



A comprehensive set of resource use indicators from the micro to the macro level

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Abstract:

Many of today's most urgent environmental problems arise from ever increasing volumes of worldwide production and consumption and the associated use of natural resources, such as raw materials (renewable and non-renewable), energy, water and land. Indicators for the measurement of resource use in physical terms are essential for a sustainable management of natural resources and for the required reduction of resource use on the global, national, company and product level. This paper analyses the current state of the art of resource use indicators and suggests a new set of complementary resource use indicators, based on existing measures for resource use. The indicator set covers the core resource input categories of materials, water and land area plus the output category of GHG emissions. All indicators take a life-cycle perspective on production and consumption activities. This set of indicators deals with the issue of the overall scale of the human production and consumption system. It can therefore be regarded as the general indicator framework, based on which more specific indicators (for example, on different environmental impacts related to natural resource use) can be calculated.

Keywords: resource use, sustainable consumption and production, material flows, Ecological Footprint, Ecological Rucksack, Carbon Footprint

1 Introduction

Due to growth of world population, continued high levels of consumption in the developed world, combined with the rapid industrialisation of countries such as China, India and Brazil, worldwide demand on natural resources and related pressures on the environment are steadily increasing. Renewable resources, and the ecological services they provide, are at great risk of degradation and collapse (see, for example, the latest “Global Environmental Outlook” by UNEP, 2007). The depletion of these ecological assets is serious, as human society is embedded within the biosphere and depends on ecosystems for a steady supply of the basic requirements for life: food, water, energy, fibres, waste sinks, and other services. At the same time, extraction of many non-renewable resources is already reaching or near a peak; some authors even describe today’s situation as “peak everything” (Heinberg, 2007).

The past 30 years saw a change in complexity and scope of environmental problems. Early environmental policy was mainly concerned with the reduction of local or regional environmental degradation through pollution of certain environmentally harmful substances, such as air pollutants, sewage effluents, and hazardous wastes. In this area, Europe has achieved significant improvements due to technological innovations and substitution of harmful substances and products. This has resulted in better environmental quality of rivers and lakes, decreasing concentrations of pollutants in ground water, successful reduction of acid rain, and improved air quality in many cities.

However, since the mid-1980s, another type of environmental problem became increasingly important, associated with global changes in production, trade and consumption patterns. These problems are more difficult to address, as they are complex, international or even global in scope, and involve multi-dimensional cause-effect-impact relationships and time-lags. Issues such as climate change, loss of biodiversity, land cover conversion and high levels of energy and resource consumption are part of this new type of environmental problems. These problems are more closely related to the overall volume (or scale) of economic activities than a result of the specific potential for environmental harm of single substances (Schmidt-Bleek, 1992). As evidence illustrates (see, for example, the State of the European Environment report by the European Environment Agency, EEA, 2005), Europe has performed much worse in this regard: many species are threatened by extinction, fish stocks are depleted, water reserves shrink, overall waste volumes have been growing, urban sprawl transforms fertile land into sealed areas, valuable soil is lost through erosion, energy consumption grows, and Europe is far away from achieving a significant reduction in greenhouse gas emissions (GHGs).

Given this serious situation, it is necessary to develop systems which measure resource use as well as its environmental, economic, and social impacts through appropriate indicators. What is not measured often gets ignored in policy processes. While standards for measuring greenhouse gas emissions (GHG) have been developed within the UN framework convention on climate change (UNFCCC), such standards on the international level are only beginning to be introduced for the issue of measuring resource use.

Based on a review of existing resource use indicators, **this paper suggests a consistent and comprehensive set of resource use indicators.** The indicator set comprises the resource input

categories of abiotic and biotic materials, water, and land area and considers greenhouse gas emissions as the most important output stemming from natural resource use.

This set of indicators can be applied on all levels of economic activity: from the micro level of products and enterprises, via the meso level of economic sectors to the macro level of countries and world regions. The suggested set of indicators can be regarded as the general indicator framework, based on which more specific indicators (for example, on different environmental impacts) can be calculated.

The paper is structured as follows. Section 2 illustrates the links between different types of natural resource use and various environmental problems stemming from resource use. Section 3 lists criteria for the identification of resource indicator sets. In section 4 we briefly review existing resource use indicators and illustrate their interrelations, in particular, how different categories of resource use are considered in the various indicators. Section 5 provides the suggestion of the resource indicator set, explains the reasons for selecting these indicators and describes, how this indicator set should be applied in practice. Section 6 concludes.

2 Resource use and environmental problems

The worldwide ecological damage caused by the production and consumption of goods and services has dramatically increased over the past decades (UNEP, 2007). The supply of goods and services is always linked to the use of natural resources, including raw materials (renewable and non-renewable), energy, water and land. Economic growth, and the related increase in production and consumption, has thus led to a strong growth in resource use.

Many of today's key environmental problems (foremost climate change, but also the loss of biodiversity, desertification, and the increasing erosion of fertile soils) are caused by the fact that the overall amounts of natural resources used in production and consumption are too large. The quantitative reduction in resource throughput along the value chain thus becomes a central objective in achieving sustainable methods of production and consumption. Terms such as "factor four" or "factor ten" were introduced in order to illustrate that a sustainable economy must reduce its resource use several fold compared to the current situation (Schmidt-Bleek, 2009).

The central categories of resource use which cause the above mentioned environmental problems are the following:

- **Consumption of materials.** Abiotic materials (fossil fuels, metals and minerals) and biotic materials (from agriculture, forestry and fishery) are the material basis of every production process. Sustainability issues related to material consumption may arise in several respects:
 - o Resource scarcity. Many abiotic resources (e.g. some fossil fuels and metals) will reach their peaks of extraction and will no longer be available in the future.
 - o Land cover changes. The cultivation of biotic resources and the extraction of abiotic resources often involve changes to the countryside and land use. In most cases this leads to a loss of biodiversity, a reduction in soil quality as well as increased erosion.

- Renewable materials: A switch to renewable (raw) materials can only happen sustainably if the total material demand is reduced. The current level of resource use cannot be met by renewable materials alone.
- Waste and emissions: The use of ever increasing quantities of raw materials and fossil energy leads to rising amounts of waste and greenhouse gas emissions. The latter can only be curtailed by a reduction of resource inputs.
- **Energy consumption.** Energy is the main driving force of production and consumption. The modern economy cannot work without a constant supply of energy. Sustainability issues related to energy consumption are:
 - Climate change. Fossil fuels continue to cover the main part of today's energy use. Their combustion produces greenhouse gases, in particular CO₂.
 - Renewable energies. The points about materials outlined above are also true for renewable energies. As the discussion about the production of biofuels has shown, a large-scale shift to a particular form of renewable energy may even have negative overall consequences for ecological sustainability.
- **Land use:** Taking a resource use perspective, land area is one of the most restrictive categories of resources since humanity only has one planet on which we have to arrange sustainable ways of meeting our demands on land (such as production of food, raw materials and renewable energies; preservation of forests and biodiversity; areas for settlement and transportation). Sustainability issues related to land use are
 - Rising intensity of land use. There has been a continuous growth of agricultural productivity over the last decades, which was only possible by an increased use of production inputs (machines, fertilizers, pesticides, irrigation, etc.). From a sustainability perspective, a reduction in the total amount of land used for food production is an important objective in order to prevent future conflicts related to land use. However, this should not be pursued through an increase in the intensity with which individual producers use their land. Instead, it should be achieved through a systematic change in food supplied and diets respectively (a reduction in the demand for and supply of meat, for example, would reduce the total area of pasture and land needed for the cultivation of animal feed).
 - Increased sealing. Each year, fertile land is lost through the expansion of land used for the construction of buildings and infrastructure. From a sustainability perspective, halting the expansion of sealed land is an important objective which would also have positive effects on the preservation of biodiversity.
 - Deforestation: The loss of forests in many world regions is the result of an increase in the amount of land used for the production of food, pasture and for the cultivation of biofuels and biomaterial.
- **Water use:** Many experts regard the growing global water use as one of the central sustainability-related topics of the 21st century.

- Water scarcity. Many countries and regions are already facing water scarcity today due to the excessive use of water for agricultural and industrial purposes. The extraction of water by humans has doubled since 1960 (WWF et al., 2008). Yet some countries with extremely high water scarcity (such as Israel) continue expanding export-oriented and highly water dependent agricultural activities. An important objective from a sustainability perspective is a reduction in the amount of water used in industry and agriculture (especially in irrigating arid regions).
- Water pollution. The increased use of water for agricultural and industrial purposes also raises the amount of polluted waste water. In agriculture, this applies to the leaching of fertilizers and pesticides into groundwater; in industry to the contamination with heavy metals or chemicals (for example in the metal or paper industry).

3 Criteria for resource use indicators

A set of resource use indicators should comply with a number of criteria.

Comprehensive and complementary coverage of all relevant resource use categories. A measurement and indicator system should account all relevant categories of resource use and must ensure that possible shifts of environmental pressures between different types of resources can be identified and illustrated.

Policy relevance. One crucial criterion is the policy relevance of a measurement system and derived set of resource use indicators. Such a set should enable monitoring and evaluating macro policies (e.g. the implementation of a tax reform, border adjustments or licence trading systems to increase energy and resource productivity) as well as more specific (sectoral and cross-sectoral) policies related to resource use (e.g. energy, transport, trade, agriculture policies). This implies that it should be possible to disaggregate indicators by economic branches.

Easy communication. Resource use indicators should be easy to communicate in order to provide relevant information not only to experts but to a large number of policy makers as well as actors from civil society. They should provide scientifically correct information, i.e. they should show whether a country or world region is moving towards reductions in natural resource use or still increasing the pressure on nature; whether a given product, process or technology is using resources more efficiently than a comparable one or has some hidden ecological drawbacks.

Application of a life-cycle-perspective. Any resource measurement system that is intended to support decisions at a national, sectoral or product level should apply a life-cycle perspective. This requires including the resource use along the whole life cycle of a product, i.e. in the production chain, during the use of the product as well as in waste treatment and recycling. In studies on natural resource use at the national level, a life-cycle perspective implies taking into account the indirect resource requirements of imported and exported products¹, in order to capture possible shifts of environmental pressures related to domestic production or consumption to other countries and world regions (OECD, 2007b).

¹ Indirect flows of imported products have also been termed “upstream” flows or “embodied flows”.

Avoiding double counting. Resource use indicators should – to the extent possible – be additive across products, sectors and countries. Applying this principle restrictively, indicators could either reflect domestic environmental pressures related to domestic production (such as indicators on domestic material or water extraction).² Or they could be constructed according to a consumption principle, where resource requirements are *allocated to final consumption*; examples from MFA include Domestic Material Consumption (DMC) and Total Material Consumption (TMC). In recent years, it was disputed whether environmental responsibility should be allocated to producers or consumers only or shared between the two (for example, Lenzen et al., 2007; Rodrigues and Domingos, 2008).

Measuring resource use at different scales. Depending on the issue of concern, measurements of resource use should be applicable at different levels of economic activities (see OECD, 2007b). Assessments at the micro level focus on resource use and resource productivity of products and organizations. Resource use and resource productivity of specific economic sectors (mining, chemicals, iron and steel, etc.) is assessed at the meso level. Economy-wide studies measure resource use and resource productivity of regions within countries³, countries or world regions (macro level). Measurement systems and derived indicators of resource use and resource productivity should be designed in a consistent manner across different scales. It should therefore be possible to consistently aggregate or disaggregate resource use indicators from products via sectors to countries. For example, macro-indicators on resource consumption related to final demand in one country should, conceptually, equal the sum of all final products and services consumed in that country.

Integration with the System of National Accounts. A system for measuring resource use should be compatible with the economic System of National Accounts (SNA) (Radermacher, 1992) as implemented in the UN SEEA system (United Nations, 2003) or the European NAMEA (National Accounting Matrix including Environmental Accounts) approach (EUROSTAT, 2008). This allows a consistent analysis of the interaction between the economy and the environment and the assessment of the environmental implications of different patterns of production and consumption.

4 Existing measurement systems and indicators

The past 15 to 20 years saw rapidly increasing interest in the quantitative assessment of the interrelations between the socio-economic system and nature. This chapter provides a short review of existing measurement systems and resource use indicators.

The UN environmental-economic accounting system “SEEA”: the international framework for collecting environmental data and calculating resource use indicators. The most relevant international framework for measuring resource use (and more generally, for assessing the interactions between the economy and the environment) is the “System for integrated Environmental Economic Accounting (SEEA)” by the United Nations (for the latest version see United Nations, 2003), which sets guidelines for integration of environmental data into the

² This would follow a production-oriented accounting principle, as it is, for example, implemented in the Kyoto protocol.
Peters, G. 2008. From production-based to consumption-based national emission inventories. *Ecological Economics* 65, 13-23..

³ Regional studies are sometimes also termed applications on the “meso” level.

statistical system and the standard economic “System of National Accounts”. The SEEA system is currently being revised and will be published in an updated and revised version in 2012.

4.1 Methodologies to measure resource use

Five main categories of resource input. Five basic categories of natural resources serve as inputs to production and consumption processes: biotic materials, abiotic materials, air (for combustion processes), water and land area (see also United Nations, 2003). For each of these categories, different methodologies have been developed.

Biotic and: material flow accounting and analysis (MFA). Material flow accounting and analysis (MFA) is an approach, which focuses on the use of different materials by human activities. MFA builds on concepts of material and energy balancing, which were introduced already more than 30 years ago. The basic unit for MFA calculations is weight (kilograms or tonnes). Based on national or international statistical data, MFA calculates the domestic extraction of resources, as well as physical imports and exports. Biotic materials cover production from agriculture, forestry, fishery, and hunting; abiotic materials cover minerals (metal ores, industrial and construction minerals) and fossil energy carriers (coal, oil, gas, peat). Since the beginning of the 1990s, when first material flow accounts on the national level were presented, MFA has been a rapidly growing field of scientific interest, and major efforts have been undertaken to harmonise methodological approaches developed by different research teams. In international working groups on MFA, standardisation for accounting and analysing material flows on the national level was achieved and published in methodological guidebooks by EUROSTAT (2007a) and the OECD (2007b). In many EU and OECD countries, MFA is already part of the official environmental statistics reporting system. MFA data are also available for an increasing number of emerging and developing countries (see OECD, 2007a).

In addition to the accounting of material flows on the economy-wide level (global, national, regional), MFA-based approaches have also been developed and applied for products. The concept of “Material Input per Service Unit (MIPS)” was developed at the Wuppertal Institute for Climate, Environment and Energy in Germany and aims at illustrating material inputs required along the whole life-cycle of a product: from resource extraction (e.g. mining) and refining via manufacturing and trade to consumption and finally treatment or disposal (Schmidt-Bleek, 1992). These lifecycle-wide material inputs (also known as the ecological rucksack of a product) visualise the cumulated environmental pressures, which are in general invisible to final consumers.

Air accounts as the link to greenhouse gas emissions. Air is a key resource input to combustion and other processes and serves as a balancing item to establish material balances e.g. for the use of fossil fuels, producing CO₂ from O₂ in the air and carbon in the fuels. For indicators such as the Ecological Footprint or the Carbon Footprint (see below), this category of resource input is therefore of importance in the underlying accounting method.

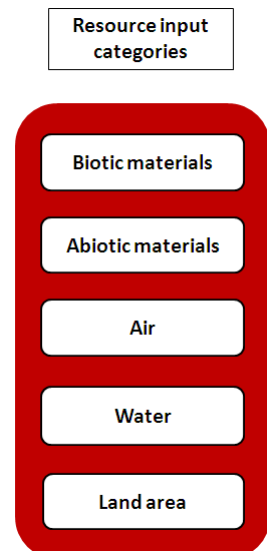


Figure 1: Basic categories of resource input to production and consumption

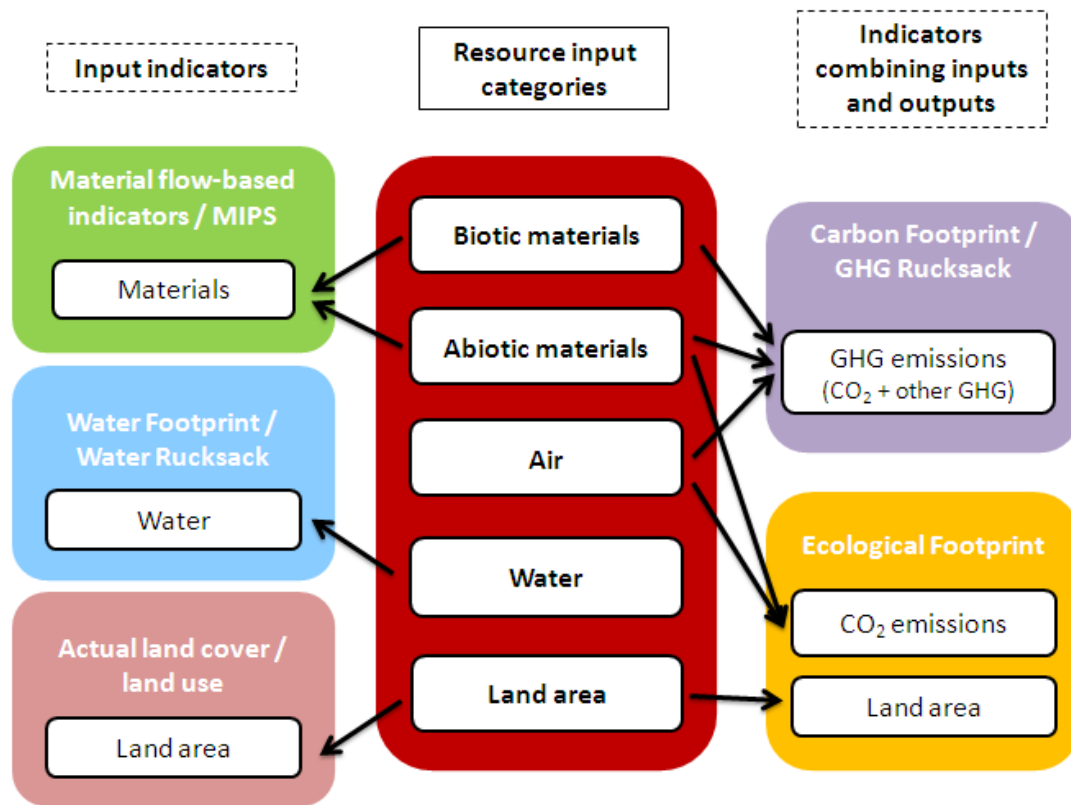
Water accounts on the national and the product level. The use of water is an issue with increasing policy relevance. Water accounts are included both in statistical systems on the national level (for example, Olsen, 2003) and in studies on the so-called “Water Footprint of Nations” (Chapagain and Hoekstra, 2004). Also an increasing number of “Water Footprints” are calculated on the product (for example, Chapagain and Hoekstra, 2007) and on the business level. However, Water Footprint data for non-agricultural products are still scarce. Water accounts often distinguish between withdraws of water from rivers, lakes and aquifers (surface and ground water, the so-called “blue water”) that is used in agriculture, industry and for domestic purposes, as well as water from rainfall (“green water”) that is used to grow crops. The impact of water withdrawals depends largely on where and when water is extracted. A link to the renewable water stocks for the specific geographic region or country is particularly useful for an appropriate interpretation of water flow-based indicators.

Land area: land cover and land use accounts. Land cover accounts are generally established from satellite images applying a certain resolution (grid system). For example, the EU Corine (Coordination of Information on the Environment) land cover (CLC) system, which is used by the European Environment Agency (EEA) for producing and reporting land cover change accounts, is based on satellite images in a 100 m x 100 m grid (EEA, 2006). Such systems aim at describing the geographical patterns of different land cover types across a country or region, the way they change over time and the processes that drive these transformations. Recently, there is increasing interest in quantifying the land area embodied in internationally traded products (Würtenberger et al., 2006).

4.2 Indicators based on the core categories of resource use

Based on this system of five main categories of resource inputs, a number of indicators can be calculated. Two main types of indicators can be distinguished: input indicators (left side of the diagram) and indicators, which refer to outputs or combine inputs and parts of the generated outputs, in particular GHG emissions (right side of the diagram).

Figure 2: The system of resource use indicators derived from the core resource use categories



Input-oriented indicators include indicators derived from MFA accounts. **Material flow-based indicators** on the economy-wide level comprise input, consumption, trade and productivity indicators and are expressed in mass units. Material flow-based indicators have been integrated in the EU's Structural Indicator Set, which evaluates progress of the Lisbon Strategy, and provide the headline indicator for the theme "Sustainable Consumption and Production" in the EU set on Sustainable Development Indicators (EUROSTAT, 2007b). On the level of single products, the indicator MIPS is applied (Ritthof et al., 2002; Schmidt-Bleek et al., 1998). There are also current attempts to link quantitative data on the amounts of resources consumed (from material flow accounts) with factors informing about the specific environmental harm (global warming, toxicity, land intensity, etc.) of different types of materials. These impact factors are derived from so-called "Life Cycle Assessment (LCA)" data bases. The most advanced indicator presented so far is called "Environmentally weighted Material Consumption (EMC)" and was presented by the University of Leiden in the Netherlands (see van der Voet et al., 2005).

Water indicators, such as **Water Footprints** and **Water Rucksacks** account for the water input in production or consumption processes in the unit of liters. Conceptually similar to the Ecological Footprint, the Water Footprint shows the extent of water use related to the consumption of people. The Water Footprint of a country is defined as the volume of water needed for the production of the goods and services consumed by the inhabitants of a country. The Water Footprint concept was developed by academics and has been applied in a number of studies, including reports from the UN Environment Programme (UNEP).

Indicators on **actual land cover and land use** (expressed in hectares or m²) and related changes illustrate the actual land area required to produce a product or service (micro level) or all the goods

produced or consumed in a region or country (macro level). Particularly valuable are indicators, which illustrate the change of land cover and land use from one year to another (e.g. expansion of built-up land on the cost of agricultural land) (see EEA, 2006). On the product level, LCA databases, such as the ecoinvent database, also include data on the land area necessary for the production of goods.

The **Ecological Footprint** is an indicator, which combines both resource input aspects and parts of the resource outputs generated (CO₂ emissions). The Footprint is defined as the total biologically productive land and water areas required to produce the resources a population consumes, and to assimilate the waste it generates. Its purpose is to answer the question of how much regenerative capacity of the biosphere is occupied by the resource consumption of the inhabitants of different countries (Wackernagel et al., 1999). The Ecological Footprint provides a bookkeeping system of biocapacity: by comparing the land appropriation of the population of a country with the ecological capacity available within a country or world-wide, national (or global) ecological deficits or ecological reserves can be quantified. National Ecological Footprint accounts build to a large extent on data from national material flow accounts and land use accounts (see above). They start from a population's resource consumption (domestically harvested resources plus imports minus exports) expressed in mass flows (tonnes per year). These physical flows are then converted into area equivalents, expressed in an artificial unit of so-called "global hectares" (these are hectares with world-average biologic productivity). This approach is repeated for six major "land types": crop land, pasture, fisheries area, forest land, built-up area, and energy land. Built-up area is typically calculated based on land cover and land use accounts. The last category of energy land illustrates which amount of biologically productive land (forests) is required to absorb for the excess CO₂ released by these nations. Ecological Footprint calculations have been carried out for almost all countries of the world by Global Footprint Network (WWF et al., 2008). The Footprint approach is also widely used for regional and local sustainability assessments. Standards for Ecological Footprints on the national have been elaborated; those for products are currently being developed (GFN Standards Committee, 2009).

Finally, the **Carbon Footprint** (or GHG rucksack) assesses greenhouse gas emissions (CO₂ and other GHGs) throughout the complete supply chain of goods and services consumed in a region or country utilising a lifecycle approach (normally measured in grams or kilograms of CO₂ equivalents). The Carbon Footprint concept is currently being applied in a number of projects aiming to develop a new labelling system for products informing about the climate impacts of consumption (BSI, 2008).

5 The suggested set of resource use indicators

Taking into account the criteria listed in section 3, we suggest the following set of complementary resource use categories and related indicators. The set covers the core resource input categories of materials, water and land area plus the output category of GHG emissions, since climate change is generally regarded as the most pressing environmental problem. We illustrate the suggested set for two levels: the product level and the national level. It is possible to cover also other levels of activities with this indicator set (for example, companies, economic sectors, etc.). It shall be emphasised that all indicators take a life-cycle perspective. In studies on natural resource use at

the national level, a life-cycle perspective implies taking into account the indirect resource requirements of imported and exported products, in order to capture possible shifts of environmental pressures related to domestic production or consumption to other countries and world regions. For the assessment of resource use on product level, the life cycle approach comprises all (direct and embodied) resources used from cradle to grave. The suggested methods and indicators are therefore oriented towards Life Cycle Assessment / LCA, a standardised method to assess resource use and the related environmental impacts along products life cycles from cradle to grave/cradle.

Table 1: The suggested system of resource use indicators on the product and the national level

Resource use category		Product level		National level	
Materials	biotic	Material Rucksack of products	biotic	Material flow-based indicators of countries <small>(including materials embodied in imports and exports)</small>	biotic
	abiotic		abiotic		abiotic
Water		Water Rucksack / Water Footprint of products		Water Rucksack / Water Footprint of countries <small>(including water embodied in imports and exports)</small>	
Land area		Actual land use of products		Actual land use of countries <small>(including land embodied in imports and exports)</small>	
GHG emissions		Carbon Footprint of products		National GHG emissions <small>(including GHG emissions embodied in imports and exports)</small>	

For the categories of **biotic and abiotic materials**, the concept of the Ecological Rucksack is suggested for the product level, following the calculation guidelines of the MIPS concept (see above). On the macro level, a large number of indicators can be derived from national material flow accounts (OECD, 2007b). We suggest using material consumption indicators such as Total Material Consumption (TMC) as the main headline indicator. This will allow an aggregation across countries without double counting, and the incorporation of indirect flows from product import and export, unlike the simpler Domestic Material Consumption (DMC) which does not incorporate indirect flows. DMC is already part of the EU Sustainable Development Indicator set, while TMC is the targeted indicator for the future, once data are available.

On the product level, **water** inputs can be accounted applying the concept of Water Rucksack or Water Footprints. In addition to blue water (see above), the Water Footprint concept also includes green water. Also on the national level, Water Rucksacks or Water Footprints can be calculated. In parallel to the calculation of material flow-based indicators, national indicators on water consumption add the water embodied in imports to the water extracted domestically and subtract water embodied in exports to other countries.

The actual **land area** of products reflects the life-cycle wide demand on actual land area for the production of goods or services. National land cover and land use inventories allow illustrating the land use of countries. Again it would be necessary to add the actual land use of imported products and subtract the land use of exported products in order to calculate a national indicator on actual land use from a consumption perspective.

The category of **GHG emissions** refers to the concept for calculating Carbon Footprints, a life-cycle-wide GHG balance at the product level (see, for example, BSI, 2008). On the national level, the current system of Kyoto GHG inventories represents a production (or territory) accounting principle. Also regarding this category, consumption-based indicators can be calculated through considering GHG emissions embodied in internationally-traded products (Peters, 2008).

5.1 Explanation for suggesting this set of indicators

A set of indicators delivers more solid information than a single indicator. Key criteria in the evaluation were the coverage of all relevant categories of resource use in order to monitor shifts of environmental pressure and a well-founded basis for policy making and target setting. These criteria can be better fulfilled by applying a set of indicators instead of only one indicator (e.g. Carbon Footprint). A set of indicators covers resource use in a complementary manner and allows setting resource-specific targets and evaluating specific resource policies. This approach has also been applied in the original Environmental Space (ES) studies in the 1990s, which assessed ES separately in different categories of resource use (non-renewable raw materials, wood, energy, water, land use). The suggested set of indicators avoids counting the same resources twice (with the exception of inputs of fossil fuels producing CO₂ and biotic material inputs, which produce GHG emissions other than CO₂, which are accounted in the material flow indicators and the Carbon Footprint).

The set of indicators focuses on resource use amounts instead of specific environmental impacts. In a world which increasingly faces limits of ecosystem capacities and resource scarcities, reducing the amounts of used natural resources becomes the central determining factor for a sustainable global development. While environmental impact indicators deal with issues of substitution of specific environmentally harmful materials and substances, this set of indicator deals with the issue of the overall scale of the human production and consumption system. It thus points to reduction rather than substitution. The set of indicators can therefore be regarded as the general indicator framework, based on which more specific indicators (for example, on different environmental impacts) can be calculated. This set of indicators also allows establishing direct links to social and development issues, including resource poverty and a fair distribution of global resources among the inhabitants of this planet.

For acceptance by policy makers, a strong link to the statistical system is desirable. We suggest including measurement methods and indicators, which have a strong link to the statistical system on the Member State and EU level. The example of MFA-based indicators (included in the EU sets of Sustainable Development and Structural Indicators) illustrates that indicators with a solid statistical background are more accepted in policy spheres as are other indicators, which have been developed outside the statistical system of environmental accounting. The set of indicators therefore includes indicators, which are close to real statistical data and do not require

transformation and modelling of data.

The Ecological Footprint is not included in the set of indicators. The suggested indicator set does not include one overall indicator of resource use, which integrates several categories into one number. Such indicators enable an easier communication of overall results, as a large number of complex interrelations between the economy and the environment are illustrated in easily understandable terms; the Ecological Footprint is the most prominent example for this type of indicator. However, at the same time, this approach entails a number of important disadvantages, which shall be discussed using the example of the Ecological Footprint:

- Some resource categories cannot or can only indirectly be measured. GHG emissions other than CO₂ are currently not accounted in the Footprint and abiotic materials are only indirectly accounted through the demand for energy and land area for extraction and processing.
- Important information is lost in the data transformation procedure. For example, actual land demand of a product or country cannot be analysed with the Footprint.
- Strong assumptions have to be applied, in order to transform different types of primary data (e.g. material flows, land use, CO₂ emissions) into one common unit of calculation; for example, transforming CO₂ emissions into hypothetical forest areas, which is frequently criticised, as the sequestration is not actually happening.

We therefore suggest measuring and illustrating different aspects of resource use in the original units (e.g. material consumption and carbon emissions in mass, water use in litres, land area in hectares), without transforming them into a single artificial unit of measurement.

This set of resource use indicators is complementary to the basket of indicators measuring the environmental impacts related to resource use. The EU Resource Strategy primarily aims at de-coupling environmental impacts of resource use from GDP. In 2007, DG Environment funded a first project, which evaluated different indicators of resource use regarding their suitability to illustrate the related negative environmental impacts. The research team, including SERI, suggested a basket of four indicators, which should be further improved and integrated: the Ecological Footprint illustrating the impacts on biocapacity and (global) carrying capacity, Environmentally-weighted Material Consumption (EMC) reflecting the specific environmental impacts of materials and products, Human Appropriation of Net Primary Consumption (HANPP) indicating the intensity of ecosystem use and Land and Ecosystem Accounts (LEAC) illustrating the drivers for land cover and land use changes, which have implications for biodiversity and ecosystem services. The indicator set suggested in this paper complements this basket of impact indicators through providing the information on the underlying volumes; in fact, in several cases, the indicator set is the physical basis for properly calculating these impact indicators (for example, solid accounts of material consumption of products or countries is one of the main data basis for calculating the Ecological Footprint or the EMC of countries).

5.2 State of the art and research needs for the suggested indicators

Accounting standards already exist or are currently being developed. Some of the accounting methods underlying the suggested set of indicators already exist in an internationally standardised format: this holds for material flow-based indicators on the product and the country level, Carbon Footprint or Kyoto inventories of GHGs. The accounting method for other categories, in particular

for water and land are currently being developed. As the measurement systems covering different types of resource use have been developed separately, further methodological harmonisation is still required, in order to improve the comparability of the results. This requires in particular defining common system boundaries for accounting resource use.

For some of the suggested indicators, data is already available for both products and countries. Data on material consumption in the EU countries is collected by Eurostat (EUROSTAT, 2007a) and MIPS calculations on the product level exist for a variety of products (see www.mips-online.org). Water Footprints exist for a large number of countries as well as for (mostly agricultural) products (see www.waterfootprint.org). Data on actual land cover and land use is available for Europe through the European Environment Agency (EEA, 2006), while data on land demand of products is very patchy, with the exception of biomass products, for which the UN Food and Agricultural Organisation maintains a data base (see <http://faostat.fao.org>). Since 1990 data on the territorial GHG emissions of countries are available from United Nations Framework Convention on Climate Change (UNFCCC), provided in the annual GHG inventory submissions by Annex I Parties and in the national communications under the Convention by non-Annex I Parties. First data sets on the Carbon Footprint of countries have also been presented (see www.carbonfootprintofnations.com).

Data gaps exist particularly regarding resources embodied in internationally traded products. The data base for calculating those parts of resource use, which relate to indirect (or embodied) environmental effects, is still weak in all methods of the suggested indicator set. Some first data sets are available for the categories of materials, water and GHG emissions. Data on indirect land imported through the consumption of products is almost completely missing.

The Eurostat Data Centres will greatly improve availability of data on resource use. Eurostat currently sets up a Data Centre on Natural Resources and Products, which will cover all resource categories described in this paper. This data base will be a key step towards better availability of data for all the indicators suggested in the indicator set, as consistent data will be collected from the product via the sector to the country level.

Sustainability limits for different categories of resource use need to be defined. The identification of sustainability limits for each of the resource use categories is one of the key issues for further development of the suggested set of indicators. For GHG emissions, a per capita target of around 2 tons of CO₂ (equivalents) per inhabitant has been formulated. Other such targets need to be defined on a basis, which is as scientific as possible. These targets could refer to the maximum amount of biomass extraction from a given area of crop lands and forests or the maximum uptake of fresh water, given the limited capacity for water renewal. Only with a system of limits for each of the categories, trade-offs between different options can be properly evaluated (see below).

5.3 Applying the set of indicators in practice

Data should be illustrated in aggregated and disaggregated form. The suggested indicators can be applied as an aggregated number (headline indicator), but also be disaggregated into components, such as different abiotic materials in the material flow-based indicators or different categories of land areas (agricultural land, forest land, built-up land, etc.). Disaggregation is often

necessary, in order to link the resource use indicators closer to specific environmental problems and ensure a proper evaluation of results and trends. Also the links to related impact indicators can be established on a disaggregated level. Such environmental problems include e.g. the expansion of built-up land for transport infrastructure or the expansion of agricultural land for production of bioenergy and biomaterials; or the substitution of metal ores by new compound materials or biomaterials.

The regional/local context should be considered in the interpretation of the indicators.

When interpreting resource use indicators, the regional or local context should be taken into account to the extent possible. In particular indicators on water use depend critically on the local or regional availability of renewable water; a certain Water Footprint of a product could be problematic in one country, but sustainable in another.

Trade-offs can be identified with the set of indicators and related sustainability limits.

In a system of indicators illustrating the different types of resource use plus sustainability limits for each of the categories, trade-offs between different options can be analysed. For example, higher production of biofuels would likely decrease the abiotic resource indicator (less fossil fuels) and, depending on the type of biofuels, also the related GHG emissions. On the other hand, this would translate into increased demand for land area and water. The set of indicators and related limits can illustrate, whether an improvement in one category leads to an unsustainable situation in another category.

Simplified assessment based on secondary data. The life-cycle wide assessment of resource use of products can be performed based on primary (company-specific) data for a specific supply chain or partly based on secondary data from a data base.

On the national level, indicators of production *and* of consumption should be calculated.

In the traditional environmental accounting frameworks (such as the one applied in the Kyoto protocol), environmental pressures are accounted according to a territory principle (production principle), i.e. accounted where it occurs. In contrast, a consumption perspective is necessary to illustrate the global environmental pressures related to the final consumption of goods and services by a given population. However, methods to account the global resource use related to consumption in one country are still under development and refinement due to the lack of data on embodied environmental factors in international trade (see above).

The set of indicators should be applied in number of EU policy processes.

The measurement system could play an important role in the revision of the Resource Strategy (due 2010) and help setting concrete targets for different types of resources. Such targets and related policies are also required for an effective implementation of the Action Plan on Sustainable Consumption and Production. Empirical evidence generated with this indicator set should also support the statement that a substantial reduction of the negative environmental impacts related to resource use will need to address also the issue of overall *levels* of resource use in Europe. The indicator set could also play a role in EU impact assessments and sustainability impact assessments, when a number of policy options are compared. Other policy areas, where this indicator set could be useful are green public procurement, structural and cohesion funds and development aid.

6 An exemplary case study for the suggested indicators

The suggested indicator set has been tested in a comparative case study on low-energy light bulbs and light bulbs, carried out on behalf of an Austrian platform for industry and retailing (ECR Austria), with the objective to demonstrate that the proposed indicator set can be calculated based on secondary data from life cycle inventory data and LCA data bases. For the calculation of the indicator set, material input data, energy input data including the underlying energy mix as well as the water input data (e.g. process water) have to be collected for the different stages of the life-cycle. Simplifying the data gathering process for the life-cycle wide assessment of a product, data for indirect (embodied) resource inputs, which do not occur on the production site, are retrieved from specific LCA data bases. Even if no primary data on the direct resource inputs are available, secondary data of an LCA-study or an LCA data base can be employed. The example calculation below was based on a life cycle inventory of an existing LCA study (Pfeifer, 1994).

The input-oriented indicators Abiotic Material Rucksack, Biotic Material Rucksack and Water Rucksack were calculated following the MIPS approach. For each input, a specific MIPS factor for the indirect resource use (including energy) for the categories abiotic materials, biotic materials and water were selected from Schmidt-Bleek (1998) and the MIPS data base at the Wuppertal Institute for Climate, Environment and Energy (Wuppertal Institute, 2003). The CO₂-e factors for calculating the Carbon Footprint are provided e.g. by the data base ecoinvent (ecoinvent centre), ProBas (German Federal Environment Agency (UBA)), GEMIS (Öko-Institut e.V.) or International Reference Life Cycle Data System (ILCD) (European Commission JRC) (Hinterberger et al., 2008). The results refer the service unit of 8.000 operating hours, which allows a comparison between low-energy light bulbs and light bulb, since it considers the unequal life-time of the two options. The case study results are presented in Table 2.

Table 2: Case study results for the comparison of low-energy light bulbs and light bulbs

Results for 8.000 operating hours	low-energy light bulbs	light bulb
Abiotic Material Rucksack [kg]	110	576
Biotic Material Rucksack [kg]	0,02	0,04
Water Rucksack [l]	2.971	16.023
Actual land use [m²]*	0,0003	0,002
Carbon Footprint [kg]**	34	182
* only direct land use of the production site		
** only carbon dioxide emissions		

The Abiotic Material Rucksack for low-energy light bulbs is about five times lower as for light bulbs. The Abiotic Material Rucksack is primary caused by the energy use in the use phase (95% for low-energy light bulbs; 99% for light bulbs), which refers to the Austrian energy mix. The Carbon

Footprint, which in this case study only accounted for carbon dioxide emissions, is also mainly driven by the use phase, therefore the Carbon Footprint for the low-energy light bulbs is, in accordance with the Abiotic Material Rucksack, about five times lower than for light bulbs. The Carbon Footprint for the production phase is only about 1.2 times lower than for light bulbs. Considering the assumptions made for the service unit of 8.000 operating hours, the Carbon Footprint of producing a single low-energy light bulb is higher than for a single light bulb. The results for Biotic Material Rucksack are negligibly small, which is typical for this specific product category. The Water Rucksack for low-energy light bulbs is mainly driven by the energy use in the use phase influenced by the Austrian energy mix (98% low-energy light bulbs, 99,5% light bulb), but also by water intense materials such as aluminum or polycarbonate. The actual land use for both products is of a very small dimension, since only the direct land use of the product site was considered, due to the lack of data on indirect actual land use. If the Ecological Footprint, which can be divided into actual land and hypothetical forest area required for the sequestration of CO₂-emissions, would be calculated based on these data, it would mainly consist of carbon sequestration land.

Besides the confirmation of the feasibility of assessing the advocated indicator set on product level, the case study results demonstrate the benefits of an indicator set which covers the main environmental categories.

7 Conclusions

This paper developed a comprehensive set of resource use indicators, which addresses primarily environmental problems related to the overall scale of production and consumption in Europe and its global implications. The suggested set of indicators therefore focuses on the absolute amounts of resource use instead of specific environmental impacts. For some of the indicators, data is already available for both products and countries. The suggested set of indicators can therefore be implemented in a reasonable time frame. However, resources should be devoted to improve data availability particularly for indicators related to land and water use as well as for natural resources embodied in internationally traded products. The upcoming Eurostat data centre on natural resources and products will considerably increase the availability of data for the indicator calculation. In order to allow a proper evaluation of these indicators and resulting necessary trade-offs between them from a sustainability point of view, the identification of sustainability limits for each of the different resource categories should be a high priority in the near future. The set of indicators should then feed into a number of EU policy processes and help to better assess the impact of EU policies on natural resources, both within Europe and globally.

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