Assessing the Ecological Footprint

A look at the WWF's Living Planet Report 2002

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Chapter 1: Introduction

The belief that there are limits to progress and prosperity seems to be as old as humankind. Throughout the ages, doomsday prophecies have been used to describe what would happen if humankind attempted to cross those limits. The Bible shows how limits are determined by divine interference from God, who never allowed the tower of Babel to reach the sky. Malthus' "An Essay on the Principle of Population", published in 1798, was the first to put the limits in a scientific context. Malthus wrote the essay at a young age; it was short, and it was published anonymously. He could not have envisaged that his basic ideas would still be reproduced some 200 years later. Malthus' theory was that while the World's population is growing exponentially, the production of food grows only linearly. Consequently disaster is inevitable at some point.

In the early 1970s Malthus' theory was embraced by the Club of Rome. In 'Limits to Growth' (1972) and 'Beyond the Limits to Growth' (1992), the Club of Rome argued that an exponential rise in the degradation of nature (caused by population growth, economic growth and pollution) would outpace the fixed capacity of the World's ecosystems. In the environmental debate concepts such as 'carrying capacity', 'living planet index' and 'ecological footprints' emerged as measurements of the adverse anthropogenic impact on nature's ecosystems.

The concept of the ecological footprint was developed and quantified by William Rees and Mathis Wackernagel in the early 1990s as an elaboration of the 'carrying capacity' concept.[1] It is a concept in the making, which has changed and improved throughout the 1990s. In the latest ecological footprint article[2] (published in the Proceedings of the National Academy of Science 2002), the footprint is calculated for the entire World.

A few months after the publication of the article, the WWF published its latest Living Planet Report (WWF 2002) based on the same global calculation methods used in the ecological footprint. The message in the report was clear: we need 1.2 Earth's to meet the demand of humankind in a sustainable way, and if we do not change our current ways, we will be faced with a regular collapse in human welfare by 2030.

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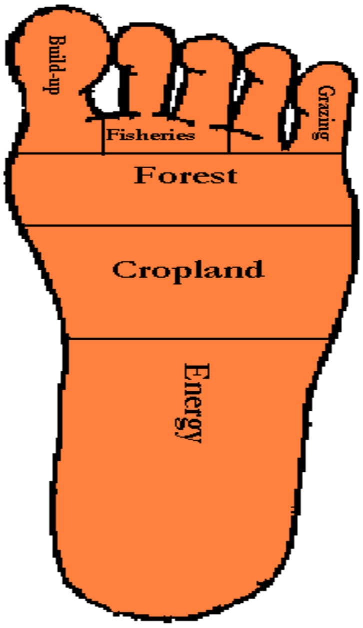
[1] (Wackernagel & Rees 1994) p. 369.
[2] (Wackernagel et al. 2002).

This report from the Danish national Environmental Assessment Institute will assess the scientific validity of this latest doomsday’s prophecy.

Chapter 2: Description of the ecological footprint[3]

The ecological footprint is an aggregated measure consisting of six categories: cropland, grazing land, forest land, fishing ground, energy footprint and built-up land. The footprint for a category represents the area used to produce the goods from that area. The area demands for these categories are added up to estimate total global footprint. The footprint drawing below gives a tentative indication of the relative size between the six categories:



The use of a simple concept has certain advantages but also drawbacks. A clear advantage is that it encompasses many of humankind's needs and aggregates these needs into a single figure. Such a simple and easily comprehensible figure also has a potential value in supporting the democratic debate on environmental policies. However, what if such a number is only marginally relevant?

In the Living Planet Report, Earth's supply of biological resources is estimated at 11.4 billion hectares, equivalent to a little less than one-fourth of Earth's surface. This area is also known as bio-capacity or the Earth's supply. The physical hectares in the different categories are translated into normalised, global hectares by means of equivalence factors. The equivalence factors are used to transform the primary

[3] Unless otherwise indicated, the references used in this chapter are taken from WWF 2002.

biomass productivity of the different types of land (e.g. cropland) into a global average primary biomass productivity. This makes it possible to compare the production of biomass from different types of areas. A type of area like cropland with above-average production will have an equivalence factor higher than one.

In the following the six categories are described along with their development over time.

First category: the global cropland area

The cropland footprint includes the area needed to produce all food (grain, fruits, vegetables but also coffee, tea, tobacco, etc) and non-food crops (cereal for animals, cotton, rubber, etc). FAO estimates that cropland covers an area of about 1.5 billion hectares worldwide. After conversion into global hectares of average bioproductivity on the basis of equivalence factors, the cropland area more than doubles to 3.2 billion global hectares indicating that the bioproductive capacity of cropland is more than twice as high as the average global hectare. Cropland, by the way, seems to be the only factor in the ecological footprint that produces biocapacity, which is directly essential for the survival of humankind.

The cropland footprint of a particular country is determined by the country’s consumption of commodities produced on cropland worldwide. Western countries have a per capita footprint that is more than twice as large as the World’s average. This relatively large footprint reflects a higher calorie intake in the developed countries as well as consumption of more luxurious commodities (coffee, tobacco, cotton, etc).

Global cropland trends

The global cropland area by and large remained unchanged in the period 1961-1999 (growing by less than 10 percent) despite a doubling of the population. The WWF report points out that this development has been possible because irrigation, the use of fertilisers and technological progress in general that have improved crop yields. Contrary to the other factors included in the Ecological Footprint, improvements in cropland productivity seem to be able to keep pace with the increase in population growth and the rise in consumption. Whether this development will continue is of course an open question. It is, however, important to note that increases in cropland biocapacity are not necessarily restrained by present day maximal yields. Professor Ausubel estimates that “if during the next 60 to 70 years, the World farmer reaches the average yield of today’s US corn grower, ten billion people will need only half of today’s cropland while they eat today’s US calories"[4]. Thus, there is reason to believe that the increase in future cropland areas will be minimal – just as it has been in the last forty years. In the latest FAO report on '*Agriculture towards 2015/2030'*[5], FAO explicitly discusses the use of land in agricultural production and the extra availability of agricultural land. FAO estimates that, in addition to the current about 1.5 billion hectares (or 11% of Earth's land surface) that is used for agricultural purposes, an additional 2.9 billion hectares have crop production potential. This corresponds to 6.1 billion global hectares. Of this area about 45% is forested.[6] So there is ample room for bringing in new agricultural land and none of it needs be forested. Actually, the FAO estimates a much lower increase in land use of about 0.12 billion hectares up to 2030 in developing countries (developed countries will probably not increase their area at all), which is an increase of 12%. This means that agricultural land usage will go from 32% of potential land use to 36% in 2030. Globally, this probably means an increase in agricultural land use from 11% to 12% of the land surface.

Category two: the global grazing land area

The global area used as grazing land corresponds to our consumption of meat, dairy products, hides, and wool that come from livestock which are not crop-fed, but occupy permanent pastures. The World's grazing livestock population comprises mainly cattle, sheep and goats, but also includes horses, asses, and camels. There are 3.5 billion hectares of natural and semi-natural grassland and pasture area in the World. The area is calculated using FAO data from 2001.

Global grazing land trends

The global demand for grazing land has grown from 0.3 billion global hectares in 1961 to 0.8 billion global hectares in 1999. This increase has to a great extent been achieved at the expense of forest land. There was an eight-fold disparity between the grazing land footprints per country in 1999, which was mainly due to the greater proportion of meat and dairy products in the diets of the richer nations. An important reason for the growth in global demand for grazing land is that grazing land productivity has not grown as much as cropland productivity. This can partly be explained by the fact that grazing land is normally a common resource and consequently not in focus when improving efficiency.

[4] (Ausubel 2002) p. 3
[5] (FAO 2000).
[6] FAO 2000 in chapter 'Prospects by major sector: Crop production' page 9.

Category three: the global forest land area

The forest footprint is the area required to produce forest products which are consumed globally. The footprint includes all timber products, whether in the form of sawn wood, wood-based panels or fibreboard, as well as pulp, paper and paperboard. It does not include non-timber forest products such as wild fruit, nuts, fibres, or bushmeat. Wood or charcoal burnt as fuel are included in the energy footprint. To calculate the national forest footprint, national consumption of forest products is converted into the forest area required to produce them. Countries with high per capita consumption of wood products tend to have extensive forests. This is potentially sustainable and makes good ecological sense as long as their consumption remains within their forests' biological capacity.

Global forest trends

The World average forest footprint was 1.0 billion global hectares in 1961. The 1999 figure was 1.6 billion global hectares. According to the FAO there were approximately 3.8 billion hectares of forest in 1999. With a biological productivity that is 35 per cent higher than the average global hectare, the 3.8 billion hectares correspond to 5.1 billion global hectares of biocapacity. The fact that the average forest footprint is well within Earth's biological capacity indicates that the World's forests can meet the demand for wood products.

Category four: the global fishing ground area

The global fishing ground footprint is the area required to produce the fish and seafood products that countries consume. This includes all marine and freshwater fish, crustaceans (such as shrimp) and cephalopods (such as squid) as well as all fishmeal products and oils that are fed to animals and farmed fish. It also includes an additional component in most countries – roughly 40 per cent – to allow for bycatches, which are generally discarded back to the sea. The actual catches are multiplied by a factor of 1.4 to estimate actual catches. Fish species are not equal in terms of their biological productivity requirements. A kilogram of fish that lives high up the food chain on tropic level four, e.g. cod, will have a footprint that is ten times larger than a kilogram of fish one level below (tropic level three), e.g. herring, because the production of a kilogram of cod requires ten times as much of primary production in the oceans. Consequently a country's fishing ground footprint takes account of fish species as well as the quantity of fish consumed.

Global fishing trends

In 1961 the footprint relating to fishing was 0.3 billion global hectares. In 1999 it was 0.8 billion global hectares. This corresponds to 2.3 billion physical hectares.

This number should be compared with a total World ocean surface area of 38 billion hectares. For this reason about 36 billion hectares are not included in the biocapacity figures. The global fishing ground footprint grew by 2.6 per cent a year on average between 1961 and 1999. On average, there is a 14-fold difference in per capita fish and seafood consumption between high and low-income countries.

Category five: the global built-up land footprint

This category of footprint comprises infrastructure for housing, transportation, industrial production as well as hydroelectric power installations. The global built-up land is the least documented category, since low- resolution satellite images are not able to capture dispersed infrastructure and roads. It is assumed that built-up land replaces arable land since human settlements are mainly located in the most fertile areas of a country.

Global trends in the built-up land footprint

The area demand in 1961 is estimated at 0.3 billion global hectares, growing to 0.6 billion global hectares following the growth rate of the World population in the period.

Category six: the global energy footprint

The global energy footprint is the area required to sustain the World's energy consumption. It encompasses four types of energy: fossil fuels (coal, oil and natural gas), biomass (fuel wood and charcoal), nuclear power and hydropower. The footprint of fossil fuel combustion is calculated as the area of forest that would be required to absorb carbon dioxide emissions, excluding the proportion that is absorbed by the oceans (estimated to 35%).[7] The footprint of biomass fuel is calculated as the area of forest needed to grow the biomass. These two calculations result in approximately the same area requirement per unit of energy consumed. Nuclear power is included in the energy footprint and counted as being equivalent to fossil fuel per unit of energy, although nuclear power stations do not emit carbon dioxide. Excluding nuclear power would reduce the WWF energy footprint by more than 7 per cent corresponding to 0,5 billion global hectares or almost the build-up land footprint (0.6 billion global hectares).[8] The footprint of hydropower is the area occupied by hydroelectric dams and reservoirs. National and regional energy footprints are adjusted for the energy embodied in traded goods. This means that the energy used to make a product manufactured in one country but consumed in

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[7] (WWF 2002) p. 31.
[8] See calculations in section 'The Ecological Footprint's problematic inclusion of energy

another is subtracted from the footprint of the producer country and added to that of the consumer country.

Global energy footprint trends

In 1961 the energy footprint was 2.5 billion global hectares, and in 1999 it was 6.7 billion global hectares. This is the fastest growing component of the global ecological footprint in the period. Of all the components of the ecological footprint, the per capita energy footprint features the greatest disparity between rich and poor, with a 16-fold difference between high and low income countries.

The figure below illustrates development in the six WWF categories over time.

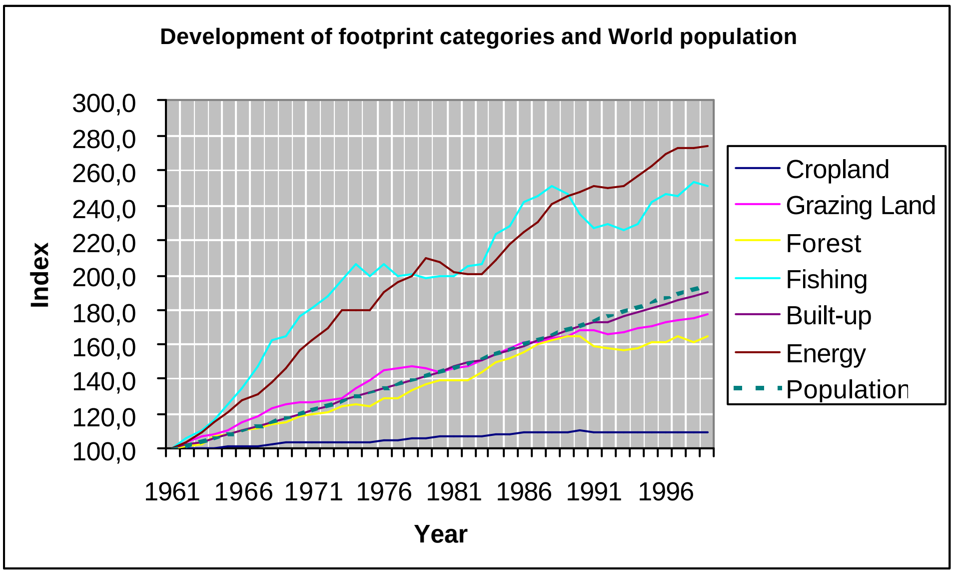


Figure 1. Development of the footprint in the six WWF categories as well as World population. 1961=Index 100. Source: (Wackernagel et al. 2002).

The figure shows that the footprint of cropland has grown with 10 per cent in the period although the World population has doubled. The footprint of grazing land, forests and build-up land has grown less than the population whereas the footprint of energy and fishing has grown faster. The figure below illustrates the relative sizes of the 6 categories in 1961 and 1999:

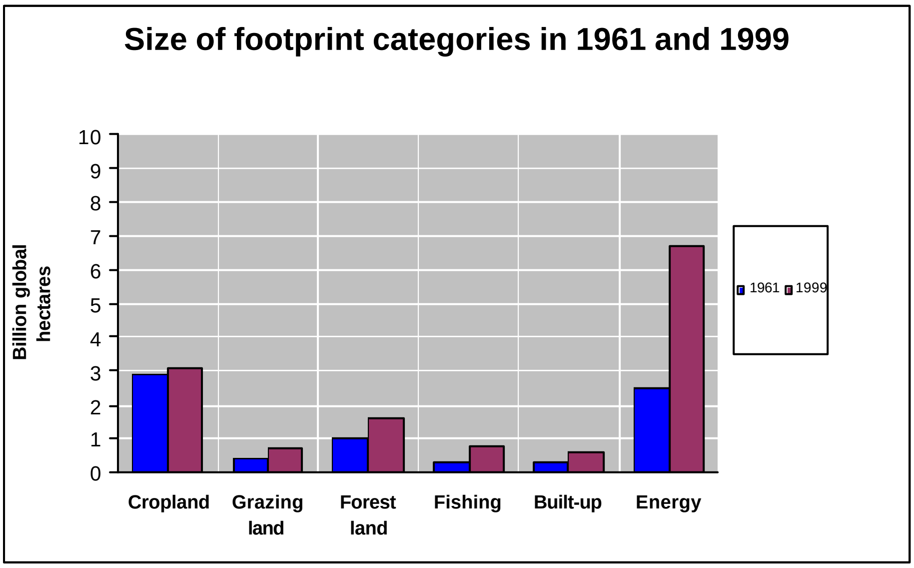


Figure 2. Size of the 6 footprint categories in 1961 and 1999. Source: Living Planet Report 2002.

It can be seen from the figure that the footprint from energy and cropland are by far the largest footprints while fishing, grazing land and built-up land are less significant. The growth in the footprint of energy seen in the previous figure is therefore much more important than the growth in fisheries.

The aggregation of the ecological footprint has some serious limitations and drawbacks. The next section will highlight some of the most important areas.

Chapter 3: The ecological footprint's limitations

The analytical capacity of the ecological footprint has been discussed in the scientific community, primarily in the *Ecological Economics* magazine. In 2000, a special issue of the magazine (vol. 32) was devoted to the ecological footprint debate, and many scholars seized the opportunity to pinpoint the concept's analytical limitations. We will briefly present some of the most substantial arguments and counter-arguments here.

Media attention

In general the concept has been accused of being a weak analytical tool devised with the purpose of attracting media attention. Moffatt (2000) ruthlessly argues that the concept "in itself is nothing more than an important attention grabbing device"[9], while Kooten & Bulte (2000) more diplomatically point out that "it is less a scientific measure than one designed to raise public awareness and influence politics"[10] The weak analytical capacity can be traced to several interrelated factors.

Strong sustainability

The ecological footprint builds on a strong sustainability interpretation (Haberl et al. (2001), E. Roth et al. (2000), Kooten & Bulten (2000)). This is hardly surprising since, in one of their early presentations of the ecological footprint, Wackernagel & Rees characterised "strong sustainability" as the basic principle for ecological thought.[11]

A strong sustainability interpretation reflects the fundamental belief that sustainability is a matter of ecological status quo – either in the form of a stable amount of stored energy or in respect of the atmospheric concentration of carbon dioxide. Strong sustainability can either build on the assumption that the degree of substitution between most natural capital and man-made capital is close to none or it can be traced to the assumption that nature has an intrinsic value that should be preserved. It is generally argued that at least some critical, irreversible natural capital stock should not be declining over time, since substitution with man-made capital is not likely to be feasible.[12] Whether atmospheric concentrations of carbon dioxide belong to this category is questionable. Although there is widespread consensus that carbon dioxide atmospheric concentrations must stabilise in the

9 (Moffatt 2000), p. 360.
10 (van Kooten & Bulte 2000), p. 385
11 (Wackernagel&Rees, W. 1994) p. 367.
12 (Hanley et al. 1997) p. 428-30.

future, it is not clear whether the situation is critical at this point in time. It is expected that energy consumption will become increasingly less carbon intensive in the near future and that renewables are likely to take over as the dominant source of energy in the middle of the 21st century.[13] Thus, carbon dioxide emission is likely to be a temporary problem since technological progress spurs the development of alternative sources of energy. As Ausubel (2000) puts it: "The trend toward 'decarbonization' is the heart of understanding the evolution of energy system."[14] Once this development has taken place – and this development is currently technically feasible – the concentration of carbon dioxide will stop increasing and eventually decline.

Failing to acknowledge that at least some degree of substitution is possible could lead to a biased ecological footprint. It is not evident that a sustainable path of development cannot be one where disinvestment in some types of natural capital – including carbon dioxide concentration – occurs. As Kooten & Bulte (2000) point out there is no reason to assume that the current stock of natural capital is somehow optimal.[15]

That the footprint should build on a strong sustainability interpretation has been somewhat disputed by the ecological footprint's lead architects (Wackernagel (1999); Wackernagel & Silverstein (2000), Rees (2000), Wackernagel & Yount (2000)). They argue that a much stricter interpretation of sustainability could have been applied by which future generations would be compensated for current consumption of energy in the form of an equivalent amount of another type of stored energy.[16] However, it could be argued that humankind actually *does* compensate future generations with an equivalent amount of another type of stored energy. Not only have the known oil reserves been growing five-fold during the last forty years but we also leave future generations more diversified sources (and thus more choices) for energy usage.[17] As a result, the footprint's sustainability interpretation that "merely suggests that fossil fuels users rectify the damage they have caused the biosphere"[18] might actually be as strong as – if not stronger than - a sustainability focus on stored energy. Consequently the sustainability interpretation underlying the energy footprint seems too strict and not in accordance with mainstream ecological

[13] (Ausubel 2000); (Chakravorty & et al. 1997).
[14] (Ausubel 2000) p. 18.
[15] (van Kooten&Bulte, E. 2000) p. 388.
[16] (Wackernagel & Silverstein 2000) p. 392.
[17] (Lomborg 2001) p. 124.
[18] (Wackernagel&Silverstein, J. 2000) p.392.

economics that assumes at least some substitution between different types of capital.[19]

Sustainability at all?

Others argue that the ecological footprint is not a measure of sustainability at all. Vuuren & Smeets (1999) argue that the role of ecological footprint is limited as an indicator for sustainability, and Troell et al. (2002) state that the "ecological footprint is not an indicator of sustainability as no economic or social indicators are included."[20] This criticism is closely related to the discussion of sustainability outlined above. Only by accepting a very strong sustainability interpretation can economic and social indicators be excluded. If nature's capital is to be kept constant for nature's own good, then no economic and social indicators are needed, but if humankind is to be included in the equation then economic and social indicators cannot be left out. It is therefore possible to speak about sustainability without including economic and social indicators but it should be acknowledged that the degree of sustainability is very limited in scope. It is therefore questionable whether Costanza's arguments in support of the footprint can stand-alone. Costanza (2000) argues that the footprint forces us to "assume that biophysical limits cannot be overcome, unless and until it can be shown that they can be"[21] and that the ecological footprint is "a measure of how much faith in technology is required in order to consider current consumption patterns sustainable."[22] It has to be added in this context that the 'biophysical limit' is a one-dimensional measure of what is perceived to be the biggest remaining environmental problem: carbon dioxide emissions. Applying a strong sustainability interpretation on such a one-dimensional measure makes it somewhat problematic as a tool for evaluating faith in technology and human progress.

Single numeriare

Several scholars have pointed to the problems of constructing an aggregated indicator for sustainability (Bergh & Verbruggen (1999), Costanza (2000), Ferng (2002), van Vuuren & Smeets (2000), Opschoor(2000)). In our view, the problem is not an aggregated indicator as such. Aggregation and simplification are accepted and often necessary measures in much scientific research. However, these measures should not be achieved by sacrificing explanatory, descriptive and predictive power. In contrast, simplicity and aggregation should be used to create a tool that can improve a theory's analytical power. In the case of the ecological footprint it is difficult to see that either of these purposes has been the driving force behind the

[19] (Hanley et al. 1997).
[20] (Troell et al. 2002), p. 3.
[21] (Costanza 2000) p. 342.

concept. The predictive power of the concept is limited as Wackernagel himself points out: the method does “not say anything about how rapidly the natural stock is becoming depleted in the process or for how long such depletion … can continue.”[23] Indeed, Rees points out that “prediction was never the intent”[24]. The explanatory capacity does not seem to have been improved by an aggregation. We would agree with Opschoor (2000) and Bergh & Verbruggen (2000) that the concept actually hides what are the causes of the results (carbon dioxide emissions) rather than bringing it out to light. It is an unnecessarily complex way of saying what we already know: For the last forty years we have been emitting an increasing amount of carbon dioxide into the atmosphere. Moreover, only a one-dimensional solution to the problem is presented: forest planting.

Static concept

No one would dispute that ecological footprints are static by nature. Rees argues that the concept “was not intended to provide a dynamic window to the future but rather a snapshot in time.”[25] The question is whether (and by how much) it is problematic to apply a static concept in an analysis? Ecological footprint by itself does not have predictive power. Since policy decisions address future development, the concept should preferably include some predictive power. The method of examining historical time series of ecological footprint can yield some information but as Moffatt notes “such historical studies may unearth the process leading to unsustainable practices at different spatial scales. More importantly, however, is the need to develop a dynamic approach for exploring different scenarios of development.”[26]

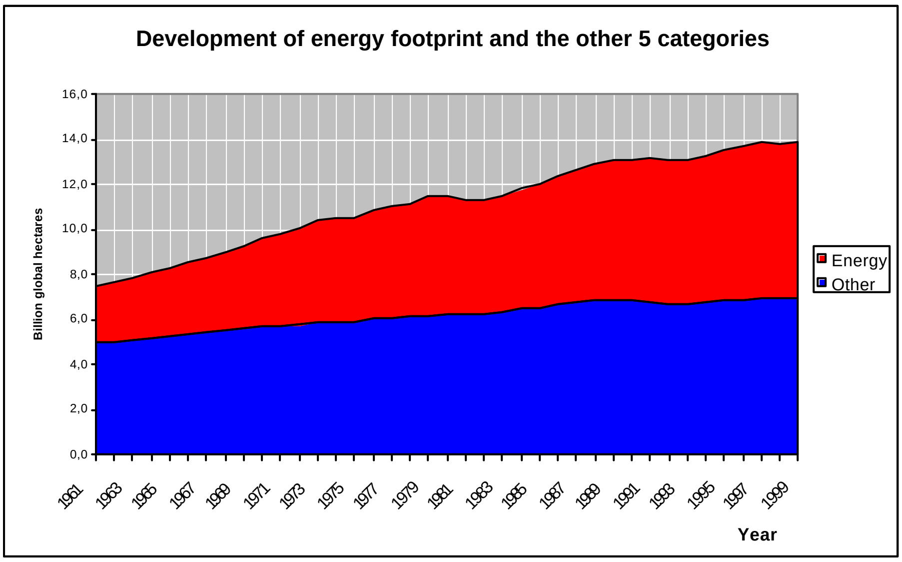
[22] (Costanza 2000) p. 342.
23 (Wackernagel et al. 2002) p. 3.
24 (Rees 2000) p. 373.
25 (Rees 2000) p. 373.
26 (Moffatt 2000) p. 360.

Chapter 4: The problematic inclusion of energy consumption

The energy problem

It is evident that the overshooting-results in the Living Planet Report are driven by a single factor: energy consumption. In both cases, energy consumption accounts for about half of the total ecological footprint size and the increases in ecological footprints for the last forty years have mainly been caused by increases in energy consumption.

Figure 3. Comparison of the size of the energy footprint and the sum of the 5 other categories



(cropland, grazing land, fisheries, build-up land and forests). Source:(Wackernagel et al. 2002).

It is perfectly legitimate to have such an all-determining factor in a balance sheet. Yet, the methodological demands to this factor should match the all-determining role that it possesses. It is therefore noteworthy that by far the most criticism against the ecological footprint has either centred on the whole concept of including energy or on the method for including it.[27] One of the supporters of the ecological footprint, Ferguson, admits that the idea of basing the energy footprint on the "land area needed to absorb the carbon emitted by burning fossil fuels is regarded by most eco-footprinters, including especially ourselves, as being hard to defend.".[28]

Many of the problems addressed in the previous section apply to the energy footprint as well. The energy footprint is static, it builds on a strong sustainability

[27] (Herendeen 2000), (Ayres 2000) , (van Kooten&Bulte, E. 2000), (van den Bergh & Harmen Verbruggen 1999), (van Vuuren & Smeets 2000).

interpretation, it underestimates the role of technological progress and does not assume that technology (i.e. renewable energy) can be used to reduce the concentration of carbon dioxide.

Epistemological problem

The question of whether carbon dioxide should be included in the footprint is closely related to the understanding of sustainability and to the degree of sustainability one wishes to obtain. This inclusion poses an epistemological problem in that it forces a problem that belongs to another dimension into the conceptual framework of physical land area. This calls for difficult decisions and subjective assumptions. This is even more of a problem when the conversion factor is only based on a single option: forest carbon dioxide absorption[29] [30].

Nuclear power

The inclusion of energy also leads to methodological difficulties. The energy produced at nuclear power plants is incorporated in the ecological footprint. The argument for including energy generated by nuclear power in the energy footprint is based on the existence of 'inconclusive data about the long term area demand of nuclear power'.[31] The "long-term area demand of nuclear power" must be the storage facilities needed for the nuclear power waste products. However, it is unlikely that this waste will be stored on the surface of the Earth. Consequently the area demanded will not affect Earth's biocapacity. Nuclear energy thus presents a methodological problem for the authors of the ecological footprint that has not been solved satisfactorily. Even though nuclear power produces waste material that remains radioactive for many hundreds of years to come, it is unclear how raising forests should prevent or reduce the effects of this waste. If we exclude nuclear power from the energy footprint it will fall by 7.1 per cent – and not by less than 4 per cent as stated in the WWF report[32] – causing the overall ecological overshoot to drop by 21 per cent (from 2.28 gha to 1.8 gha)[33]

Marginal economics

Bergh & Verbruggen (1999) point out that the method for sequestering carbon dioxide does not follow the basic economic principles of marginal economic analysis

[28] (Ferguson 2002) p. 310.
[29] Another method - called the fuelwood method - is also used. The method assumes that the energyconsumption today should be replaced by fuelwood and calculates the area needed to produce the fuelwood. The two methods give the same result.
[30] It could be argued that a more straightforward and logical way of including land area in the energy footprint would be to include the implications using fossil fuel – for example the area of land flooded because of a rising sea level or the creation of deserts as a result of rising temperatures.
[31] (WWF 2002), p. 32.
[32] (WWF 2002), p. 32: "Excluding Nuclear Power would reduce the global energy footprint by less than 4 per cent".
[33] The calculation error has been accepted by Mathis Wackernagel (personal correspondence).

and rational behaviour. Forests serve many purposes and carbon dioxide sequestration is but one of them. Therefore there might very well be a rationale in having more forest than we have at present. However, planting forests with the purpose of sequestering carbon dioxide will become increasingly expensive since arable land becomes increasingly scarce. The whole scenario becomes unrealistic and the extremely land-intensive strategy is bound to become physically unfeasible in the end.

Alternative methods

There is no doubt that the proposed calculation method for measuring the extent of the carbon dioxide problem is emotionally appealing. Determining the forest area needed to stabilise the atmospheric carbon dioxide concentration is an interesting figure if forests were to single-handedly clean up after humankind – albeit mostly for academic discussions. Nevertheless, there are other ways of reducing carbon dioxide concentrations in the atmosphere. Wackernagel & Yount (2000) admit that "the current prevailing method of sequestering fossil fuel generated carbon dioxide can only be a temporary solution and that there may be cheaper and less space-intensive methods".[34] One method could be to abandon the focus on sequestration and to "deal with energy on the basis of the area needed to convert energy sustainable".[35] It might be true that "there is no widespread human-made process available to remove carbon dioxide from the atmosphere"[36] although great efforts are being made throughout the World to find such a method. However, reducing carbon dioxide concentrations can be achieved equally effectively by lowering carbon dioxide emissions. This could be done by increasing energy efficiency, by turning to less carbon intense forms of energy, or by turning to energy sources with close to zero emissions such as nuclear or renewable energy. In this report we will focus on non-organic renewable energy which constitutes a realistic alternative. It has, for example, been estimated that Denmark can rely on as much as 50 per cent of the electricity consumption coming from wind turbines alone without sacrificing the constant availability of energy that society relies on.[37]

Renewable Energy

Including renewable energy in the energy footprint is by no means a new idea. Wackernagel & Rees (1996) briefly pointed to an alternative approach including the biomass used to produce ethanol and methanol. But as Ferguson stated in 1999 the ecological footprint "need to extend way beyond using biomass to produce ethanol

[34] (Wackernagel & Yount 2000), p. 26.
[35] (Ferguson A. 1999) p. 1.
[36] (Wackernagel&Silverstein, J. 2000), p. 393, note 2.
[37] (RISØ & ELSAM & Elkraft 1994).

and methanol, which were the only things mentioned by Wackernagel and Rees"[38]. The alternative interpretation of the energy footprint, suggested by Ferguson (1999, 2001, 2002) is that instead of basing the energy footprint on the forest area needed to absorb carbon dioxide, the footprint could include the area of land needed to produce the specified energy as renewable energy. Although Ferguson does not take the idea very far (see chapter 6), it seems to be a possible alternative and much more efficient way of incorporating energy in the ecological footprint. The most important implications of the above interpretation are listed and commented below.

Land use

Table 1 lists the energy production per square metre for several renewable energy carriers (Stöglehner 2002) and (Ferguson A. 1999; Ferguson A. et al. 2001). What is striking is the difference in energy outcome per area between the organic renewable sources of energy and the non-organic renewable sources of energy. If renewable energy is produced using the best technology available, the area needed decreases by a factor of hundred or more.

Table 1. Estimates of yield of different renewable sources. Source Stöglehner 2002, Ferguson 1999 and Ferguson et al. 2001

Renewable type	**Renewable energy source**	**Yield [MJ/m2/year]**
Non-organic	Electricity photovoltaic	440
Non-organic	Electricity wind	900
Non-organic	Electricity water power	100
Non-organic	Solar heating	1200
Organic	Wood extensive	7.3
Organic	Wood intensive	18.79
Organic	Straw as by-product	4.3
Organic	Miscanthus	25.39
Organic	Rape oil	5.81
Organic	Methyl ester of rapeseed	4.72
Organic	Ethanol from sugar cane	9.3
Organic	Ethanol from sugar beet	8.0
Organic	Ethanol from wood	4.6
Organic	Ethanol from wheat	4.61
Organic	Ethanol from maize	1.59
Organic	Methanol from wood	11.67
Organic	Biogas & digestor gas & landfill gas	4.98
Mixture	Fergusson estimate	10

[38] (Ferguson A. et al. 2001) p. 1.

The locations

Production of non-organic renewable energy does not have to take place in areas suited for biological production, which means that Earth's supply of resources is not restricted to approximately one-fourth of the land surface (11.4 billion hectares) identified as the biological productive area. For example, wind turbines could be located in arid areas such as deserts or at sea where they are typically more productive and take up less productive land, if any. The same goes for wave energy which could be produced on the vast oceans. The production of energy by photovoltaics is well suited to be situated in biologically unproductive areas such as sunny deserts or on buildings.

Productivity growth

The productivity growth in renewable resources has increased dramatically in modern times. Naturally, the same cannot be said about the productivity of forests. The energy production per unit of area from renewable sources seems to be able to grow exponentially as technological advances improves productivity (Morthorst 1998); (Ahmed 1994). These improvements in productivity result in a reduced area to produce a certain amount of energy. An example of a renewable source that has shown a major increase in productivity is wind turbines. Wind turbines have shown a rapid development in size and production capacity. The figure below illustrates the development in productivity and size over a 17 year period:

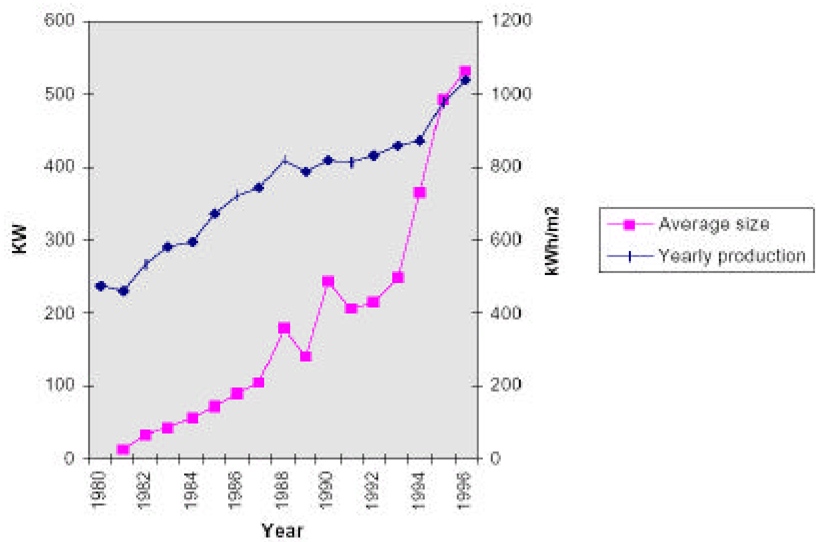


Figure 4. Development in the productivity of wind turbines. Please note that the area in the yearly production is the vertical area covered by the wings of the turbines and not the surface area as counted in ecological footprint. Source: (Morthorst 1998)

Wind turbines have increased their productivity as illustrated by the blue line on the figure[39] by an average of 5% annually from 1980 to 2001, equalling approximately a 3-fold increase in productivity in two decades. Furthermore, wind turbines are growing in size as shown by the pink line. This growth in size and productivity has resulted in a 100-fold increase in energy production per wind turbine in just 15 years.[40] The growing energy-productivity of wind turbines has a direct impact on the area needed to produce a given amount of electricity since fewer turbines can produce a given amount of energy. Yet another example of the rapid growth in renewable resources is the development of solar cells. Over a period of 30 years, the cheapest solar cells have become three times as effective.[41] Already today, it is indeed possible to shift major elements of energy production from production based on fossil fuels to production based on renewable resources. It should be stressed that this would be very expensive. However, it is not at all unrealistic that energy demand can be met by renewable energy sources in the future.

In chapter 6 of this report we will introduce an alternative method of calculating the ecological footprint based on non-organic renewable energy (like wind turbines and photovoltaics). In the coming chapter we will look at the projections made by WWF.

[39] Productivity is measured as production of energy per square metre covered by the arms of the wind turbine.
[40] Data taken from the Danish Wind Industry Association homepage (http://www.windpower.org/da/faqs.htm#anchor450134).
41 (Ahmed 1994).

Chapter 5: Critique of WWF's projections

Including projections

The part of the WWF report, which has generated most attention and newspaper headlines, is the projections made for the next 100 years. 'Wanted: New Earth by 2050' was the Observer headline July 7th 2002. The WWF projects a possible collapse in human welfare by 2030. It is positive that the WWF's Living Planet Report 2002 seeks to overcome one of the limitations relating to the ecological footprint concept by attempting – by means of future scenarios – to give some indication of the severity and relevance of the overshooting problem. A dynamic World model is used to "explore what may happen when the human footprint exceeds global capacity."[42] However, in doing so the report faces a new problem of how to generate accurate, trustworthy projections. The WWF projections are based on the World3 computer model.[43] In a *standard scenario* with no policy changes in the next 50 years, the model predicts that the human ecological footprint will demand 2.5 planets by 2040 and then start to drop as Earth's ecosystems collapse. The Human Welfare Index, which is an approximation of the UN's human development index, will similarly increase at first but then start to decline by 2030.[44]

Basic assumption

The data used in the World3 model is collected by official international organisations. However, as we shall later analyse in greater detail, the projections generated differ from those of all other official international organisations. The WWF argues that the difference in projections can be explained by the fact that many international organisations implicitly assume that the Earth will be able to sustain continued population growth and economic growth. According to the WWF, it would have been better to have *"incorporated feedback or constraints on future growth imposed by the Earth's natural ecosystems"*.[45] One would probably agree with the WWF that indeed there are constraints to growth, although one might also argue that the constraints have more to do with politics, culture and management. The difficult part is to model these constraints correctly.

[42] (WWF 2002) p. 19.
[43] The data behind the projections in (WWF 2002) was kindly made available to us through Jorgen Randers.
[44] (WWF 2002) p. 19.
[45] (WWF 2002) p. 18.

The collapse

There are three determining factors in play in the projection of HWI: a life expectancy index, an educational index and an index for global GDP. Each of these three indexes comprises one third of HWI. The development as projected by WWF is illustrated in the figure below.

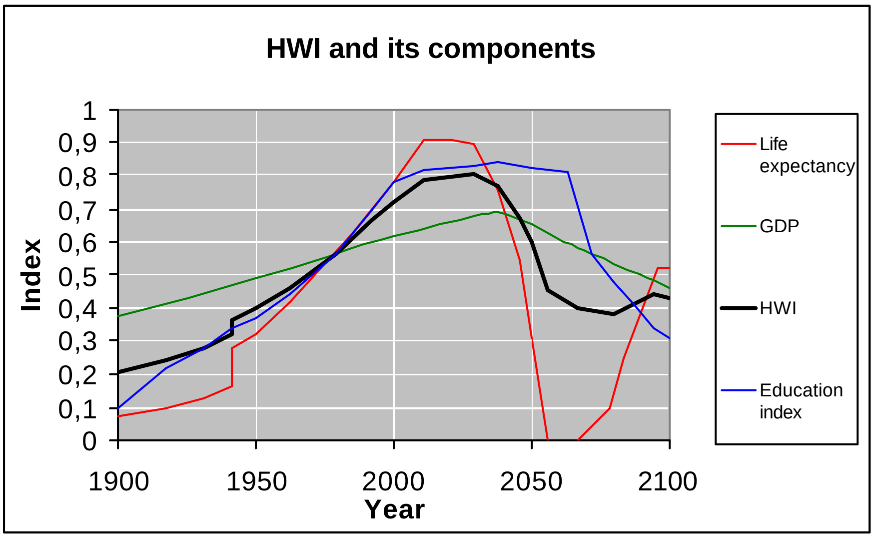


Figure 5. HWI development and the index components in the World3 model. Source: Data from Jorgen Randers, Standard scenario.

WWF predicts that HWI will drop in the near future. According to the authors the drop will take place when "the Earth's productive ecosystems are no longer able to sustain the high levels of human consumption." [46]

In order to evaluate this gloomy projection from the World3 model, we will first look at the earlier projections of the model, and then look at some fundamental issues of dynamic modelling and causality in the model. As a final point we compare the scenarios presented in the Living Planet Report 2002 with projections by leading international organisations.

Limits to Growth

The WWF projections are based on a modified version of the World3 model that was used to generate the overshooting predictions of the "Limits to Growth" report in 1972. [47] This report contained many ominous predictions, which can be evaluated empirically today. Almost every quantitative prediction that was generated at the time and that can be evaluated today turned out to be wrong.

[46] (WWF 2002) p. 19.
[47] (Meadows et al. 1972).

Wrong predictions

Famously, the predictions of the future availability of vital minerals were far off the mark. Here is a list of mineral resources predictions that has not come true:

Table 2. Predictions from 'Limits to Growth' p. 58-60.

Resource	Estimated to be exhausted by
Gold	1981
Mercury	1985
Silver	1985
Tin	1987
Zinc	1990
Copper	1993
Lead	1993
Tungsten	2000
Aluminium	2003

Limits to Growth also predicted that there would be a desperate shortage of arable land by 2000 as a result of exponential population growth on a finite Earth. [48] This has not happened either.

Food prices were predicted to rise so much that people would starve by 2000. [49] Today, however, food prices have never been lower.

It was stated that pollution seemed to increase exponentially over time. Time has proven this to be wrong since most pollutants have *declined* over time in spite of sustained economic growth. This is often referred to as a *de-coupling* of economic growth and environmental degradation. One exception to this rule so far is carbon dioxide emission, which has recently been widely accepted as a major contributor to global warming.

Beyond the Limits

Finally, Limits to Growth predicted that we would run out of oil by 1992[50]. This has not happened and it does not seem to happen in the foreseeable future. On the contrary, known reserves are growing[51]. In fact, this has led Greenpeace to argue

[48] (Meadows et al. 1972) p. 51.
[49] (Meadows et al. 1972) p. 52.
[50] (Meadows et al. 1972) p.58.
[51] (Lomborg 2001) p.124.

that "we are in a second World oil crisis. But in the 1970s the problem was a shortage of oil. This time round the problem is that we have too much."[52]

With little improvement the World3 model was reused in a second report called "Beyond The Limits", issued in 1992 by some of the same authors. In this report many of their previous predictions were contradicted (table 3):

Table 3. Predictions from The Limits to Growth and Beyond the Limits

Subject	The Limits to Growth, 1972	Beyond the Limits, 1992
Food and hunger	Shortages will occur by 2000. Food prises will rise by 2000. Deaths from malnutrition are caused by a combination of social and physical limitations. (p.52)	"Hunger does not persist in the World because of physical limits – not yet, anyway." (p. 49)
Oil and energy	Known oil reserves: 455 billion barrels. (p. 58) World will run out of oil by 1992. (p. 58)	"There is no scarcity of energy on Earth." (p. 77) "The point is *not* that the World is about to run out of natural gas."(p. 73)
Vital materials	Many vital materials will be exhausted by the year 2000.	"Something happened in the mid-1970s to interrupt what had been a smooth exponential growth trend [of material consumption.]" (p. 80)
Pollution	Pollution seems to increase exponentially over time.	"The industrialised countries have managed to decrease greatly some of the most visible and easily handled pollutants" (p. 87) "There has been partial success in decreasing some but not all, of the most common air and water pollutants." (p.86)

Despite these statements, the fundamental structure of the World3 computer model remained the same and new predictions were put forward. Because the book is more recent, there are of course fewer predictions that can be empirical evaluated today. However, a number of important elements should be noted.

In the 'standard scenario' – 'standard' meaning that the authors use what they consider to be the most realistic numbers and no policy intervention – it is actually

[52] Greenpeace webpage 2000.

stated that food per capita should have peaked already (in 1994) and should now be on its way back down.[53] This can easily be tested empirically. In the period 1994 to 2000 the calorie intake per capita rose by more than three per cent from 2719 to 2805 per day.[54] This is more than twice the growth rate of the preceding six-year period. So the prediction was wrong. In addition, the model produced many other predictions that at present cannot be evaluated but seem to be unlikely. It is claimed that by 2010 the average life expectancy rate will begin its fall to a level that is lower than at the beginning of the twentieth century. This would be equivalent to a life expectancy somewhere in the thirties. 2010 will also be the year in which industrial output and consumer goods per person peak, only to decline in the rest of the century to just five per cent of the original level. Global GDP per capita income of the World will drop to that of present-day Sudan.

Overshooting tendency

These were the predictions of the World3 model – the model that is also used in the Living Planet Report. Nearly all the predictions that can be checked today have proved to be incorrect, and in all scenarios the end result has been overshooting and collapse – even on the assumption of 'unlimited' resources, pollution control, increased agricultural productivity and 'perfect' birth control.[55] The authors note that "the application of technological solutions alone has prolonged the period of population and industrial growth, but it has not removed the ultimate limits to that growth."[56]

Lethal model

Professor Nordhaus (1992) has explored the structure of the model in greater detail to determine how the continuous flows of overshooting scenarios were actually generated. He finds that the inherent nature of the model is that of overshoot and collapse. Nordhaus lists a set of 'lethal' conditions that are implicit in the model. Every single one of them is enough to eventually lead to collapse. The essence of these conditions is the existence of essential resources (i.e. that can never be substituted), an exponentially mounting burden on these resources and the exclusion technological progress and innovation in the model. By taking his starting point in a simple growth model, Nordhaus demonstrated that if technological progress was included, the drag from resources and diminishing returns would be offset by an increase in total factor productivity of 0.0025 percent a year.[57] This is a fraction of the current increase in World factor productivity. In other words, the

[53] (Meadows & et al. 1992) p. 133.
[54] (FAO 2002).
[55] (Meadows et al. 1972) p. 140.
[56] (Meadows&et al. 1992) p. 141.
[57] (Nordhaus W. 1992) p. 16.

overshooting and collapse of the model seems to be easily avoided through empirical development in technological progress - had the authors allowed for such factor.

Inaccessible projections

The WWF projections are based on a forthcoming publication by Jorgen Randers which will be the third publication in the 'Limits to Growth' series. The fact this publication is not yet available makes it difficult to assess the quality of the results. Hence, a more thorough investigation of the WWF's World3 calculations will unfortunately have to wait until this publication is made public. It is problematic that the WWF chooses to publicise projections based on an unfinished, inaccessible report.

Questionable causality

As the documentation for the new adaptation of the World3 model is not yet available, we return to figure 5 as our basis for investigating the causality in the model. Understanding causality is key in determining the dynamics responsible for the collapse predictions of the model.

The WWF Human Welfare Index (HWI) is an approximation of the UN's Human Development Index (HDI) and therefore based on three underlying factors: Life Expectancy Index (LEI), Education Index (EI) and the Gross Domestic Production Index (GDPI).

Education Index

Although it is expected that the World will maintain growth in GDP until 2040, the EI almost stops growing from now on. This is puzzling since education and human capital are factors that could be expected to be determined somewhat exogenously in relation to the global ecosystems. How can problems with the global ecosystems constrain educational levels under steadily increasing economic growth? Do we suddenly run out of paper to print books? The fact that the education index is proxied with 'global service output per capita' does not seem to provide an answer because that proxy should also be closely related to economic development.

There are few projections of human literacy and education. Lutz and Goujon (2001) have produced some rare projections of future educational levels, which can be compared to the WWF projections. Lutz & Goujon's projections are based on two scenarios of the educational level in the adult population in 2030 – an optimistic and a 'business as usual' scenario.[58] The educated proportion of the population in 2030

[58] (Lutz & Goujon 2001) p. 328.

is used as an approximation of the education index. The point of departure for both the WWF and Lutz & Goujon's projections are indexed according to the UNDP's basic education index for 2000. The result is shown in the figure below. While the WWF index flattens out in the near future, the Lutz & Goujon predictions continue to climb in both scenarios. Combined with the lack of thoughts on reasonable causality, this makes it likely that the WWF predictions are unreasonable and that the World's educational standard will continue to grow into the future.

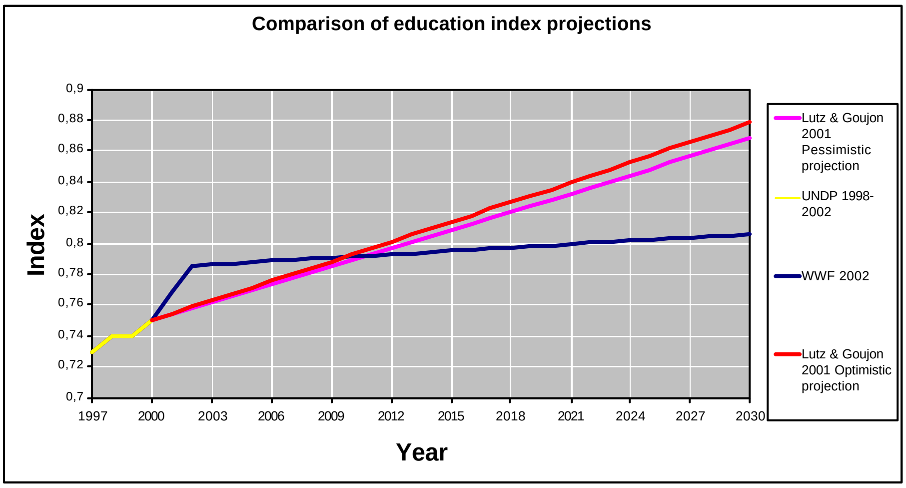


Figure 6. Projections of education index. Source: Lutz & Goujon (2001) and WWF.

Life Expectancy index

The WWF projection of the LEI is gloomy indeed. From 2030 the graph plummets until 2060 when the World's life expectancy ends somewhere below 25 years compared to 67 years today. Both from a scientific and moral perspective, such a big drop in LEI should not be left unexplained. The most likely explanation is that toxic pollutants in the WWF scenario are to blame for this unprecedented decline in life expectancy.

The United Nations Population Division, under the Department of Economic and Social Affairs (DESA), has produced their own projections of life expectancy. In figure 7, these projections of life expectancy have been adjusted so as to become comparable to the UNDP's Life Expectancy Index, and they are plotted together with the WWF projections. It is evident that both the steep increase occurring in the near future and the dramatic nosedive around 2050 predicted by the World3 model are distinctly different from the UN's DESA projection[59].

[59] DESA bases its projections on expected development in fertility rates, projected survival curves and gender gaps in various development regions (World Population Ageing 1950-2050, p.5-8).

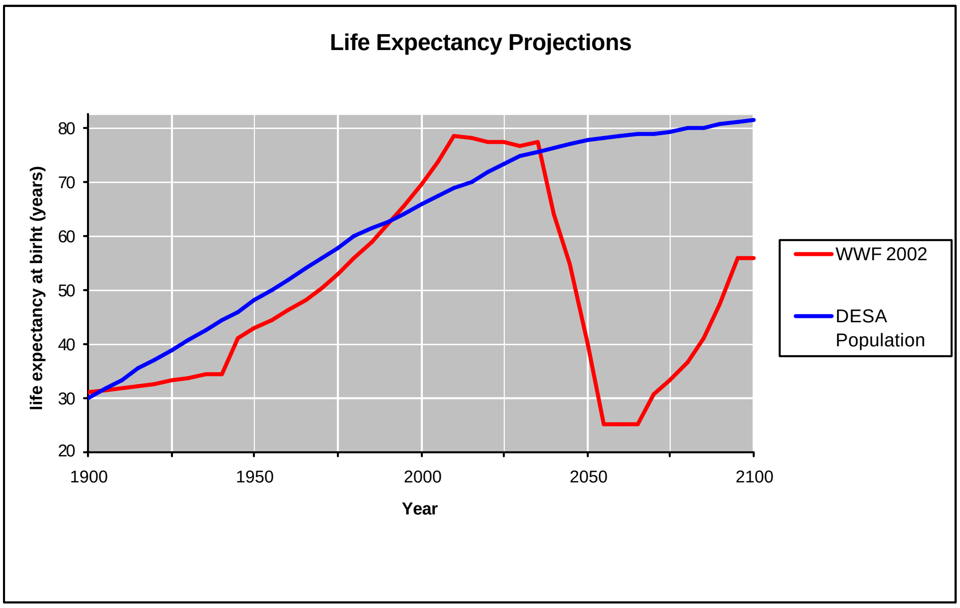


Figure 7. Projections of life expectancy. Source: WWF, UN DESA.

GDP Index

The index that seems to be most unaffected by the collapse of ecosystems is the GDP per capita index. This is indeed a paradox since income growth has been held responsible for the depletion of Earth's ecosystems – yet, growth seems to be little affected by the ecosystem collapse. Instead, the causality seems to be a drop in life expectancy inducing lower economic growth.

Many official international organisations have projected the future development of GDP per capita. These projections will be described in greater detail on the following pages. For illustration purposes we have only included the estimates of UN's climate panels IPCC (2001) for future economic growth along side the WWF projections of GDP. The difference between the official IPCC estimate and the WWF estimate in 2100 is between eight- and forty-fold.

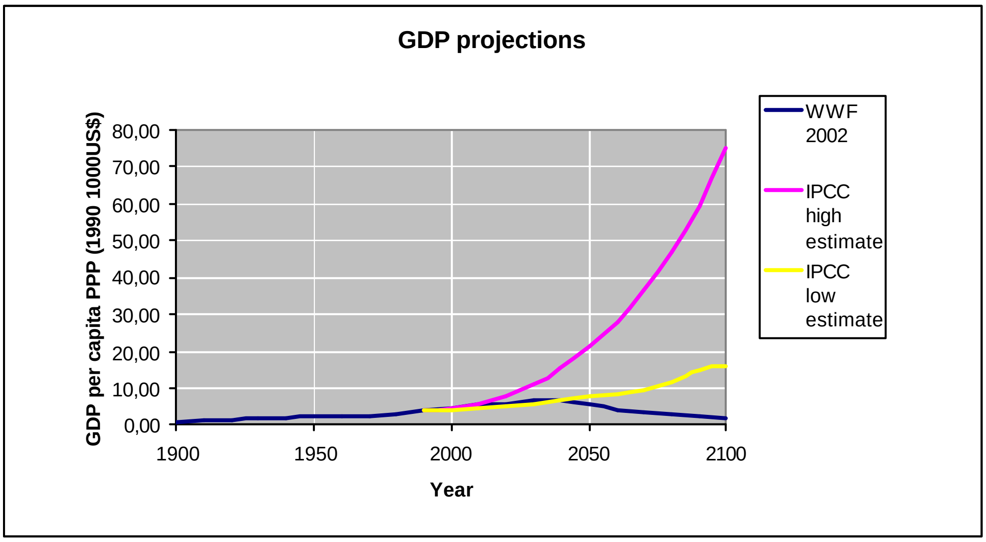


Figure 8. Projections of GDP development from WWF and the UN's climate panel, IPCC 2001. The low estimate is taken from the A2 scenario and the high estimate is taken from the A1B scenario. Source: IPCC (2001) and WWF.

Other GDP projections

The WWF projections of collapse differ considerably from the projections made by all other official international organisations. In the following we will briefly contrast the WWF's collapse scenario with that of official international agencies.

World Bank, IMF, OECD

In its Environmental Outlook report, the OECD assumes – based on World Bank and IMF projections – that in the period from 1980 to 2020 real GDP will more than double from 1980 to 2020 in OECD countries and more than quadruple in non-OECD countries.[60] In their latest World Bank Report the World Bank estimates that the global economic growth will be 3 per cent annually for the next 50 years.[61]

IPCC

According to the new scenarios presented by the International Panel of Climate Change (IPCC 2000), the World will be between 10 and 26 times as rich in 2100 as it is today and income differences among the World's regions are expected to diminish, which will result in a more equal World. In other words, on a *worst* case basis, human wealth will be at least 10 times higher than today – and the multiplicative increase will be even higher in the developing World.[62]

[60] (OECD 2001) p.58-59.
[61] (World Bank 2002) p.3.
[62] (IPCC 2000) p.6.

Global Scenario Group

The Global Scenario Group operates with a reference scenario where World GDP has more than quadrupled in 2050 as compared with today's level, resulting in an increase of 150 per cent in GDP *per capita* (SEI 1998).[63]

UNDP

In the World Energy Assessment Report published by the UNDP (2001), the scenario predicting the *lowest* economic growth still exhibits a significant rise in gross World product from USD 20 trillion in 1990 and USD 75 trillion in 2050 to USD 200 trillion in 2100. According to the report, this increase in the World's overall wealth will take place concurrently with a reduction in poverty and income gaps.[64]

Lack of Logic

From a theoretical, logical and empirical point of view, the trends of the three underlying indicators seem inconsistent and are left without comments in WWF's Living Planet Report.

According to the WWF, the overshooting of energy is expected to cause a sudden decline in human welfare by 2030 as the Earth's existing biological capacity collapses. It is unclear what exactly should cause this collapse. There is little doubt that an increase in atmospheric concentrations of carbon dioxide causes global warming. By 2030, according to IPCC estimates, global warming can at worst have resulted in a one-degree increase in global temperatures (IPCC 2000). How this one-degree rise in temperature can be the cause of a catastrophic collapse in the World's ecological system is not explained in the report. Since the chain of events leading to this collapse is not obvious, it would have been expedient if the authors had elaborated on the underlying logic of the result. How can a one-degree increase in temperature cause human life expectancy to begin plummeting by 2030?

Possible explanation

Carbon dioxide has only been incorporated in the World3 model as general pollution[65]. This is tantamount to stretching meaningful causality both from an ecological point of view and in terms of model methodology. Carbon dioxide is a non-toxic substance and not a pollutant. The result of treating carbon dioxide as a pollutant creates a situation with an exponential rise in toxic pollutants suffocating the Earth's population. Since the World3 model cannot deal effectively with carbon dioxide emission, it would be logic to assume that the authors would have drawn on other projection models that are capable of including carbon dioxide emissions, for

[63] (Raskin et al. 1998) p.xii.
[64] (UNDP 2000) p.19.
[65] This has been confirmed by Jorgen Randers.

example the IPCC models.

Chapter 6: An improved method for estimating ecological footprints

Alternative calculation

The size of the WWF energy footprint rests on two major assumptions. One is a strong sustainability interpretation according to which there is a need to stabilise the atmospheric concentrations of carbon dioxide regardless of the costs. The other assumption is that this stabilisation should take place through forest sequestration. In other words, the WWF footprint measures how many global hectares are needed if we leave it to the forests to stabilise atmospheric carbon dioxide.

We have previously argued that the size of the WWF ecological footprint is highly sensitive to a change in the assumption of strong sustainability. In this section we will present an alternative way of calculating the ecological footprint by altering the assumption of planting forests. For the sake of argument we will accept that carbon dioxide concentrations should be stabilised but we will argue that it makes sense to require that such stabilisation should be achieved the most area-efficient way namely the use of renewable energy. In our view, this strategy meets the central premises of calculating the footprint. It will have a direct impact on the emission and atmospheric concentrations of carbon dioxide and, just like forests, renewable energy can easily be translated into area units. Our calculation will be based on the technology currently available. Consequently there are no implicit assumptions of future technological progress that could have biased our estimate in a more positive direction. The calculation will be of a highly hypothetical nature. Just like growing forests to sequester *all* carbon dioxide emissions cannot be a practical recommendation because it would be prohibitively expensive a considerable upgrading of the World's renewable resources is likewise highly speculative and very expensive.

The advantages

We see several advantages of substituting the forest area needed to sequester carbon dioxide with the area of renewables needed to perform the same task. The latter solution makes it possible to include technological progress and advances much more directly in the energy footprint. The calculation based on forests includes technological progress only in the form of energy consumption that can be avoided by enhancing energy efficiency. This type of calculation makes it evident that energy efficiency gains have not been able to keep pace with the increase in energy consumption, thus resulting in a net increase in carbon dioxide emissions. However, this is only part of the story. Technological progress does not only result in efficiency gains in relation to a single energy type (fossil fuels) but also in the search for alternative forms of energy. If the WWF ecological footprint should really measure "what is – not what could be"[66] it should have included the discovery of other types of energy.

Our calculation based on the area needed to stabilise atmospheric carbon dioxide by renewable energy has the advantage of actually being feasible and that we will not run out of land.

Reneable energy

Ferguson (1999,2002) has calculated that about 100 GJ per hectare seems to be the right energy/land ratio when renewable energy sources are taken into account.[67] This calculation is based on the estimated mean net energy density that can be captured per hectare, and is equivalent to the energy capture by sugar canes. Ferguson presents this as the likely ratio in a scenario where humans have exclusively to use renewable energy sources. However, the right comparison between the two calculations (forest sequestration vs. renewable energy) does not have to be based on realism but on hypothetical yet technologically feasible options. Substituting forest carbon dioxide capture with non-organic renewable sources such as wind turbines and photovoltaic energy is a feasible alternative. As previously pointed out, these types of energy sources take up very little space, are technically feasible and have proven high productivity gains.

In our calculations, we assume a combination of different non-organic renewables. With the present level of technology, it would be realistic to assume that the World can cover no more than half of its energy consumption from these renewable energy sources. However, it seems equally reasonable to expect that a great deal of the remaining half could be based on less carbon-intense energy sources such as natural gas. If the World's oceans will absorb the same amount of carbon dioxide as in 1999, the World's energy footprint would decrease year by year. [68]

The nice thing about this calculation of the ecological footprint is that it is both technologically *and* practically feasible. Based on the estimate for wind energy on 900 MJ/m2*yr in table 1, the area required in a scenario where wind turbines are

[66] (Wackernagel 1999) p. 317.
[67] (Ferguson A. 1999) p. 152, (Ferguson 2002) p. 311.

producing 50% of the energy consumed in the World is only 0.02 billion hectares.[69] A new offshore wind park suggests a slightly higher figure of 0.17 billion hectares one possible reason being that limiting the space needed is not a success parameter in real wind turbine projects. [70]

However, both these figures should be compared to the 2.48 billion hectares required in the tree-planting solution. The area needed is reduced by between 93% and 99% if the alternative solution is chosen. Assuming that forest planting should by itself solve the problem completely ignores the technological development that could minimise the problem.

Consequences

By applying renewable energy in our calculations, the energy footprint is negligible and has little impact on the total footprint. The area needed to produce energy without carbon dioxide is 0.02 billion global hectares that could easily be placed on non-productive land. Using this as a starting point, the footprint per capita for the last forty years can be approximated[71]:

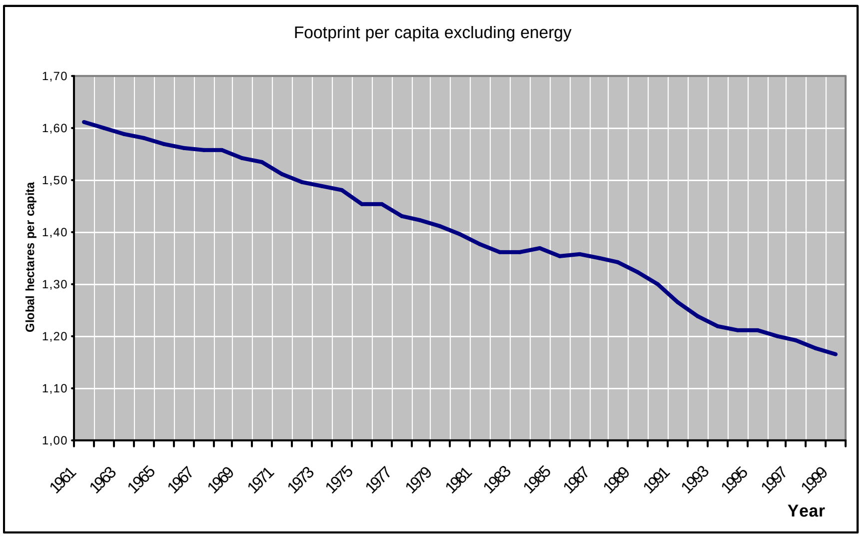


Figure 9. The development of WWF footprint when excluding the energy footprint. Source: PNAS.

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[68] This is so because the atmosphere's carbon dioxide concentrations and not the emissions determine the ocean's absorption rate.
[69] Total consumption world according to WWF=357,7E12 MJ/yr and each sqauremeter with windpower yields 900 MJ/m2*yr (Stöglender (2003)). This results in an area demand of 0.02 bill ha.
[70] Area covered by windmills: 20 km2 = 20E6 m2. Estimated energyproduction=2.16E9 MJ/yr. This results in an energy density=108 MJ/yr / 20E6 m2 = 108 MJ/yr*m2. This results in an area demand of 0.17 bill ha. The figures are taken from the park of wind turbines at Horns Rev i Denmark (http://www.hornsrev.dk/).

[71] Since the energy footprint could not have been left out in 1961 where renewable technology was still in the Embryo State, the correct graph would have a higher initial value and a steeper downwards slope.

During the forty-year period, the size of the footprint per capita has fallen by at least 27 %. This indicates an ongoing trend towards greater sustainability per capita for the environmental indicators included in the ecological footprint. A boy born today will by this calculation put much less strain on the ecological system compared to his parents.

Projections

The figure below illustrates the projected development of the ecological footprint under two assumptions: the development experienced during the past forty years will continue into the next 50 years; and the actual increase in population follows the UN estimation in their 2000 report.[72] It should be noted that these population projections are in the process of being revised down, which will of course lead to even lower projections of the ecological footprint.[73]

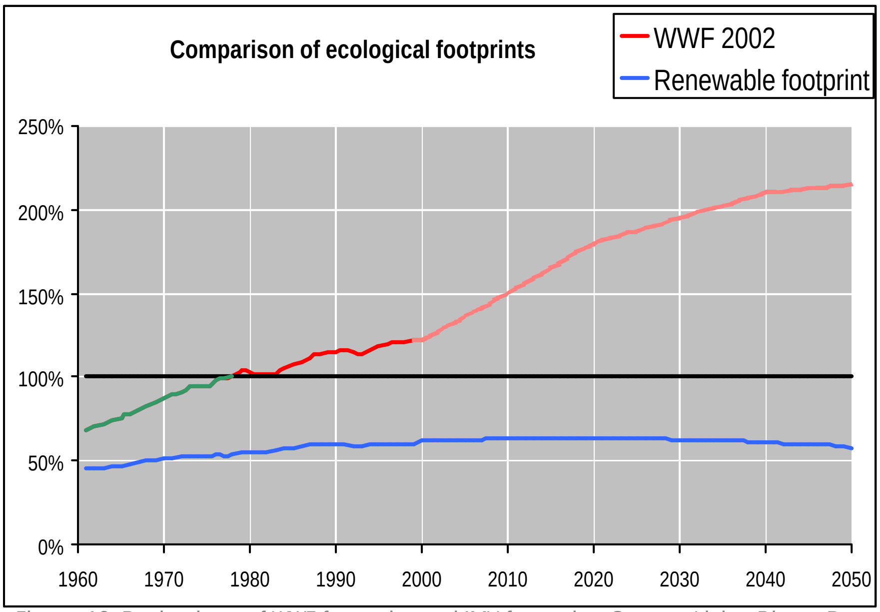

Figure 10. Projections of WWF footprint and IMV footprint. Source: Living Planet Report 2002 and own calculations.

The above figure indicates that we are well below the Earth's biocapacity and that we will continue to stay so at least until 2050. The slight decrease in the global ecological footprint after 2020 is the direct result of a declining population growth ratio and the continuing technological progress.

[72] (UN).

Even if we assume that the reduction in footprint size is put to a halt, thus leaving us at the 1999 level of 1.17 hectares per capita, global demand will still be lower than global capacity in 2100. Using *present size* per capita footprints – disregarding the fact it has dropped by a little less than one per cent every year for the last forty years – the are required in 2100 will still be lower than the global biological capacity.

The conclusion is that the footprint is highly sensitive to a change of calculation method. If this superior alternative method is chosen the population's demand will not exceed the Earth's biological capacity - not even when population figures increases in the future.

Economic growth

It could be argued that population growth is not the only factor that could drive up the ecological footprint. If it is assumed that Worldwide economic growth will be much higher in the next fifty years than it has been in the past forty years, there may be an additional increase in the ecological footprint. There are several factors that make this an unlikely scenario. On a theoretical level, increased economic growth go hand in hand with technological progress. Consequently it is very likely that the economic growth of tomorrow will not be based on today's technology for energy consumption. On an empirical level, the ecological footprint provides the evidence that in the last forty years economic growth has been decoupled from the size of the footprint as illustrated by the figure below:

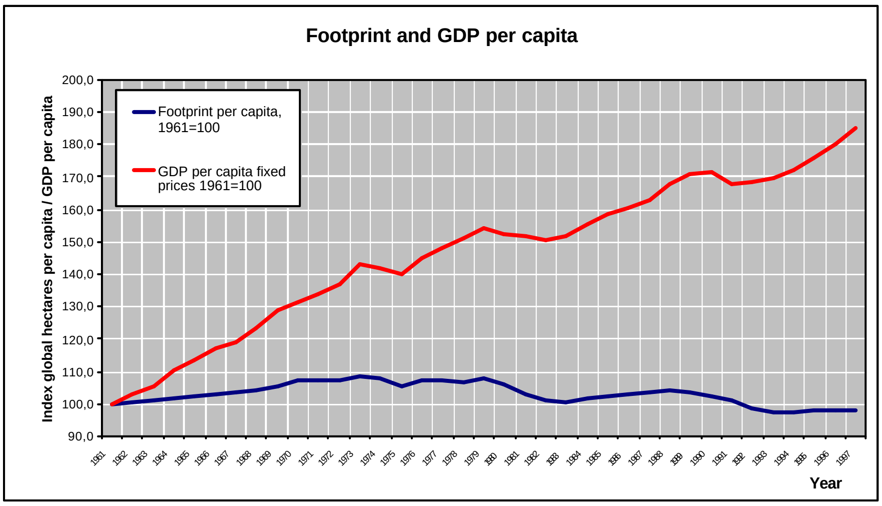

Figure 11. The development of GDP per capita and the WWF ecological footprint. Source: Living Planet Report.

[73] (New Scientist 2002) p. 38-41.

Economic growth by itself does not seem to spur a larger footprint and as such it is hardly an independent factor for expanding the footprint in the future.

The costs

The previous sections showed that changing the calculation method applied from a focus on forest sequestration to a focus on technologically feasible types of renewable energy implies that WWF ecological overshooting is a chimera both today and in projections of future trends. Does this mean that it would be a good idea to implement this solution in order to achieve sustainability? It depends on whether you believe that carbon dioxide concentrations should be stabilised now *regardless of the costs*. To take that position, it is necessary to accept that the footprint's one-dimensional measure is an accurate measure of sustainability and that sustainability corresponds to status quo in the global ecosystems. Otherwise, one have to compare the costs and benefits of solving the carbon dioxide problem with the costs and benefits of solving other pressing global problems. To address this issue adequately is beyond the current report.

Chapter 7: Conclusion

The WWF Living Planet Report 2002 tells us that we need 1,2 Earth's to satisfy our demand in a sustainable way and that if we do not change our current ways, we will be faced with a regular collapse in human welfare by 2030.

In this report we have argued that these statements build on a weak scientific foundation.

Ecological footprint is a one-dimensional figure that relies on an extremely ecocentric sustainability understanding. Moreover, the inclusion of energy in the footprint was found to be questionable and highly sensitive to a change of calculation method. While the WWF's energy footprint (the area needed for forest sequestration) takes up more than half of Earth's biocapacity, it diminishes significantly when the calculation is based on non-organic renewables. By making this change, the ecological overshooting turns out to be a chimera as the area needed is reduced by more than a factor hundred leaving humankind with sustainable space in abundance. It should be noted, however, that this alternative calculation method should not be interpreted as leading to a 'better' or 'improved' footprint. It should be clear from our report that there is no 'right' ecological footprint. Rather, our own calculation is used to illustrate the arbitrary nature of the calculations behind the footprint size.

The WWF presents some very ominous predictions for the mid-century generations: A global life expectancy age of 25, a global GDP per capita of present day Sudan and a less and less educated world. Our investigation of the dire predictions concludes that they have been generated by excluding technological progress and human creativity from a model that already has an inherent mathematical tendency to overshoot and collapse. The WFF projections go against future projection generated by official international institutes (UNDP, UNEP, World Bank and UN DESA) that unanimous conclude that the future generations are likely to be much richer, healthier and more equal.

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