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On behalf of the Federal Environment Agency

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Scientific assessment and evaluation of the indicator "Ecological Footprint"

Final Report

Vienna, 24.1.2007

Executive summary

The Ecological Footprint has proven one of the most successful indicators for communicating the concept of environmental sustainability and the physical limits of our planet. In the past decade the Ecological Footprint has developed into one of the most important measures for resource use in production and consumption at the international level and it is used by a large number of institutions for evaluating impacts of human activities on the environment.

The Ecological Footprint is used by companies, municipal and local planning institutions as well as environmental and development NGOs all around the world. However, examples of the application of the Ecological Footprint at the national level are rare.

So far, no overall assessment and evaluation of this indicator for its possible use as a sustainability indicator for Germany has been carried out. The objective of the project *Scientific assessment and evaluation of the indicator “Ecological Footprint“*, which has been commissioned by the Federal Environment Agency (UBA) in Dessau, Germany, was to close this gap. The project was a corporation between the Sustainable Europe Research Institute (SERI), Vienna, Austria, Ecologic, Berlin and Best Foot Forward (BFF) in Oxford, UK.

Project objectives and outline of this report

The project had four major objectives:

1. Describing the state of the art of the calculation of the Ecological Footprint and providing a review of existing calculation methods.
2. Analysis of underlying data using the National Footprint Accounts of Germany and presentation of the main problems with regard to data quality. Furthermore, the identification and assessment of alternative national data sources for Germany.
3. Critical analysis of existing Ecological Footprint calculations with particular focus on the weak points in the calculation method as well as the meaningfulness and interpretability of the indicator.
4. Formulation and presentation of recommendations on how identified weak points could be improved (in particular with regard to data sets and calculation methods) and for which fields of application the Ecological Footprint seems appropriate.

The project report consists of five chapters. Chapter 1 gives an introduction to the project. Chapter 2 contains a description of the standard calculation method, a short review of existing Ecological Footprint studies at the national level, a summary of the most recent calculations of Germany’s Footprint and the strengths of the indicator. Chapter 3 investigates the data base of the National Footprint Accounts of Germany, identifies the main weak points and evaluates alternative data sources from national statistics. Chapter 4 on the one hand illustrates the weak points and critiques of this method and the calculation and aggregation of primary data, and, on the other hand discusses important aspects regarding the meaningfulness and interpretability of the Ecological Footprint. The final chapter 5 contains the conclusions regarding the use of alternative data, the improvement of weak points and applications of this indicator at the national level.

Results of the assessment

The Ecological Footprint is – also according to its proponents – no overarching indicator for sustainability, but is regarded as *one* key criterion for environmental sustainability. The Footprint has been developed to answer the crucial question how much biocapacity is used by human activities and how much biocapacity is available on a sustainable basis.

In the past years, the **calculation method of the Ecological Footprint** at the national level has been continuously advanced and improved. Important issues concerning, for example, the interpretation of time series of Footprints could be solved due to these improvements. The currently developed *Ecological Footprint Standards* will significantly contribute to the international standardisation of the calculation method. Also, the **quality and consistency** has improved with regard to both primary data and used coefficients.

There are some **major advantages of the Ecological Footprint compared to other methods and indicators**: it enables demonstrating very complex interrelationships and interdependences between production and consumption activities and their pressures on the ecosystems in a simple and easily understandable way. Therefore, it is particularly useful for communication and education purposes. The Ecological Footprint can be calculated and integrated at different levels (e.g. companies, cities, nations) in a consistent way. In addition, it is presently the only resource-use indicator with global time series of comparative data for all countries.

Even though the method has been improved, a **number of critical points** regarding the Ecological Footprint concept remain that concern the fundamental characteristics of this indicator. For example, one concern is that the Footprint aggregates different environmental categories (such as the use of renewable resources, energy, land use and CO_2-emissions) into one overall number, applying a multitude of calculation factors in an often insufficiently transparent way. The fact that the indicator refers to the category “land area”, but the calculated unit of “global hectares” abstracts from actual land use is another issue. Furthermore, the Footprint only indirectly incorporates the dimension of non-renewable resources. Finally, the Footprint claims to measure global limits for sustainable resource use and to quantify overuse of ecological assets, but the calculation are based on a number of (often criticised) assumptions.

Recommendations

This project elaborated recommendations with regard to the use of alternative data sets, improvements of calculation methods and the application of the indicator.

Key **recommendations regarding the improvement of the data base** include the improvement of the transparency and comprehensibility of the data, the use of sensitivity analysis to identify priority areas, the matching of Footprint data with national statistics, the comparison of alternative data sets and the adjustment of estimations, as well as the verification of international hypotheses and improved trade data resolution.

The following **recommendations for methodological improvements** are presented in this report: supporting the research programme for the improvement of the calculation method co-ordinated by the Global Footprint Network, which addresses a large number of the critiques identified in this report; the improvement of links to existing environmental accounting systems (for example the integrated environmental-economic accounts of the German Federal Statistical Office) as well as taking into account the origin and destination of traded products in order to better assess the interdependences of international trade.

For what kind of **applications** the Ecological Footprint is suitable is determined by its specific characteristics and properties. The advantages and disadvantages of this indicator compared to other measures of environmental sustainability have to be evaluated carefully by the users.

The extraordinary usefulness of the indicator Ecological Footprint for communication and teaching purposes is undeniable. An extended and intensified use of the indicator for environmental and sustainability teaching is therefore recommended without reservation. Furthermore, the Ecological Footprint is a useful indicator for a region or a country to illustrate overall resource consumption in terms of different environmental categories being aggregated into one indicator. Since the calculation method is standardised on the global level, Ecological Footprints are useful for international comparisons between countries in different world regions.

The improved integration of Footprint data (together with other indicators) into integrated environmental-economic models would facilitate the future use of the Ecological Footprint to analyse major sustainability issues. For example, estimating the implications of improved eco-efficiency and transformations in the energy supply mix or changes in the demand of certain traded products caused by different lifestyles.

At the same time the Ecological Footprint is not an appropriate measure for a number of sustainability-related topics. These include biodiversity, conservation of ecosystems, resource management (particularly non-renewable resources), specific environmental impacts of resource use, as well as key aspects of other sustainability dimensions, such as social equity, health and quality of life.

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1 Introduction

In the past decade the indicator Ecological Footprint developed into one of the most important measures for resource consumption of production and consumption activities on the international level.

Today, the Footprint is mainly used as a communication instrument for issues of environmental sustainability and for awareness raising. It is applied by a large number of institutions around the globe, above all municipal and local administrations, educational institutions, companies and NGOs.

So far, no overall assessment and evaluation of this indicator for its possible use as a sustainability indicator for Germany exists. The project *Scientific assessment and evaluation of the indicator "Ecological Footprint"* aimed at closing this gap.

The project had four major objectives:

1. Describing the state-of-art of the calculation of the Ecological Footprint and generating a review of existing calculation methods.
2. Analysis of underlying data using the National Footprint Accounts of Germany and presentation of the main problems with regard to data quality. Furthermore, the identification and assessment of alternative data sources for Germany.
3. Critical analysis of existing Ecological Footprint calculations with particular focus on the weak points of the calculation method as well as the meaningfulness and interpretability of the indicator.
4. Formulation and presentation of recommendations how identified weak points could be improved (in particular with regard to data sets and calculation methods) and for which fields of application the Ecological Footprint seems appropriate.

It is important to mention, that – due to time restrictions – this project focused on the national (macro) level and the possible application of the indicator in national institutions. Therefore, no assessment of applications on other levels (municipal, regional, company and household level) could be carried out.

The project was a co-operation between the Sustainable Europe Research Institute (SERI), Vienna, Austria, Ecologic, Berlin and Best Foot Forward (BFF) in Oxford, UK. Thus, objectivity of the assessment of this indicator could be guaranteed, while at the same time internationally recognized expertise in the area of Ecological Footprinting could be directly involved in the project.

This final report consists of four main chapters:

Chapter 2 contains a description of the standard calculation method (2.1), as well as a short review of existing Ecological Footprint studies on the national level (2.2). Section 2.3 delivers a summary of the recent calculations of Germany's Footprint and section 2.4 discusses the strengths of the indicator Ecological Footprint.

Chapter 3 investigates the data base of the National Footprint Accounts for Germany. In section 3.1 the main weak points are identified. Alternative data sources from national statistics are compiled and evaluated in section 3.2.

Chapter 4 of the final report on the one hand shows the drawbacks and the points of critique of this method and the calculation and aggregation of primary data to the overall Footprint

(4.1.). On the other hand the fundamental aspects with regard to the meaningfulness and interpretability of the Footprint for a policy-oriented use are explained in section 4.2.

The final chapter 5 contains the conclusions regarding the use of alternative data (5.1), regarding the improvement of weak points in the methodology (5.1) and regarding the application of the indicator on the national level (5.3).

2 Foundations

This chapter provides the foundation for a better understanding of the indicator “Ecological Footprint”. The current calculation method is presented in detail and an overview of existing research work at the national level is given. Recent data for the Ecological Footprint of Germany are discussed and the advantages of the Footprint concept are summarized.

2.1 Summary of the method

In the early 1990ies, the basic concept of the Ecological Footprint was developed by Mathis Wackernagel and William Rees (Rees and Wackernagel, 1992). The objective of the authors was to develop a strategic instrument able to translate increasing criticism of the unsustainability of human lifestyles into common action. They were and are convinced that human society can not be regarded separately from nature and that human activities always have to be analysed in an environmental context. From this perspective, economic or demographic growth trends have to be interpreted and assessed within the constraints imposed by natural limits (Wackernagel and Rees, 1996).

The Ecological Footprint is a sustainability indicator that compares anthropogenic demand for natural resources with their supply provided by ecosystems. It is a “strong sustainability” indicator, applying the assumption that natural assets can - to a limited extent only - be substituted by manmade assets, which “weak sustainability” would permit (Ekins et al., 2003).

Ecological Footprint calculations do not account all natural assets. They include only those which have been referred to as “critical natural capital”. Critical natural capital is defined as those parts of the natural environment that perform important and irreplaceable functions (Ekins, 2003), and, in the words of Wackernagel, “are essential for carbon-based life” (Wackernagel et al., 2005). This kind of life-supporting natural capital enables the biosphere to regenerate its capacity and to renew natural resources. Monetary valuation methods are not adequate for these assessments, since climate stability, the absorbance capacity of the biosphere, soil fertility, and other aspects are not, or not sufficiently, reflected in market prices. For this reason, the calculation of the resource capacity and the regeneration capacity of our planet is not possible in monetary units (Wackernagel et al., 2005). The Ecological Footprint therefore uses biophysical units to measure human consumption of materials, energy, and land area.

The Ecological Footprint shows how much land area is required to sustain the socio-economic use of resources for a certain period of time (in the majority of cases one year) with available technologies and given resource management conditions and to provide infrastructure and absorb waste and pollutants (GFN, 2006a). Both land and water surfaces are taken into account.

The term “Ecological Footprint Accounting“ in the strict sense only refers to the demand side and would therefore correctly be termed “Ecological Footprint and Biocapacity Calculation”, because it also involves the supply side (Schaefer et al., 2006). In the following, however, the more common and shorter term „Ecological Footprint Accounting“ is used.

The Footprint indicator is not designed as a model for future developments, but it primarily describes the area requirements for past periods, for which socio-economic and biophysical data are available (Wackernagel and Ferguson, 1999).

In the past 15 years, the calculation method of the Ecological Footprint has been continuously improved and advanced. The Global Footprint Network and its more than 70 partner organisations are working on consistent and transparent calculation methods and a standardisation to enable international comparisons and to establish the indicator as a basis for political decision-making (GFN, 2005). Since June 2006, the first version of standardisation guidelines (Ecological Footprint Standards 2006) is available for download from the website of the Global Footprint Network (http://www.footprintstandards.org).

2.1.1. Basic assumptions for the calculation of the Ecological Footprint

Each year the Global Footprint Network publishes the „National Footprint and Biocapacity Accounts“, which illustrates the state of the art of the calculation method (GFN, 2006a; Wackernagel et al., 2004b; Wackernagel et al., 2005).

Footprint calculations are subject to six basic assumptions (GFN, 2006a):

- The majority of anthropogenic resource use and the resulting amounts of waste and emissions can be identified.
- Most of the resource and waste flows can be measured in bioproductive areas, required for their supply and absorption. Immensurable amounts are not included in the calculation.
- Different bioproductive areas can be converted into one single measure (the “global hectare”), which corresponds to the global average productivity.
- Since each global hectare of a given year reflects the same bioproductivity, they can be summed up.
- If the human resource demand as well as the natural supply is measured in global hectares, direct comparison is possible.
- The calculated demand for land area can exceed its supply.

The first calculations of the Ecological Footprint were based on a “Component approach”, i.e. all relevant consumption categories are identified and the footprints of each of the categories are calculated independently using data from „Life Cycle Analysis“ (LCA) and aggregated in a final step. This “bottom up“ approach shows several drawbacks, because LCA data, which measure material and energy consumption of single goods or services from the production via consumption to disposal, are sometimes unreliable and incomplete. In addition, one is confronted with the problem of possible double counting of some components and the different production efficiencies in the production of similar goods.

Due to the implementation of the currently preferred “compound method”, the majority of these methodological weak points could be solved, as this top down approach uses already aggregated data sets at the national level, and therefore a detailed knowledge on single final demand patterns is no longer necessary. However, the underlying data have to be reliable in order to derive robust results with this method (Wackernagel et al., 2005).

The national Footprint calculations are based on economic and biophysical data, published by internationally recognized institutions such as the Food and Agriculture Organization of the United Nations (FAO), the International Energy Agency (IEA), the UN Statistics Division (UN COMTRADE) or the Intergovernmental Panel on Climate Change (IPCC). Expert studies published in scientific journals are also used as data sources (GFN, 2006a). A big share of these data refers to the field of material flows, as applied also in Material Flow Analysis (MFAs). For this reason, the Global Footprint Network is a part of an initiative lead by SERI for the harmonisation of basic data between the “Ecological Footprint Accounts“ and the MFA at the national level (for more detailed information see section 5.1).

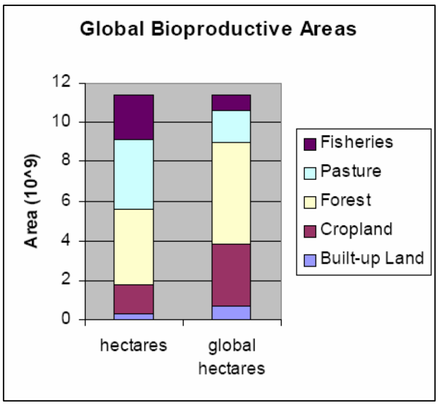
The Footprint calculation can be regarded as an equation, balancing the natural supply of the planet, the so-called biocapacity, and the anthropogenic demand, the so-called Ecological Footprint. In order to make the two sub-systems, “Total Ecological Footprint“ and “Total Biological Capacity“, comparable a common measure is essential. Therefore, both human consumption of renewable and non-renewable resources and the biocapacity are measured in global hectares.

2.1.2. Global hectares

The application of global hectares as a measurement unit addresses the question of how much of the worldwide available biocapacity is used by a certain activity (Wackernagel et al., 2005).

Each global hectare represents the same amount of natural productivity. The sum of global and real hectares is normalised and therefore has the same size. Figure 1 illustrates that this leads to a high valuation of “cropland” and “forest” in global hectares, since these areas have a higher productivity compared to other land categories.

Figure 1: Bioproductive areas in hectares and global hectares



Source: Wackernagel et al., 2005

In the normalisation of global hectares, changes in productivity over time have so far not been taken into account. Therefore, the Living Planet Report 2006 (WWF et al., 2006) for the first time introduced the measurement unit “constant global 2003 hectares”. The productivity of constant global hectares is assumed to be constant over time. „Constant 2003 hectares“ of different years correspond to the productivity of the year 2003. The year 2003 has been chosen as a reference year, since this year has the most recent data available. One global hectare for the year 2003, therefore, equals a constant global 2003 hectare. One global hectare of the year 2000 corresponds to only 99%, a global hectare of the year 1970 to only 89% of a constant 2003 hectare, illustrating the smaller productivity of past years. Constant global hectares allow for a better illustration of time trends (GFN, 2006a).

The calculation method of the constant annual-specific global hectares should still be improved in the future. For example, changes in the productivity of different land categories over time should be included (GFN, 2006a). One potential indicator for this productivity loss is HANPP („Human Appropriation of Net Primary Production“) (Haberl et al., 2004).

Another alternative for the calculation of global hectares is the calculation of actual hectares, which is meaningful if the question of how much physical land is *actually* used by a specific activity is to be answered (Wackernagel et al., 2004a, see chapter 4).

2.1.3. The calculation of the Total Ecological Footprint

The total demand of a country is calculated as “Consumption = Production + Imports – Exports”. Exported goods are assigned to the country in which they are consumed as final demand. Ecological Footprints follow the principle of consumer responsibility in contrast to producer responsibility, where exports are assigned to the exporting country (Lenzen et al., 2006). Secondary products (e.g. flour or cellulose) are transformed into primary products (e.g. wheat and timber) and are thereby included in the calculation (GFN, 2006a). Area requirements of the primary products are determined in global hectares; the conversion of secondary products is based on local yields.[1] In the next step, the Footprint of secondary products is added to the total Footprint, if the products are traded. If the secondary product is consumed in the country of products, its Footprint remains part of the primary product (Wackernagel et al., 2005).

The embodied energy of products is measured independently from the country of production. For exports, country-specific equivalence factors are used, and for imports, global average values are used in order to convert embodied energy into CO_2 emissions and to determine the corresponding land areas (Wackernagel et al., 2005).

The land use categories

On the highest level of aggregation, total consumption of a country is divided into five bioproductive components and one hypothetical area of “energy land”. In addition, the six land use categories can be split up into different consumption categories such as food, services and mobility.

The six land use categories are:

- Cropland

Crops are produced on cropland (e.g. fields and fruit plantations). Due to the significantly differing productivity of different croplands, this category is divided into “primary cropland” and “marginal cropland”.

- Grazing land

The demand for grazing land by livestock (and the subsequent animal products) is calculated by subtracting all documented sources of feed, such as crops and fish flour, from the overall food demand of animals.

[1] This causes inconsistencies in the calculation method (see Chapter 4 for more detailed information).

- Fisheries

Fish consumption is assigned to the productive water areas. Fishing grounds are evaluated according to their supply capacity of animal protein in comparison to the capacity of grazing lands.

- Forest area

Harvested timber products are assigned to the forests. The FAO defines areas with a tree coverage of more than 10% as forest (Wackernagel et al., 2005).

- Built-up land

It is assumed that the infrastructure is built on cropland, since the majority of urban areas are built on fertile areas. Water dams and reservoirs are in this category, as each category is assigned only to its primary function in order to avoid double counting.

- “Carbon land“

For the estimation of land requirements for the use of fossil energy three major methods are proposed:

(a) Calculation of the area required to provide the same amount of energy as provided by fossil energy with alternative energies from agriculture and forestry (e.g. ethanol from agriculture or methanol from forestry).

(b) Calculation of the area required to provide the same energy amount as provided by fossil energy with renewable energy sources, especially timber. The basis for this consideration is that the total amount of energy available for mankind should not be reduced by creating an area necessary to provide alternative energy for future generations.

(c) Calculation of the forest area required to absorb the CO_2 emissions from use of fossil energy (sequestration).

Most Footprint studies on the national level apply the third method, which is calculating the consumption in CO_2 emissions, subtracting the annual amount absorbed by oceans, as a third of total emissions are estimated to be absorbed by oceans. The area needed for absorbing CO_2 emissions is estimated as a hypothetical sequestration area, (i.e. the forest area that would be necessary to absorb these CO_2 emissions; see chapter 4).

Due to the lack of other quantification methods, nuclear energy is treated as fossil energy in the current calculation method, which means that the energy produced by nuclear reactors is converted into land areas via CO_2-equivalents.

The conversion into global hectares

The conversion of national consumption of renewable resources into global hectares is undertaken in two steps. First, consumption is divided by the average global yield of the area underlying the respective consumption category. Built-up land is multiplied by the yield factor of harvested products. CO_2 emissions are divided by the absorbance capacity of the forest stocks (GFN, 2006a).

In the second calculation step, the resulting yields are multiplied with the appropriate equivalence factor, which reflects the different productivity levels of the various land area categories. Thereby, equivalence factors convert the specific land categories, such as grazing land and crop land, into a normalised unit of bioproductive area (Wackernagel et al., 2005).

Table 1: Equivalence Factors 2003

Area Type	Equivalence Factor [gha/ha]
Primary Cropland	2.21
Forest	1.34
Grazing Land	0.49
Marine	0.36
Inland Water	0.36
Built	2.21

Source: GFN, 2006a

The equivalence factors for “cropland“, “grazing land“, “forest“ and “built-up area“ are taken from the *Global Agro-Ecological Zones (GAEZ)* model, which was developed by the International Institute for Applied Systems Analysis (IIASA) and the FAO in 2000 (IIASA and FAO, 2000). In contrast to previous calculation methods, these equivalence factors are based on potential instead of actual yields from domestic biocapacity (see Table 1). Thus, they are independent from actual productivity, which can vary significantly depending on the use of external inputs such as energy, fertilisers, pesticides, etc.

The area equivalents resulting from the two calculation steps can then be aggregated to generate the total Ecological Footprint in global hectares.

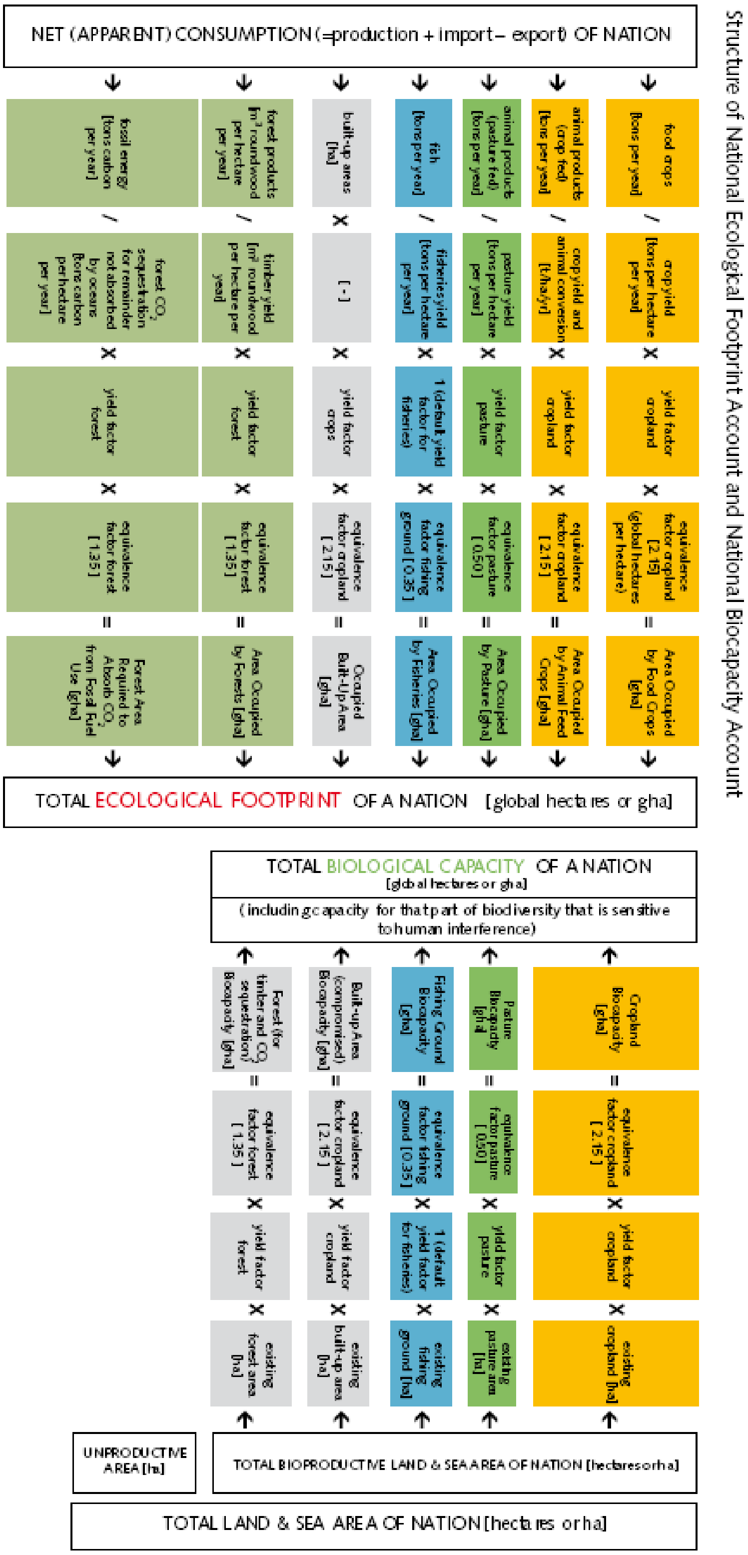
Figure 2 provides a graphical illustration of the calculation method of the Ecological Footprint. The figure is taken from the „National Footprint and Biocapacity Accounts 2005“ (Wackernagel et al., 2005).

2.1.4. The calculation of the “Total biological capacity“

Bioproductive areas are defined as areas that provide photosynthetic processes and thus biomass accumulation, which can be used for human activities. Non-productive areas, for example the open sea, marginal areas and deserts are not considered (Lenzen and Murray, 2003). In the year 2003, our planet comprised approximately 11.2 billion hectares of land and water areas (GFN, 2006a). In comparison, this number was 11.4 billion hectares in the year 2004, according to previous calculation assumptions (Schaefer et al., 2006), and only 8.3 billion hectares in the year 1997 (Wackernagel et al., 1997).

Dividing this area (2003) by 6.3 billion people – the number of people on this planet in the year 2003 – results in a bioproductive area of 1.8 hectares per capita. This calculation assumes that no area is explicitly reserved for other species (GFN, 2006). This contrasts former calculation methods, which reserved 12% of the total bioproductive area for the purpose of nature conservation and protection of biodiversity (Wackernagel et al., 1997). The Global Footprint Network argues that the question, how much land area should be reserved for other species, would be a political decision, which GFN does not want to pre-determine (GFN, 2006).

Figure 2: Structure for the calculation of the Footprint and Biocapacity



Notice: This illustration includes no secondary products and no nuclear energy.

Source: From Stokar et al., 2006b based on GFN (2005)

The right side of Figure 2 illustrates the calculation of the „Total biological capacity“. First, total available bioproductive area of a nation is identified and allocated to the different land categories. The available land area for absorbance of CO_2 is calculated as available forest area.

These bioproductive areas of a country are multiplied by so-called yield factors (see Table 2), with built-up areas being multiplied with the crop factor of harvesting products and “Carbon land” with the factor of forest area. Yield factors measure the difference in productivity of one specific area (e.g. grazing land) compared to the global average productivity of the same area. Yield factors are calculated for all countries and for each year based on international statistics, mainly from the FAO.

Table 2: Yield factors of selected nations (2003)

	Primary cropland	Forest	Grazing Land	Ocean Fisheries
World average	1.0	1.0	1.0	1.0
Germany	2.3	3.9	2.2	1.1
Laos	0.8	0.2	2.7	1.0
New Zealand	2.2	2.5	2.5	0.2
Zambia	0.5	0.3	1.5	1.1

Source: GFN, 2006a

Table 2 reveals that the crop land of Germany is 2.3 times as productive as the average global crop land and that forest areas in Laos possesses only 20% of the average global productivity of forests.

The resulting yield, which now is globally comparable, is again multiplied by the equivalence factor (see Figure 2), which standardises varying yields of different land categories on a global level.

The result of the calculation is the total national available biocapacity expressed in global hectares. This includes the capacity of the ecosystems to produce economically useable renewable resources with available technologies and current resource management practices and to absorb waste and emissions.

2.1.5. The ecological deficit

If the national Ecological Footprint is compared with the national available biocapacity, one can estimate whether or not available natural capital is sufficient to sustain given consumption and production patterns. If the Ecological Footprint exceeds biocapacity, a so-called ecological deficit results. Thus, the investigated country consumes more natural resources than it is able to provide. An ecological deficit can originate from two factors: either a country imports biocapacity from abroad (ecological trading deficit) or it overexploits its own or the global natural resources (e.g. by overgrazing or by emitting CO_2 that cannot be absorbed within the country and is accumulated in the atmosphere). At the global level such an overuse is called “overshoot”, an overuse of the long-term carrying capacity (Wackernagel et al., 2005).

The Footprint method is designed to underestimate the area demand in case of uncertainty (Wackernagel et al., 2005). Activities excluded from the calculation range from the emission of pollutants to the atmosphere that cannot be absorbed, the consideration of water consumption and the consumption of non renewable resources such as minerals and ores (for more detailed information see section 4.1.).

2.2 Review of existing studies

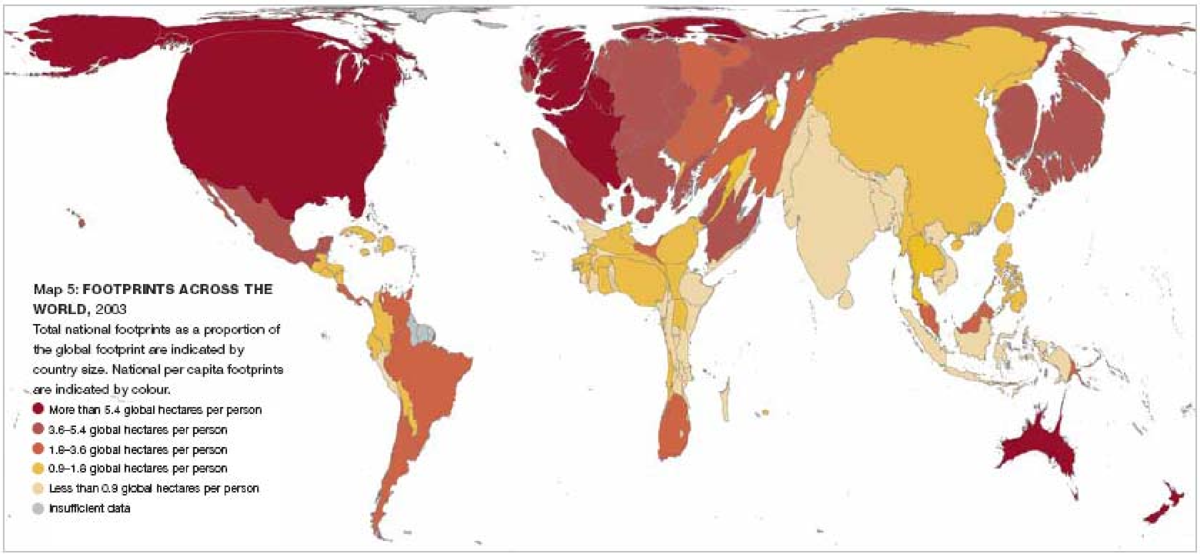
2.2.1. Footprint of Nations and Living Planet Reports

The study "The Footprint of Nations" (Wackernagel et al., 1997) compared the Footprint of 52 countries, which are home to 80% of the world population. In this report, national consumption quantities were for the first time compared with the available biocapacity using the Footprint indicator. The authors concluded that mankind consumes around one third more natural resources than nature can supply. Only 10 of 52 nations had a Footprint per capita below the global available biocapacity of 1.7 hectares at that time.

In 1998, the first Living Planet Report (LPR) was published, with the aim of documenting the continued disappearance of nature on our plant (WWF and World Conservation Monitoring Centre, 1998). Since the year 2000, not only the Living Planet Index but also the Ecological Footprint has been applied as a sustainability indicator. The WWF and its partner organisations have published LPRs in 2000, 2002, 2004 and 2006, calculating the Footprint of all countries in the world with more than 1 million inhabitants. Since 2004 the Global Footprint Network serves as official partner of the WWF.

In 2002, scenarios analyses of future Footprints were published for the first time (WWF et al., 2002). The LPR 2006 calculated the Footprint in constant 2003 global hectares instead of global hectares, with the objective to increase comparability of Footprints over time. By weighting a world map by national Footprints, differences between the Footprints were illustrated through graphical distortions (see Figure 3).

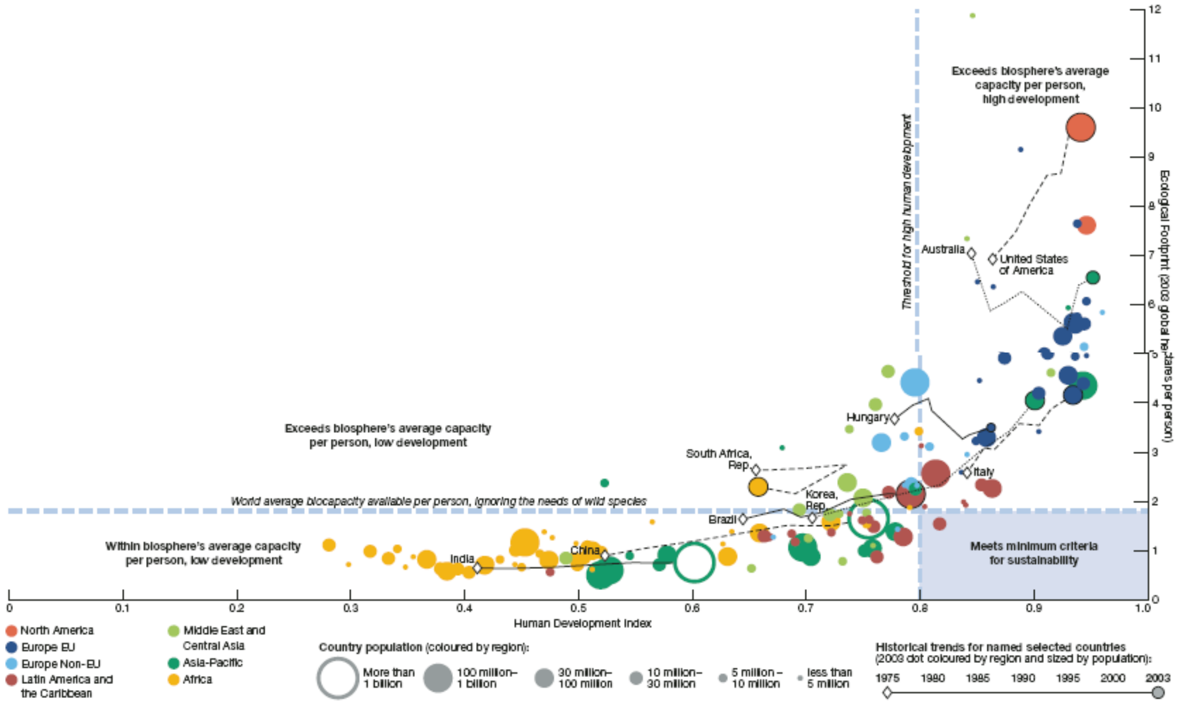
Figure 3: National Footprints as a proportion of the global Footprint



Source: WWF et al., 2006

In 2006 the Footprint was graphically linked with the Human Development Index (HDI); see Figure 4 (WWF et al., 2006).

Figure 4: Ecological Footprint and Human Development Index



Source: WWF et al., 2006

In 2005, two region-specific reports were published: *Europe 2005: The Ecological Footprint* (WWF et al., 2005a) and *Asia Pacific 2005: The Ecological Footprint and Natural Wealth* (WWF et al., 2005b). The European report for the first time illustrated the country of origin of imports to Europe and graphically illustrated the European ecological trading deficit. The Asia-Pacific report included graphs of biocapacity exports of selected Asian countries to other parts of the world.

So far, the Ecological Footprint has been calculated for 150 nations from 1961 to 2003 by the Global Footprint Network (GFN), which publishes the annual state-of-the-art of the Footprint calculations (GFN, 2006a). Significant methodological improvements since 2004 include a simplified calculation for grazing land, a more exact measurement of CO_2-absorbance and forest productivity and the incorporation of IEA and COMTRADE data sets in the calculation. In addition, the calculation of embodied energy of traded products has been improved since 2005 (GFN, 2006). For a summary of Footprints of all countries in the year 2002 see Annex A1.

2.2.2. National studies

Apart from the studies of WWF and the GFN, a number of articles have been published in scientific journals dealing with the subject of national Ecological Footprints. A representative selection of these studies is listed in the following:

Nick et al. (1999) investigated seven different sustainability indicators, including the Ecological Footprint, and their meaningfulness for Scotland from 1980 to 1993. The study concluded that the use of single indicators leads to differing implications with regard to Scotland's sustainability and recommended a set of indicators for further sustainability research.

Van Vuuren and Smeets published national studies for Benin, Bhutan, Costa Rica and Netherlands for the years 1980, 1987 and 1994. They used local yields for their calculations in order to demonstrate the actual land appropriation of these countries. The single Footprint components were not aggregated. "Carbon land" was illustrated separately (van Vuuren and Smeets, 2000).

Haberl et al. (2001) published a study on the Footprints of Austria from 1926 to 1995, which were calculated using three different methods. These methods included the assumption of constant average global yields of the year 1995, of variable average global yields for each year and of variable annual regional yields. The authors concluded that different yield assumptions influenced the results of the Footprint calculations by a factor of two or more (see also section 4.1).

Wackernagel and colleagues calculated the Ecological Footprint for Austria, the Philippines and South Korea from 1961 to 1999. In this article, the calculation in global hectares was compared with the actual land-use approach. The authors conclude that both approaches answered different questions and provided different results, but due to continuing methodological improvement, the results of the two approaches have converged with regard to time series trends (Wackernagel et al., 2004a).

Bicknell et al. (1998) were the first to use input-output analysis, with the aim of estimating the national Footprint of New Zealand. McDonald and Patterson extended this method for 16 independent regions in New Zealand (McDonald and Patterson, 2004). Both studies applied regional yields for grazing land, cultivable land and forests and refrained from using equivalence factors.

Lenzen and Murray (2001) presented a study on the national Footprint of Australia also based on input-output analysis. They evaluated consumption on the basis of actual local land use and emission data, which were evaluated by weighting factors based on different degrees of land disturbance. In addition, demographic factors were taken into account.

In 2005 a very detailed report regarding the sustainable development of Wales and the implications for political decision-makers was published. The study combined material flows, Ecological Footprints and future scenarios in order to provide a comprehensive picture (Barrett et al., 2005).

Wiedmann et al. (2006b) also used input-output analysis for allocating the aggregated national Footprint to different consumption categories. The applied method was also a step forward towards the standardisation of the Footprint, as it is replicable for other countries.

In a study in 2005, van Vuuren and Bouwman modelled the development of Footprints in 17 world regions for the years 1995 to 2050 with the support of the IMAGE 2.2 modelling tools. Based on historical data from 1975 to 1995, scenarios of "Business as usual", "market forces", "security focus" and "sustainability focus" were developed in terms of global and local yields (van Vuuren and Bouwman, 2005).

McDonald et al. (2006) calculated the national Footprint of New Zealand for 2001, distinguishing different age groups and estimated the Footprint for the year 2051 in order to consider continuing age shifts in society in the Footprint calculations.

2.3 The Ecological Footprint of Germany

The most recent data for the Ecological Footprint of Germany were calculated by the Global Footprint Network for 2003 (GFN, 2006b). With a population of almost 82 million, the Footprint amounts to around 375 million global hectares, or 4.55 global hectares per capita. The global average is 2.19 global hectares. If all countries of the world would consume as much natural resources, humankind would require 2.5 planets to satisfy its demands. The demand in Germany amounts to 375 global hectares and its biocapacity supplies only 143 million global hectares. Thus, compared to 1.82 global hectares available world-wide, Germany ranks below global average with only 1.74 global hectares. The national biocapacity is by far not sufficient to satisfy national demand. The ecological deficit of Germany – the difference of the two values – amounts to 232 million global hectares in 2003.

The composition of the Footprint is listed in Table 3. The demand on energy areas or CO_2-absorbance areas in Germany attracts particular attention, as it makes up 63% of the total Footprint (with a value of 235 million global hectares). It becomes apparent that the total Footprint is to a large extent influenced by the area of energy/CO_2. This fact has to be communicated by a disaggregated presentation of the total number in order to guarantee an adequate interpretation of the indicator.

The demand for crop products represents 16% and the demand for forestry products 11% of the total Footprint. The demands for grazing land, fishing products and built up land are summed up to 11%.

Only the national biocapacity of forests exceeds the demand for forestry products. All other categories lack capacity to satisfy the respective demand.

Table 3: The Ecological Footprint of Germany in global hectares, 2003

Ecological Footprint		in %	in %	**Biocapacity**	
Grazing land demand	14.788	4	0	4.750	Grazing land
Fish	9.567	3	0	2.336	Fishing grounds
Forestry products	39.640	11	48	68.424	Forest area
Harvesting products	60.317	16	38	54.331	Crop land
Built up land	14.049	4	10	13.786	Built up land
CO_2-absorbance area	235.642	63	0		
Total Footprint	**375.175**	100	100	**143.627**	**Available biocapacity**

Source: GFN, 2006b

In the international comparison, Germany is ranked 23rd of all available (152) national studies for the year 2003, between Israel (rank 22) and Lithuania (rank 24). With 11.9 hectares per capita, the Arabian Emirates possess the largest Footprint (rank 1); the smallest Footprint can be found for Afghanistan with 0.1 hectares per capita (WWF et al., 2006).

A summary of the results of Germanys Footprint Accounts of the Global Footprint Network is appended in Annex A2.

2.4 The strengths of the indicator “Ecological Footprint”

The Ecological Footprint is one of the most successful indicators, if not the most successful worldwide for communicating the concept of environmental sustainability and the physical limits of our planet. Recognised journals such as *National Geographic*, *Time Magazine* and „*Bild der Wissenschaft*“, as well as newspapers such as *Le Monde, The Times* and the *Frankfurter Allgemeine* have published a number of extensive articles on the Ecological Footprint.

The recent Living Planet Report, published in October 2006, has seen more than 700 entries in “Google” in many different languages worldwide.

The method for calculating the Ecological Footprint is applied by a large number of institutions for the evaluation of environmental impacts. Users are companies, municipal and local planning institutions, and environmental and development organisations from all continents. The WWF recently started a program entitled “One Planet Business”, with the objective to elaborate strategies for reducing the Footprint together with major enterprises of different industries, for instance the automobile and food industry (WWF, 2006).

At the regional level, the Footprint has become a key indicator for assessing success or failure of regional sustainability policy (see for example, Barrett et al., 2006; Lewan and Simmons, 2001).

An illustrative presentation of complex interrelations

The major advantage of the indicator Ecological Footprint in comparison to other environmental indicators and indicator sets is the aggregation of different environmental dimensions into one single number. Thus, it is an indicator that integrates such diverse aspects such as consumption of renewable resources, CO_2 emissions as a climate impacting gas and the increasing transformation of fertile into built-up land.[2] This fact leads to significant advantages in particular for non-scientific users, as very complex interactions between human consumption and the effects on the ecosystems can be demonstrated and communicated in a very simple and understandable way (Rees, 2000).

Furthermore, the calculation of the available biocapacity of the planet allows comparing human natural resource consumption (demand side) with the long-term available capacities of ecosystems (supply side). Thereby, the Footprint can illustrate whether or not the current consumption level is below or already above the long-run sustainable level. The calculation of sustainability limits enables the definition of a concrete and vivid target for the reduction of human resource consumption and the calculation of how many planets would be required, if all people on earth would have the same consumption level as the inhabitants of the USA or Europe. This demonstrates the necessity of a change in human production and consumption patterns towards a more environmentally benign form that provides people in developing countries with possibilities to improve their standard of living without a massive overshoot of the capacity limits of our planet.

[2] This is related to a number of methodological difficulties, which are discussed in more detail in chapter 6.

These aspects are crucial points of strength of the Footprint concept compared to other sustainability concepts, such as the Factor 4/10 concept, which also demands a drastic reduction of resource use especially in the rich industrialised counties, but does not or can not define exact limits for sustainable resource consumption levels. The Ecological Footprint is not confronted with the problem of the definition of sustainable levels for the use of non-renewable resources, since it explicitly focuses on renewable resources.

Environmental Education and Communication

Until now, the Ecological Footprint mainly fulfils educational and communication purposes. As a study by Barrett et al. (2004) pointed out, 100% of the local administrations in the UK that used the Ecological Footprint as an indicator for their communities and regions, indicated rising public awareness for issues related to sustainable consumption as their central goal. As the second most important category, respondents stated that they wanted to produce teaching materials based on the results. Policy analysis and evaluation were only of minor interest for these local and regional applications.

The Ecological Footprint is the most commonly used indicator for the evaluation of personal lifestyles. A large number of institutions in different countries published questionnaires in the internet, where one's personal Ecological Footprint can be calculated:

- Redefining Progress (myfootprint.org); USA
- Projektagentur „Zukunftsfähiges Berlin"; Germany
- WWF Swiss
- Greenpeace CEE, Austria
- Sustainable Footprint; Netherlands
- Environmental Protection Agency Victoria; Australia
- Best Foot Forward; Great Britain

These questionnaires are an important tool to make non-specialists familiar with topics such as environmental sustainability and sustainable consumption and to connect complex global interrelations with tangible every-day purchasing and consumption decisions (Barrett et al., 2004).

Vertical integration

An important methodological strength of the Footprint concept is the fact that Footprints can be calculated and compared consistently at different levels of social activities. Footprint calculations exist on the level of single products and services, on the level of organisations (companies, etc.), at the city and regional level, as well as the national and international level. These levels can be integrated vertically: goods are produced in companies, companies form economic sectors and the economy consists of different economic sectors.

Worldwide country comparisons in the Living Planet Report

The "Living Planet Report", which is published biannually by the Global Footprint Network in co-operation with the WWF and other organisations (see literature overview above), is the only existing report that is documenting resource consumption in a comprehensive manner at the global level. Through the use of a methodically standardised calculation of the National Footprint Accounts for all countries of the world, published by the Global Footprint Network, it is possible to analyse the Footprints of all world regions in a consistently comparable way. This provides significant advantages in the communication of issues of global resource distribution and fairness. For this reason, the Ecological Footprint is also used in other publications devoted to the analysis of world-wide environmental developments (for example Wuppertal Institut, 2005), because standardised data are not yet available for other resource use indicators, such as material consumption.[3]

The “Global Footprint Network“

Global Footprint Network is a non-profit organisation dedicated to advancing the scientific rigor and practical application of the Ecological Footprint. It comprises more than 70 partner organisations spanning six continents. Since its inception in 2003, Global Footprint Network has made significant progress towards achieving its goals.

Currently, 22 countries are likely to adopt the Ecological Footprint and are working with Global Footprint Network. These countries include Australia, Brazil, Canada, China, Finland, France, Germany, Italy, Mexico, Russia, South Africa, Switzerland, and the United Kingdom.

Many of the world's largest environmental agencies and constituencies are already using the Ecological Footprint to accelerate global sustainability, including EPA Victoria (Australia), the European Environment Agency (EEA), the Finish Ministry of Environment, the nation of Wales, and large NGOs like NRG4SD (with 50 regional government participants), ICLEI (with 650 local government members worldwide), and WWF (with 5 million global supporters).

Leading scientists and politicians are supporting and endorsing Global Footprint Network's work. In addition to a 23-member advisory board, which includes four former ministers, as well as Professor Wangari Maathai, winner of the 2004 Nobel Prize for Peace, José Manuel Barroso, President of the European Commission, who endorsed the recent report "Europe 2005: The Ecological Footprint", and Catherine Day, Director General of the EEA, who has expressed her support for the Ecological Footprint and for Global Footprint Network's work.

[3] Until now, only world-wide data of resource extraction exist that do not include imports and exports of materials (see www.materialflows.net for global trend analysis and download of extraction data).

3 Data analysis

3.1 Analysis and assessment of the German National Footprint Accounts

In this chapter the structure of the Ecological Footprint Accounts and their sensitivity is described. The development of the Footprint Standards and the well-known problems of the footprint calculation are discussed. An example for the calculation of single values of the Accounts is given and the application of the Monte-Carlo Method is explained as a sensitivity analysis method.

3.1.1. National Footprint Accounts

The National Footprint Accounts are a comprehensive ecological accounting system that calculates the Ecological Footprint and biocapacity of the world and 150 nations from 1961 through the present. National Footprint accounts are updated annually based on the latest complete data sets available, which usually entails a time lag of about three years. This system has grown significantly since the earliest calculations more than ten years ago, and results are now in use by practitioners and educators throughout the world.

The Footprint Standards

The purpose of Standards for Ecological Footprint (see chapter 2), adopted in June 2006, is to encourage the generation of mutually comparable and high-quality results. Such standards aim to make analyses robust, transparent, and reliable, and therefore lead to results that are trusted and relevant for decision makers at all levels.

There are two parts to the Ecological Footprint Standards:

1. Applications Standards define requirements for calculating Footprint results, to ensure that Footprint calculations are conducted in a consistent manner, so that results are reproducible and comparable with other studies employing common boundary definitions.
2. Communication Standards define requirements for reporting Footprint results, to ensure that project reports do not distort the intention nor misrepresent the limitations of the National Accounts.

Structure of the accounts

Ecological Footprint Accounts consist of the following sections (for more detailed information according the distinct points see chapter 2)

1). Crop products;

2). Animal products;

3). Fisheries;

4). Forest products;

5). Energy consumption;

6). Built-up area;

7). Land use;

8). Yield factors;

9). Equivalence factors;

10). Results;

11). References;

12). Footprint intensities;

13). Other tools;

14). Trade details;

Data sources

The following major data sources are being used by the National Footprint Accounts (see Chapter 2 and Chapter 3.2):

1. Food and Agriculture Organisation of the United Nations (UN FAO)
2. Statistical Office of the European Communities (EUROSTAT)
3. European Environment Agency (EEA)
4. Intergovernmental Panel on Climate Change (IPCC)
5. Stockholm Environment Institute (SEI)
6. United Nations Commodity Trade Statistics Database (COMTRADE)
7. World Resources Institute (WRI)

3.1.2. How National Accounts work: The example of wheat

The following example illustrates the ‘top down’ calculation procedure used in the national footprint accounts focusing on wheat production.

The total Ecological Footprint of Germany is calculated according to the formula (1).

Where Pop is population of Germany; EF_Comp(i) – is an Ecological Footprint component

$$EF = \frac{Pop}{1000} * \sum_{i-1}^{I} EF(i) \qquad (1)$$

Where Pop is population of Germany; *EF_Comp*(i) – is an Ecological Footprint component.

1) The set *i* is composed of the following elements: Cropland
2) Grazing Area
3) Marine
4) Timber
5) Wood Fuel
6) Fossil Fuels
7) Nuclear
8) Built up Area

Considering for example the Ecological Footprint of cropland, then results from (1):

$$EF(Cropland) = \sum_{k}^{K} EF(Cropland, k), \qquad (2)$$

Where the set *k* is composed of:

1) Primary Cropland

2) Unharvested Cropland

The primary crop land consist again of several sub categories:

$$EF(Cropland, \Pr imary) = \sum_{f}^{F} EF(Cropland, \Pr imary, f), \quad (3)$$

Where the set f is composed of

1. Production;
2. Imports;
3. Changes and
4. Exports.

The production consists of:

$$EF(Cropland, \Pr imary, \Pr oduction) = \sum_{c}^{C} EF(Cropland, \Pr imary, \Pr oduction, c) \quad (4)$$

Where the set c is composed of 57 different crops, including wheat and other agricultural plants, calculated as following:

$$EF(Cropland, \Pr imary, \Pr oduction, Wheat) = \frac{EFF\_\Pr od \& * MCF * YF * EqF}{EF\_Yield * Pop}, \quad (5)$$

Where:

- EFF_Prod = Production – Seed (Effective production, UN FAO is used as a source of data here) = effective production

MCF= $\begin{cases} 1 \\ \dfrac{National\_Area\_of\_Wheat}{National\_Arable\_Cropland * 1000} \end{cases}$

MCF= *Multiple cropping factor*, chosen among the value “1” and the relation of the total area of crop to the total national arable cropland.

YF= $\dfrac{World\_Area\_Crop}{National\_Area\_Crop}$; (*Yield factor*);

EqF= $\dfrac{GAEZ\_Index\_\Pr imary\_Cropland}{GAEZ\_Average}$; (equivalence factor)

EF_Yield= $World\_Yield\_Wheat * Natinal\_Seed\_Factor$,

Where,

World_Yield_Wheat= $\dfrac{World\_Yield\_Wheat\_\Pr oduction}{World\_Yield\_Wheat\_Cropland}$ and

National_Seed_Factor=

$$\frac{(National\_Seed\_Wheat\_\Pr oduction - National\_Seed\_Wheat\_Seed)}{National\_Seed\_Wheat\_\Pr oduction}$$

The example above illustrates the nature of the computations and highlights the fact that the calculation procedure is rather complex, and that a variation in a lot of the primary variables would make a relatively small contribution to the final result, the value of the total ecological footprint.

3.1.3. Known issues with Ecological Footprint Accounts

Though there are several critiques of the ecological footprint as a concept (see chapter 4.1) relatively few studies have undertaken a detailed critique of the National Footprint Accounts spreadsheets.

The most comprehensive compendium of issues is held by the Global Footprint Network – producers of the Accounts. These problems, omissions and bugs have been collected and collated from Network members over several years based on the experiences of those partner organisations in undertaking studies which make use of the Accounts.

The National Standards Committee it tasked with reviewing and assessing the severity of the issues and recommending remedial action along with a prioritisation schedule. This work is on-going and GFN have not been able to, at this stage, provide a clear timetable for addressing the necessary work.

Here we set out the key issues with the Accounts. Note that we have excluded conceptual critiques of the Accounts or attempted to summarise future methodological enhancements (for more detail see chapter 4.1) except where they relate to the accuracy – or potential accuracy – of the current method. Instead the focus is on technical issues.

Generic

Reliability of international data sets

As noted elsewhere, the NFA make use of large international datasets (for example, from the FAO and UN). These, in turn, have been obtained from National Governments. During this process transformational errors can – and do - occur.

The study of Ireland (Curry et al., in press) found several examples of this:

- Physical export data recorded in litres (as opposed to the more usual practice of using tonnes) had been omitted in the Comtrade data received from the UN.
- Allocation errors had occurred when mapping the national data – in SITC Rev. 1 – to the classification system used by Comtrade (SITC Rev. 3).

There have also been many isolated examples of errors in the FAO data. These have been identified where discrepancies have been noted between nationally and internationally reported data. For example, Best Foot Forward has been in discussions with the FAO over the reporting of cattle stocks in the UK.

Transparency and documentation

The Accounts are poorly documented and the Accounts spreadsheets are unnecessarily complicated. The Global Footprint Network is aware of this and are planning, subject to funding, improve the quality and detail of the documentation to improve the transparency of the calculations. (explicit measures are in chapter 5.2.1).

Quality control

The 150-Country National Accounts are necessarily 'mass produced' using automated data import and available international datasets. Where assumptions have to be made they are generally globally-derived. To individually tailor or audit individual Country Accounts would be a substantial undertaking and outside the capabilities of the Global Footprint Network.

To overcome this, it has been proposed that National Accounts are individually audited by a partnership of National organisations, working together with the Global Footprint Network, to check for errors in the source data and refine the data and assumptions used where more accurate National data is available.

This Quality Control system would result in 'star rated' Accounts whose results would be more robust.

Sensitivity analysis

No formal sensitivity analysis of the Accounts has, to our knowledge, even been completed. This is, in part, due to the fact that the source data used does not include confidence limits. Ideally, the German Accounts should be subject to a sensitivity analysis. The first tentative steps towards this are included in this document using the Monte Carlo technique.

Crop products

Excluded crops

This section makes extensive use of German FAO data (the FAO food balance sheet) - to estimate the food consumption of residents - and is therefore particularly sensitive to errors in national production (tonnages), harvest area (by crop) and yields (t/ha). Information on some crops is also excluded due to 'duplication or insufficient data'. The following may be of relevance in Germany:

- Honey
- Hard Fibres, Other
- Hops, peppermint, and other misc. crops

Feed embodied energy estimates

Embodied energy estimates for the crops used for feed are also calculated here (see Animal Products Section) based on the kcal/cap/day figures for each product provided by FAO. The assumption is that the calorific value of food when digested by humans is the same as that for animals. This assumption is untested. In addition, some calorific values are missing and US data is used to fill the gaps. This section would benefit from comparisons with existing German data on the calorific values of different types of animal feed.

Cropland used for different crop types

There are global assumptions made about the type of crops grown in on primary and marginal cropland. These should be validated for Germany.

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Animal products

‘Not Applicable’ data

This section also makes extensive use of German FAO data (the FAO food balance sheet) and is therefore particularly sensitive to errors in national production tonnages and feed tonnages. Some data is considered ‘not applicable’ to Germany and this needs to be checked.

Milk footprint

There is a known bug in the calculation of the footprint of milk products. The formula used does not adjust the various milk products for their relative calorific value. Correcting this, and using German values, would improve the accuracy of the German footprint.

Fish oil

Problems with calculating the footprint of Fish Oil has resulted in it being removed from the footprint accounts. This is a known bug.

Animal feed volumes and energy contents

The Accounts make average assumptions about the volume of feed, and its energy content, to apportion the footprint to animal products. In the case of Germany these average assumptions could be improved upon as the feed demand appears to be *greater* than the estimated available feed.

Grazing land

A ‘capping factor’ is applied when estimating the productivity of pasture land. This assumption should be tested for Germany.

Fisheries

Fisheries yields
Current global fisheries yields are based on a total available Net Primary Productivity estimates for the world and an estimate of the maximum sustainable harvest rate for global fisheries. These assumptions should be checked and adapted for Germany.

In addition, the availability of NPP does not always act as the limiting factor on fisheries. Rather, quality of the existing fish stock (including number of reproductive individuals) and dynamics of the reproduction of an individual fishery determine the actual regeneration rate of a marine area.

These assumptions should be checked and adapted for Germany.

Coastal estuaries

Coastal estuaries – and wetlands - are not currently included in either Footprint or Biocapacity Accounts. Ideally, the contribution of these should be assessed for Germany.

Fishmeal

There is a known bug which relates to the calculation of fishmeal for feed. Ideally, the global assumption used should be validated for Germany

Exclusive economic zone

There appears to be an error in the source data relating to the size of the Exclusive Economic Zone and Continental Shelf allocated to Germany. The latter is larger than the former. However, this would appear to have no impact on the footprint calculation.

Sustainable yields

The factors used for sustainable fish yields used for Germany need to be validated, in order to reflect national conditions.

Forest products

Forestry yields

Discrepancies between nationally-derived and international data for forestry yields have been discovered in both the Finnish and French National Accounts. In particular, the loss factors (which reflect the amount of timber that is lost from disease, windfall, fires etc. and that is felled but not used) need to be scrutinized. These can substantially alter the effective yield (the usable yield from a forest).

Energy consumption

Nuclear energy

The current Accounts do not differentiate between nuclear and fossil-derived electricity. Research is on-going to address this and the results of this should be incorporated into the German Accounts.

Carbon sequestration

The demand on biocapacity associated with the emissions of carbon dioxide is currently calculated by estimating the area of forested land that would be required to close the carbon cycle and sequester the emissions. This is rightly a global assumption – as CO_2 is a global pollutant – but in the German Accounts it might also be informative to calculate the biomass equivalent (the replacement land needed to grow alternative fuels) as a more didactic reference point.

Variations in the data sources

The total CO_2 emissions from the Germany economy are variously quoted as 798.24 Mt per annum (Source: CDIAC) and 854.29 Mt/yr (Source: IEA). The Accounts for Germany contain both figures and use – in preference – the IEA ‘sector approach’ figures. These figures should be checked against other German sources.

Hydro land

The Accounts include a global estimate for the land use for hydro electricity generation (hectares inundated per GJ). This figure should be checked with German data.

Built up area and land use

Cropland estimate and built-up area

Built-up land is currently accounted in both Footprint and biocapacity calculations as equivalent to cropland. This global assumption needs to be tested for Germany using historical data on the quality of land which is currently built upon.[4]

Land use intensity

[4] As experts at a workshop at the Federal Environment Agency (6.12.2006) confirmed, these assumptions should be valid for most cases in Germany.

The current accounts do not explicitly deal with issues of land use intensity. Hence whether land is currently over-grazed or unsustainably farmed is only noticeable in future accounts – when it would appear as a loss in bioproductivity. It would be appropriate to compare the land use in the Accounts with German estimates of sustainable land use.

Ratio between national unharvested and world unharvested land

This figure is expressed as a global average but should be specifically calculated for Germany.

Trade details

Trade of goods

This is the section of the Accounts where the most assumptions are made and, hence, where most variability is to be expected. The experience of working on the Ireland Accounts supports this presumption.(Curry et al., in press).

The Accounts assume global average world figures for the embodied energy of imported goods. No specific adjustments are made for the carbon intensity of the energy used in the country of origin or distance travelled. To undertake this calculation for even a single Country would be a substantial undertaking. However, it would improve the accuracy of the footprint and should be considered for Germany.

The trade section also includes a ‘capping factor’ which aims to prevent outlying (typically erroneous) data from distorting the footprint of the trade balance. This capping factor is price-based and, in some cases, it has been found this approach excludes valid data. This should be checked for Germany.

Trade of services

The trade method used in the Accounts, based on physical flows of resources, does not include the international trade in services. In an economy with a significant service sector, such as Germany, the direct and indirect effects of services could significantly influence the total footprint. An attempt should be made to quantify this for Germany

Tourism

The impact of tourism is excluded from the Accounts. This should be investigated for Germany both the effect on the overall footprint of Germans visiting other countries and the implications of foreign visitors consuming resources within Germany. Currently, all consumption within Germany is attributable on a per capita basis to residents only.

3.1.4. Preliminary Monte Carlo Sensitivity Analysis

Although outside of the current project brief, it was considered that a Monte Carlo Analysis could provide a valuable insight into the sensitivity of the National Footprint Account to variations in source data and the Account’s own in-built assumptions – many of which were highlighted in the earlier section

Monte Carlo methods are a widely used class of computational algorithms for simulating the behaviour of various physical and mathematical systems. They are distinguished from other simulation methods (such as molecular dynamics) by being stochastic, that is nondeterministic in some manner - usually by using random numbers (or, more often, pseudo-random numbers) - as opposed to deterministic algorithms. Because of the repetition of algorithms and the large number of calculations involved, Monte Carlo is a method suited to calculation using a computer, utilizing many techniques of computer simulation. More broadly, Monte Carlo methods are useful for modelling phenomena with significant uncertainty in inputs, such as the calculation of risk in business.

Here we present a preliminary Monte Carlo Analysis which attempts to model the impact of variations in the primary data and parameters on the final result, the total Ecological Footprint figure. The total number of cells studied in this project was 5866. The software package Crystal Ball, a graphically oriented forecasting and risk analysis program was used to undertake simulations.

The undertaken research is a first tentative step towards a detailed sensitivity analysis of Ecological Footprint accounts.

Results

Sensitivity of German Ecological Footprint was studied based on the assumption that EF parameters are normally distributed around their means with standard deviations equal to 10% of the means. The means correspond to the actual values of the National Footprint Accounts.

Table 4: Statistical characteristics of the simulation results

Statistic	Fit: Student’s	Forecast values
Mean	396,872	398,122
Median	396,872	396,786
Standard deviation	396,872	288,465
Variance	4,659,848,900	4,603,845,568
Coefficient of variance	0.1720	0.1704

Figure 5: Sensitivity of the Ecological Footprint for Germany, precision control for the mean at 1%, 95% confidence level.

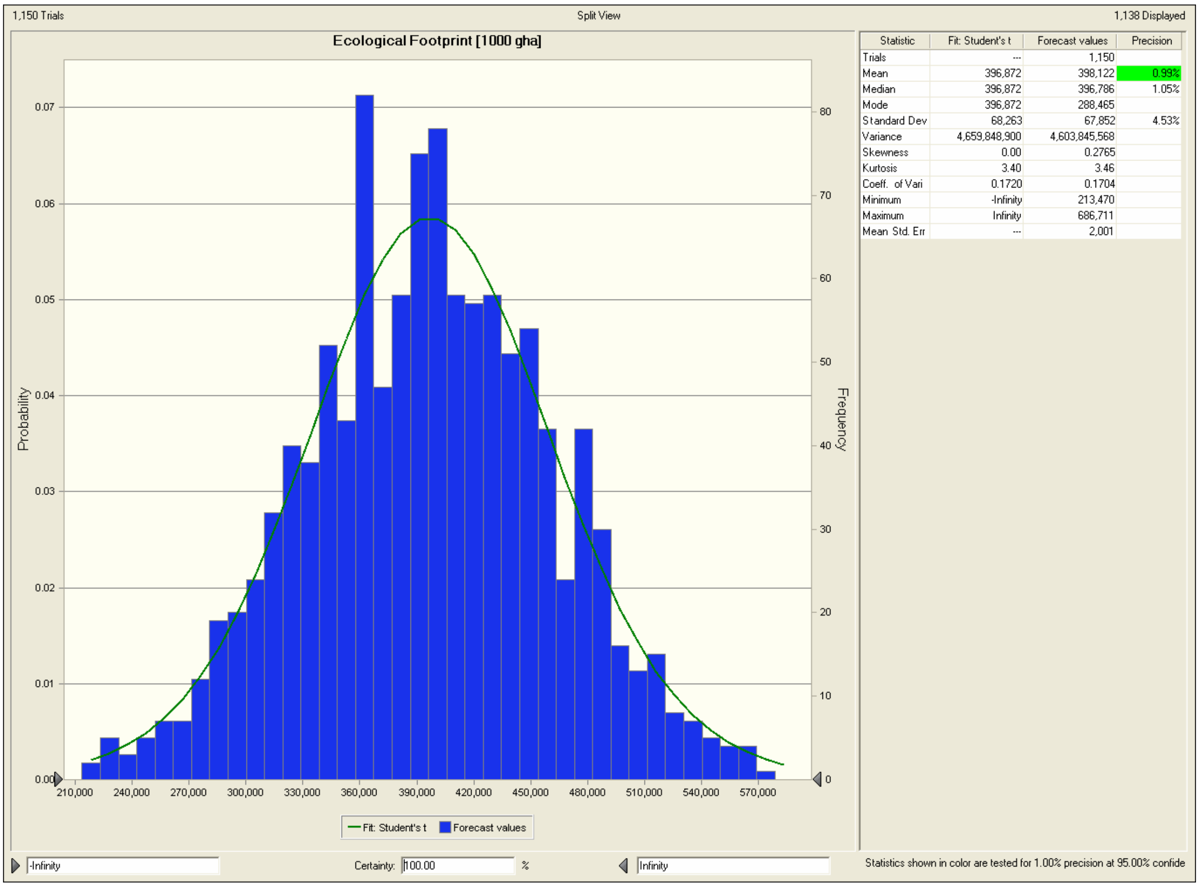


Figure 5 depicts the simulated distribution of the Ecological Footprint of Germany obtained as a result of the 1150 trials of National Footprint Account parameters. The number of trials was determined by the precision control level of 1% and the 95% confidence level. A word of caution should be said about this distribution, since the standard deviations of individual parameters were assumed to be equal to 10% of their means, which may or may not be a valid assumption. Standard deviations of actual parameters could be higher or lower than 10%, which would affect the results of such an experiment.

The results of the simulation experienced are listed in Table 5.

Table 5: Results of Monte Carlo simulation experiments, precision control for the mean at 1%, 95% confidence level.

	Section	**EF Category**	**Global/ German**	**Contribution to variance**
1	VII Land Use	Total Dry World Land Area	Global	-0.040178859
2	VII Land Use	Total World Area	Global	0.035834923
3	I Crop Products	World Cereals Harvested Area	Global	0.018168326
4	V. Energy Consumption	Terrestrial Sequestration	Global	-0.014680107
5	V. Energy Consumption	CO_2 Sector Approach	German	0.00986159
6	IV Forest products	EF Equivalence Factor Forest	Global	0.005590464
7	V. Energy Consumption	World CO_2 Emissions	Global	0.002418254

As can be seen from Table 5, the most important sensitivity points can be grouped into several categories according to the nature and the magnitude of their impact:

I Crop products:

- World Cereals Harvested Area 1.8%

IV. Forest products:

- EF Equivalence Factor Forest 0.6%

V. Energy consumption:

- Terrestrial Sequestration factor -1.5%
- Total CO_2 Sectoral Approach 1.0%
- World CO_2 Emissions 0.2%

VII. Land use:

- Total Dry World Land Area -4.0%
- Total World Area 3.6%

The first seven variables that consistently appear at the top of the list of factors contributing to the variance in the Ecological Footprint of Germany are responsible for 12.7% of the total variation in Ecological Footprint (See Figure 5). The contribution to the total variance of other individual parameters is considerably smaller, but in total the contribution is significant and amounts to 87.3% of the variance in the German Ecological Footprint.

Figure 6 depicts the correlation coefficients among the parameters and the total value of the Ecological Footprint of Germany. The direction and length of the bar reflect the sign and the value of the respected correlation coefficient.

Figure 6. Rank Correlation, Ecological Footprint, Germany, 2003

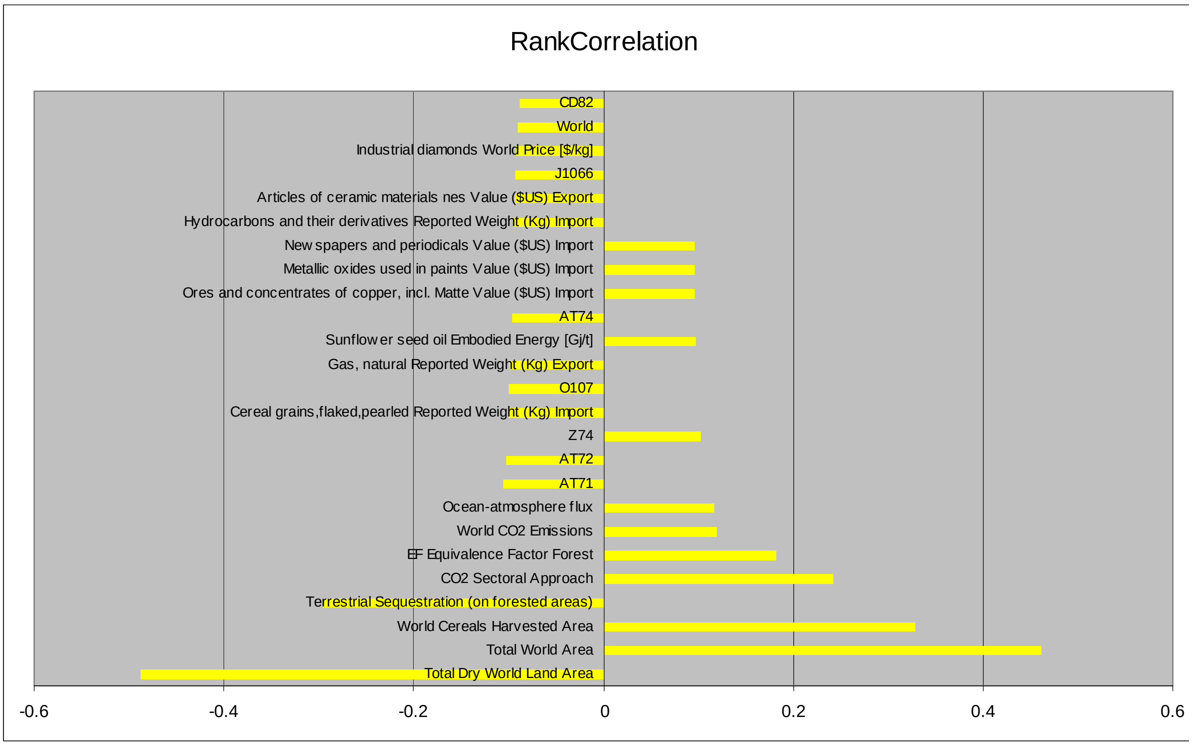


Figure 7 shows the contribution of the first 25 factors to the variance, which influences the total value of the ecological footprint. It is shown that for example the equivalent factor of wood is 0.0055 of the total variance, "World Cereals Harvested Area" 0.0181, etc.

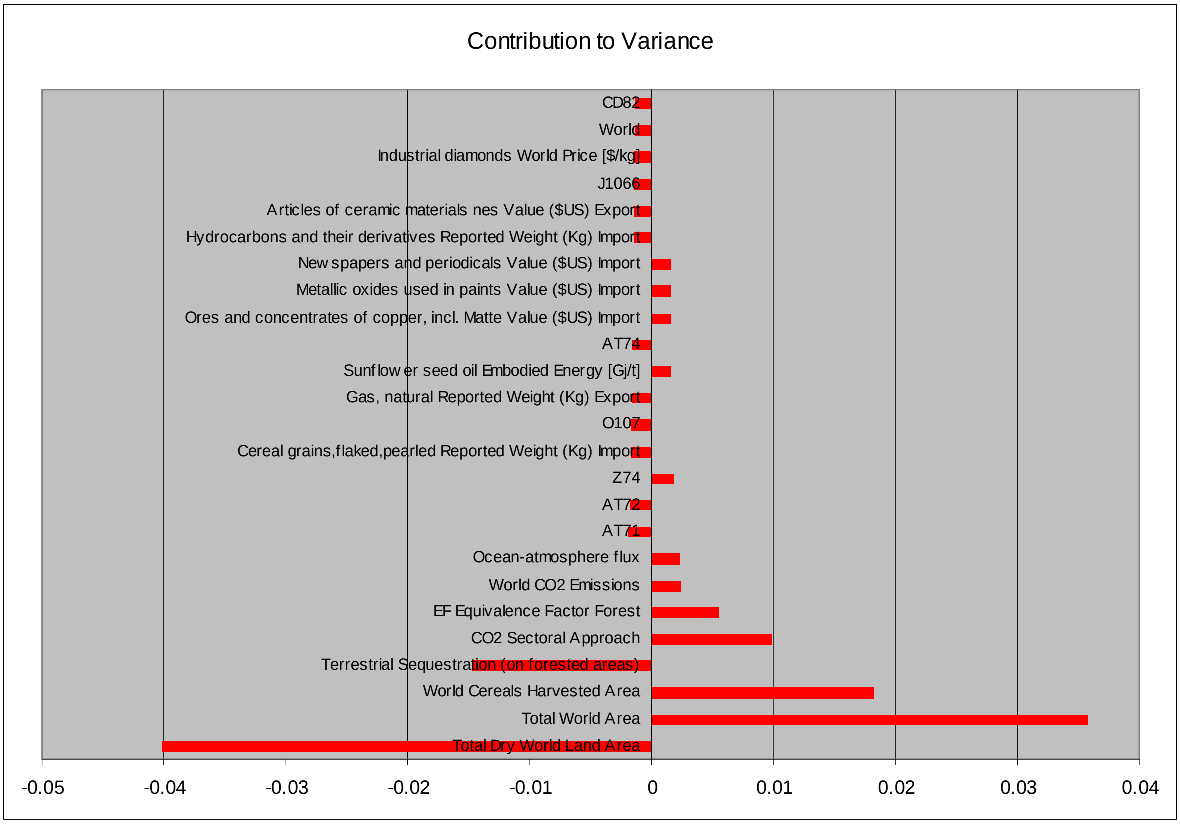
3.1.5. Conclusions

Section 3.1.3 catalogues the key issues with the Accounts and, in particular, factors which need to be addressed for Germany. The relative impact on the overall footprint of making these changes is impossible to quantify without further research.

The Monte Carlo is helpful in indicating those values (each contained within a cell) in the Accounts which have the most significant influence on the overall ecological footprint.

These consequences were classified as either global – that is all Accounts would be affected were the values to be adjusted – or Germany-specific. In the latter case the value relates to German data and thus the German Accounts only would be affected.

Figure 7: Sensitivity of the Ecological Footprint, Germany, 2003.



The Global parameters, which have a substantial impact on the total Ecological Footprint occurs within the following sections of the National Footprint Accounts:

- I crop products
- IV forestry products
- V energy consumption
- VII land use

The German parameters, producing the highest impact belong to the categories of:

- V energy consumption

Looking at the individual values – each equates to a single cell – that have the greatest influence, the most important of these is the CO_2 Sectoral Approach, contributing almost 1% to the variance in the total Ecological Footprint of Germany.

Combining the conclusions from this preliminary Monte Carlo analysis, which the catalogue of Key Issues outlined earlier, it is clear that a first priority is to establish the accuracy of the CO2 raw data and assumptions used in the German Accounts (contained mainly within the Energy Consumption section). Variations in this would have the most significant impact on the headline result.

Further to this, efforts should be directed to validating the data used in the rest of the accounts prioritising Crop Products, Fisheries, Energy Consumption and Trade Details sections.

In particular, the following are considered a priority:

- Error checking of data sources used to ensure that German National Data is being correctly reported by FAO, COMTRADE etc. and accurately incorporated into the Accounts. Data should be checked for both errors and omissions. This is particularly important in the Trade Details section.
- Estimates for the embodied energy and volumes of animal feed. These appear in both the Crop and Animal Products section.
- Fisheries yields should be checked against German National data.
- Forestry yields should be checked against German National data

A way forward could be to group the 5866 variables represented in the Monte-Carlo analysis into categories and study overall impacts of the all equivalence factors, international trade, primary production, yield factors, etc. It should be underlined however, that due to the stochastic nature of the Monte-Carlo analysis and the structure of the Ecological Footprint calculations, the order and magnitude of impact of the factors from one run[5] of Monte Carlo analysis to the other can be slightly different. This fact underlines the importance of the first seven factors stably appearing at the top of the ranking and points out the special properties of the problem at hand, where the majority of the parameters have individually small, but collectively significant impact.

3.2 Analysis and assessment of alternative data sets for Germany

In this section we analyse and evaluate possible alternative data sources from national statistics that could be used for the calculation of the Ecological Footprint of Germany.

For this task, the spreadsheets of the “National Footprint Accounts – Germany 2003 – 2006 edition” (GFN, 2006b) were provided by GFN. The data used here refer to the year 2003. The assessment is carried out according to the six main categories (and their sub-categories) of the Ecological Footprint.

(1) crop products

(2) animal products

(3) fisheries

(4) forest products

(5) energy consumption

(6) built-up land and land use, including “hydro” land

Problems in the analysis arose from the fact that data sets used in the spreadsheets could not be not directly compared with alternative data sets, mainly due to fact that they were not available for the year 2003.

Furthermore, definitions and data sets used for single goods and categories often could not be clarified. In addition, original data and statistics underlying the published data compendia could not be tested. Only those national statistical data were used for testing their adequacy for the calculation of the German Ecological Footprint, if they were freely available and

[5] A run in the context of Ecological Footprint Accounts is a series of over 1000 calculations in each of which random numbers with respected statistical properties are generated in each of the modelled cells.

accessible. Concerning the original data, information and advice was provided by the German Federal Statistical Office, referred to in more detail in the following.

Table 7 briefly summarises all results as well as the sources of this research.

Categories 1-4

Assessing of the online and freely available data (Annual Statistical Report, Environmental-Economic Accounts, environmental data UBA) for **agricultural, forestry and fishing products** revealed that this kind of data in its published form is not adequate for the calculation of the Ecological Footprint. Due to the multiplicity of inquiry data and categories, these data can only provide an overview or aggregated information. In addition, foreign trade statistics underlie specific secrecy obligations; therefore original data can not be published.

According to the Federal Statistic Office of Germany, it is possible to obtain detailed information on foreign trade statistics. This also holds true for data from the Official Agricultural Statistics, Forestry Statistics, etc. User rights have to be clarified with the Federal Statistical Office.

The product inventories in foreign trade statistics list all goods, for which data have been collected. This compendium involves more than 9000 goods and covers all goods of categories 1-4 that are used for the calculation of the Ecological Footprint. In many cases the classification detail is higher compared to FAO data.

Only a limited amount of information regarding the use of products (e.g. domestic supply, feed, seed, food manufacture, waste) could be found. According to the Federal Statistical Office, information on the use of agricultural goods for food production, animal feed production, and agriculture itself (e.g. seeds) as well as information on the use of forestry products are currently compiled by the Federal Agriculture Research Institute in Braunschweig. These data have been assessed for 45 different production methods and should be compiled every four years. Until now these data are available until the year 1999.

Additional data concerning the consumption of goods can be obtained from the Federal Ministry for Alimentation, Agriculture and Consumer Protection of Germany (BMELV) or at the central market and price report agency (ZMP).

To what extent it makes sense to substitute data from the FAO by national data has to be investigated by a direct data comparison (e.g. of the year 2003). There is no doubt that national data are of higher precision and greater disaggregation. In general, it should be taken into account that FAO data are generated from national sources and are therefore not the only possible source of errors.

Category 5

For the area of CO_2 emissions, the UBA data bank exists, which provides data at the national level (UBA emission trend tables), in rather aggregated data categories (e.g. energy-related emissions, industry processes, agriculture, waste management, including the corresponding subcategories) The differentiation level of the data categories is, therefore, below the one of the IEA.

The Environmental-Economic Accounts of the Federal Statistical Office (Tables for Chapter 6) offer an interesting alternative or extension of the IEA method, since they include an allocation of emissions to different branches of production. These calculations are based on UBA data.

Data categories of the UGR are in some cases more disaggregated than those from IEA, so it could be desirable to include selected subcategories of the UGR in the Footprint calculations.

For the field of CO_2-sequestration of forests in Germany, a calculation in the framework of the “UBA trend tables” exists. They are also dealing with sequestration in carbon sinks. However, the sequestration Footprint aims for the calculation of sink areas necessary to absorb worldwide CO_2 emissions, following a method of IPCC or FAO. To our knowledge, such calculations have not been carried out for Germany.

For the calculation of energy from imported goods at the national level, use of the Probas-database of UBA could be considered. This database provides the cumulated energy requirements (KEA) for a range of products. The objective of the assessment of the cumulated energy requirements is to present and aggregate the energy input for the production of a good or services along the whole production chain. KEA in the Probas-database does not include energy requirements for the utilisation or disposal phase. This data base could be an alternative starting point for the calculation of the energy used for the production of goods abroad. However, the energy input would need to be converted into CO_2 emissions, as it is a more meaningful criterion for environmental assessments compared to KEA. In general, it seems more meaningful for a large number of goods to use international standardised data instead of varying national data.

Category 6

Data for **land use** (including built-up land) can be generated from the **ATKIS-Data** (Federal topographic information system). These data provide a higher geometrical and content resolution than that used in current Ecological Footprint analysis. Also, the category hydro land could be generated from these data sets. As a future data source for land use, the DeCover-Data or maybe the **CORINE Land cover 2006-Data** could be considered.

Results of a Swiss Study on the comparison of national and international data

In a recently published study from four Swiss Federal Departments (Stokar et al., 2006b), data sets of the Global Footprint Network (GFN) were compared with national data sets. Based on this analysis and with improved data, the Ecological Footprint of Switzerland has been recalculated. Based on the assumption that the data sets of GFN for Germany and Switzerland possess similar quality and that statistics of these two countries have similar preciseness and structure, the results from this study could be expected for a similar study for Germany.

Table 6 shows the results of the single categories of the Ecological Footprint. For almost all categories data deviate only marginally. Therefore, the international data sets can be regarded as a reliable data source. In addition, the Swiss study highlights problems and deficits of the data sets in the areas of “energy” and “built-up land” and recommends the use of national data in these cases. Based on results of the category “energy”, GFN has reviewed the calculation basis and has included the national data of Switzerland into the calculations. Table 8 illustrates the results of the comparison between national (Swiss) and international data.

Table 6: Results of the comparison between national and international data

Categories	Differences between national and international data	Results
Crop products	There are methodological differences with regard to units and secondary products	Impact of differences on final results are marginal
Animal products	Comparable statistics	International data can be used
Fisheries	Differences in units and categories	International data are plausible
Forestry products	Small differences of primary products. Secondary products are more problematic due to comparability problems of units.	Not clear, whether national data have better quality. Recommendation: use of national data
Energy consumption	1% difference in nuclear energy and 2% in fossil energy.	comparable data and reliable results
	A data filter used to eliminate implausible data, generates data distortions.	Initiated by this study GFN plans to change this filter.
Built-up land and land use	The data of 2002 are comparable, but the international data time series is problematic, since there are hardly any data points.	For the Swiss study national data are used.

Source: Von Stokar et al., 2006b

Table 7: Analysis and Assessment of alternative, free accessible Data for Germany

Categories	Standard Source	Alternative Source	Evaluation	Summary of evaluation
Crop Products	FAOSTAT food balance sheets & database*	Statistical Yearbook (StBA)*	Aggregated production data (in ha; dt/ha); Import-/ Export-Data (in Mio. €; %); exotic products are missing; background: federal agriculture statistics, land use census, business statistics of the *BMELV*	**Statistical Annual Report + UGR** provide only highly aggregated information, partly only in € or % units. **Statistics of BMELV** often very detailed: data seem to be appropriate to some extent as alternative data source. But original data (federal agricultural statistics, foreign trade statistic) have to be reviewed by the **StBA**. According to StBA these data possess a high degree of preciseness and disaggregation and are therefore regarded as an adequate alternative data source. (This also refers to the categories of animal products, fish and forestry products)
		UGR* (StBA)	Aggregated information on the use of biotic resources (herbal biomass) as well as import/export (in t)	
		UBA Environmental data*	No relevant information	
		BMELV-Statistics*	Foreign trade statistics and monthly statistical reports (import/export/production) for several categories (in t; €). Very detailed, partly significant deviations from FAO data (basis: *StBA-Data,* evaluation made by BMELV+BLE)	
		StBA-Data bank (GENESIS-Online)	Use requires licence (Therefore the data have not been reviewed yet)	
Animal Products	FAOSTAT food balance sheets & database*	Statistical Yearbook (StBA)*	Aggregated product information (in ha; dt/ha); import and export data (in Mio. €; %); partly in high disaggregation, basis: see "crop products"	**Statistical Annual Report + UGR** provide only highly aggregated information, partly only in € or % units. **Statistic of BMELV** often very detailed: data seem to some extent appropriate as alternative data source. But original data (federal agricultural statistic, foreign trade statistic) have to be reviewed by the **StBA**.
		UGR* (StBA)	Aggregated information for the use of biotic raw materials (animal biomass) as well as imports and exports (in t)	
		UBA Environmental data*	No relevant information	
		BMELV-Statistic	see "crop products"	
		StBA-Data bank (GENESIS-Online)	Use requires licence (Therefore the data have not been reviewed yet)	
Fisheries	FAOSTAT food balance sheets	Statistical Yearbook (StBA)*	Aggregated import and export data (in Mio. €; %) for fish and fishery products	**Statistical Annual Report + UGR** provide only highly aggregated information, partly only in € or % units. **Statistic of the BMELV** more detailed, but not as highly disaggregated as FAO data. According to the product register of the foreign trade statistic (Chapter 3) this category is collected in high detail.
		UGR* (StBA)	Aggregated information on the use of biotic raw materials (fishery: catch quantity of open sea and costal fishery as well as inland water fishery) as well as import/ export (in t)	
		BMELV-Statistic*	Aggregated information on the use of different fish species as well as import/ export (in t)	
		StBA-Data bank (GENESIS-Online)	Use requires licence (Therefore the data have not been reviewed yet)	

Categories	Standard Source	Alternative Source	Evaluation	Summary of evaluation
Forest Products	FAO forestry data (to some extent): Temperate and Boreal Forest Resource Assessment (TBFRA)	Statistical Yearbook (StBA)*	Aggregated import and export data (in Mio. €; %); timber production in m^3 (subdivided into tree species and use of timber) Basis: felling statistics	**Statistical Annual Report + UGR** provide only highly aggregated information. **UGR + Statistics of the BMELV:** in general detailed information. Use as an alternative data source is possible. Furthermore, original data of the felling statistics and the foreign trade statistic have to be reviewed.
		UGR* (StBA)	Partly very detailed information including imports and exports (in t, m^3) of the use/stock of timber and timber products (see 13, forest resource accounting)	
		UBA Enviornamental data*	No relevant information	
		BMELV-Statistic*	Statistical monthly report (timber foreign trade, timber stock , timber products, timber semi-products, timber assortments, timber consumption and timber sales)	
Energy consumption a) CO_2-consumption	IEA CO_2 emissions from fuel combustion	UBA-Emission-trend tables*	Includes rather aggregated data categories (such as energy-related emissions, industrial processes, agriculture, waste management with the related subdivisions, the degree of differentiation of the data categories therefore is below the data of IEA)	The UGR are of interest as an alternative or additional method to the IEA, as they provide a more precise allocation of emissions to various sources. Comparison of data should be done cautiously, as the emission sources are not defined in detail and differences of reported emission values were identified (for instance for timber products), with underlying causes remaining unclear.
		UGR* (StBA)	The UGR are based on UBA data. Partly the UGR classifies more deeply than the IEA (for instance with regard to the Commercial and Public Services, Machinery, etc.). In this context it has to be considered whether a more detailed classification could be useful for allocating emissions to emission sources.	
b) Embodied energy of imported goods	UN COMTRADE	Probas data bank UBA/ Eco-Institutes	Supplies data of the cumulated energy requirements for products (KEA). The goal of the assessment of the cumulated energy requirement is to aggregate and illustrate energy inputs along the whole intermediary chain. The KEA of the Probas data bank refers not to the energy input of the use and the waste disposal period.	It is in question which methodological differences exist for the data generation (boundary definition, primary data). For a large number of products international standardized data should be used. For this reason switching to KEA is not recommended.
c) CO_2-Sequestration	IPCC Approach	No national approach for the calculation of a CO_2 Sequestration Footprint	The UBA emission trend tables also contain information on the CO_2 in sinks (forests), so emissions are subtracted. To our knowledge, no methods exist for the calculation of demand for sinks for the absorbance of the all CO_2 produced in Germany.	
Built-up land & land use		CORINE Landcover (CLC) 2006	The data update 2006/2007 provides an addendum by high resolution satellite data. Currently available data (CLC 1990/2000) possess only low geometric and thematic resolution.	**ATKIS**-Data (in processed form) could supply more detailed information. Future prospect: **DeCover-**Data as an optimal data base for the determination of "built-up area" or land coverage and land use. Quality of data of **CLC 2006** has to be reviewed.
		ATKIS	Data with high geometric resolution (3-10 m); high disaggregation of land use and built-up land in the ATKIS object type catalogue. Problem: partly not very user friendly data format (efficient data use can not be guaranteed)	

Categories	Standard Source	Alternative Source	Evaluation	Summary of evaluation
	CORINE Landcover	DeCover	Projects 2005-2008, objective: improvement of the timeliness and the quality and the information content of the national available data for land cover (e.g. ATKIS, CLC) with a geometric precision of 10m.	
Hydro land	British Petroleum	ATKIS	See: ATKIS- description above; in the object type catalogue there exist among other terms: water works and dams.	**ATKIS**-data provide more precise data.

- Data are available online and freely accessible

Abbreviations:

ATKIS - Amtlich Topografisch-Kartografisches Informationssystem
BMELV - Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz
BLE - Bundesanstalt für Ernährung und Landwirtschaft
CORINE - Coordination of Information on the Environment
IEA - International Energy Agency
DeCover - Deutsche Landcover-Datenbasis für Bund- und Länder-Aufgaben
StBA - Statistisches Bundesamt Deutschland
UBA - Umweltbundesamt
UGR - Umweltökonomische Gesamtrechnungen des StBA

Difficulties with data research:

- Data sets of the FAO not always directly comparable, since national data for 2003 have often not been available.
- National, online accessible data sets are in general processed data sets of the StBA, BMELV etc, for this reason no conclusions on the structure of the raw data were possible. (These data, which should be available at StBA, should be reviewed according their contents and categories).
- Missing definitions of products (what lies behind the single categories of the FAO data and the national data?)

4 Method and interpretability

4.1 Analysis of methodological weaknesses and points of criticism

In this chapter we analyse different areas of methodological weaknesses and points of criticism on the concept of the Ecological Footprint. This analysis represents the basis for the elaboration of suggestions for improvements of the method described in section 5.2.

The several points of critiques can be summarised in seven thematic categories:

- Questions concerning the conceptual basis of the indicator
- Integration of different environmental categories
- Questions concerning aggregation
- Assumptions of land use
- Intransparencies and problems with data processing
- The Footprint of energy consumption and CO_2 emissions
- Global impacts and the role of international trade

4.1.1. Questions concerning the conceptual basis of the indicator

Weak sustainability versus strong sustainability

The Ecological Footprint is based on the concept of strong sustainability. It postulates the basic assumption that natural capital and man-made capital are not substitutable but that the production of man-made capital depends on the availability of intact natural capital. Therefore it is an objective of the Footprint developers to maintain natural capital (at least the share of critical natural capital, see above) and only use the annual “interest” in terms of regenerative flows of energy and biomass (Wackernagel and Rees, 1996).

Advocates of weak sustainability claim that the wealth of a society can be guaranteed in the long term, if the total of nature- and man-made capital is not decreasing. This implicates that the different kinds of capital are exchangeable. Such an approach builds the foundation of indicators such as “Green GDP” or “Genuine Savings”. Some authors argue that there is no reason that the actual stock of natural capital is supposed to be optimal and worth of preservation and that therefore at least a certain degree of substitution can be regarded as a step towards sustainability. Such an approach would reduce the size of the Ecological Footprint since the environmental impacts of human activities would receive less weight.

This argument is accepted by the advocates of the concept. If the substitution of natural capital by man-made capital should cause for example less energy consumption (e.g. through the construction of wind energy plants with natural resources such as metals) then this development would actually have a positive effect on the Footprint.

Connectivity to other environmental accounting and indicator systems

The Footprint is a highly aggregated indicator of anthropogenic resource consumption. It is based on a large number of diverse primary statistics, especially data on material flows, energy consumption, CO_2 emissions and land use by infrastructure and construction activities.

The accounting system of the Ecological Footprint was developed in parallel to other integrated environmental accounting systems; including for example the economic-environmental accounts (Umweltökonomische Gesamtrechnung) in Germany, the NAMEA (National Accounting Matrix including Environment Accounts) system at European level or the SEEA (Integrated System of Economic and Environmental Accounts) system at UN level. At least until now it is not intended that the Ecological Footprint is integrated as an indicator into these systems. Some aspects are important in this context:

- The design of the national footprint accounts is not directly linked to the definition of system boundaries of the System of National Accounts (SNA), as national material and energy flow accounting and land use accounting (as satellite accounts for SNA) do.
- Therefore it is not possible to combine the Ecological Footprint with indicators of the SNA (such as the GDP at macro level or production outputs on the sectoral level) to "interlinkage indicators". Especially in the context of national studies (such those published in the Living Planet Report) the Footprint is not used as an efficiency and productivity indicator yet.
- The Footprint chooses a macro perspective and does not distinguish between resources, which enter the production process and resources that are directly consumed by private households.
- A relatively high amount of calculation steps has to be performed in the process from the diverse primary statistics to the final indicator. These steps are often not sufficiently transparent and documented (see below).
- The Footprint at the national level is normally not disaggregated into economic sectors. However, first studies have been presented, illustrating how an assignment of single Footprint categories to different economic sectors could be performed (see literature overview in section 2.2).

These are some main reasons why the Footprint has not yet accessed official environmental statistics on the national and international level.

The recently started campaign "10 by 10" of GFN aims to promote this process. The objective of the campaign is to position the Footprint as a central measure for national sustainability within the next 10 years in selected countries (e.g. Switzerland, Ireland, Finland, Japan, Chile and South Africa (see section 5.1).

Intransparency of assumptions and lack of detailed documentation

An often highlighted weak point of the Footprint concept is that the construction of such a highly aggregated indicator includes several selection steps, which are based on decisions often not sufficiently transparent. This includes for example the integration or exclusion of certain input variables (which resources are taken into account in the indicator), the selection of certain calculation factors (e.g. equivalence factors) as well as the application of techniques in order to close data gaps (see Schaefer et al., 2006 for these points of critiques). So far, many of these processes are not or not sufficiently documented in the National Accounts.

This deficit has been explicitly accepted by the Global Footprint Network; a higher degree of transparency and a better documentation of the calculation steps have been defined as an explicit goal, which shall be reached within the next years (see section 5.2).

4.1.2. Integration of different environmental categories

The Ecological Footprint measures the bioproductive area necessary for resource consumption and absorbance of emissions and waste of a country (or a region, or a company). But only that part of resource consumption is converted into land areas, which is renewable or produces yields (Wackernagel et al., 2004b). In the first instance this includes raw materials and products that consist (mainly) of biomass (e.g. cereals, but also meat and milk, furniture, clothes, etc.). Therefore, in an assessment with the Ecological Footprint, a wide range of non-renewable resources, emissions and environmental impacts are not covered (RPA, 2005). These topics will be discussed in the following sections.

Emissions and waste

In the currently established calculation method of the Ecological Footprint (GFN, 2006a) only CO_2 emissions caused by the combustion of fossil energy sources (oil, coal, gas) are included in the calculations. Emissions of other greenhouse gases, other emissions as well as waste are not considered (Lenzen and Murray, 2003).

Individual studies have suggested improvements in order to measure other greenhouse gases and emissions of non-energetic sources. For example, in an Australian study, Lenzen and Murray (2001) considered in addition to CO_2 also the greenhouse gases CH_4, N_2O, CF_4 and C_2F_6 as well as emissions of non-energetic sources such as deforestation, fermentation caused by livestock farming, industrial processes and leakage of natural gas. All these emissions are converted into CO_2 equivalents and included into the Ecological Footprint as a new category called “emission land”.

However, these suggestions have not yet been integrated in the common calculation method. The Global Footprint Network (2006a) states that at this point of time there is no reliable scientific basis with regard to the breakdown of greenhouse gases, which impedes estimating the biocapacity necessary to absorb greenhouse gases, which is therefore not yet possible in a satisfying way. In the future, methods should be found that also take into account other greenhouse gases.

Some critics (ECOTEC, 2001) argue, that for this reasons the Footprint cannot perform an overall assessment of environmental impacts; however, also other aggregated indicators of resource consumption, mainly those stemming from material flow analysis, are confronted with the same argument (for example, Klejin, 2001; van der Voet et al., 2005).

The counter argument of other authors (Lewan and Simmons, 2001) is that the Ecological Footprint never claimed to incorporate all human impacts on the environment. Rather it provides a conservative estimate and recognises that processes harming the biosphere irreversibly (extinction of species, deforestation, and exploitation of fossil resources) are not measured. However, precaution is recommended if policy measures lead to a worsening of impacts not measured with the Footprint, while an improvement of e.g. the CO_2 performance is achieved at the same time (RPA, 2005).

Non-renewable resources

The Ecological Footprint only captures the use of renewable resources, while the physical use of non-renewable resources (minerals, ores, and fossil fuels) is not directly incorporated in the calculation. Therefore, the Ecological Footprint has a different focus than other resource indicators such as those based on material flow analysis, as in latter case the largest share of total resource consumption is determined by non-renewable resources.

The Footprint concept considers fossil energy (oil, coal, gas) only indirectly in terms of CO_2 emissions, which are caused by combustion. In addition, the demand for mineral products (e.g. metals, industrial minerals and other mineral-based products) is only considered in terms of process energy, required for production. The amounts of used ores or minerals themselves are not included in the Footprint Accounts. Similar to energy consumption of fossil fuels, process energy is converted into CO_2 absorbance area (Erb et al., 2002).

Water consumption

Ecological footprint calculations exclude direct measurement of consumption and use of fresh water. The supply of fresh water is captured indirectly by the loss of biocapacity, but since it is not a biologically produced good, it is not directly measured by the Footprint concept (GFN, 2006a). However, the Living Planet Reports integrate water extraction and water consumption as additional indicators (WWF et al., 2006).

4.1.3. Questions concerning aggregation

Use of the quantitative unit “land area”

The aggregation of several land area categories into an overall indicator has been criticized by many authors (van den Bergh and Verbruggen, 1999; van Kooten and Bulte, 1999). The main point of critique is that the different kinds of environmental impacts are combined into one single indicator, which impedes illustrating the diverse impacts of various kinds of land use. As pointed out before, the Ecological Footprint indeed measures mass- and energy flows, but does not consider qualitative aspects. For example, the consequences of deforestation (erosion, landslides,...) or the environmental and health risks caused by heavy metals, radioactive substances or oil accidents are not taken into account. Nonetheless the Ecological Footprint doesn’t claim to be an overall sustainability indicator, but only an important indicator for the measurement of environmental sustainability.

By referring to the production area, which forms the basis for resource use, the physical amounts of consumption can be compared and added up. Thereby, yield data fulfils the function of weighting and standardisation. However, the direct link to environmental impacts is lost; this is a basic problem with all aggregated indicators of resource use (van der Voet et al., 2005).

The weighting factors selected for data processing satisfy ecological rules and thermodynamic laws, but do not consider social aspects. They neither reflect relative scarcity over time nor spatial differences (van den Bergh and Verbruggen, 1999).

From the critics’ point of view, this problem is reinforced by the choice of a weighting system, which assumes a fixed substitution rate between different categories of land use. This fixed substitution rate leads to an identical weight of different categories, even though they have very different environmental impacts. For example, land use of infrastructure is given the same weight as land use for agriculture, although land used for the supply of transport infrastructure and construction has stronger impacts on the environment than land used for pastures. Considering these assumptions the footprint method could lead to results that are undesirable from both an environmental and a socio-economic point of view (van den Bergh and Verbruggen, 1999).

The aggregation of real and hypothetically appropriated areas

In its calculations, the Ecological Footprint aggregates two diverse dimensions of land use: first, actual land required for the supply of products such as food or timber or directly built-up land and, secondly, hypothetical forestry areas, which would be necessary if all CO_2 emissions caused by the combustion of fossil fuels would be completely absorbed through additional biomass (for details see below).

Some authors (for example, van den Bergh and Verbruggen, 1999) highlight that this could lead to misinterpretations in the sense of false preciseness, not only concerning the general public and political decision makers, but also environmentalists and scientists.

However, Mathis Wackernagel argues that these areas are not hypothetical but rather demonstrate the real overshoot of the biocapacity of our planet.

An investigation of specific sustainability-relevant problems, connected with increasing land demand by human beings, can not be conducted with this conception of the indicator. The use of the global hectare unit (see section 4.2) leads to the fact that regional and national policies aiming at a reduction of land use can not be evaluated with the Footprint.

4.1.4. Assumptions concerning land use

The restriction to biologically productive areas

The Ecological Footprint only includes those land and water areas in its calculations that supply biological productivity useful for human beings. Areas which are not usable for humanity (e.g. deserts and polar glacier regions) are not considered in the calculation of biocapacity, as – according to Wackernagel et al. (2005) – the concentration of renewable resources in these areas is too small to contribute significantly to the overall biocapacity. In addition, wetlands and coastal river deltas are not considered by the Footprint or the biocapacity calculation due to a lack of data.

Thereby, almost 40% of the land surface is excluded from the calculations, although they could provide important ecosystem services, such as biodiversity conservation. Also several indigenous populations exist, which are since centuries living in biological unproductive regions (e.g. desert biotopes). The differentiation between land, which is usable or non-usable land for human populations, is partly a subjective decision (Lenzen and Murray, 2003).

Wackernagel et al. (2005) estimate that between 80% and 90% of the world-wide biological capacity is included in the estimated global available bioproductive areas (60% of the land areas plus coastal water systems). According to RPA (2005) this exclusion of areas could lead to an underestimation of the global available biocapacity by 10-20%.

On the other side, the Global Footprint Network argues, that biocapacity tends to be overestimated as activities, which have negative impacts on the regeneration ability of biocapacity are not taken into account. These include the use of materials, for which the natural systems does not possess assimilation capacities (e.g. Plutonium, PCPs, CFCs etc.) as well as processes that harm the biosphere irreversibly (e.g. deforestation, desertification, etc.).

In addition, other aspects of the calculation influence the over- and underestimation of the Footprint and the biocapacity, which will be explained in detail below.

(Un)sustainability of actual land use practices

Lenzen and Murray (2003) point out that the properties of land areas and the derivation from the original state cannot be captured by a productivity-based calculation approach. Land, which has been transformed into streets or buildings, has changed its original state dramatically, while land used for extensive pastures or forestry hardly differs from the original state. However, both categories are weighted equally in the calculations.

For this reason the standard Footprint calculation is not adequate for detailed regional analyses, as region-specific, economic, political, technological, environmental and climatic aspects are not taken into account. For this reason methods should be developed, which integrate reliable data into the calculation of the Ecological Footprint, illustrating the unsustainability of different activities and the resilience of ecosystems.

As a possible step in this direction, Lenzen and Murray (2001) developed an alternative approach for the consideration of qualitative conditions of land use. In this method, six categories ranging from "slightly disturbed" to "consumed" (build-up land), are assigned to different weights between 0 and 1. For the calculation of a disturbance-based Footprint this area has to be multiplied with the corresponding land condition factor. Thereby, a value is created that reflects the area as well as its qualitative state.

Nevertheless, this modified approach has so far not been considered in the Standard Footprint Accounts published by GFN (see section 5.2).

The issue of multi-functionality of land use

In the concept of the Ecological Footprint, each land area is assigned to one single category of use. Possibilities of multifunctional land use patterns are thus not considered. This avoids double counting of land areas (WWF et al., 2004), but could lead to an overestimation of the Footprint or an underestimation of available biocapacity (RPA, 2005).

Users of the Footprint method admit that this assumption is a necessary simplification and argue that certain land use forms actually are mutually exclusive; for example, an area can only be used either as a pasture, a forest or built-up land.

This argument is different with regard to issue of CO_2 sequestration, biodiversity and water. Critics of the Footprint argue that activities such as CO_2 sequestration, biodiversity conservation and forestry are not necessarily mutually exclusive (RPA, 2005). Supporters (Wackernagel et al., 1999) argue that forestation areas are required to absorb significant amounts of CO_2 and that these areas show lower biodiversity than mature forest systems. In addition, CO_2 forests could not be used for logging, as cutting of trees undermines the possibility of CO_2 sequestration.

The direct inclusion of water consumption and water supply into the Footprint concept – neither of which is taken into account in the current method – could lead to a change in assumptions regarding multiple use of land areas, since for example forest areas could also be used for the purpose of water supply.

Assumptions concerning land use changes

The method of the Ecological Footprint assumes that built-up land for infrastructure always substitutes agriculturally productive land. The argument behind is that the majority of human settlements have emerged in highly productive regions. Therefore, built-up land is treated with equivalence factors for agriculture in the Footprint Accounts.

This assumption has several important implications. First, it tends to result in an overestimation of appropriated biocapacity. Second, this could lead to a counter-intuitive development as countries, which build up their infrastructure on areas other than agricultural areas could therefore expand their Footprint as well as their biocapacity. Therefore, some researchers suggest to either calculating the biocapacity of built-up land according to the land type, which was transformed, or completely excluding the category of built-up land is from the Footprint Accounts, as built-up land is not a bioproductive category.

The consideration of areas for the biodiversity conservation

Earlier studies of the Ecological Footprint at the national level reserved an area of 12% of the total biologically productive area as conservation area for biodiversity (Wackernagel et al., 1999; Wackernagel et al., 1997). In the series of the Living Planet Reports (for the most recent report, see WWF et al., 2006), no area has been reserved separately, although it is emphasised that the appropriation of biocapacity by humans shows negative effects on biodiversity. How much biocapacity remains unused by mankind and consequently could serve as a buffer for the conservation of biodiversity, would be a political decision, which should not be anticipated by the Footprint concept (Wackernagel et al., 2005).

4.1.5. Intransparencies and problems with data processing

Global versus national yield factors

The standard method for the calculation of the Ecological Footprint applies global yield factors to convert national demand of different product categories into the unit global hectare (one exception are the so-called secondary products, see next subchapter).

A number of studies demonstrate that application of different yield factors to consumption data results in significant changes in the size of the Footprint. For example Haberl et al. (2001) showed that different assumptions about the yield factor can cause changes in results by (at least) a factor of 2.

The most important difference results from the use of global versus national yield factors for the conversion of consumption quantities into hectares. Which of these conversion methods is applied, mainly depends on the research question: if it should be calculated how much of the physical land area (independent of its bioproductivity) is actually appropriated for providing all goods and services consumed by society, then national (or even local) yield factors should be applied. If in contrast the question is what appropriation of areas by consumption occurs in different countries at different points of time, then global yield factors are to be preferred as they allow direct comparability (Haberl et al., 2001).

Harmonisation of different methods led to an increasing consistency of results produced with different methods and that it can be assumed that both methods provide trends with similar directions (Wackernagel et al., 2004a).

The use of the unit "physical hectare" instead of "global hectare" would allow better connecting studies on land use with the concept of socio-economic metabolism (and therefore methods such as material flow analysis, Haberl et al., 2001).

Global versus national productivities in primary and secondary products

As Wiedmann and Lenzen (forthcoming) point out, an inconsistency in the current calculation method arises regarding the use of factors for the conversion of primary and secondary products (Wackernagel et al., 2005). While primary goods (such as cereals and wood) are converted by global factors, national factors are applied for secondary goods (such as food or furniture), reflecting national production structures. Eco-efficiency improvements are therefore only reflected in the production of secondary goods, but not in primary products. While the Footprint shrinks, if a baker produces more bread with one kilogram of flour, changes concerning the technology in agriculture and forestry have no influence on the Footprint, as global average factors are used in this case. Therefore, the Footprint is “blind” to changes in the management of biotic raw materials and primary goods. To allow comparisons Wiedmann and Lenzen (forthcoming) therefore suggest using either global or national factors for all product categories.

Direct versus indirect land appropriation

In the usual Footprint calculations, measured land areas are mainly referred to as areas, which are directly used by households or directly required by producers to supply consumer goods.

Besides, the National Footprint Accounts present the Ecological Footprint as an aggregated number for a country as a whole, which does not allow detailed statements about the Footprint of economic sectors or specific categories of final demand or consumption activities. Therefore, it is not possible to illustrate the indirect resource flows and environmental consequences, which result from the manifold relationships between economic activities. For example, in the calculation of Footprints of service activities only directly used resource inputs for their provision are covered, which in general are quite low. Indirect resources flows, which emerge, as a large number of intermediary production and inputs are required from other sectors, in order to provide a service, remain unconsidered. However, these indirect resource flows explain a large part of the resource use of services and therefore must be taken into account in the assessment of overall resource use.

Input-output-models allow the user to capture indirect resource demands. First attempts exist to link input-output models with the National Footprint Accounts (Bicknell et al., 1998; Simmons et al., 2006a; Wiedmann et al., 2006c). Input-output models are based on the basic assumption that changes in final demand induce both direct and indirect effects on the economy (Miller and Blair, 1985). They allow a very detailed analysis, as both the production sphere and the area of final demand are dissagregated. Furthermore, imports and exports can be considered in the analysis, which improves the calculation of ecological deficits or ecological reserves (Lenzen and Murray, 2003).

The consideration of tourism

RPA (2005) discuss the way tourism is integrated into Footprint studies. In most studies, the consumption of tourists is allocated to the country in which the tourists stay for holiday and not to the home country of the tourists, which is in conflict with the common assignment principle of the Footprint. However, in some studies, corrections have been made, which are founded on two main assumptions: (1) that all tourists travel by plane and (2) that tourists show the same consumption pattern as in their home countries (whereas several studies show that this is mostly not the case).

Possible approaches for a correction of the Footprint are:

- A partitioning of the (same) overall Footprint of a country to the population without tourists and in comparison to the population plus tourists.
- The calculation of the Footprint of tourists and a presentation of the Footprint of a country with and without that fraction.
- A deduction of the share of the Footprint caused by tourists.

However, the last two methods can be used only incompletely. For example, values concerning mobility and alimentation can be adjusted, whereas the fraction of energy use (e.g. by hotels or services) is not corrected.

4.1.6. The Footprint of energy consumption and CO_2 emissions

Calculation methods for the CO_2 Footprint concerning fossil energy sources

One of the main points of critique regarding the calculation methods of the Ecological Footprint is the energy component, which represents more than 50% of the overall Footprint for most industrial countries (RPA, 2005; van den Bergh and Verbruggen, 1999). Furthermore, this fraction of the Footprint is responsible for the biggest part of the overall growth since 1960 (EAI, 2002). A key issue is the conversion of the CO_2 emitted from fossil fuel consumption and its transformation into land areas via surface area, which would be necessary to completely absorb emitted CO_2 in forest areas. Thereby, the area for the use of fossil energy sources does not represent real, but a hypothetical occupation of land.

Critics of this method argue that this calculation method would reflect the interest of proponents of the Footprint in using the concept of "strong sustainability", which assumes that current generations have to take responsibility for the accumulation (or sequestration) of their emitted CO_2.

Some authors (EAI, 2002) depict CO_2 emissions only as a temporary problem which will be eliminated by future technology developments and therefore is overrated in the calculation of the Footprint. Counter to this perspective, one could argue that both the possible long-term consequences of an anthropogenic climate change prohibit a careless treatment of this issue and even in case of a temporary problem, this problem requires to be reflected in current indicators of environmental sustainability.

Furthermore, van den Berg and Verbruggen (1999) criticised that the Footprint only refers to emission problems of energy use and do not consider the scarcity of fossil energy sources. The authors point out to three problem areas associated with the method: (1) that possibly not enough land is available to provide the necessary forest areas, (2) that this solution depends on the availability and costs of land, as well as on the productivity of the forestation and (3) that this method does not consider the economic marginal cost rate, which could lead to the fact that in the future other and cheaper methods of CO_2 sequestration could be applied, instead of the sequestration via forest areas.

Reduction of the energy Footprint through new technologies

Several authors (for example, Ayres, 2000; EAI, 2002) argue, that the calculation method of the energy Footprint – and here mainly the important CO_2 component – influences the overall result to a too large extent.

They present alternative calculation methods, which calculate the energy area by potential renewable abiotic energy sources (e.g. wind energy, geothermic energy, etc.). In comparison to CO_2 sequestration, this method results in a significantly decreased demand for land area for provision of the same quantity of energy, not at least as of the energy supply can take place also on non-productive areas (for example deserts and open sea) and consequently would not use bioproductive areas on earth, which could be used for other purposes.

In the criticism on the calculation concerning the energy component of the Footprint, also other (future) kinds of CO_2 sequestration (e.g. pumped into oceans or oil- and gas-deposits) are frequently mentioned, which are not yet considered in the actual calculation method and could also reduce the forest areas needed for sequestration. However, these kinds of CO_2 sequestration are not yet applied and therefore cannot be considered in the calculation of the Footprint. The calculation method could be changed in the future, if new means technologies for sequestration are actually available. Furthermore, these methods (e.g. sedimentation on the ocean ground) must be critically reviewed, as ecological consequences are not yet clarified.

However, alternative calculation methods of the energy Footprint result in a dramatic change of the overall global Footprint, which – according to these assumptions – remained almost constant since 1960. Furthermore, they show a slight decrease in projections until 2050 under the assumption of technological improvements of renewable abiotic energy sources, whereas the Footprint calculated according to the original method shows a continuous increase. Therefore, the calculation of scenarios with different assumptions regarding the energy mix is an important point for further methodological development (see section 5.2).

The consideration of technology changes

The calculation of the energy component is frequently criticised, because less CO_2-intensive forms of energy production and technical progress, potentially resulting in the reduction of the Footprint, are not taken into account (Ayres, 2000; EAI, 2002). Nonetheless, it must be argued that these kinds of energy production are taken into account – in a dimension, in which they are used with given technologies today. Other kinds of energy production and technical progress (e.g. to increase energy efficiency) could reduce the use of fossil energy sources and the amount of CO_2 emissions and would decrease the Ecological Footprint, applying the existing method.

With minor consideration of technological changes, particularly in the energy sectors, the Footprint is criticised as a static concept, which cannot provide a foundation for political measures and strategies (Ayres, 2000; EAI, 2002). However, the Footprint is explicitly an instrument to measure the consumption of nature at a given point of time and is able to reflect technological changes in the future. Similar critique could be formulated for any indicator (environment indicators or also GDP), which measures the state of the society at a given time and with a defined method.

The consideration of non-fossil energy sources

For different energy sources, the Footprint concept applies different methods to integrate them into the calculation of the indicator (see chapter 2).

- The area for an energetic use of biomass is added to the calculation via the forest component.
- Nuclear energy is converted with the same method that is used to calculate the CO_2 Footprint. For this, the energy content of nuclear energy is converted into areas for CO_2 sequestration, which would be necessary, if the same energy would be extracted

from fossil energy sources. This leads to the critique that nuclear energy is often regarded less CO_2-intensive than fossil energy.

- The share of hydro power is integrated via the area occupied by the embankment dam and reservoirs and is consequently added to the category “built-up land”.

Critics (for example, RPA, 2005) argue that these assumptions reflect the obligation of the developer of the Footprint to the concept of strong sustainability, which also allocate relatively area-conserving energy sources with high environmental impacts and consequences for future generations (particularly nuclear energy) a large land area.

The Global Footprint Network argues that the calculation of nuclear energy via compensation areas is only an intermediate solution. A possible approach would be to define nuclear energy not as land usage category, but as a consumption category (as electricity from nuclear energy).

Summarising, it must be emphasised that the Global Footprint Network is aware of these points of critique and is continuously working on an improvement of the method. At the moment, a large group of Footprint experts from the Global Footprint Network is working on a definition of future research agendas for further improvements (see section 5.2).

4.1.7. Global impacts and the role of international trade

Missing geographic assignment of trade flows and environmental impacts

Especially due to incomplete data, the current calculation method does not enable a geographic assignment of trade flows and environmental impacts, which are caused by the Footprint of a region or a country.

Due to international trade, the consequences of environmental impacts related to the production and consumption of goods and services are distributed over the whole planet. The Footprint can not specify these impacts geographically, since the international trade data set does not provide information, from which country or world region imported goods originate.

Therefore, no assessment of the distribution of environmental burdens between industrial, emerging and developing countries, caused by the international division of labour on global markets, can be performed. This aspect gains importance from the point of view of sustainability assessments, as, for example, the European economy reduces the extraction of natural resources within their borders, substituting them by imports of resource-intense products from other world regions (Giljum and Eisenmenger, 2004; Schütz et al., 2004).

It is the explicit objective of the institutions integrated in the Global Footprint Network to address this aspect. A first attempt was made in two studies by the Global Footprint Network in 2005. In the study of the Footprint of Europe (WWF et al., 2005a), a world map was presented, which shows the lands of origin of resources imported to Europe in a quantitative manner. The study of the Asia-Pacific region (WWF et al., 2005b) illustrates quantitatively for the countries China, Japan and Thailand, to which countries their biocapacity is exported. However, it has to be considered that only parts of the exported biocapacity actually originate from these countries, while the remaining share is imported from other countries (mainly in the form of raw materials from developing countries).

In order to comprehensively consider the interrelations of international production chains in the calculations, the use of a multi-regional economy-environment model is necessary, which could calculate the indirect (or embodied) environmental requirements of traded goods (Giljum, 2005; Wiedmann et al., 2006a).

World average data for embodied energy of traded goods

In conventional Footprint Accounts, the embodied Footprint of traded goods is calculated by multiplying the physical quantity of imports by a coefficient (gha/ton), which reflects energy requirements and emission intensities along the whole production life cycle, determined with the help of life cycle assessments. Currently, only a single data set related to these coefficients exists in the Footprint Accounts for all countries; in other words, the Footprint intensity of imports of a specific product is independent from all environmentally relevant factors of the exporting country. Among others, these factors include the application of certain technologies in extraction sectors, energy use and energy mix in the processing of raw materials and products as well as transport intensity. It thus makes no difference, from which country or world region a product is imported, which significantly simplifies the real situation and can cause substantial errors. Due to these simplifications, no statement can be made on how changes in the trade structure would affect the Ecological Footprint of a country (Lenzen and Murray, 2003).

In the most recent Living Planet Report (WWF et al., 2006), the Global Footprint Network admits that the national Footprint is biased due to the fact that natural resources as well as waste of exported goods have not been sufficiently represented in the calculations. This affects especially those countries where trade flows are significant compared to the domestic economy.

However, this current weakness is also explicitly specified by the Global Footprint Network and further developments of the trade component of the Footprint have been announced. It is also intended that in the future the Footprint should include tradable services.

Finally, it has to be mentioned, that the non-availability of trade data and indirect environmental impacts are not a specific problem of the Footprint Accounts. These problems have been frequently discussed in relation to other environmental accounting systems (e.g. material flow analysis at the national level), (see Giljum et al., 2006).

Trade versus autonomy

Critics of the Ecological Footprint argue that the concept involves a prejudice against international and interregional trade and therefore it is not an objective indicator, since the Footprint of a specified population is compared to the biocapacity of a region or a country. This would lead to the interpretation, that autonomy is the intended solution (van den Bergh and Verbruggen, 1999). Through exploitation of comparative advantages (such as the rich endowment with natural resources in countries such as Canada or Australia), international trade could contribute to the distribution of environmental pollution related to the production of goods to those world regions with the least sensitive ecosystems (van den Bergh and Verbruggen 1999).

Wackernagel and colleagues counterargue that the Footprint has no general bias against international trade. However, they highlight that the continuously intensified international trade in the majority of cases does not lead to the reduction, but to an increase in environmental burden and that this would lead to an ever increasing exploitation of natural resources of our planet (Wackernagel and Giljum, 2001). Furthermore, the Footprint concept clarifies that on a limited planet not all countries could be net importers of natural resources (Lewan and Simmons, 2001). And due to the highly increasing demand of resources of new industrialising countries such as China and India, new important economies become net importers, dramatically increasing the pressure on global natural resources.

4.2 Assessment of the meaningfulness and interpretability of the indicator

Beyond issues of quality of data and calculations methods, the basic question arises of how meaningful the concept of the Ecological Footprint is and which conclusions can be drawn from the calculation of this indicator. This part of the report discusses this question with regard to selected aspects that play a significant role in the current debates about the Footprint: the concept of the "global hectare", the differentiation between the Ecological Footprint of production and consumption and the concept of the ecological deficit.

4.2.1. Advantages and disadvantages of the unit "global hectare"

The global hectare is used as the standard unit in the Footprint Accounts (see chapter 2). On the one hand, the introduction of this calculation unit enables the depiction of biological resources and their use in area units, their aggregation and world-wide comparison. On the other hand, this standardisation leads to restrictions of the meaningfulness of the indicator. Advantages and disadvantages of the unit "global hectare" are discussed below.

Advantages

Land area is an easily understandable metric. The global hectare enables the use of an easily understandable spatial unit – hectares – to illustrate and communicate the complex and abstract concept of biocapacity. The popularity of the Ecological Footprint stems to a large extent from the immediate understanding people have for surface area as a reference for resource use.

Standard measurement unit. A key benefit of the global hectare is at the same time the reason for its introduction, as it provides a standard spatial metric for calculating the relationship between the Earth's biologically productive areas and humans' resource demands on those areas. As an international standard, the global hectare also enables meaningful comparisons between different nations' Ecological Footprints.

Disadvantages

Global hectares are not real hectares. The global hectare is an accounting convention that does not represent physical reality. Though it is defined in reports on Ecological Footprints, the global hectare and its relationship to real hectares is not immediately understandable. At the national level, the number of global hectares of bioproductive area does not equal the actual bioproductive land area of a country, as the average biological capacity of a country differs from the global average biological capacity.

Real land-use issues cannot be directly analysed. There are two main reasons:

- Through summing up of real areas (food, timber, built-up land) and hypothetical areas (CO_2 sequestration) to the aggregated indicator, it is no longer possible to differentiate between real and hypothetical land use.
- Due to the application of the unit "global hectare", regional/national aspects of land use can not be considered.

For example no statement can be provided, how much land area within a country is required for domestic consumption, as it is not illustrated, how the Ecological Footprint is distributed between the analysed country and other countries. The disadvantage of using an abstract indicator becomes particularly apparent in the assessment of single economic sectors, where data, which indicate resource extraction from actual land areas, would enable a better analysis of real land use problems. In addition, as built-up land is converted in the same way as cropland, the real dimension of land use for infrastructure is not visible. For example, it would not be possible to capture the political objective of the German Sustainability Strategy to reduce the appropriation of land area for settlements and transportation with the Ecological Footprint.

Further key points, which were already discussed in detail in section 4.1, are:

Heterogeneous calculation factors. Calculating the yield and equivalence factors demand assumptions that differ significantly among existing Footprint studies. Continued improvement of the methods to calculate yield and equivalence factors will also change the size of the Ecological Footprint compared to previous studies, without those changes being related to actual changes in the supply of biological resources or their use by humans.

Primary and secondary products treated inconsistently. As pointed out by Wiedmann and Lenzen (forthcoming), the global hectares required for primary products are identical world-wide, whereas the energy component of the Ecological Footprint of secondary domestic products differs according to a nation’s mix of energy sources.

Embodied energy of imports is not differentiated according to the country of origin. Another issue related to the energy component of secondary products is that imported products are attributed a global average level of embodied energy, whereas the Footprint for energy used to produce domestic goods is determined by national circumstances.

4.2.2. Footprint of consumption or production?

The Ecological Footprint can be applied flexibly as an aggregated measure for both consumption and production of a country. So far, it was generally used to assess resource use related to consumption. The national Footprint calculations in the Living Planet Report are also presented this way, as are freely available personal or household Footprint calculators and the Footprints of cities and regions. However, scientists as well as enterprises are working on an adaptation of the Ecological Footprint as an indicator for resource use of production (Lenzen et al., 2006). In the following, we compare the conception and meaningfulness of both consumption and production Footprints.

Advantages of consumption Footprints

Consumption Footprints include related production. The scope of Ecological Footprints of consumption and production, contrary to what their names imply, are not mutually exclusive. In fact, consumption studies, including the national Footprint calculation, measure resources used along the production chains of consumer goods. The national Footprint thus includes those resource required for the production of goods consumed by a nation. Added are those resources required for the distribution of goods as well as resources required for the absorption of waste (as in the case of CO_2). This type of Ecological Footprint therefore comprises the resource use related to both consumption and production.

Consumption Footprints address consumers. Resource use for consumption and post-consumption stages of a product is often negligible in comparison to production stages. Resource requirements along the product life cycle are often not transparent to the consumer, and environmental policy rarely addresses the consumption side. The Ecological Footprint is an appropriate measure to illustrate the relationship between consumption and resources necessary for production and can therefore form a basis for environmental policy oriented at consumer behaviour.

The consumption Footprint includes resource use beyond national borders. Resource use abroad for domestic consumption has significantly expanded due to intensified international trade. The growing importance of global resource management is evident through environmental problems (e.g. climate change) and governance regimes, which are developing in parallel.

Ecological Footprints of production and their advantages

Although there is currently no standardised production Footprint based on the now standardised “component method”, it could be simply derived from the general formula for calculating national Footprints. As explained in detail in chapter 2, the formula for the national Footprint as a consumption indicator adds up resource requirements for domestic production, imports and stock changes and subtracts exports. A national production Footprint could be calculated based on resource consumption of domestic production under consideration of stock changes.

Calculated using these basic formulas, the national Footprints of consumption and production cannot be added up to a measure of total resource use, as double-counting would occur. However, they could be used independently to support different policy objectives.

Advantage: the production Footprint illustrates resource use within the borders of national jurisdiction. Production considered in the current Footprint calculation includes the production of foreign goods, whereas domestic production for export remains unconsidered. As long as the Ecological Footprint of consumption does not differentiate between domestic and foreign production, it is not a useful tool for justifying or assessing policy measures, which aim at a reduction of resource use of production. A national production Footprint would be more appropriate for regulations on the supply side, as it assesses total resource use of production within national boundaries, including exported goods.

Additionally, the Footprint of production would allow a more differentiated analysis of the issue of tourism, as target countries of tourism (e.g. Austria, Greece or Turkey) generate an important part of their national value added from tourism, an aspect, which is not considered by strictly adhering to the consumption principle.

4.2.3. The meaning of ecological deficit and “overshoot”

Definition of terms

Ecological deficit. In the Ecological Footprint methodology, an *ecological deficit* occurs if the Ecological Footprint of a population exceeds the biocapacity available for that population. Applied at the national level, this implies that a nation’s Ecological Footprint exceeds the biocapacity of this country. Exceeding the limits can occur through importing resources from outside the nation’s boundaries or through liquidating domestic resource stocks. The opposite condition, where biocapacity exceeds the Ecological Footprint, is called *ecological reserve* (GFN, 2006a).

Ecological overshoot. Occurs when humanity’s total demand on nature exceeds the biosphere’s regenerative capacity. Ecological overshoot equals Earth’s total ecological deficit. As no biological resources can be imported from outside the planet, overshoot is only possible through the liquidation of global ecological assets (GFN, 2006a).

Earth share (biological capacity available per person). A term related to those explained above is *Earth share*, which refers to the average amount of biocapacity (measured in global hectares) available for each inhabitant on Earth. It is calculated dividing Earth’s total biocapacity by world population. According to calculations by GFN, available biological capacity per person was 1.8 global hectares in 2003. This expresses the amount of resources that would lead to balancing Ecological Footprint and biocapacity based on an equal per capita allocation.

Evaluation

As an indicator for consumption of ecological resources, the Ecological Footprint provides an explicit connection between the consumed and available resources. The terms ecological deficit and ecological overshoot thus are thus the central metrics to evaluate environmental sustainability of human consumption.

Ecological overshoot. Comparing biological resources with their use by humans clearly points to the liquidation of ecological resources and a reduction in the planet’s overall biocapacity. Ecological overshoot is thus an unambiguous sign for the imbalance in the planet’s ecological accounts, with negative impacts on ecosystems. In this sense, the Ecological Footprint fulfils a useful function as an effective headline indicator for global sustainability.

As mentioned previously in chapter 2, the Ecological Footprint is an indicator for strong sustainability, which does not regard man-made capital as an equivalent substitution for natural capital. This orientation toward the preservation of planet’s natural capital makes the ecological overshoot the central metric of interest in the Ecological Footprint methodology. Critics of strong sustainability argue that ecological overshoot can be compensated through the substitution of man-made capital for lost natural capital. If not starting from the concept of strong sustainability, it is therefore less clear which conclusions can be drawn from an ecological overshoot.

Ecological deficit. Ecological Footprint statistics at the national level typically illustrate whether a nation holds an ecological deficit or an ecological reserve. However, even from the viewpoint of strong sustainability, the concept of ecological deficit is problematic.

The central issue here is to what extent it makes sense to compare the consumption of a country with the biocapacity available in that country. According to the Ecological Footprint, high-consumption countries that are endowed with large quantities of biological resources (e.g. Canada or Finland) seemingly do not have problems with their resource consumption, as it remains below their biocapacity. On the contrary, some countries with very low Ecological Footprints per capita may still run a significant ecological deficit (e.g. Bangladesh). What conclusion shall be drawn? What rights do people have to use their nation’s resources and to supplement those resources through trade? Implicit in these questions is the concept of *Earth share*. Thus, the question arises how Earth’s resources shall be allocated among humans.

Several conclusions to this question are possible, including:

- All inhabitants of the world have an equal right to consume biological resources, regardless of where they are produced. This is also the foundation of the so-called Environmental Space Concept (see SERI and FoEE, 2005).