro-duction) Dust part.			Wastes: use of deposition capacity	Dust particles	Dust particles noise
Consumption/ use/end of life	Dust particles	Interference water cycle	Soil loss, sealing	Interference with erosion	Habitat loss	noise
Afflicted ecosystem services	*Local air quality, climate*	*Local water quality*	*Reduction of productive soil*	*Resource depletion, waste accumulation*	*Wildlife, biodiversi ty*	*Silence (??)*

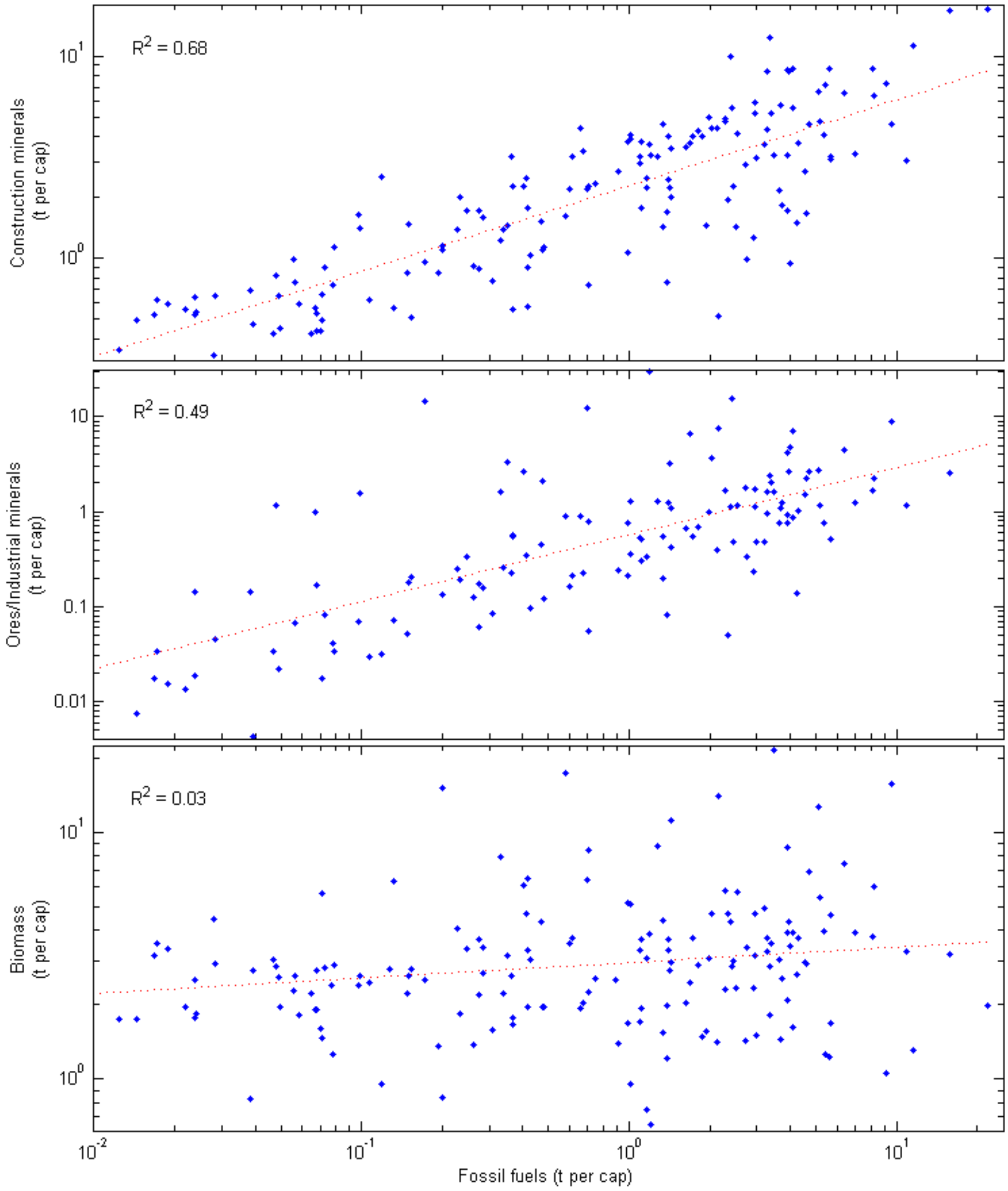
Associated fossil fuel use →
Associated land use →
Associated water use →

indirect impacts captured with other resource use

It would be useful to design a moderate R&D programme to find a pragmatic strategy and draw the necessary distinctions and valuations from existing LCA work to feed into that kind of algorithm and apply some sensitivity analyses to find out which effects are worth while pursuing. In the end, this might become a tool that is both robust and flexible.

How much use of other resources like fossil fuels, land or water is associated with the focal resource can be – under certain assumptions – modelled from the given international MFA data. As discussed above, the use of different resources is typically interlinked: it is not possible to extract resources without consequences in terms of energy, land, and water, or to change land use without modifying water cycles, and so on. The DPSIR approach expressed through the extended IPAT formulation may be the best way to quantify the population-economy-resource-impact nexus, but since it treats each resource separately, it does not analyse the coupling between resources. However, the intra-resource links should not be ignored, since they may be the key to sustainability policy success or failure. As an example, in figure 60 we show the correlations (or lack thereof) between fossil fuels and other material flows. Fossil fuels are very strongly correlated with construction minerals, significantly correlated with ores/industrial minerals, and not at all with biomass. Climate, energy, and resource policy are clearly best understood together in terms of their implications. Moreover, the large scale substitution of biomass for fossil fuels would clearly represent a massive change in biomass flows with immense environmental consequences.

Figure 60: Coupling between fossil fuel consumption and other types of resources



Source: ca. 160 countries for the year 2000, based on data from Steinberger et al., 2010

Because of this strong statistical (and causal) interrelation of the quantities of various resources used, it is a great challenge to estimate "indirect impacts" (such as the impact of the use of a specific material resource **and** the impact of the energy use associated with it) without ending up with double counting. We therefore suggest to focus on direct impacts, but care for system completeness by taking into account all resources used by a particular social system.

Across time, a "double decoupling" could be proven (or disproven) by comparing the total impacts (Impacts (t)) on the system level as modelled through the IPAT formula across time with the time line of total resource use. This would actually allow a test of the relative dependence or independence of the two indicators.

6.4 Empirical findings to the interrelation between resource use and environmental impacts

Indicators measuring environmental impacts of resource use are scarce. This reflects the above mentioned difficulties concerning the link between resources and impacts and the lack of clarity in definitions and coverage of impacts as such. Environmental impact assessments also do not take a material flow perspective but rather take a consumption or product perspective. (see for example Hertwich et al., 2009, p. 45ff, Nielsen et al., 2004, p. 18, Tukker and Jansen, 2006)

Currently mainly two aggregate indicators are applied that are supposed to measure environmental impacts on the macro level, i.e. the Environmentally Weighted Material Consumption (EMC) and the Ecological Footprint (EF).

The EMC (van der Voet et al., 2005a, 2005b and 2009) combines material flow data (basically DMC) with Life Cycle Assessment (LCA) data by multiplying material consumption with environmental impacts. “For every considered material, an estimate is made of its contribution to environmental problems throughout its life cycle. This includes not only the impacts related to the material itself, but also the impacts of auxiliary materials, energy used for its extraction and production, emissions of impurities and pollutants included in the material during use or waste treatment, etcetera. Energy use in the consumption phase is not allocated to the materials' chains.” (van der Voet et al., 2005b, p. 6f) For determining environmental impacts, 13 impact categories are applied, i.e. abiotic resource depletion, land use, global warming, ozone layer depletion, four types of toxicity, acidification, eutrophication, smog formation, radiation, and final solid waste formation. (van der Voet et al., 2005a) These impact categories were applied to 6 material groups containing 100 materials. (Nielsen et al., 2005) Results of the 13 separate impact calculations are then weighted and aggregated to arrive at EMC.

The Ecological Footprint (EF) was originally not defined as impact measure but rather as a headline indicator of high communicative power which combines information from resource use with CO_2 emissions and land use. “The Ecological Footprint measures how much biologically productive land and water area is required to provide the resources consumed and absorb the wastes generated by a human population, taking into account prevailing technology. The annual production of biologically provided resources, called biocapacity, is also measured as part of the methodology. The Ecological Footprint and biocapacity are each measured in global hectares, a standardised unit of measurement equal to 1 hectare with global average bioproductivity.” (Best et al., 2008, p. 3f)

The EF meanwhile reached high visibility and calculations are conducted for all countries in the world also in time series. The main strength of the EF is that it refers to a very comprehensive benchmark – land area. Furthermore, results appear to be self explaining. However, there are several methodological weaknesses (see for example Haberl et al., 2001) the EF suffers from.

The EMC or the EF are either applied individually and taken as a rough proxy for environmental impacts, or they are combined with other indicators. As an example of the latter, the EEA promotes the “Environmental Sustainability Dashboard (basket of indicators)” which includes the EMC, the Ecological Footprint, Human Appropriation of Net Primary Production (HANPP), and Land and Ecosystem Accounts (LEAC) (Best et al., 2008).

Another accounting framework is given by Environmentally Extended Input Output Analysis (EE-IOA) (see for example Moll et al., 2004). This approach combines Input Output Tables with national accounting matrices including environmental accounts (NAMEA) which contain information on the most prominent emissions, wastes and resource use. The information from NAMEA matrices is then fed into Input Output Tables. This reveals how environmental pressures are allocated to economic sectors and how they then are distributed to other branches or final consumption categories. By that, the accumulated pressures throughout the production process can be calculated and allocated to final consumption categories. (Moll and Watson, 2009, p. 13f) However, no aggregate indicator was yet derived from these approaches.

Results from studies on material use and environmental impacts

Moll et al. (2004) conducted an analysis of the link between resource use and impacts and identified the following interrelations: Fossil fuel use (measured in TMR) showed high correlation with generation of bulk wastes, fairly high with global warming potential and potential acidifying effects. The latter is due to the combustion during fossil fuel use. Metals correlated high to medium (depending on the correlation measure used) with global warming potential, tropospheric ozone forming potential and waste generation, and fairly high to medium with potential acidifying effect. The analysis was conducted for Germany, where metal extraction is not an important activity. In countries that do engage in metal extraction, a high correlation can be expected between metals and bulk wastes (mining wastes and overburden). Industrial and construction minerals correlated high with bulk wastes, and moderately high correlation with impact potentials related to air emissions due to the high energy requirements in processing industries such as ceramics. Biomass resources correlated only with impact potentials related to air emissions such as methane emissions and the contribution to global warming potential and tropospheric ozone forming potential or NH_3 emissions contributing to potential acidifying effect. (Moll et al., 2004, p. 38ff)

In a follow up study, Moll and Watson (2009) described agriculture, the electricity industry, transport services and some basic manufacturing industries (refinery and chemical products, non-metallic mineral products, basic metals) as the sectors that contributed most to environmental impacts. They account for 75% of greenhouse gas emissions, 93% of acidifying emissions and 84% of emissions of ground ozone precursors. Related to economic growth, Moll et al. described the EU as successful in “decoupling air emissions from growth in production. Production-related emissions of acidifying gases and tropospheric ozone precursors decreased by 17% and 28% respectively between 1995 and 2004 despite an economic growth of 27%. Production-related greenhouse gas emissions remained fairly stable during the same period.” (Moll and Watson, 2009, p. 39f) Decoupling was to a significant extent achieved through a shift towards service sectors and moving heavy industry abroad. (Moll and Watson, 2009, p. 33f)

EMC measures categorize intensive agriculture as causing highest environmental impacts followed by construction activities. (van der Voet et al., 2005b, p. 8ff) On a more detailed level, highest environmental impacts were identified for the following products: 1. animal products, 2. crops, 3. plastics, 4. oil for heating and transport, 5. concrete, 6. hard coal for electricity, 7. brown coal for electricity, 8. iron and steel, 9. gas for heating, 10. paper and board, followed by glass, oil for electricity, aluminium, ceramics, gas for electricity, clay, lead, nickel, hard coal for heating, and zinc. Among metals, van der Voet et al. (2005b) identified iron and steel, aluminium, copper and zinc as the metals with the highest environmental impact due to emissions of heavy metals and emissions from fuel combustion during the various stages of processing.

In general, very small flows with high impact potential hardly show up as significant flows in EMC measures. Likewise, large material flows with low impact potentials do not count either. Material flows of high relevance due to significant environmental impacts are large material flows with a reasonably high score on more than one impact category. Among those the authors found agricultural biomass materials and fossil energy carriers as well as bulk metals such as steel and aluminium. (EEA, 2005c, p. 6f)

EMC trends (1992 to 2000) show that some countries decreased their environmental impacts, others increased, and some remained stable. (see van der Voet et al., 2005b, p. 8) For the 28 countries (EU15 + AC13) in total, the EMC per capita remained rather stable. On the country level, largest increase could be observed for Portugal, Spain and Greece. Related to GDP, the EMC/€ showed a decrease over time. The same trend can be observed for the individual countries but with different rates of improvement. Van der Voet et al. (2005b) identified as the single largest contribution to eco-efficiency in Europe the reduction in the use of coal.

The high importance of agriculture is confirmed in studies using the product approach. Agriculture is again classified as one of the sectors that contribute most to global environmental impacts. (see for example Nielsen et al., 2004) Among the impacts from agricultural activities are eutrophication through ammonia from animal manure or nitrate and phosphorus emissions to water, acidification, global warming through enteric fermentation and manure management, and ecotoxicity through pesticides. Apart from this, agriculture puts serious pressure on water resources and on land area. (Nielsen et al., 2004, p. 20) The impact of agriculture on habitat change is described in FAO reports which state that agricultural land is expanding in 70% of countries (Swilling and Fischer-Kowalski, 2010 p. 23f).

Moreover, “industrial” agriculture is very energy intensive and puts pressure on land and water resources. Swilling and Fischer-Kowalski (2010) argue that “currently about half of the world's land is used for agriculture and 70% of total water use”. This is expected to aggravate with increasing animal production. Demand for animal fodder is expected to increase to 40–50% of global cereal production in 2050 (Aiking et al., 2006 cited in Swilling and Fischer-Kowalski, 2010 p. 24f; Erb et al. 2009a).

Fossil fuels are fundamental to the functioning of the industrial mode of production and modern lifestyles and thus used intensively by industrial societies. Impacts from the use of fossil fuels include global warming, acidification, eutrophication and toxicity. Additionally, scarcity of fossil fuels is an issue. Physical limits are not yet reached but peak oil for example is expected to be passed in the near future. Alternative fossil fuel sources (e.g. tar sands) are sought and increasingly used. However, environmental impacts from these are not yet clear (Hertwich et al., 2009, p. 74f).

Environmental impacts of metals are related to the energy intensive mining and refining processes (about 7% of world's energy use is demanded by the metals sector) and cause air, water and soil pollution. Further environmental impacts occur due to accumulation of metals in wastes and resulting toxicity which affects human and ecosystem health (Hertwich et al., 2009, p. 74f).

Further pressure on the environment is expected due to falling ore grades and resulting increases in energy demand. Technological development and new applications add another perspective: “Metals, such as platinum, indium and selenium, are scarce and are mostly mined as co- or by-products. In view of their high impacts per kg, this may cause priority orders to change. Other by-produced metals include cadmium (a by-product of zinc) and mercury (a by-product of natural gas). The issue of co- and by-produced metals is very unique. Their supply is unrelated to their demand and therefore market fluctuations may cause enormous price fluctuations as well. Any policies aimed at phasing out toxic heavy metals fail for this reason and have unwanted side-effects. Both scarcity and pollution problems behave differently for these materials. Recycling poses difficulties and requires careful design (Reuter et al., 2005; Buchert, 2008), and may, moreover, not always be the best option from a sustainability point of view (Hagelücken and Meskers, 2009)” (cited in Hertwich et al., 2009, p. 74f).

In the 8 studies reviewed in Nielsen et al. (2004) construction materials were identified as a material group of high environmental significance (see also EEA, 2005c, p. 6f) Extraction of construction minerals leads to noise and air pollution, and cement production causes high amounts of CO_2 emissions. However, the high relevance is mostly result of building up infrastructure (for transport and housing) and resulting demand for energy and metals inputs, but also of the land area needed, and finally due to the significant quantities of construction minerals required. In case the energy use related to heating of buildings is attributed to construction minerals the environmental impacts even become more significant. (Hertwich et al., 2009, p. 75-79). Another important issue about construction minerals is the link to land area. Extraction of construction minerals as well as built artefacts (buildings, built infrastructure) require considerable amounts of land area and soil sealing is considered among the three most important threats to European soils next to erosion, and contamination (EEA, 2005c, p. 6f). See also section 3.3 on land use.

To summarize: impacts from the use of fossil fuels mainly arise from combustion and related CO_2 emissions. Biomass use puts pressure on land and water resources, and contributes to climate change, land degradation, and biodiversity loss. Extraction of industrial minerals and ores requires a lot of energy, and adds to ecotoxicity. Finally, bulk construction materials contribute to land degradation, wastes and CO_2 emissions due to transport activities and cement production.

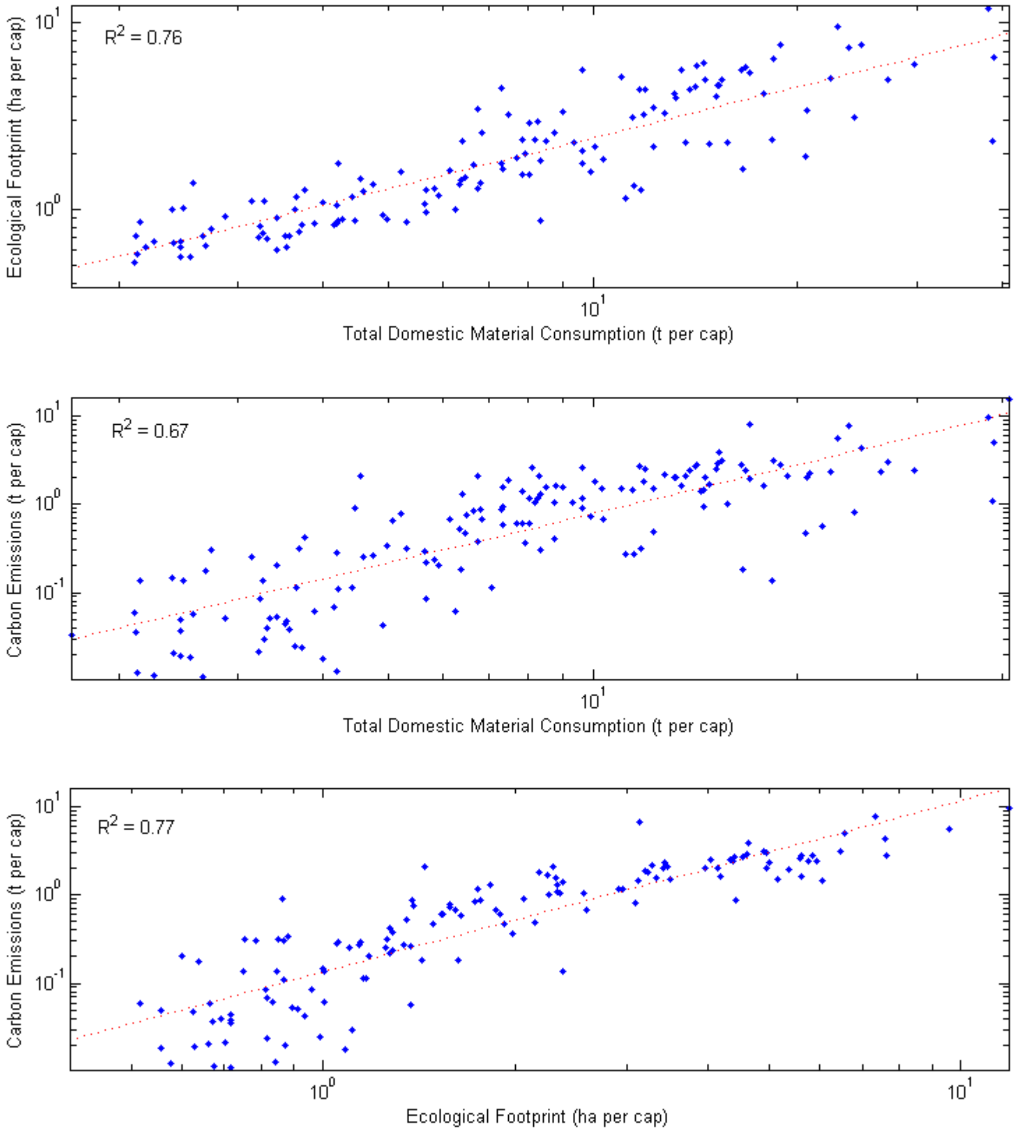
Finally, we want to look at the links between material use, carbon emissions as the most important category among impact potentials and the Ecological Footprint as a representative of an applied impact measure. Figure 61 correlates the results for ca. 160 countries and shows that the three variables are highly correlated. Material use, impact potentials and the EF thus show similar results, which supports the strong mutual link between resource use and environmental impacts.

The high correlations support the strong link between resource use and environmental impacts that researchers already stated such as scholars engaged in the UNEP Resource Panel who “found environmental impacts closely proportional to the volumes of extraction and use of the respective resource”. (Swilling and Fischer-Kowalski, 2010, p. 23) Some researchers therefore claim that “reducing resource use in absolute terms will automatically lead to fewer impacts, even if we do not know precisely how much a change in resource consumption will change the resulting environmental impacts”. (EEA, 2005c, p. 60)

It can be concluded that so far, no comprehensive impact coefficients per unit resource use have been calculated. To our knowledge, no quantitative time series data for environmental impacts exists, not even for specific countries or specific impacts. And finally, the few aggregate impact indicators that have been constructed (EMC, ecological footprint) are criticised for a number of methodological weaknesses and are far from satisfactory with regard to measuring environmental impacts and far from ready for use in regular monitoring and reporting.

Additionally, the results for environmental impacts from resource use excerpted above are rather illustrating environmental impacts from economic sectors or activities than impacts from material use. This step towards relating environmental impacts to resource use still has to be taken but is possible with reasonable effort.

Figure 61: Correlation between Ecological Footprint and Carbon Emissions with DMC, and of Carbon Emissions with Ecological Footprint



Source: ca. 160 countries for the year 2000, based on data from Steinberger et al 2010

6.5 Targets for resource use and environmental impacts

The open question that follows from the above given arguments is whether it is possible to set targets on the reduction of environmental impacts or of resource use. The answer is not an easy one and for several reasons we will not propose specific targets at this point. First, we argued before that there is still a lack of consistent and agreed upon indicators as well as empirical data for environmental impacts. But a serious discussion of targets needs 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. And thirdly, they must be comprehensive and integrative in terms of resource use.

Targeting environmental impacts or resource use can be approached from different angles. The underlying condition is sustainable development and its double components: preserving the capacity of the earth to sustain humans, to produce resources and to absorb residues; equal distribution of the benefits of resource use – including the planetary waste absorptive capacity – in the future as compared to unequality in past or present. There must be room for development of those in need, and there must be a converging trajectory in the future.

Following these principles, we can discuss targets 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.

6.5.1 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). 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.

A general target on resource use does not seam plausible. The aggregated materials are too different in terms of their characteristics, their possible environmental impacts from use, their availability, their use in economic sectors and for specific products etc. Thus, possible targeting only makes sense on a more disaggregated level.

Fossil fuels make up roughly 50 billion metric tons of annual global resource extraction, about one fifth (20%) consists of fossil fuels (coal, petroleum, natural gas). With regard to fossil fuels, possible future scarcities are meanwhile undisputed. 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.

Another 30% of global resource extraction consists of biomass, a renewable energy carrier. There is currently a heated debate as to what the limits on biomass extraction are or ought to be. On the one hand, there is major concern over the disappearance of the last pristine wilderness areas and tropical rainforests, and an associated loss of biodiversity. On the other hand, there is some hope in further increasing area productivity so to allow for increased harvests, although increased use of mineral fertilizers will probably be required also. 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., 2009a). The relation between biomass and scarcity is complex: 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 land use intensity on the managed areas.

A small fraction, roughly 10%, of global resource extraction 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 fertilizer minerals. 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” (UNEP, 2010, Hashimoto et al., 2007).

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 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.

6.5.2 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 recent 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 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. If an atmospheric CO_2 concentration above 450 ppm is to be avoided, annual fossil fuel combustion (and cement production) 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. Thus, from the perspective of keeping world climate change below a dangerous threshold, there follows the target to reduce global fossil fuel combustion gradually much below present levels. The same would apply to 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. The substitution of forest cover by cultivated land leads to net emissions of CO_2 to the atmosphere. Thus, insofar as the increase of biomass use implies an extension of agricultural land, it also has climate implications. Similarly, the increase in grazing animal livestock (which was driving some of the most recent global rise in biomass use) leads to an increase in greenhouse gas emissions in the form of methane from bacterial action in the stomachs of ruminants. The contribution of the livestock sector to global greenhouse gas emissions (18%, measured in CO_2 equivalents) is larger than that of transport (FAO, 2006). 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. (See also McMichael et al., 2007).

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.

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). Consequently, if the use of fossil fuels is constrained, the use of construction materials will be, 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. (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!)

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

Economic activity is about providing societies specific services and benefits. Sustainability thus is about resource productivity in the sense of providing a maximum benefit for people at the expense of a minimum of resources. This 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.).

Social wellbeing is usually expressed with GDP or economic welfare. However, other measures for social wellbeing such as the HDI do better in reflecting social welfare. Resource use such as the primary energy supply of countries can then be related to the development of HDI or social wellbeing. 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%. This means an increase in energy productivity – in producing human life chances - of 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.

The main implication of this result is that basic human needs can be met at lower and lower resource use levels, or that reductions in resource use do not have to come at a cost of lower living standards, if their implementation is done correctly.

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 (e.g. 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. The second largest “reducible” share refers to food people eat (or drink) in excess of their metabolic needs – food overconsumption can be estimated to roughly 1/6 of the food consumed. 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 (Smil, 2002, Erb et al., 2009a, McMichael et al., 2007).

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 (see Krausmann et al., 2008b, Fischer-Kowalski et al., 2007), 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. The same also applies to industrialized European countries with stable metabolic rates and no endogenous population growth when facing immigration pressures. Within a very short time period, immigrant populations may be expected to adjust to the metabolic rates of the host countries. 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).

6.5.4 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. This is the inverse of material intensity; insofar, dematerialization is equivalent to raising resource productivity. 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 (Jevon's paradox) (see Polimeni and Alcott, 2008, Binswanger, 2001, Holm and Englund, 2009, Alcott, 2005, Ayres et al., 2007).

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, of 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 weight is highest in the phase of extraction (if all materials that will ever be incorporated in the final commodity are counted), this weight 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 weight of the product does not, like its value, "disappear", but remains constant.

If an indicator like resource productivity relates the value (or the value added) 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 / unit of weight) 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). This problem has to be kept in mind when interpreting economic resource productivities.

In the past two-and-a-half decades, resource productivity in industrial countries has been consistently rising 1-3 percent annually, about at the same pace as GDP. In developing countries though, such a trend cannot consistently be found. 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 size of the GDP. In a cross country correlation for 175 countries in the year 2000, Steinberger et al. (2010) found a very strong correlation between GDP/cap and the material resource productivity indicator GDP/DMC, with a goodness-of-fit R2 of 0.84.

Despite these precautions, using economic material productivity as a basis for political targets makes a lot of sense, particularly if this is one among other targets (as it is, for example, in the Japanese "3R: reduce, reuse, recyle" policy (Ministry of the Environment, 2008, Hashimoto et al., 2008)). Without increases in productivity, one cannot expect to be able to save 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.

This discourse about targeting and possible approaches shows the difficulty of this task. At the moment, no clear recommendation can be given towards setting a specific target. However, some conditions can be derived from the above mentioned arguments that can feed into policy debates on the setting of targets:

- Any targeting has to bear in mind the mutual dependencies of resources, resource use and environmental impacts. A systemic view can help preventing from overlooking some outsourcing or shifting of effects.
- Targets on resource use or environmental impacts have to be linked to other existing policies such as climate policies, agricultural policies, energy policies etc.
- Setting targets on the aggregate level is not reasonable – neither for environmental impacts nor for resource use.

7 Acronyms

bio: billion
cap: capita
CO2: Carbon dioxide
DE: Domestic (material) Extraction (used)
DMC: Domestic Material Consumption
DMI: Domestic material input
GDP: Gross Domestic Product
ha: hectare
HANPP: Human appropriation of net primary production
km^2: square kilometre
LCA: Life Cycle Assessment
MER: Market Exchange Rate
MFA: Material flow accounting
mio: million
PPP: Purchasing Power Parity
RME: Raw Material Equivalen
RP: Resource Productivity
t: metric ton
yr: year

List of countries

EU-15: Austria (AT), Belgium/Luxembourg (BE), Denmark (DK), Finland (FI), France (FR), Germany (DE), Greece (GR), Ireland (IE), Italy (IT), Netherlands (NL), Portugal (PT), Spain (ES), Sweden (SE), United Kingdom (UK).

EU-27: EU-15, Bulgaria (BG), Cyprus (CY), Czech Republic (CZ), Estonia (EE), Hungary (HU), Latvia (LV), Lithuania (LT), Malta (MT), Poland (PL), Romania (RO), Slovak Republic (SK), Slovenia (SI).

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