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ANALYSIS

National natural capital accounting with the ecological footprint concept

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Abstract

There is a growing consensus among natural and social scientists that sustainability depends on maintaining natural capital. However, progress to put this ecological condition to practice has been slow, not least because of the inability of making these objectives measurable. Therefore, to overcome this obstacle, assessment frameworks for natural capital are needed. This study presents a simple framework for national and global natural capital accounting. It demonstrates, using the example of Italy, an accounting framework which tracks national economies' energy and resource throughput and translates them into biologically productive areas necessary to produce these flows. This calculation has been applied to over 52 countries. With this framework, based on the ecological footprint concept, human consumption can be compared with natural capital production at the global and national level, using existing data. © 1999 Elsevier Science B.V. All rights reserved.

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1. Introduction

Human life and all human activities depend on nature. The implication of this ecological maxim is obvious: to be sustainable humanity must live

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within nature's carrying capacity. Ecological economists would say that for achieving (strong) sustainability, humanity must therefore maintain the planet's natural capital stocks (Daly and Cobb, 1989; Pearce et al., 1989).

Sustainability has now become a universal policy goal—at least in the official rhetoric. For example, living sustainably was the challenge set forward by the UN Brundtland Commission (WCED, 1987) and confirmed by over 100 heads of state at the Earth Summit in Rio in 1992. Ten years after Brundtland and 5 years after Rio, however, we live in an even more hazardous world with more consumption, more waste, more people and more poverty, but with less biodiversity, less forest area, less available fresh water, less soil and less stratospheric ozone layer (UNDP, 1994; WRI, 1996; Brown et al., 1997a,b). Humanity is further away from sustainability. To make sustainability a reality, we must measure where we are now and how far we need to go. We need measuring tools to determine whether humanity's demand remains within the interests of the globe's natural capital stocks. In this respect, there have been some positive developments since Rio, as these essential tools for governance, business management and grassroots campaigns have made substantial headway (e.g. Vitousek et al., 1986; Buitenkamp et al., 1992; Schmidt-Bleek, 1994; Duchin and Lange, 1994; Ayres and Simmonis 1995; Wackernagel and Rees, 1996). All of these approaches are not only in agreement, but, in most cases, also compatible as they build on the same principle: accounting in some way or other humanity's energy and resource throughput. They may differ, however, in their scope (such as analysis of products, businesses or regions), presentation (such as way of aggregation), or level of detail, but all try to make the ecological condition of sustainability measurable.

To translate the strong sustainability criterion into concrete numbers and to examine whether society lives within its ecological capacity, a first overview needs to account for natural capital and its uses at the national and global level. As demonstrated in this study and explained through the example of Italy, the ecological footprint concept offers a methodologically simple but comprehensive way for such an accounting task. It tracks national economies' energy and resource throughput and translates them into biologically productive areas necessary to produce these flows. Also, it compares this resource and energy consumption to the ecological capacity available in the country. To make the calculations (which have been applied to over 52 countries) replicatable and accessible, they rely exclusively on publicly available United Nations data. Thereby, they interpret readily available data sets from an ecological perspective. In this way, the calculations become starting points for more comprehensive and reliable analyses.

The results obtained by these footprint analyses are briefly presented. Also, possibilities and limitations of this tool are discussed, including a short comparison of the presented tool to Peter Vitousek, et al.'s, study on human appropriation of the products of photosynthesis (1986), an intellectual predecessor of ecological footprint analysis.

2. Calculating the ecological footprint of nations

2.1. Ecological footprints and natural capital

Everybody (from a single individual to a whole city or country) has an impact on the Earth because they consume the products and services of nature. Their ecological impact corresponds to the amount of nature they occupy in order to live. These are, to a large extent, measurable quantities of natural capital they require in order to function. In this study, we measure this quantity by asking how much nature people use to sustain themselves. More precisely, we quantify, nation by nation, the biologically productive and mutually exclusive areas necessary to continuously provide for people's resource supplies and the absorption of their wastes, using prevailing technology. In other words, we calculate the 'ecological footprints' of these countries (Wackernagel and Rees, 1996).

As ecological services are a precondition for human life rather than a substitutable value, this energy and resource accounting needs to be in biophysical units. Monetary analysis is misleading as it suggests substitutability, allows for the discounting of the future and focuses on marginal rather than absolute values, to mention only a few limitations (Rees and Wackernagel, 1998). For example, the monetary study by Costanza et al. (1997), of the value of natural capital flows is an excellent approach for awareness building. However, it is not suitable for pointing to action, identifying ecological limits, or describing competing uses of nature.

The ecological footprint represents the critical natural capital requirements of a defined economy or population in terms of the corresponding biologically productive areas. Evidently, the area of the footprint depends on the population size, material living standards, used technology and ecological productivity. For most industrial regions, a significant part of the footprint area exceeds what is available locally. This leads to their appropriation from the global carrying capacity. It is important to recognize that ecological footprints do not overlap, the carrying capacity appropriated by one economy is not available to another—people are competing for ecological space.

Productive land is a good proxy for natural capital and many of the resource flows and essential life support services that this capital provides. Land area communicates the finite character of the world in readily understandable terms, the area in each ecosystem category is roughly proportional to its photosynthetic potential for low entropy biomass production, the quality of the land is an indicator of the functional integrity of related ecosystems and their potential long-term production (> 50 years). These characteristics of real biophysical wealth are rarely reflected in the money price of land as a commodity.

Ecological footprint calculations are based on two simple facts: first, we can keep track of most of the resources we consume and many of the wastes we generate; and second, most of these resource and waste flows can be converted to a biologically productive area necessary to provide these functions. Thus, ecological footprints show us how much nature nations use. In reality, this footprint is obviously not a continuous piece of land. Because of international trade, the land and water areas used by most global citizens are scattered all over the planet. It would take a great deal of research to determine where their exact locations are. In simple terms, the occupied space is calculated by adding up the areas (adjusted for their biological productivity) that are necessary to provide us with all the ecological services we consume. In this way, these ecological footprints can be compared to the biological capacity available within each country.

2.2. The method used for national footprint accounting

The study, originally commissioned by the Earth Council for the Rio + 5 Forum held in Rio de Janeiro in March 1997 and since improved, examines 52 nations which contain 80% of the global population and generate 95% of the World Domestic Product (Wackernagel et al., 1997). Each nation is analyzed by estimating its national consumption in biophysical terms, using agricultural or biological yield figures to translate the consumption into areas of biological production and, finally, aggregating the results into total footprint areas. National footprints are among the most reliable estimates as most of the necessary data for footprint calculations such as ecological productivity, resource production and trade are already measured by national statistical institutes. In fact, most of these data are available through United Nations publications which have been used for the national estimates (UN, 1994; FAO, 1994; UNCTAD, 1994; FAO, 1995a,b; UN, 1995; WRI, 1996).

The national assessments are based on 1993 data, the last year for which, at the time of the study in early 1997, we had a complete data set to work with. By now, all 1995 data should be available. The main resource and energy flows are analyzed on a spreadsheet of 132 rows and 15 columns. Tables 1–3 show, using the example of Italy, the slightly simplified structure of the spreadsheet calculation. The entire spreadsheet 'ef-italy.xls' can be downloaded from http://www.iclei.org/iclei/efcalcs.htm. The electronic spreadsheets of all 52 nations are available

Table 1
Calculation of the Italian's average Ecological Footprint (1993) data

Categories Units if not specified	Yield (global average) (kg/ha)	Biological production (t)	Import (t)	Export (t)	Apparent consumption (t)	Footprint component (ha/cap)
Foods						
.'Average' meat and pasture yield	74	4 071 000	1 202 735	251 381	5 022 354	
..Bovine, goat, mutton and buffalo meat	33	1 268 000	403 342	99 865	1 571 477	0.8377 Pasture
..Other meat	457	2 803 000	799 393	151 516	3 450 877	0.0248 Arable land
.Dairy (in milk equiv.)		10 300 000	6 008 878	1 333 558	14 975 321	0.5219 Pasture
..Milk	502	10 300 000	2 731 168	24 688		
..Cheese	50		284 284	110 767		
..Butter	50		43 487	20 120		
.Marine fish	29	Consumption of harvested fish:			30 kg/cap	1.0457 Sea
.Cereals	2744	19 690 000	8 183 680	1 785 768	26 087 912	0.1664 Arable land
..Wheat			5 022 934			
..Cereal preparations				1 105 445		
.Animal feed	2744		3 500 736		3 500 736	0.0223 Arable land
.Veg and fruit	18 000	33 323 000	2 613 956	5 185 679	30 751 277	0.0299 Arable land
..Veg etc.			1 637 857	2 018 627		
..Fresh fruit			1 041 266	2 391 700		
...Roots and tubers	12 607	2 137 000	460 453	256 868	2 340 585	0.0032 Arable land
...Pulses	852	192 000	377 897	3327	566 570	0.0116 Arable land
.Coffee and tea	566		566 496		566 496	0.0175 Arable land
.Cocoa	454				80 917	0.0031 Arable land
.Sugar	4893	1 544 000	137 780	35 966	1 645 814	0.0059 Arable land
.Oil seed (incl. soya)	1856	334 000	1 779 574	1269	2 112 305	0.0199 Arable land

Table 1 (Continued)

Categories	Yield (global average)	Biological production	Import	Export	Apparent consumption	Footprint component
Units if not specified	(kg/ha)	(t)	(t)	(t)	(t)	(ha/cap)
Timber (in roundwood equivalent, m3)	1.99	7 538 000	25 595 596	4 339 118	28 794 478	0.2533 Forest
.Roundwood (m3/ha, m3)	Waste factors		5 775 000	41 000	15 594 000	% Used for:
.Fire wood	0.53 in RWE		392 000	6000	5 288 000	9% Fire wood
.Direct roundwood consumption (m3)	1 in RWE				1 115 000	4% Mines
.Sawnwood (m3)	1.50 in RWE		5 992 000	496 000	7 213 000	36% Sawn wood
.Wood-based panels (m3)	2.25 in RWE		869 000	632 000	3 657 000	27% Panels
.Wood pulp (t)	1.98 in RWE		2 591 000	42 000	2 981 000	
.Paper and paperboard (t)	0.98 in RWE		2 995 000	1 455 000	7 559 000	24% Paper
Other crops						
.Tobacco	1548	145 000	67 271	124 460	87 811	0.0010 Arable land
.Cotton	1000		381 273		381 273	0.0067 Arable land
.Jute	1500				26 344	0.0003 Arable land
.Rubber	1000				110 172	0.0019 Arable land
.Wool	15				280 775	0.3277 Pasture
.Hide	74				684 639	0.1620 Pasture

The top section of the calculation spreadsheet analyzes Italy's consumption of 19 biotic resources and its subproducts. The rows represent resource types, while the columns contain the yield, biological production, import and export. This is used to calculate the apparent consumption and the footprint component for each resource. (RWE in the timber section stands for roundwood equivalent in cubic meters).
(Population of Italy, 57 127 000).

Table 2

Commercial energy balance:	Specific energy footprint global average in (GJ/ha per year)	Amount consumed (GJ/year per cap)	Footprint component (ha/cap)
Coal	55	12	0.2221 Fossil energy land
Liquid fossil fuel	71	57	0.8071 Fossil energy land
Fossil gas	93	46	0.4927 Fossil energy land
Total fossil fuel consumption:		115	
Nuclear energy (thermal)	71	0	0.0000 Fossil energy land
Energy embodied in trade (assumed to be fossil)	71	−7	−0.0980 Fossil energy land
Hydro-electric energy	1000	3	0.0028 Built-up area

The middle section of the spreadsheet provides the commercial energy analysis for Italy in various energy categories. The category of embodied energy in net imports is calculated from an energy balance of 55 main trade categories (not included in the table).

through the International Council of Local Environmental Initiatives.[1]

The spreadsheet is composed of three main sections. The upper section of the spreadsheet assesses Italy's consumption of 19 basic biotic resources, including its subproducts (Table 1). The rows represent resource types, while the columns show the yield[2], the production, import and export. It also presents the apparent consumption and the footprint component for each resource, both of which are calculated from the previous information. Apparent consumption is calculated by adding imports to production and subtracting exports. We call consumption 'apparent consumption' as it varies from true household consumption because of the resources it includes that are processed for export goods while excluding the resources that are embodied in imported finished products. This error can be mitigated through more detailed trade flow analyses. Consumption also includes the waste between production and final consumption. In the case of forestry and dairy products, all the processed trade items of their secondary products such as wood panels, pulp, cheese or butter are converted into their roundwood or raw milk equivalent. This is done to get a more accurate estimate of real household consumption.

We use 'biological productive areas with world average productivity' as a common measurement unit for footprints and ecological capacity. Using a common standard makes national footprints comparable. Also, it allows for the nation's footprint to be directly contrasted with the globally available biological capacity. Furthermore, the urbanites of the world, the most significant consumer group, do not live from the local ecological production but consume commodities from all over the world.

Using estimates from the Food and Agriculture Organization of the United Nations (FAO, 1995a) of world average yield, consumption and waste absorption are translated into appropriated biologically-productive areas. Thus, the consumption quantities are divided by their corresponding (world average) biological productivity which shows the land and sea areas necessary to sustain the consumption. These areas form a part of the total footprint. For example, in the case of potatoes, the footprint component would be:

[1] To receive the *Ecological Footprints of Nations* report with the electronic spreadsheets, contact ICLEI at < iclei@iclei.org >

[2] For more details on the references used, consult the spreadsheet.

Table 3
Footprint summary

Demand				Supply			
Footprint (per capita)				Existing bio-capacity within country (per capita)			
Category	Total (ha/cap)	Equivalence factor (—)	Equivalent total (ha/cap)	Category	Yield factor	National area (ha/cap)	Yield adjusted equiv. Area (ha/cap)
Fossil energy	1.4	1.1	1.6	CO_2 absorption land		0.00	0.00
Built-up area	0.1	2.8	0.2	Built-up area	1.49	0.04	0.17
Arable land	0.3	2.8	0.9	Arable land	1.49	0.21	0.87
Pasture	1.8	0.5	1.0	Pasture	6.50	0.08	0.26
Forest	0.3	1.1	0.3	Forest	0.80	0.12	0.11
Sea	1.0	0.2	0.2	Sea	1.00	0.32	0.07
				Total existing		0.8	1.5
Total used			**4.2**	Total available	(Minus 12% for biodiversity)		**1.3**

Other indicators (expressed in average land with world average productivity in [ha/capita] or [%]): −2.9, Italy's national ecological deficit; −2.2, Italy's 'global deficit' (1997); 31%, Italy's capacity as percentage of its footprint; and 210%, Italy's per capita footprint compared with the global per capita bio-capacity (for 1997).
The bottom section of the spreadsheet summarizes the footprint results and compares them to the available bio-capacity of Italy and the world.

$$\frac{\text{Production}_{\text{potatoes}} + \text{Import}_{\text{potatoes}} - \text{Export}_{\text{potatoes}}}{\text{Yield}_{\text{potatoes}}} = \text{Footprint\_component}_{\text{potatoes}}$$

The energy component for potatoes needed for agriculture (tractors, fertilizers, pesticides, etc.) and processing (transportation, packaging, distribution and cooking) is already included in the energy balance of Italy (as shown below) and does not need to be calculated separately.

In the row description, capitalized names stand for main groups. Rows starting with a capitalized letter show a main trade category. Row description with a dot ('.') in front indicate subcategories. Two dots ('..') mean sub-subcategory. Wherever possible, the most general categories were used. These categories and subcategories are identified by bold print (if both sub categories and categories are included, this would lead to double counting). To keep the calculation as simple as possible, the footprints are always estimated using the broadest categories possible (i.e. the most general level at which data is available). In the spreadsheet, the biophysical information is accompanied by monetary data, which is used to check the order of magnitude of the figures and to help extrapolate the biophysical figures where data is missing. The reference columns point to the data source.

The middle section calculates the footprint of Italy's commercial energy consumption (Table 2). Energy is analyzed separately from other resources for a number of reasons. First, it occupies a significant share of a country's footprint. Second, the United Nations statistical offices provide the most detailed data for this particular resource consumption category. Third, the accuracy of these energy statistics is superior to the estimates one could calculate from the trade statistics. And last but not least, these consumption statistics are easily available. For example, the World Resources Institute lists the essence of the UN energy statistics for each country including: total commercial energy consumption; traditional fuels consumed; and hydro and nuclear electricity production, etc. (WRI, 1996). In the footprint accounting here, five kinds of commercial energy are distinguished: fossil gas, liquid fossil fuel, solid fossil fuel, firewood and hydropower. Nuclear power is calculated as if it was fossil fuel.[3] Other kinds are considered negligible in their present contribution over-all. Firewood is included in the biotic resources. The land use of hydro-electricity is estimated by dividing total production by the typical space use of hydro dams and corresponding corridor spaces for transmission rows. For the present calculations, an average of 1000 GJ per ha and year is assumed. For fossil gas, liquid fossil fuel and solid fossil fuel, we estimate 1 ha of footprint for the annual consumption of 93, 71 and 55 GJ, respectively. This is calculated by assessing the land requirements for the corresponding CO_2 absorption, using data from the Intergovernmental Panel on Climate Change (1997). Slightly larger footprints would result if the fossil fuel footprint was calculated with the land areas necessary for growing biochemical substitutes (Wackernagel and Rees, 1996).

There is one slight complication with national energy balances. The national energy account needs to be corrected for trade, some of the energy needs to be deducted from the national account as it is consumed to produce export goods, while the energy embodied in import goods needs to be added. In other words, this balance adjusts the amount of directly consumed energy within the boundaries of a country by the embodied energy that enters and leaves the country through the import and export of finished products. The energy intensity data is taken from Hofstetter (1992). The embodied energy in net imports is calculated from an energy balance of 55 main trade categories, multiplying imports and exports with their respective energy intensities and summing up these energy amounts. In Italy's case, net trade leads to the export of embodied energy at the rate of 7 GJ per year and person. To keep the table shorter, this part of the spreadsheet

[3] The total energy generated by nuclear power plants worldwide, compared to all the agricultural products lost in the year of the Chernobyl accident and the productive areas lost for human use in the exclusion zone around the reactors for many generations to come, suggests that the footprint of nuclear power so far may have been larger than that of fossil fuels. Thus, nuclear power is calculated as equal to fossil fuel (Wackernagel and Rees, 1996).

calculation is not included in the printed table, but is included in the spreadsheet available from the ICLEI server.

In the final section, Italy's footprint and its ecological capacity are summarized into two boxes (Table 3). To aggregate the used arable land, pasture, forest and sea areas in a more accurate and realistic way, they are multiplied with 'equivalence factors'. Without this adjustment, the totals would be distorted, as the various ecological categories represent large differences in biological productivity. For example, arable land is far more bio-productive than average pasture. Therefore, equivalency factors are introduced which scale the area of each ecological category in proportion to their yield. For example, the arable land factor of 2.8 shows that arable land can produce 2.8 times more biomass than biologically productive world average space. Through this scaling, the total bio-capacity of the world is not distorted, the global total, scaled with the equivalency factors, adds up to the same amount as the global total expressed in true physical spaces. As a result, the average Italian's footprint adds up to 4.2 ha, including sea space. We present all results in per capita figures to make Italy's footprint comparable to that of other countries. Multiplying the per capita data by 57 million people, Italy's present population[4], gives the total footprint of Italy.

The right box shows how much biologically productive capacity exists within the country and, for comparison, in the world. Obviously, these areas are multiplied by the equivalency factors as well. In addition, as the yield of Italy's land areas is higher than world average, its physical bioproductive areas are multiplied by the factors by which the local yield exceeds the world average (second column in the supply part of the table). We call these factors the 'yield factors'. A yield factor of 1.5, for example, means that the local yield of this ecosystem category is 50% higher than world average—absorbing 50% more CO_2 or producing 50% more potatoes per ha. As shown, Italy's yield adjusted ecological capacity measures 1.5 ha per Italian.[5] Since we have no data on the differential yield of all the countries' Exclusive Economic Zone, the yield factor of the sea for all countries is 1. For built-up land, the yield factor is equal to the one of arable land, as settlements are typically located on such land.

3. Analyzing the results

3.1. Biological production available on this planet

All of these footprint ha represent competing uses of nature. More specifically, fossil energy land is the land that we should reserve for CO_2 absorption. However, insignificantly little area is set aside to absorb CO_2. In other words, neither the biochemical energy of the used fossil fuel is replaced nor its waste products absorbed. In this respect, humanity is living off nature's capital rather than its interests. Listing the ecological space for CO_2 absorption separately from biodiversity preservation and forests does not imply double counting. For absorbing large quantities of CO_2, recently reforested areas or immature forests are necessary. Older forests absorb significantly less CO_2. These 'new' forests, in contrast, do not have the 'old' biodiversity. Also, CO_2 absorbing forests cannot be used for timber production, as this would release the gases again in the harvesting and wood transformation processes. However, these CO_2 absorbing spaces can provide other simultaneous functions such as water regulation, soil building and erosion prevention. In addition, consuming fossil fuel based products or burning fossil fuels can release toxic pollutants, an additional ecological hazard still missing in these footprint calculations (for example, plastics can contain heavy metals such as cadmium etc.).

Arable land is, ecologically speaking, the most productive area as it can grow the largest amount of plant biomass. According to the Food and

[4] Population figures for all countries are taken from the World Resources Institute, 1996. *World Resources 1996-1997 Database*, Washington DC: WRI. file "hd16101.wk1".

[5] Note that the used yield factors overestimate the true biological potential of industrialized agriculture with heavy fertilizer use.

Agriculture Organization of the United Nations (FAO), nearly all of the best arable land, or about 1.35 billion ha, is already under cultivation. Ten million ha of it are abandoned annually because of serious degradation (Pimentel and Pimentel, 1996). This means that today, there exist less than 0.25 ha per capita world-wide of such highly productive land.

Pasture is grazing land for dairy and cattle farming. Most of the 3.35 billion ha of pasture, or 0.6 ha per person, are significantly less productive than arable land. For example, its potential for accumulating biomass is much lower than that of arable land. In addition, conversion efficiencies from plant to animal biomass reduce the available biochemical energy to humans by typically a factor of ten. Expansion of pastures has been a main cause of shrinking forest areas.

Forest includes farmed or natural forests that can yield timber products. Of course, they secure many other functions too, such as erosion prevention, climate stability, maintenance of hydrological cycles and if they are managed properly, biodiversity protection. From the 5.1 billion ha covering our planet, 1.7 billion ha are classified as wooded land with less than 10% tree cover. The 5.1 billion ha correspond to 0.9 ha per person on this planet. Today, most of the forests left occupy ecologically less productive land with the exception of some few remaining inaccessible jungle areas.

Built-up areas host human settlements and roads and extend approximately 0.06 ha per capita world-wide. As most human settlements are located in the most fertile areas of the world, built-up land often leads to the irrevocable loss of significant amounts of ecological capacity.

The sea covers 36.6 billion ha of the planet, or a little over 6 ha per person. Roughly 0.5 ha out of these 6 ha contain over 95% of the sea's ecological production (Cox and Atkins, 1979; Pauly and Christensen, 1995; Wada, 1996). This marine production is already harvested to the maximum. Because the fish that people desire are high up in the food chain, the food gains from sea space remain limited. These 0.5 ha provide approximately 18 kg of fish per year of which only 12 kg end up on people's dining tables, thereby securing only 1.5% of humanity's caloric intake. Measuring the ecological activity of the sea by its area (rather than its volume as many intuitively think) makes ecological sense. It is surface which determines its productivity, both the capturing of solar energy and the gas exchanges with the atmosphere are proportional to the surface.

3.2. The ecological benchmark: how much nature is there per global citizen?

Adding up the biologically productive land per capita world-wide, including 0.25 ha of arable land, 0.6 ha of pasture, 0.9 ha of forest, 0.06 ha of built-up land and 0.5 ha sea space, shows that there exists 2.3 ha of biologically productive space per global citizen. Not all of that space is available to human use as this area should also provide habitat for the 30 million fellow species with whom humanity shares this planet. According to the World Commission on Environment and Development, at least 12% of the ecological capacity, representing all ecosystem types, should be preserved for biodiversity protection (WCED, 1987). This 12% share is most likely insufficient for securing biodiversity (Noss, 1991; Noss and Cooperrider, 1994), but conserving more may be politically unfeasible. By accepting 12% as the magic number for biodiversity preservation, for the purpose of the calculations presented here, it follows that from the approximately 2.3 ha per capita of biologically productive area which exist on our planet (in 1997), only 2 ha per capita of land and sea space are available for human use. These 2 ha become the ecological benchmark figure for comparing people's ecological footprints. It is the mathematical average of the current ecological reality. Therefore, with current population numbers, the challenge is to reduce the average footprint to at least this size. Assuming no further ecological degradation, the amount of available biologically productive space will drop to 1.2 ha per capita once the world population reaches its predicted 10 billion. If current demographic growth trends persist, this will happen in little more than 30 years.

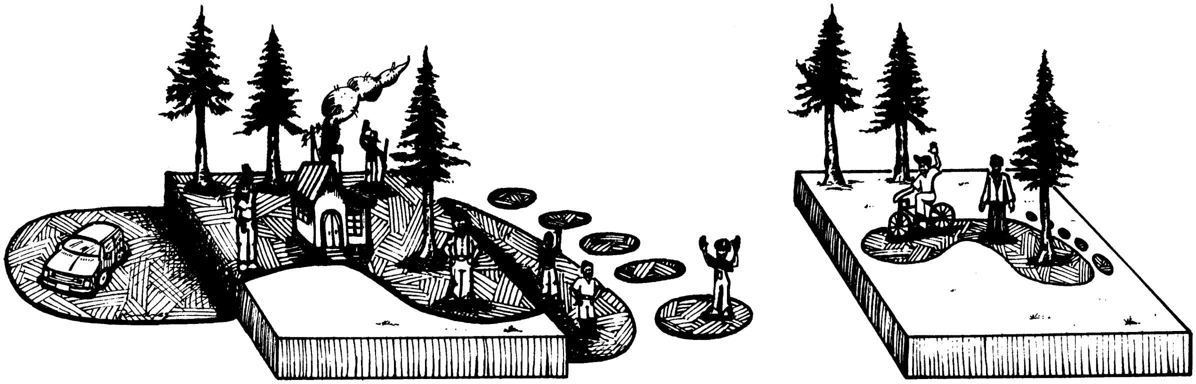

Fig. 1. National ecological deficits. The ecological footprint measures how much biological capacity people occupy. Some countries claim more biological capacity than there is within their boundaries. This means that they run a national ecological deficit. Consequently, they need to import their missing ecological capacity—or deplete their local natural capital stocks (left). Regions and countries with footprints smaller than their capacity are living within their territory's ecological means (right). Often, however, the remaining capacity is used for producing export goods rather than keeping it as a reserve. In contrast, a region's 'global ecological deficit' refers to the gap between the average consumption of a person living in that region (measured as footprint) and the bio-capacity available per person in the world.

3.3. The case of Italy and the other 51 analyzed countries

As shown in the case of Italy presented in Table 3, the average citizen occupies 4.2 ha of biologically productive space, while there is 1.3 ha available, less than the 2 ha per capita available in the world. As the footprint and the ecological capacity available within Italy are both measured in the same units, they can be compared directly. If, as in the case of Italy, the ecological footprint of a country is larger than the available ecological capacity, the country runs a 'national ecological deficit' (see Fig. 1). In the case of Italy, the national deficit is 2.9 ha per person. In other words, Italy could (with its own biological capacity) only supply the current standard of living of one-third of its population. Table 4 shows the results for the other 51 analyzed countries and the world as a whole. One of the findings of these calculations was that humanity as a whole has a footprint larger than the ecological carrying capacity of the world.

This global overshoot is only temporarily possible as long as there are natural capital stocks to be depleted. And this is indeed the case today: deforestation; erosion; and CO_2 accumulation or groundwater exhaustion are the corresponding phenomena. Such overshoot may not be dangerous if it is considered a temporary use rather than the base of continued economic growth. However, we fear it is the latter which characterizes humanity's current path.

Most of the countries that are listed in Table 4 present the situation at the global level. Only 12 of them live on footprints smaller than what the Earth can offer per global citizen. Also, all but 17 of them run a national ecological deficit, using more than what is available from within their boundaries. In consequence, the 52 countries together use 35% more bio-capacity than is available from within their countries. The calculation method documented here leads generally to larger footprints than the rough assessments presented in earlier publications like Wackernagel and Rees (1996). The reasons are that: (a) the use of the sea is included; (b) pasture yield is based on a world average estimate lower than assumed before; (c) forest yield and CO_2 absorption is based on a lower, but more accurately assessed, global average timber productivity as published by the Intergovernmental Panel on Climate Change (IPCC, 1997); and (d) the calculation builds on a more complete set of consumption data. This should make the new method more accurate than the previous one.

Table 4
The ecological footprint of nations: For each country, this table lists its 1997 population, ecological footprint, available bio-capacity and national ecological deficit—the last three on a per capita basis. For a nation's total ecological footprint, multiply the per capita data by the country's population

	Population (in 1997)	Ecological footprint (ha/cap)	Available bio-capacity (ha/cap)	Ecological deficit (if negative) (ha/cap)
		(Expressed in area with world average yield, 1993 data)		
Argentina	35 405 000	3.9	4.6	0.7
Australia	18 550 000	9.0	14.0	5.0
Austria	8 053 000	4.1	3.1	−1.0
Bangladesh	125 898 000	0.5	0.3	−0.2
Belgium	10 174 000	5.0	1.2	−3.8
Brazil	167 046 000	3.1	6.7	3.6
Canada	30 101 000	7.7	9.6	1.9
Chile	14 691 000	2.5	3.2	0.7
China	1 247 315 000	1.2	0.8	−0.4
Colombia	36 200 000	2.0	4.1	2.1
Costa Rica	3 575 000	2.5	2.5	0.0
Czech Rep	10 311 000	4.5	4.0	−0.5
Denmark	5 194 000	5.9	5.2	−0.7
Egypt	65 445 000	1.2	0.2	−1.0
Ethiopia	58 414 000	0.8	0.5	−0.3
Finland	5 149 000	6.0	8.6	2.6
France	58 433 000	4.1	4.2	0.1
Germany	81 845 000	5.3	1.9	−3.4
Greece	10 512 000	4.1	1.5	−2.6
Hong Kong	5 913 000	5.1	0.0	−5.1
Hungary	10 037 000	3.1	2.1	−1.0
Iceland	274 000	7.4	21.7	14.3
India	970 230 000	0.8	0.5	−0.3
Indonesia	203 631 000	1.4	2.6	1.2
Ireland	3 577 000	5.9	6.5	0.6
Israel	5 854 000	3.4	0.3	−3.1
Italy	57 247 000	4.2	1.3	−2.9
Japan	125 672 000	4.3	0.9	−3.4
Jordan	5 849 000	1.9	0.1	−1.8
Korea, Rep	45 864 000	3.4	0.5	−2.9
Malaysia	21 018 000	3.3	3.7	0.4
Mexico	97 245 000	2.6	1.4	−1.2
Netherlands	15 697 000	5.3	1.7	−3.6
New Zealand	3 654 000	7.6	20.4	12.8
Nigeria	118 369 000	1.5	0.6	−0.9
Norway	4 375 000	6.2	6.3	0.1
Pakistan	148 686 000	0.8	0.5	−0.3
Peru	24 691 000	1.6	7.7	6.1
Philippines	70 375 000	1.5	0.9	−0.6
Poland, Rep	38 521 000	4.1	2.0	−2.1
Portugal	9 814 000	3.8	2.9	−0.9
Russian Federation	146 381 000	6.0	3.7	−2.3
Singapore	2 899 000	6.9	0.1	−6.8
South Africa	43 325 000	3.2	1.3	−1.9

Table 4 (Continued)

	Population (in 1997)	Ecological footprint (ha/cap)	Available bio-capacity (ha/cap)	Ecological deficit (if negative) (ha/cap)
		(Expressed in area with world average yield, 1993 data)		
Spain	39 729 000	3.8	2.2	−1.6
Sweden	8 862 000	5.9	7.0	1.1
Switzerland	7 332 000	5.0	1.8	−3.2
Thailand	60 046 000	2.8	1.2	−1.6
Turkey	64 293 000	2.1	1.3	−0.8
United Kingdom	58 587 000	5.2	1.7	−3.5
United States of America	268 189 000	10.3	6.7	−3.6
Venezuela	22 777 000	3.8	2.7	−1.1
World	5 892 480 000	2.8	2.1 (2.0 for 1997)	−0.7 (−0.8 for 1997)

These calculations give us an account of the ecological capacity used and available for each country or the world. Thereby, they indicate the natural capital used. They provide us therefore with information of both the stocks and the flows they produce.

4. Methodological limitations and opportunities

Without any doubt, the calculations presented in this study are still characterized by many limitations. One is the data source. United Nations statistics may not be complete and consistent among countries or over time. However they are the best available source for international comparisons. (A more detailed assessment of Sweden using national data is now in preparation (Wackernagel et al., 1998)). The assessments allow us to direct attention to the magnitude of humanity's use of nature. The accuracy of the assessment would profit from more detailed productivity assessments, particularly for animal products and forests. Methodologically, the assessments could be made more complete by including the ecological spaces used for freshwater use, the absorption of still left out waste products and contaminants. Currently, we are working on a project to add the freshwater component into the footprint, an aspect of particular importance in arid areas of the world.[6] Contamination, however, may be more difficult—or in some cases even impossible—to accurately represent within the ecological footprint framework. Clearly, excessive toxicity makes ecosystems no longer available for human use. Still, lower levels of (persistent) contaminants without clear impacts on the biological productivity of ecosystems may still threaten human health as, for example, in the case of the endocrine disrupters or other cancer provoking compounds. In these events, footprints can only be estimated through proxy calculations, for example by assessing the biophysical resources necessary to rectify the damage. The inclusion of all possible aspects of ecological impact into footprint assessments may lead to levels of sophistication that miss the main purpose of this tool: providing a big picture analysis to put the various competing human uses of the biosphere in each other's context.

That humanity's footprint is larger than the world does not contradict the earlier findings of others, particularly the widely cited study realized by Vitousek et al. (1986). Using conservative estimates, they analyzed the human appropriation of

[6] In many temperate countries like Sweden or Canada, freshwater use may not occupy significant additional bio-productive spaces. In arid places, however, the use of one cubic meter of fresh water may mean the loss of at least one kilogram of biomass production, extrapolating from respiration data for cereals (Postel, 1996).

the products of photosynthesis and concluded that 'nearly 40% of potential terrestrial net primary productivity is used directly, co-opted or foregone because of human activities'. While a superficial perusal of their findings may suggest that in the early 1980s (when the data was compiled) the world was only 40% filled with human activity, this is not really the case. In reality, the 'remaining' 60% are the hardest to exploit—or in fact they may be unexploitable for humans. Why Vitousek's estimates are underestimates can be shown with two examples: fisheries and forestry.

- Fisheries: While Vitousek et al. (1986) calculated for the fresh-water and marine ecosystem an appropriation of 2 Petagrams (Pg or 10^{15} g) fish biomass out of a net primary production of 92.4 (all expressed in dry-weight), Pauly and Christensen (1995) found in a more detailed analysis that the ratio is more in the order of 6–14 Pg out of 126 Pg—this at a time when global fish productivity may have reached its maximum potential according to the FAO (1993) in Weber, 1994). In other words, an exploitation rate of 5–12% of the net primary production corresponded, in fact, to the maximum rate of exploitation—at this seemingly low appropriation percentage, the sea is already claimed by humans in its entirety.
- Forestry: Vitousek et al. (1986) estimate a forest use of 13.6 out of 48.7 Pg, or 28%. Again, there are good reasons to believe that this is a maximum exploitation rate. Roundwood harvest today has reached 3.4 billion m^3 per year world wide (FAO, 1995c). According to our estimate based on optimistic FAO data, the maximum sustainable yield world-wide may reach 5 billion m^3 per year. This suggests that the exploitation percentage would already be at 68% or above. In light of rapid deforestation (which admittedly is not caused solely by timber harvesting), even today's roundwood harvest rate may already be too high. In other words, it may be unlikely that the remaining 32% can be harvested in a sustainable way. Furthermore, Vitousek et al. (1986) did not count the necessity to absorb CO_2 which would claim additional and rather large newly reforested areas.

These ecological footprint studies confirm the conservative findings of Vitousek et al. (1986) and extend them by including more ecological services (such as the assimilation of waste products as CO_2) and by distinguishing between the productive quality of various ecological capacities. Footprint studies also reflect the efficiency of human resource use. For example, incorporating national flows, it accounts automatically for the national resource savings through the recycling of materials.

5. Conclusions

This footprint framework offers a cheap and rapid natural capital appraisal for nations with which human demands can be compared with nature's available supply for human use. The footprint is an accounting tool that can aggregate ecological consumption in an ecologically meaningful way. It gives us, therefore, a realistic picture of where we are in ecological terms. This is what we need to know to achieve sustainable development, securing people's quality of life within the means of nature. It requires improving many people's quality of life while reducing humanity's footprint. Impossible? No. Three complementary strategies can reduce footprints while not compromising our quality of life. We can: (a) increase nature's productivity per unit of land, e.g. terraces on mountain slopes, solar collectors on unused roof areas or less wasteful agricultural systems (Pimentel and Pimentel, 1996); (b) do the same with less through the better use of the harvested resources, e.g. eco-efficient technology such as smart lamps or heat-pumps (Weizsäcker et al., 1995); or (c) consume less by being fewer people and consuming less per capita, e.g. by avoiding car-ownership and disposable products. This simpler and less expensive life-style may buy people more leisure time and be less harsh on their health (Dominguez and Robin, 1992).

The described calculation framework becomes a starting point for more complete national and regional accounting of ecological flows and services. As such accounts can be summarized in a single number, they may prove to be useful counterparts to the conventional Gross Domestic Product (GDP) measures. Ecological footprints can become an easy-to-read measurement tool for ecological sustainability. By summarizing the diverse ecological impacts in an ecologically meaningful way, it helps to communicate the magnitude of the issues and provides a context for tangible action (Robins, 1995). By addressing population number and per capita consumption, it reconciles the population-consumption debate and underlines the necessity to address both. As footprints do not measure people's quality of life, the other imperative for sustainability, they need to be complemented by social indicators to cover progress toward sustainability comprehensively. However, by providing a clear measure of our use of nature, they point out the sustainable limits of the biosphere and show which projects and programs help humanity to live within the means of nature.

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