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The Ecological Footprint of Benin, Bhutan, Costa Rica and the Netherlands

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Abstract

The Ecological Footprint (EF) has received much attention as a potential indicator for sustainable development over the last years. In this report, the EF concept has been applied to four different countries, i.e. Benin, Bhutan, Costa Rica and the Netherlands in 1980, 1987 and 1994. The results of the assessment are discussed and the experiences are used to discuss the current potential and limitations of the EF as a sustainable development indicator. The originally defined methodology has been slightly adapted: 1) the report focuses on individual components of the EF (land and carbon dioxide emissions) instead of focuses on the aggregated EF and 2) the land use calculations are based on local yields instead of global average yields. Although per capita and total land use highly differ among the four countries, available data suggests increasing land use in all four countries while per capita land use decreases. The EF for carbon dioxide emissions increases for all four countries both per capita and in absolute terms. Differences in productivity, aggregation (of different resources) and multi-functional land use have been shown to be important obstacles in EF application – depending on the assessment objective. However, despite the obstacles, the study concludes that the EF has been successful in providing an interesting basis for discussion on environmental effects of consumption patterns - including those outside the national borders - and on equity concerning resource use.

Preface

This report was produced by the National Institute of Public Health and the Environment as a study within the project ‘Multidisciplinary Indicators for Sustainable Development’. Within this project, institutes in Benin, Bhutan, Costa Rica and the Netherlands are collaborating to develop indicators for sustainable development and looking into the current environmental and economic situations of these countries, along with the relationships to culture and social aspects. This study applies the Ecological Footprint (EF) concept to the above-mentioned countries. Assessing the EF of these totally different (but all small) countries also indicates the current possibilities and limitations of the footprint as indicator for other countries and situations. In other words, the results of the study could be considered as case-studies supporting the general discussion on the applicability and usefulness of the EF concept within the report. The report also supports ongoing discussion within RIVM on application of the EF in the context of RIVM’s national state-of-the-environment report (*Milieubalans*) and the fifth environmental outlook report (*Milieuverkenning*). In this context – and to gain more insight in (un)certainties - also earlier studies for the Netherlands have been focussed on for comparison. The actual data and calculations for this report may be requested from the authors as a separate appendix to the report.

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Contents

List of abbreviations

CBS	Statistics Netherlands
CO_2	carbon dioxide
EF	Ecological Footprint
EUS	Environmental Utility Space
FAO	Food and Agricultural Organisation of the United Nations.
GDP	Gross Domestic Product
ha.	Hectare (100m. x 100m.)
IMAGE	Integrated Model to Assess the Greenhouse Effect (RIVM)
NGO	Non-governmental organisation
RIVM	National Institute of Public Health and the Environment
UN	United Nations
UN-CSD	United Nations Commission on Sustainable Development
UN-DESIPA	United Nations-Department for Economic and Social Information and Policy Analysis
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
VROM	Ministry of Housing, Spatial Planning and Environment (the Netherlands)
WCED	World Commission on Environment and Development

Summary

The "Ecological Footprint" (EF) was defined some years ago as the total amount of ecologically productive land required to support the consumption of a given population, wherever that land is located. The EF is receiving much attention as a potential indicator for sustainable development. The central metaphor of the EF is probably the most important reason for its popularity: i.e. the expression of the impacts of human consumption in terms of a visible footprint made on the natural carrying capacity. In addition, as a concept, the EF covers simultaneously several issues relevant for sustainable development such as:

- reallocation of environmental pressure to other countries,
- squandering of resources and the equity issue in resource use,
- as well as impacts of the use of renewable resources, trade and changes in consumption patterns.

The EF can be determined on various scales (individual, city, country, world). At more detailed levels, the issue of distribution of resource use plays a main role, but, at the global scale, a large EF can be a direct sign of environmental degradation. Though the EF has been calculated by several organisations, work on the indicator is still in an exploratory stage. As well as support, the EF has also received criticism, particularly related to the high level of aggregation and limitations in policy relevance. Aggregation of different types of resource use into one single indicator (land use and carbon dioxide emissions) – as done by Wackernagel and Rees – is based on a weighting system, which includes subjective choices and which has been criticised to create ‘false concreteness’.

In this study, the EF has been applied to Benin, Bhutan, Costa Rica and the Netherlands – so as to subsequently 1) review the EF concept, 2) to gain insight into trends in resource use related to consumption in these countries over time in 1980, 1987 and 1994 and 3) discuss the applicability and usefulness of the EF. The results of the last two objectives are discussed below.

Adapted methodology

On the basis of a review of earlier studies, the present study modifies the original EF calculation method of Wackernagel and Rees on several points. Specifically, the EF has been disaggregated into separate indicators for land and carbon dioxide emissions, thus, avoiding the controversial topic of combining real land use and land equivalents for carbon sequestration while holding on to the more attractive attributes of the EF concept (although outside the scope of this report, the concept of the EF could, defined in this way (see also *Box 2.2*), also be applied to other resources such as water and biodiversity). In addition, land use has been calculated on the basis of local yields to show the real land use of countries (a parameter that is more policy relevant at the national level). For comparison, calculations on the basis of global average yields have also been made (as used by Wackernagel and Rees to calculate their figures).

Results of the calculations

- The results of this study suggest that the total land use of all four countries is increasing - or in other words in none of them does absolute de-materialisation takes place in terms of land. In contrast, land use per person is decreasing in all four countries (but is too slow to

offset the increasing population). Increasing yield per product has been the most important factor behind the decrease in per capita land use. On a global scale, available land per capita is declining rapidly due to global population growth, changes in production and consumption patterns, expansion of settlements and land degradation.
- Both differences in consumption per capita and differences in yields per hectare have an impact on land use per capita. Yields are (actively) influenced by, for example, agricultural knowledge, technology and production methods, but also (passively) by natural circumstances. As a result, for international comparison, use of local yields *only* can lead to results that are difficult to compare unambiguously. Obviously, what is best depends on the objective of the comparison. The present study uses both local and global average yields calculations.
- In 1994, the calculated land use per capita on the basis of **local yields** (i.e. domestic yields and for imports, the yields of the country of origin or global average yields) is smallest for the Netherlands. Per capita land use of the Netherlands is 0.7 ha., while land use of Benin, Bhutan and Costa Rica are respectively 0.7, 0.9 and 1.2 ha. per capita.
- The Netherlands – as a densely populated country – is strongly dependent on use of land in foreign countries for its food and wood products consumption. After subtracting exports, the total amount of land used is 2 to 3 times the surface area of the Netherlands. The other three countries use a total land area smaller than the surface area of their country.
- If, instead of local yields, **global average yields** were to be used, the EF is smallest for Bhutan, followed by Benin, Costa Rica and the Netherlands (directly related to consumption levels and patterns). The results are 0.6, 0.7, 1.7 and 3.0 ha. per capita, respectively.
- Comparison of these results with other studies for the Netherlands shows this study to be near earlier estimates (most of them have less detail). However, the range in these studies is still considerable, from 0.5 to a maximum of 1.5 ha. per capita as results of differences in data and methodology.
- The EF for carbon dioxide emissions increases for all four countries, both in per capita and absolute terms (only commercial fuels are taken into account to prevent double counting with land use). For the Netherlands, the EF for 1994 is 8.9 tonne carbon dioxide per capita which is 2.2 times the global average level of 4.0 tonne carbon dioxide per capita. The EF for the Netherlands is, however, 20% lower than the domestic emissions of the country. Emissions of the other three countries are below the global average: 2.5 tonne per capita for Costa Rica and less than 0.1 tonne per capita for Benin and Bhutan.
- In all four countries, population growth can be identified as an important upward pressure on carbon dioxide emissions. In addition, in the Netherlands and Bhutan GDP per capita has increased strongly over the 1980-1994 period.

Applicability and usefulness

On the basis of this study, the following considerations can be made regarding the use of the EF concept as potential (sustainable development) indicator:

- The EF concept can, in principle, be the basis for relevant sustainable development indicators if these indicators are part of a larger set. Specific questions that EF indicators - in principle - could address are:
  - What is the current pressure of a specific population on key resources for sustainable development to support its current consumption? How does use change over time?
  - How is the current resource use distributed among different countries? What could

  this mean for future resource use - either unabated or based on redistribution of the environmental space in a more equitable way?
  - Does environmental pressure of industrialised countries shift to industrialising countries from which goods are imported?
  - What consequences does the consumption of a specific population have on the environment in other parts of the world? Does international trade result in lower and higher overall environmental pressure ?
- With regard to policy relevance, it is helpful to distinguish between direct and indirect environmental pressures (i.e. pressures originating from the country in study or originated in an exporting country as a result of consumption in the country in study)**.** For the first type of pressures, the question of responsibility is relatively clear – in the second case, moral responsibility and engagement can be leading principles.
- Although the aggregated EF might be useful in communication to a broader public, we are of the opinion that analytical soundness improves if the EF is elaborated as a set of resource indicators.
- Policy measures aimed at reducing EFs will in most cases go in the same direction as current environmental policies for mitigating greenhouse gas emissions and reducing resource squandering. Obviously, the equity issue regarding use of environmental resources is related to the distribution of financial resources – and thus akin to much broader policy themes. The main contribution of the EF here is its metaphor.
- In general, results of EFs can be interpreted more unambiguously for a specific country than for international comparison (inter alia, as result of differences in potential land use).
- Measurability problems do not seem to raise concerns. Estimates should, obviously, be used while acknowledging the uncertainties in these data.
- The analytical soundness of the indicator can still be improved further. Issues that need further attention are:
  - possibilities and limitations of aggregation of resources,
  - differences in agricultural productivity in international comparison,
  - how to handle unsustainable resource use in the context of the EF (e.g. land degradation),
  - the role of multi-functional land use, and
  - and a more direct link of the EF to the issue of biodiversity.
- Finally, the EF is a macro-indicator which cannot indicate the situation for more specific issues or (still) other important aspects of environmental sustainability not included in the indicator, such as the use chemicals or water consumption. Macro-indicators, in general, are more useful as indicators of an *un*sustainable than a sustainable situation.

In conclusion, although far from perfect, the EF concept can be concluded to provide a basis for discussion on environmental pressures of consumption patterns, geographical re-allocation of environmental pressure, the equity issue regarding the use of resources and global commons and available means to reduce the present EF – both at individual and global levels.

1. Introduction

1.1 Introduction

In the last few years, the Ecological Footprint (EF) has been frequently mentioned as a potential indicator for the environmental consequences of production and consumption patterns (Rees, 1992; Wackernagel and Rees, 1996). This indicator is defined as the total ecologically productive land (including sea) needed to support the total consumption of a given population in a sustainable way. Most of the attention for the EF originally came from environmental and educational organisations (such as The Earth Council and "De Kleine Aarde" in the Netherlands). Currently, scientists, policy-makers and politicians are increasingly becoming interested. For example, in 1998 in the Netherlands' parliament questions have been raised about the EF (Van der Steenhoven, 1998) and the Minister of Public Housing, Spatial Planning and the Environment (VROM) has expressed his ambition to use the EF concept and asked a consulting agency to look deeper into the issue (Pronk, 1998; Pronk, 1999).

The central metaphor of the EF is probably the most important reason for its popularity: i.e. the expression of impacts of human consumption in terms of a visible footprint made on the natural carrying capacity; the EF refers to the continuing dependency of human societies on nature in terms of the more obvious dependency of traditional societies on their available land. We will discuss the appealing aspects and limitations of the EF in more detail in *Chapter 2*.

Several organisations have already calculated EFs at different scale levels, ranging from individual and urban to the global scale (e.g. Wackernagel et al., 1997; Wackernagel and Richardson, 1998, Bicknell et al., 1998; Milieudienst Amsterdam, 1998; Wackernagel et al., 1999). Most of the EF work is still rather exploratory. Clearly, as well as support, the EF has also received criticism from both scientists and policy-makers (e.g. Van den Bergh and Verbruggen, 1999; UN.CSD, 1999). Therefore, explicit work still has to be done on the applicability and usefulness of the EF before it can be used in more regular state-of-the environment or sustainable-development reporting.

In this report, we will present the results of an application of the EF concept for the Netherlands and Benin, Bhutan and Costa Rica. This application is part of a larger Sustainable Development Indicators project for those four countries (see also Van Vuuren and De Kruijf, 1998). By means of this application, we aimed to gain more insight into the potential use of the EF, as well as into trends in resource use of those four countries. In addition, the current report is also produced as an input to ongoing discussions in the context of the '*Milieuverkenning*' [1]. Within this assessment, RIVM has been requested to explicitly look at the environmental consequences in other countries of consumption and production patterns in the Netherlands.

[1] The '*Milieuverkenning*' is a regularly published environmental outlook report, supporting environmental planning by the Ministry of Public Housing, Spatial Planning and the Environment.

In this report, a slightly adopted methodology has been used to calculate EFs in comparison to the work of Wackernagel et al. (1997) as explained in *Chapter 2* and *Chapter 3*. In addition, in comparison to many of the earlier footprint applications, the calculations are more detailed. Finally, we examined the way the EF for the four countries changes through time - while the EF has so-far almost always been applied as a static indicator.

1.2 Project objectives

The objective of the sustainable development indicators project in the context of Sustainable Development Agreements between the Netherlands and Benin, Bhutan and Costa Rica is to develop tools which allow assessment of trends related to sustainable development in these countries. This study applies the EF concept, first of all, in this context. However, by assessing the EF of these totally different (but small) countries, we will also indicate current possibilities and limitations of the footprint as indicator for other countries and situations. The study is also produced as input into discussions and further elaboration in the context of the RIVM's fifth environmental outlook report '*Milieuverkenning*'.

The following central aims have been chosen for analysis in the study:

- To review the EF concept as introduced by Wackernagel and Rees (1996) (and related publications);
- To calculate the EF for Benin, Bhutan, Costa Rica and the Netherlands on the basis of the chosen EF definition and data sets, and to discuss the results so as to gain insight into trends and driving forces leading to changes in the EF.
- To discuss the applicability and usefulness of the concept on the basis of the results for the four countries.

1.3 Organisation of the report

Chapter 2 describes the EF concept in more detail and discusses earlier research in this area. The chapter also pays attention to some of the appealing aspects and limitations of the EF indicator as used so-far. Next, *Chapter 3* describes the calculation procedure in this report. *Chapter 4* and *Chapter 5* discuss the results for land use and carbon dioxide emissions, respectively. *Chapter 6* compares the results of this study to those of earlier assessments. Finally, *Chapter 7* discusses the conclusions of the report in view of the objectives as stated in the previous section. The figures shown in this report are based on extensive calculations and data. These may be requested from the authors as a separate appendix to the report.

2. Concept and earlier calculations

2.1 Sustainable development and indicators

The EF has been mentioned as a potential indicator for sustainable development. As introduction to a more detailed discussion on the EF concept, it is, therefore, useful to pay some attention to sustainable development and sustainable development indicators. This discussion will focus only on relevant points for this report. We certainly do not have the pretension to provide an extensive discussion on these topics here, as a broad range of literature is already available.

Sustainable development

Many national governments and international organisations have adopted the concept of sustainable development as one of the central concepts for environmental and development policy making. The concept was introduced to the policy-making agenda by the World Commission on Environment and Development through the publication of *Our Common Future* (WCED, 1987). By using this term, the WCED report emphasised the links between environmental problems and socio-economic developments (including underdevelopment). In industrialised countries, the publication of the WCED report coincided with a period in which these countries were increasingly confronted with environmental problems. Governments in many of these countries tried to respond to those problems through a combination of technology and command-and-control type policies. For some problems - such as urban air pollution - this approach has been relatively successful. However, for others, results have been less satisfactory, for example because a constant growth of activities and consumption have partly offset the results of end-of-pipe oriented policies. A more integrated approach aimed at 'sustainable development' might provide an alternative approach here. In less industrialised countries, the relation between environment and development can be even more important as non-sustainable activities can be both a cause and a result of poverty and lack of resources (see for extensive discussions e.g. World Bank, 1992; UNDP, 1998).

Since 1987, several attempts have been made to make the concept of sustainable development more operational for decision-making. An important milestone was the United Nations Conference on Environment and Development in 1992 in Rio de Janeiro (Brazil). However, despite all attention in policy and scientific debates, there is still no single definition which is shared by all actors involved. Most people seem to agree that sustainable development encompasses both environmental, economic and social aspects - and that sustainable development refers to finding a potentially long-lasting balance between development in those three areas. At the same time, however it is clear that sustainable development is a multi-dimensional and value-linked concept and that uncertainties are large. Therefore, rather than try to strictly define sustainable development in an objective way, it seems to be more functional to use it as guiding principle to be applied heuristically (Rotmans and De Vries, 1997; Langeweg, 1998).

An important aspect of sustainable development is the management of resources. In the past, focus of resource management has been mainly on non-renewable resources such as energy and metals. More recently, attention has shifted towards the use of several renewable resources, in particular land and water. The Global Environment Outlook concluded that water and land (especially highly productive agricultural land) are key-resources for future human development (RIVM/UNEP, 1997). On the Dutch national scale, similar conclusions were drawn in the context of third National Environment Policy Plan (VROM, 1998).

Indicators for sustainable development

Since the introduction of the concept of 'sustainable development', there has been an ongoing search for indicators that could support decision-making in this context (e.g. Kuik and Verbruggen, 1991; Bakkes et al., 1994; Hammond et al., 1995; World Bank, 1996; UN.CSD, 1996; Moldan and Billharz, 1997). One can identify three type of approaches, although many intermediate ones exist:

1) Developing an aggregated indicator of sustainable development; examples of this approach are the ISEW and GPI indicators (Cobb et al., 1995, Jackson et al., 1998) and the Wealth of Nations approach of the World Bank (World Bank, 1996).
2) Developing a comprehensive assessment framework and systematically deriving indicators from these frameworks; an example of this approach is the report to the Balaton Group (Meadows, 1998).
3) Developing a set of sustainable development indicators based on consensus without a comprehensive, strictly used assessment framework; examples are the sustainable development indicator work of UN.CSD (UN.CSD, 1996) and the Sustainable Seattle project (in Moldan and Billharz, 1997).

Selection criteria are often used to determine whether a certain indicator is suitable for sustainable development. Meaningful criteria are, for instance: 1) policy relevance and utility for users, 2) analytical soundness, 3) measurability (Bakkes et al., 1994) and 4) communication to a broader public. Obviously, it is virtually impossible to comply with all those criteria at the same time – and most of the time compromises need to be made.

At the moment, there is certainly no set of sustainable development indicators or approach that can be regarded as a blueprint. In fact, because sustainable development is a value-dependent concept, it will be a very difficult task to develop an easy, universal method to test current development for sustainability. We know, however, that a complete set of indicators for sustainable development, as currently defined, should cover economic, social, environmental and institutional issues. Therefore, we have to consider the EF as just one indicator out of a much larger set as the EF only takes (a selection of) environmental issues into account.

2.2 What is the Ecological Footprint ?

The Ecological Footprint (EF) intends to provide an overview of the use of resources and the generation of waste that can be attributed to final consumption (either for a certain category or an economy as a whole) on the basis of available technology and processes. As such, it is related to earlier concepts in this area such as 'carrying capacity' and 'environmental utility space' (Weterings and Opschoor, 1994) (see *Box 2.1*). However, compared to carrying capacity, the EF concept can take into account that human populations often use resources outside their direct environments. As the discussions in Wackernagel and Rees (1996) make clear the EF can be regarded as both a conceptual model and (derived from this concept) a calculation method.

The most comprehensive of the EF applications so-far include the use of six different resources:

- crop land and pasture land (for production of food and goods),
- built-up land (to support infrastructure),
- forest (for the production of wood products),
- fish (food production) and
- carbon assimilating capacity (for carbon dioxide emissions from fossil fuels).

In the EF defined by Wackernagel and Rees (1996) these different types of resources are aggregated in terms of the amount of land. For the first four resources, this is relatively straightforward[2]. Fish consumption is translated into surface area by estimating the area of productive sea required for producing the fish. Carbon dioxide emissions are accounted for by assessing the area of carbon-sink forest required to sequester the carbon dioxide emissions associated with burning fossil fuels[3]. This is based on the assumption that increasing the carbon dioxide concentration in the atmosphere can not be regarded as sustainable.

Box 2.1: Related concepts: Carrying capacity and environmental utility space

The EF is closely related to the ecological concept of *'carrying capacity'*. Carrying capacity is defined as the population of a given species that can be supported indefinitely in a defined habitat without permanently damaging the ecosystem on which it depends. Related concepts are that of 'maximum sustainable yields' (maximum harvest that can be supported) or 'critical load' (maximum pollution or waste that can be absorbed). At the moment many studies exist that are based on these concepts, but the use of carrying capacity concept is limited for at least two reasons: 1) it is often difficult to determine the carrying capacity in a objective way and 2) carrying capacity within a certain region can be increased by means of trade. While the carrying capacity is defined in terms of maximum number of humans per hectare, the ecological footprint is defined in terms the number of hectares used per human. It can be readily adapted to incorporate trade, making it a more appropriate concept to apply to human populations (Bricknell et al., 1998).

Another related notion is that of *environmental utility space* (EUS) (e.g. Weterings and Opschoor, 1994). The EUS is defined as the potential combinations of resource use and economic welfare within sustainable boundaries. As for the EF, the globally or regionally available amount of environmental space is divided on a per capita basis among countries. In comparison with the EF, the EUS considers more types of resources and does not attempt to aggregate different resources into one denominator. An important element of the EUS approach is the maximum allowable resource use (similar to carrying capacity). Those maximum levels have been the topic of intense debate since it is (again) almost impossible to determine these boundaries on the basis of scientific information only. The EUS has been used in assessments of Friends of the Earth for the Netherlands and Europe (e.g. Buitenkamp et al., 1992).

[2] Although not all land is equally productive; this aspect will be given more attention later on in this report.

[3] Wackernagel and Rees (1996) also propose alternative measures: 1) calculating the amount of land required to produce a sustainable substitute (biofuels) for fossil fuel and 2) calculating the land area required to rebuild a substitutable form of natural capital at the same rate of fossil fuel being depleted. According to Wackernagel and Rees, these alternatives give comparable results; they decided to account for carbon dioxide emissions on the basis of 1 ha. of forest that can sequester 1 GJ of fossil fuel per year. It should be noted that the proposed methodology is not more than an accounting method. The fact that there are also other methods to reduce carbon dioxide emissions (such as energy efficiency) is not ruled out.

An interesting aspect is that the EF can be defined at different levels of scale: person, countries, the global scale or even products. This allows comparing EFs to the global average footprint or the global available land. Earlier assessments showed that about 75% of the resources consumption included in the EF is attributable to only a quarter of the world's population (thus so relating environmental issues to equity issues). In assessing the available amount of land for human consumption, Wackernagel et al. (1997) take into account that not all land can be used for human consumption, and they reserve - on the basis of the WCED report (1987) - 12% of the global land for biodiversity.

2.3 Earlier calculations

The EF has been used for country-level assessment in several reports. In *Chapter 7,* we will pay more extensive attention to the studies covering the Netherlands - comparing our results to those of earlier studies. Here, we have shortly indicate some of the main results, as a basis for our discussion on the concept.

International calculations

Wackernagel and Rees (1996) and Wackernagel et al (1997a, 1997b, 1997c) have calculated EFs for a large number of countries. Each time, the calculation method was further developed – which also means that results differ. The most advanced study published so-far is that of Wackernagel et al. (1997c)[4] (see *Table 2.1*).

Although all results are expressed in hectares, not all results refer to real land use. This is most obvious for land use for sequestration of carbon dioxide emissions. As will be explained further in this chapter, for individual countries other types of land use are weighted by Wackernagel et al. (1997c) by 1) calculating land use on the basis of global average land productivity (instead of local yields) and 2) including certain equivalence factors for different types of land use.

There are large differences in the amount of land attributed to the per capita consumption of different countries. In terms of terrestrial land, results differ from 0.5 ha. per capita for Bangladesh to 5.0 ha. per capita for the U.S.A. If also land use for carbon dioxide sequestering is included, the data suggests that humanity puts a considerable burden on global natural capital. Humanity's average ecological footprint measures 2.8 ha. of ecologically productive space, while only 2.1 ha. are available. In other words, there is not enough land available to simultaneously 1) supply food and other resources for human consumption, 2) to conserve enough natural ecosystems for keeping up biodiversity and 3) sequestering all current carbon dioxide emissions.

The share of land for carbon sequestration ranges from about 20% for the non-industrialised countries to slightly more than 50% for the industrialised countries. The area of sea used for fish production is for most countries less than 5% of their EF, with the exception of a few countries for which fish represents a major share of their protein intake such as Japan, Korea and Iceland. For these countries, the sea area is about 20% of the total EF.

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[4] The calculations of Wackernagel et al. (1997c) have been provided by Wackernagel in 1999. Earlier calculations using almost the same methodology were published as Wackernagel et al. (1997b).

There are large differences in ‘ecological deficit’ of countries, which can be explained in terms of differences in consumption levels. However, also size of a country, type of land and population density play an important role. Canada, a large, scarcely populated country with a large per capita EF has an ecological surplus, while the Netherlands, a small, densely populated country with a lower per capita EF, has an ecological deficit.

Table 2.1: Land use and ecological capacity (selected out of a larger set of more than 50 countries)

	Ecological Footprint				*Ecol. Capacity*	*Ecological surplus*
	Land use	*Carbon Seq.*	*Sea*	***Total***		
	ha./cap	*ha./cap*	*ha./cap*	*ha./cap*	*ha./cap*	*ha./cap*
Australia	5.15	3.61	0.20	**8.97**	13.98	+5.01
Bangladesh	0.48	0.04	0.03	**0.54**	0.27	-0.28
Belgium	2.44	2.33	0.23	**5.00**	1.22	-3.78
Canada	4.06	3.43	0.25	**7.74**	9.60	+1.87
China	0.67	0.50	0.04	**1.20**	0.78	-0.42
Costa Rica	2.01	0.43	0.07	**2.51**	2.51	+0.01
Czech rep.	2.34	2.10	0.06	**4.50**	3.99	-0.51
France	2.60	1.20	0.33	**4.13**	4.23	+0.10
Germany	2.39	2.70	0.23	**5.32**	1.91	-3.41
Hong-kong	1.94	3.79	0.34	**6.06**	0.03	-6.03
India	0.62	0.20	0.02	**0.84**	0.47	-0.38
Indonesia	1.05	0.23	0.12	**1.39**	2.62	+1.23
Japan	1.58	1.88	0.85	**4.30**	0.86	-3.44
Korea	1.19	1.59	0.64	**3.42**	0.49	-2.93
Netherlands	2.51	2.72	0.09	**5.32**	1.74	-3.59
Nigeria	1.10	0.34	0.05	**1.48**	0.61	-0.88
Rusia	2.68	3.04	0.32	**6.05**	3.74	-2.30
Sweden	3.67	1.87	0.32	**5.87**	7.05	+1.18
UK	2.12	2.84	0.23	**5.18**	1.72	-3.46
U.S.A.	4.95	5.15	0.25	**10.34**	6.72	-3.62
World	**1.68**	**0.96**	**0.12**	**2.76**	**2.12**	**-0.64**

Note: A negative ecological surplus indicates an ecological deficit.
Source: Wackernagel et al. (1997c)

Land used for consumption in the Netherlands

The total (real) land use for the inhabitants of the Netherlands has been assessed by several studies, including Rietveld (1985), Harjono et al. (1996), Hoek et al. (1996)/RIVM (1996, 1997)[5] and Wackernagel et al. (1997) (see *Table 2.2***).**

The study of Harjono et al. (1997) covers the highest number of land use categories, including for instance land use for leather and minerals – but for imports only. This study indicates that land use for food production and wood products, however, are by far the largest categories in terms land use (*Table 2.3***)**.

[5] The methodology is described in Hoek et al. (1996). Results are given in RIVM (1996, 1997). We will refer to the RIVM (1997) from now on.

Table 2.2: Land use, ecological capacity and ecological deficit of the Netherlands.

	Ecological Footprint			*Ecol. capacity*	*Ecological surplus*
	Real land (ha/cap)	*Carbon seq. (ha./cap)*	*Total (ha./cap)*	*(ha./cap)*	*(ha./cap)*
Rees/Wackernagel (1996)	-	-	3.3	0.2	-3.1
Wackernagel et al.(1997b)	-	-	4.7	2.8	-1.9
Wackernagel et al. (1997c)	2.5	2.7	5.2	1.7	-3.6
RIVM (1997)	0.5	-	-	-	-
Harjono et al. (1996)	1.5	-	-	-	-

Table 2.3: Land use for different categories.

Category	*Share (%)*
1. Animal feed	27
2. Oils and oil seeds	21
3. Wood (non tropical)	17
4. Beef and beef products	10
5. Wood (tropical)	8
6. Coffee, tea, cacao	5
7. Cereals	5
8. Sugar and sugar products	2
9. Vegetables and fruit	2
10. Cloths and threads	2

Source: Harjono et al., 1996.

Large differences are present between the results of these studies. The following factors play a role in this:

- **Comprehensiveness of the study.** The studies of Wackernagel and Rees (1996) and Wackernagel et al. (1997b,c) also include land for carbon sequestration – not included in the other two studies. But, also for terrestrial land use estimates, different categories are included in the studies. For instance, Harjono et al. (1996) only concentrate on land use outside the Netherlands but include a large number of categories.
- **Primary data**: The studies of RIVM (1997) and Harjono et al. (1996) are mainly based on national statistics. Wackernagel and Rees (1996) and Wackernagel et al. (1997) mainly use data from international information sources – in order to use harmonised data for different countries.
- **Local yields versus global average yields**: Wackernagel et al. (1997) use global average yields to calculate land use in order to make results for different countries more comparable. RIVM (1997), however, use local yields – which are in case of the Netherlands much higher. In case of imports, sometimes they use the yields of the country of origin.
- **Detail of the calculations:** The calculations of Harjono et al. (1996) and RIVM (1997) are more detailed than the other three studies.
- **Definitions:** An important factor for the Netherlands is the import of a large amount of fodder, used in animal husbandry and food-industries, of which products are partly exported to other European countries. The studies reviewed all deal with this aspect in a different way. Use of the term ‘net’ and ‘gross’ land use, can help to indicate whether the amount of land is corrected for exports or not (*Box 2.2*).

Box 2.2: Definition of the EFs featured here

Ecological Footprint concept: the amount of the world's carrying capacity required to support the consumption of a defined population regardless of where this capacity is used (can be calculated for various resources)
Wackernagel and Rees' Ecological Footprint (1996): total amount of ecologically productive land required to support the consumption of a given population in a sustainable way.
Gross land use: Total land attributed to imports to and domestic production of a certain defined population, measured in local (= country-specific) productivity.
Net land use: Total land required to support the consumption of a certain defined population , measured in local (= country specific) productivity.
Net land use for international comparison: Total land required to support the consumption of a certain defined population, in which equivalence factors are used to enhance comparison where there are differences in natural circumstances.
EF in terms of carbon dioxide emission: Total carbon dioxide emissions generated to support the consumption of a defined population – regardless of where these emissions are created.

2.4 Discussion on the Ecological Footprint concept

2.4.1 What makes the Ecological Footprint appealing ?

The attractive aspect of the EF is that it highlights several interrelated topics of sustainable development. On the basis of the available literature, we were able to identify several of these topics, which, taken together, could explain the current popularity of the EF (besides the metaphor mentioned in the introduction).

1. Focus on consumption

Traditional environmental policies have often been aimed at reducing emissions on the production side of the economy (industry, businesses, agriculture). However, state-of-the-environment reports on the national (RIVM, 1998), and regional and global scales (EEA, 1998; UNEP, 1997) indicate that for several environmental issues results of such policies are partly or even completely offset by an increasing level of consumption (e.g. greenhouse effect). The EF, in contrast, focuses on consumption and is able to highlight the following aspects.

- *Squandering of resources:* Several resources are – at least at the moment – limited in supply; these include safe drinking water, natural areas and biodiversity, energy and land. Squandering of resources does not only lead to resource stress but can also increases environmental pressures due to increased material flows.
- *Impacts of the size and composition of consumption patterns:* Obviously, certain consumption patterns can be regarded as more sustainable than others. Although in the past, policy initiatives aimed at changing behaviour to more sustainable patterns have not always been successful, there is considerable potential in this area (in particular via good housekeeping and conscious purchasing).
- *Geographic re-allocation of environmental pressures:*
  Traditionally, environmental pressures are mostly local or national in their characteristics. However, more-and-more decision-makers are confronted with international aspects of environmental problems. *Figure 2.1* distinguishes different types of influences between countries. We can use this figure to discuss the issue of geographic re-allocation of

environment pressures.

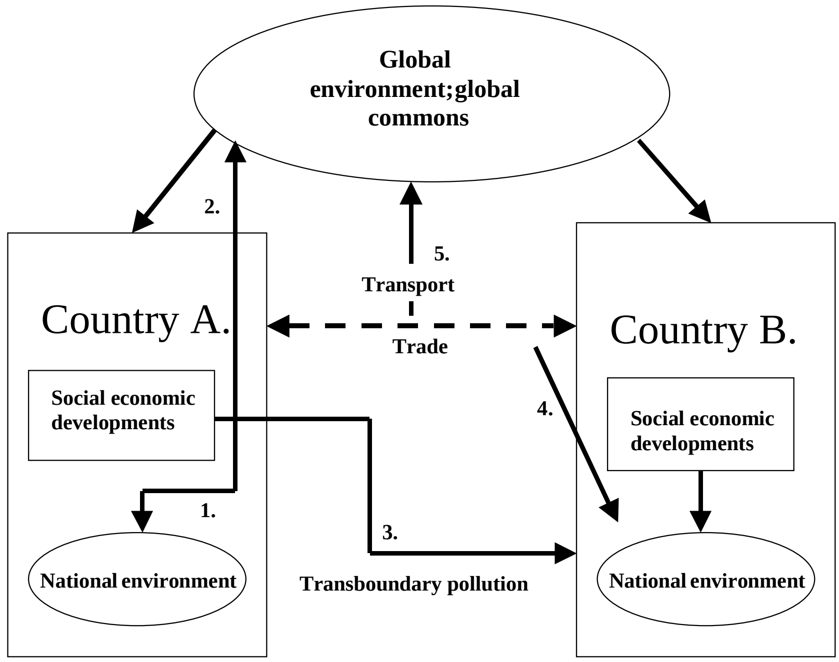

Figure 2.1: Re-allocation relationships between countries
Source: after Sips and Brieskorn, 1999.

As *Figure 2.1* shows, production and consumption within country A can cause **direct** environmental pressures at three different levels:

- within the country itself (1),
- in country B, by means of transboundary air pollution (such as acidification) (2) and
- by pressures on the global environment and global commons (e.g. carbon dioxide emissions, ozone-depleting substances and fish consumption) (3).

For all these types of pressures, country A can be identified as the direct originator of pressures, and thus, can be seen as formally responsible for environmental impacts of these pressures. In addition, however, two **indirect** forms of environmental pressure-related consumption and production in country A can be identified:

- the environmental pressures within country B that are related to imports to and consumption of country A (4),
- the environmental pressures of international transport (5). In most cases, these pressures are not attributable to individual countries and, as results, remain outside the scope of environmental management.

For environmental pressures in country B related to imports to and financial flows of country A (thus type 4) responsibility is not very clear; formally actors in country B can be identified that cause these pressures. Nevertheless, country A is engaged in these pressures – and some might argue that country A has a moral responsibility here**.** This can, for instance, be the case if country A requires very strict environmental standards for domestic production – but simultaneously imports the same products from countries that are for economic and institutional reasons not able to uphold such standards, resulting in indirect environmental degradation or human health risks.

As indicator, the EF takes all five different categories of pressures directly into account and attributes them to consumption (here of country A). It, therefore, broadens the discussion with respect to the first three types of pressures normally taken into account.

Along this line of thinking, it should be noted that production-oriented indicators do not reveal shifts in environmental pressures caused by re-allocation of production to other countries (e.g. basic industries that move to countries with lower labour costs or less strict environmental policies). For global problems, such as climate change, re-allocation reduces the effectiveness of unilateral environmental policies. Particularly for a small country with an open economy such as the Netherlands, it is relevant to include such effects in the assessments.

2. Focus on renewable resources

An attractive attribute of the EF is that it focuses on some resources identified as key resources for sustainable development (land, carbon dioxide emissions). UNEP's Global Environment Outlook, for instance, concluded that land – suffering from degradation and becoming increasingly scarce – is one of the key resources for sustainable development in most of the world's regions (UNEP, 1997).

3. Distribution of available environmental resources

The EF addresses the current distribution of resource use (by calculating the per capita footprint for individuals, cities or countries and comparing them to a global average). Assessments of environmental pressure in the next century indicate that strong economic growth in current poor parts of the world (with low-level use of resources, such as Africa and parts of Asia) could result in either an enormous increase in pressures or a claim for reallocation of the environmental space. In that case, after determining a global 'maximum allowable' level of environmental pressures for sustainable development, the question is how this can be distributed among the global population. In the context of ongoing climate change negotiations, this is already an important issue, with proposals to base burden-sharing initiatives in the next century on an equitable distribution of per capita emissions rights.

4. Focus on environmental consequences of trade

Some authors (Van der Bergh and Verbruggen, 1999) argue that the EF implicitly promotes autarchy or is against trade. However, the calculation method of the EF does not give any reason for this. Without going into too much detail, trade, in the context of sustainable development, could have both advantages (using ecologically comparative advantages of countries, providing income) and disadvantages (environmental consequences of transport, making the link between human consumption and environmental impact more complex, and potential lack of a stringent environmental law in exporting countries). If international trade is truly based on ecologically comparative advantages (including the effects of transport), it will result in a lower overall EF.

5. Communication / pro-active

Results of the EF are relatively easy to visualise. Moreover, since the EF can be calculated on a per capita basis, EFs can be compared between countries, with the global average or a potentially more sustainable level. These features allow for powerful communication of the results – which explains its popularity among advocacy groups. The EF can also be calculated for individuals – as has been done in the Netherlands for school-going youth and individuals on Eco-teams - allowing them to relate their behaviour to global objectives and encourage more environmentally-friendly behaviour.

6. Aggregation

Different authors have argued for the development of aggregated environmental indicators which are able to give a rough overview of environmental pressure or sustainability (e.g. Adriaanse et al., 1997; Jesinghaus, 1996). However, at the same time aggregation is extremely difficult and controversial for complicated systems (such as the environment), since there are no general, scientific rules or theory to weigh different impacts from an ecological perspective.

2.4.2 Points of discussion or critism

At the same time, there are several points of the EF which can be subject of discussion. This section summarises a few of these points.

1. Aggregation

The aggregation of the EF currently receives most criticism. Due to the complexity of the environmental system, weighting in indices will always be based on more indirect measures – including some kind of subjective reasoning. In the EF, an indirect weighting system is used on the basis of translating pressures into the amount of land needed to support different ecological functions[6]. Although the different resources within the EF can indeed be related to the use of land, this requires several subjective assumptions, including the assumption that for sustainable development no increase of greenhouse gas concentrations can be allowed. Van den Bergh and Verbruggen (1999) argue that by using land as an aggregated indicator, the EF could create a false concreteness. It seems to suggest that we are talking of a specific environmental resource (land) while actually it represents (at least partly) a hypothetical amount of land. Moreover, the fixed aggregation scheme does not take into account that in specific situations one resource might be scarcer than another.

2. Sustainable versus unsustainable land use

The EF pays no attention to the sustainability of current land use practices, in particular concerning soil degradation (pollution, erosion, soil nutrient depletion etc.). In cases current agricultural practices do result in soil degradation, a sustainable EF will often be larger than the current EF.

3. Productivity

In international comparison of land use, the issue of productivity (= land per unit of production) plays a major role. Productivity is influenced by human management factors, including types of product, technology and knowledge, but also natural circumstances, such as soils, climate etc. Comparing land use among countries and global regions is complicated by the fact that in some countries natural circumstances are less favourable for high agricultural productivity (we will return to this in the discussion of our results). ‘Natural yield factors’ could be included in the EF to take account of differences in natural circumstances. In current EF work, the issue is altogether avoided by relating consumption to the *global*

[6] As will be shown further in this article, the EF weighting system results in energy use accounting for over 50% of the total ecological footprint for industrialised countries. Despite the claim of subjectiveness, the present weighting system is in line with the conclusions of many environmental assessments indicating the important role of energy consumption in environmental problems of the industrialised world (e.g. EEA, 1998).

average yield[7]. For national governments, however, land use based on *local* yields might be much more relevant since these can be influenced, for instance, by increasing productivity (which might result in unsustainable land use practices). Moreover, using *local* yields means that the calculated area is equal to the real, touchable, area used for the consumption of a specific country.

4. Use of ecological capacity

Many EF studies also define the ecological capacity of countries and subtract the EF from this capacity to determine so-called ecological deficits or surpluses (e.g. Wackernagel and Rees, 1996; Wackernagel et al., 1997). These indicate whether a country, in principle, is able to supply itself with food and timber on a sustainable basis or whether it has to rely on 'net imports of land' outside its national borders – thus indicating (net) self-sufficiency[8]. On a global scale, the notion of self-sufficiency and sustainability coincide. For other scale levels, however, self-sufficiency (and the deficit/surplus) is a function of among others population density[9]. Using the ecological deficit as an indicator of sustainable development would imply self-sufficiency to be a meaningful aspect of sustainable development, but we doubt whether a large, scarcely populated, self-sufficient country with a large per capita EF should be regarded as more sustainable than a small, densely populated country with a lower per capita EF.

5. Factors complicating comparison

Several factors such as climate, availability of national resources, population density and tradition can strongly influence consumption patterns. For instance, in Canada energy consumption for heating and transportation is high, among others because of the cold climate and the low population densities.

6. Limited coverage

Some of the criticism about the EF stems from the EF as being seen as the sole indicator for sustainable development. The EF does cover only some of the aspects of sustainable development.

2.4.3. Choices made in this report

On the basis of the discussion above, we have decided to use the EF framework, but to adapt the calculation methodology slightly in order to reduce the weaknesses as discussed above.

- We will avoid the issue of aggregation as far as possible by not focusing on the aggregated EF – but on its components in their own typical units. By doing so, we are still able to keep some of the attractive features mentioned above. The EF is thus defined as 'the use of the world's carrying capacity required to support the consumption of a defined population regardless of where this capacity is used' and can be applied to different resources (land, forest, carbon assimilating capacity)'.
- We will use the notion of ecological surplus/deficit with great care. For *sustainable*

[7] This could be taken to imply that the total global highly productive and marginal lands are equally distributed to all global citizens.

[8] 'Net' self-sufficiency here indicates that more land is used by country than is available within its national borders.

[9] Among the industrialised countries, for instance, large countries with a low population density have an ecological surplus (e.g. Canada) – while small countries with a high population density (but comparable consumption patterns) have a considerable ecological deficit (e.g. the Netherlands).

development, comparison of the *per capita* EF with the average available land at the global scale is more meaningful.

- In this study, we concentrate on land use based on *local* yields. In addition, land use based on *global* yields is shown as a reference in international comparison and to show the differences in results.
- Wackernagel et al. (1997) also include consumption of fish in the EF. By doing so, the EF captures an important source of human food, which was left out before. However, again a weighting factor has to be introduced to avoid that relatively unproductive sea hectares lead to a relatively high EF for fish consuming countries. We have, therefore, decided not to include fish in our assessment.

3. The calculation method

3.1 General structure

The methodology is based on Wackernagel and Rees (1996) and Wackernagel et al. (1997). However, we introduced some changes in the methodology on the basis of the discussion in *Chapter 2*. The most fundamental differences are indicated in *Section 3.5*.

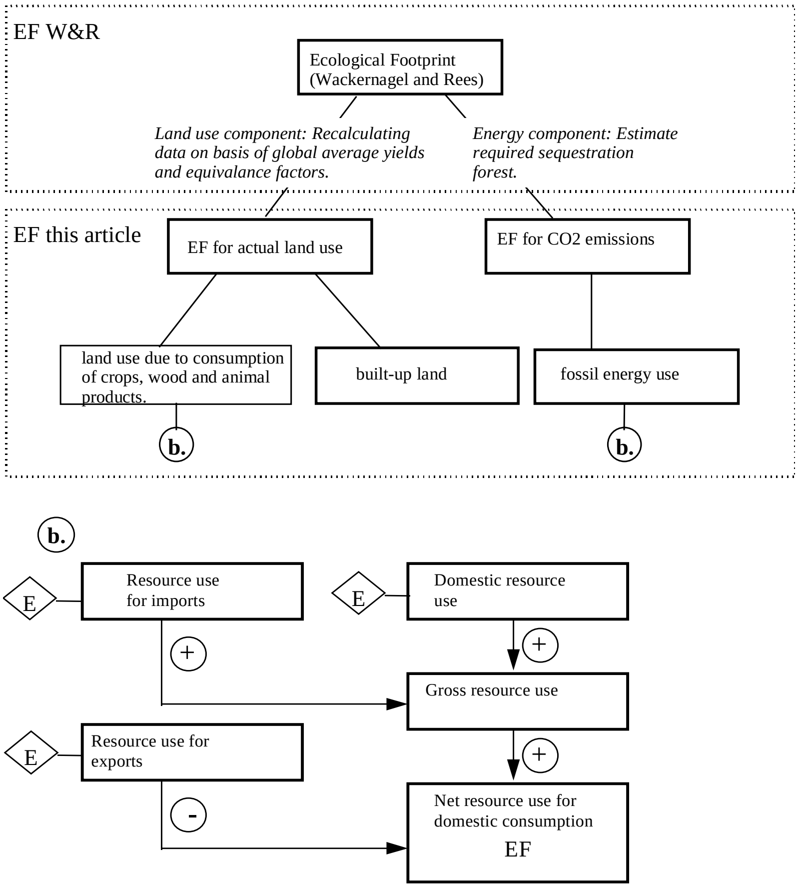

Figure 3.1: The components of the Ecological Footprint (differences in focus between Wackernagel and Rees and this report are indicated)

In our calculations, we focus at two main categories of resource:
1) the EF for land - subdivided into arable land / pastures, forest and built-up area - and
2) the ecological footprint for carbon dioxide emissions.

These elements can be aggregated into one single indicator following the definitions of Wackernagel and Rees. However, as argued before, this introduces a virtual land use category and includes an implicit valuation of different type of resources.

We have calculated the EF for three years: 1980, 1987 and 1994. In the sections below, we will discuss the methodology for the different aspects of the EF. More details are included in an separate annex (to be obtained from the authors).

3.2 Land use due to consumption of food and wood products

Calculation method

Land use for domestic consumption has been calculated by determining land use for consumption due to imports, domestic land use and subtracting land use for exports. A simplified equation for our calculations is indicated, see *Eq.* (1). For some product categories calculation schemes were more complex, as these products are further processed (e.g. wheat into bread). In that case, also imports and exports of manufactured products have to be taken into account.

For yields, see *Eq.* (1), in principle real, local yields were used – thus domestic yields for domestic production and the yields of the country of origin for imports of products. In many cases, however, the origin of exports were unknown and global average yields per hectare have been used for imported products. Sometimes, global average yields were used when domestic yields were unavailable. Finally, we have also calculated land use based completely on global average yields as a reference.

$$land\_use = \frac{prod_{dom,c}}{yield_{dom,c}} + \frac{import_c}{yield_{imp,c}} + \frac{export_c}{yield_{\exp,c}} \qquad (1)$$

Note: In *Eq.* 1 land_use is net real land use in hectares; c the different production categories, so that prod, import and export are domestic production and imports and exports, respectively, in tons per year; $yield_{dom}$ is the domestic yield in tonnes per ha. per year and $yield_{exp}$ and $yield_{imp}$ the yields that can be attributed to imports and exports. In most cases, the former has been set equal to domestic yields (except for re-exports) and the latter to the yields of the region from which products are imported; if unknown, global average yields were used.

Table 3.1: Main product groups

Categories	*Main product groups used in calculations*
Cereals	wheat (inc. flour) (1), rice (2)., maize (3)., barley (4.), other coarse grains (5).
Fruit	citrus fruit (including tropical fruit) (6.), bananas (7), other fruit (8).
Meat and other animal products[1]	cattle meat (including horse meat) (9)., milk (total fresh milk) (10), sheep and goat meat (11.), pig meat (12.), poultry (13.), eggs (total eggs) (14.)
Oil-bearing crops & derived products	oil crops (15.) tree nuts (16.), vegetable oils (17.), cakes (18.)
Pulses	pulses, total (19.)
Roots & tubers	potatoes (20.), yams (21.), cassava (22.), other roots & tubers (23.)
Stimulants	cacao beans (24.), coffee (25.), tea (26), tobacco (27.)
Sugar crops & sugar	sugar cane/sugar beets (28.), sugar, total (29.)
Vegetables	vegetables, total (30)
Wood[1]	wood for charcoal (31.), industrial round wood (32.), imports of wood products (33.), pulp, paper and paperboard (34.)
Other products	diverse products (rubber, cotton) (35.)

Note: The number of the main product groups corresponds with the numbers used in the separate Appendix containing detailed data and calculations.

Previous calculations have shown that the two most important land use categories are meat and wood (see for instance *Table 2.3*). Unfortunately, calculations for these products are relatively complicated due to production of various products in different processing stages. Conversion factors have been used to account land use to the imports and exports of different sub-products.
A total number of 35 main product groups have been used as indicated in *Table 3.1*. They are assumed to represent the total consumption of agricultural products and wood products. The chosen product groups are based on large differences between the yields per hectare, the relative importance in terms of land use and the availability of data.

Data sources
The data used in this study have been mainly taken from the statistics of the United Nations' Food and Agricultural Organisation (FAO, 1995 -1998), assuming that this would make the results more comparable between countries. We have compared these data, if available, with data from national sources (mainly from statistical offices of the countries involved). In most cases the different sources did match well; if not, we have used those considered to be most reliable on the basis of available information (as described in detail in the separate Annex). For animal and wood products in Netherlands, more data was needed than available from FAO; so, more national data have been used (e.g. CBS, 1994-1996).

The FAO database is compiled by FAO on the basis of national data. When no data are available, the FAO-database includes estimates based on expert judgement and modelling. For the Netherlands and Costa Rica more reliable and detailed information are available than for Bhutan and Benin.

3.3 Built-up area

Built-up area includes land use for housing and infrastructure (airports, industrial sites and roads). The data in this report refer only to domestic land use of built-up area (no account is taken of land use outside national borders, e.g. for tourism). Data for built-up area were difficult to obtain and have been selected from various sources:

- For Benin built-up area per capita of Nigeria has been used (Wackernagel and Rees, 1997a);
- For Bhutan, national data for 1994 have been used (Chhewang Rinzin, 1997);
- For Costa Rica, national data for 1979 and 1992 have been used (Orozco and Acuña, 1997);
- The Netherlands, national data for 1980, 1987 and 1994 have been used (CBS, 1994).

For Benin and Bhutan, domestic land use has been assumed to grow along with the size of the population. It should be noted that this type of land use is relatively small, in comparison to other forms of land use.

3.4 Carbon dioxide emissions

The calculation method

Carbon dioxide emissions were - in principle - accounted for in a similar way as for land use as indicated in *Figure 3.2*. For the 1985-1994 period for the Netherlands, earlier calculations by RIVM and Statistics Netherlands (RIVM, 1998) were used, in which the EF for carbon dioxide emissions was assessed on the basis of: 1) consumption statistics, 2) energy intensities per product and 3) types of energy consumed. For 1980, we have estimated net carbon dioxide emissions on the basis of normal carbon dioxide emissions statistics and trends in the 1985-1997 period.

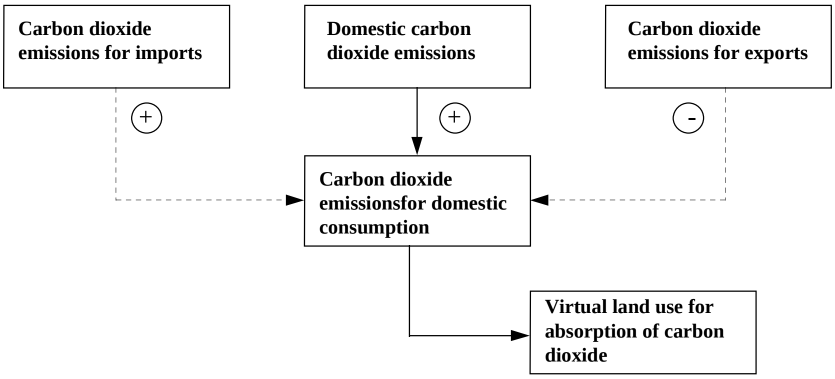

Figure 3.2: Overall methodology for carbon dioxide calculations

Domestic carbon dioxide emissions in Benin, Bhutan and Costa Rica have been calculated using energy consumption statistics as collected by Van Vuuren and De Kruijf (1998). For carbon dioxide emissions related to net imports of manufactured goods in Costa Rica, we have used the results of Wackernagel et al. (1997). For Bhutan and Benin, we have used statistics from the United Nations Trade Statistics (UN, 1983, 1990 and 1995). However, we only used them to get a very rough indication as we considered available statistics and energy intensities (which have been determined for industrialised countries only) to be insufficiently reliable to calculate the size of these emissions - and thus only used domestic emissions.

3.5 Differences between the original method and this report

Table 3.2 summarises the most important differences between the calculation method of Wackernagel and Rees and the calculations described in this report.

Table 3.2: Differences between the methodology of Wackernagel et al. (1997) and the methodology in this report

	Wackernagel et al. (1997)	*This report*
Aggregation	Focus on the aggregated EF.	Focus on the underlying indicators for land use and carbon dioxide
Elements included	• Land use for food, wood products; • Built-up land; • Carbon dioxide emissions; • Sea area for fish consumption.	• Land use for food, wood products; • Built-up land; • Carbon dioxide emissions;
Calculation of land use	23 product categories for land use Use of global average yields for agricultural products Use of equivalence factors[10] for different types of land use	35 product categories for land use Use of local yields for agricultural products; also land use based on global yields is calculated for comparison.
Calculation for carbon dioxide emissions	Energy-intensities have been used to calculate the energy embodied in imported or exported products.	Calculations have only been done for the Netherlands - for Costa Rica results of Wackernagel and Rees were used; for the other 2 countries simply domestic primary energy use has been used.
	Includes the use of fish resources	Does not include the use of fish resources[11]

[10] Wackernagel et al. (1997) realise that not all land is equally productive and that the impacts of current land use can be different with regard to future potential of this land. Therefore they multiply their main categories of land use by so-called equivalence factors (for pasture land, forest land, cropland and built-up areas: 0.54, 1.14, 2.82 and 2.82, respectively). These factors are chosen so that on the global scale total land use still equals total available land. The equivalence factors do not deal with large differences in productivity within the land use types. We have decided not to include any equivalence factors, since we intended to assess the real amount of land used by each country.

[11] The reason not to include fish is that we did not like to mix up the sea and land - this, again, requires weighting factors. This means that for countries where fish is an important of the food consumption, the EF will be typically lower.

4. Ecological Footprint for land use

4.1 Land use for consumption of agricultural products

Land use for (per capita) consumption of agricultural products can be related to the following three factors:

- consumption levels,
- yields and production methods (both domestically as for imports),
- type of consumption (some production require much more land than others).

These factors are discussed in the next sections.

4.1.1 Consumption levels

Figure 4.1 shows the consumption in the four countries in terms of calories intake per capita per day. The data refer to direct human consumption (FAO, 1998). It should be noted that not all agricultural products are directly used for human consumption; some products are processed further, part of the harvests is used as seed, another part is used as animal feed and, finally, part of the consumption is simply wasted.

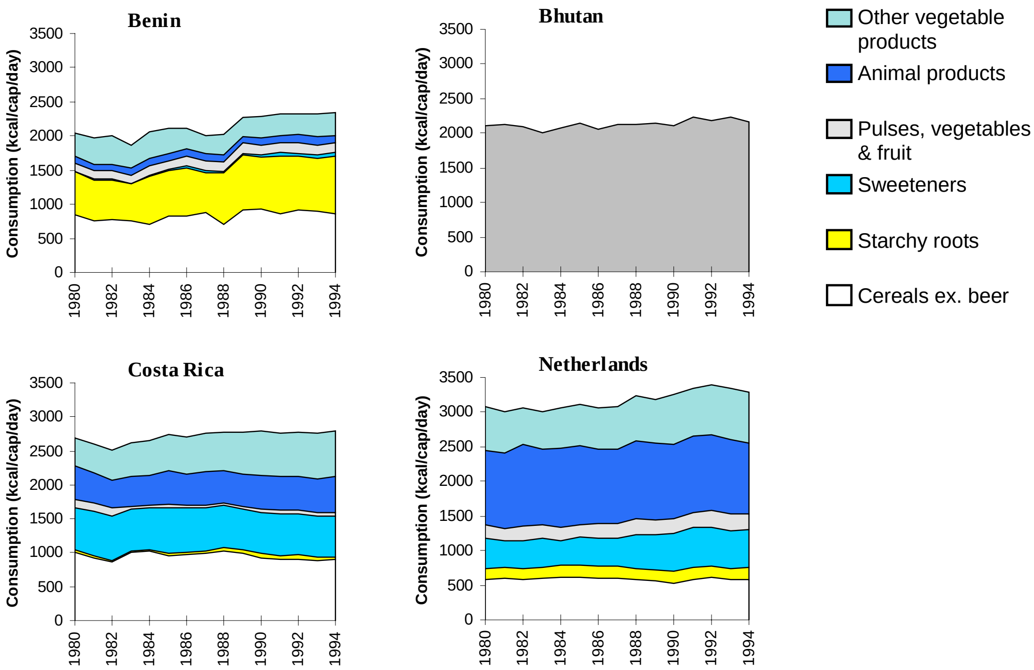

Figure 4.1: Direct consumption of agricultural products
Source: FAO, 1998.

Figure 4.1 shows that between 1980 and 1994 the consumption per capita increased in all four countries. The Netherlands have by far the largest average consumption, ca. 3000 kcal per day, which is about 1.5 times the critical level of 2100 kcal per person per day (FAO, 1996). In Costa Rica, average intake per capita is circa 600 kcal above the critical level, while in Benin and Bhutan the average intake is only slightly higher than the critical level. In Benin, occasional malnutrition occurs (partially due to seasonal availability of agricultural products). In the Netherlands, the share of animal products in total consumption is much higher than in the other three countries.

In the next sections, we will distinguish four categories of products: cereals, other crops, meat and related animal products, milk and dairy and other crops. *Figure 4.2* shows the total consumption of these categories, now including indirect consumption.

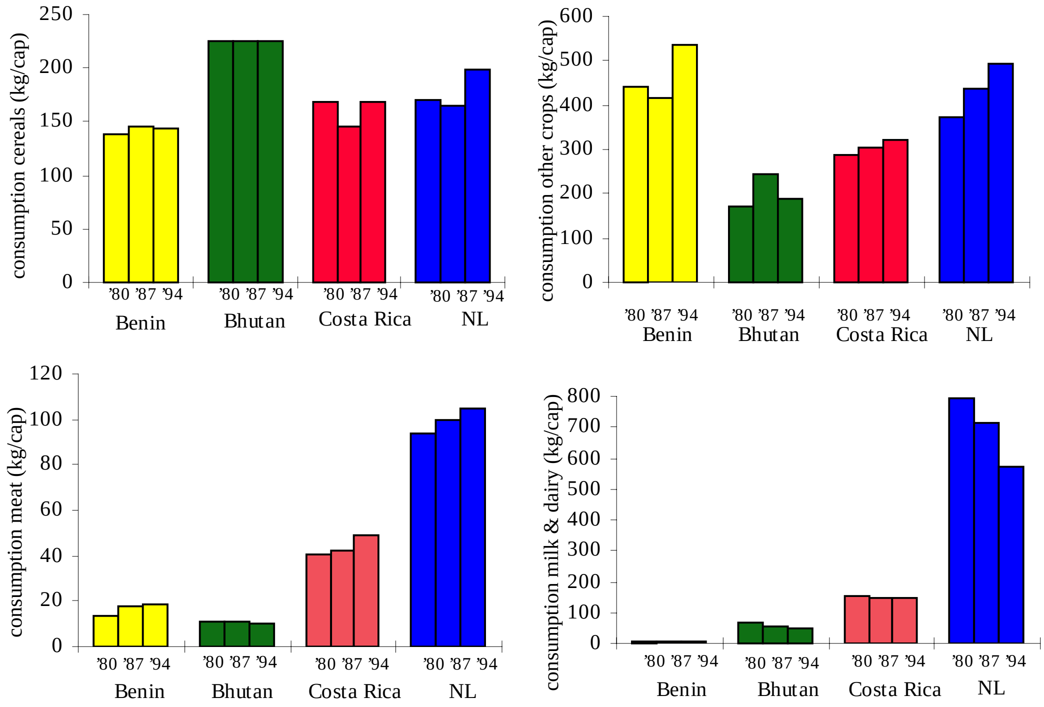

Figure 4.2: Direct and indirect consumption of agricultural products
Source: FAO, 1998.

The per capita consumption of cereals in the four countries is at a comparable level. In Benin, Costa Rica and the Netherlands, consumption per capita has increased between 1980 and 1994. According to FAO statistics, per capita cereal consumption in Bhutan decreased by more than 50% between 1980 and 1994. Other sources, however, do not indicate such a decrease. We have assumed that the decrease is a result of error and the data have been changed in constant per capita consumption.

Table 4.1: Composition of the category 'other crops' (% of total consumption).

	Benin	Bhutan	Costa Rica	The Netherlands
	% of total	% of total	% of total	% of total
fruit	6	46	45	31
oilcrops	4	2	7	6
pulses	3	1	4	1
roots & tubers	76	40	7	29
stimuli	0	0	3	5
sugar	2	4	20	16
vegetables	9	8	13	13

Note: the consumption of oil crops is included in raw equivalents and the consumption of sugar is included in sugar equivalents.

The land use category other crops includes a wide variety of products. *Table 4.1* shows the composition of the consumption in the four countries in 1994. In Benin, the category mainly consists of roots and tubers, in Bhutan of fruit and roots and tubers and in Costa Rica of fruit, sugar and vegetables. In the Netherlands, fruit, roots and tubers and sugar all contribute significantly to the total consumption of products included in this category.

Important in terms of land use is the category 'animal products'. The category can be divided into two important sub-categories: meat (including lard, prepared meat, animal fats and eggs) and milk & dairy (including milk, cheese, milk powder and other products). Consumption of meat and related products has increased in Benin, Cost Rica and the Netherlands. *Figure 4.2* shows a decreasing per capita consumption of milk and dairy in all four countries, in particular the Netherlands.

4.1.2 Yields

The yields per hectare differ strongly between the four countries (*Figure 4.3*). In general, the countries with the highest consumption rates (the Netherlands and Costa Rica) have the highest yields per hectare. In fact, differences in consumption are more than offset by differences in yield.

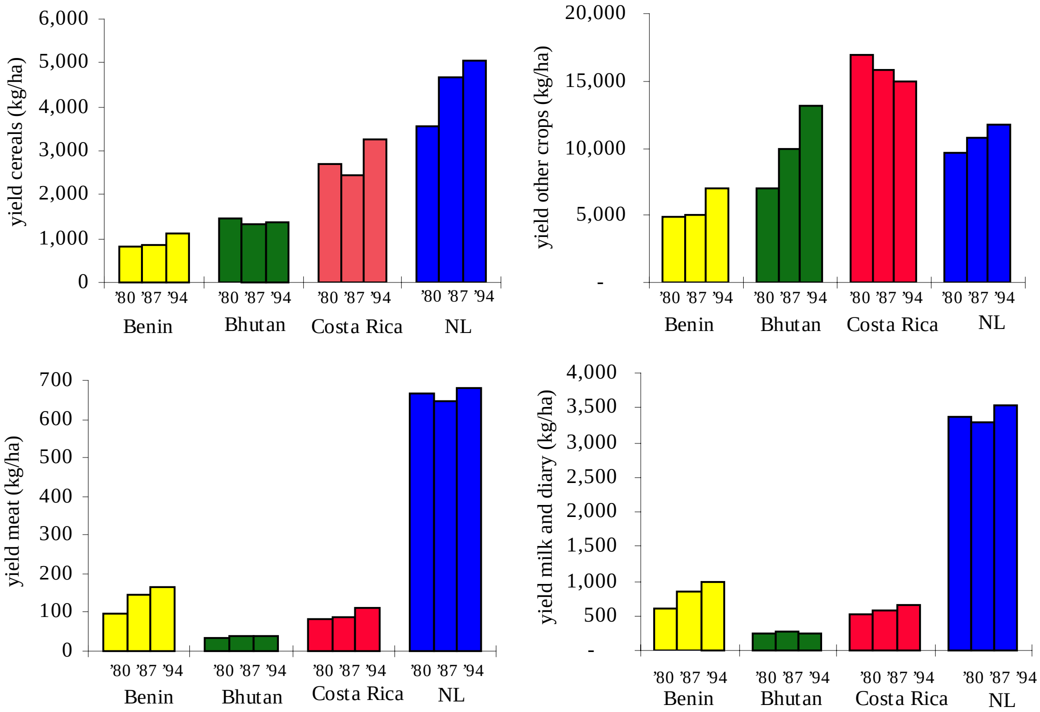

Figure 4.3: Average yields per hectare for agricultural products consumed

For most product categories yields have increased in time. Yields for the category 'other crops' are the weighed average yield of the different categories (excluding natural rubber and cotton). This means that the composition of the category influences the calculated yields. For this category, yields can therefore not be compared directly. The yields per hectare for animal products and milk and diary for the Netherlands is extremely high in comparison with the other three countries (as a result of intensive animal husbandry). The calculated yields include the land required for production of feed outside the Netherlands.

The differences in the yields per hectare in the four countries play a crucial role in the amount of land attributable to consumption of each of the countries. These yields are (actively) determined by agricultural knowledge, crops, agricultural production methods and agricultural inputs but also (passively) by natural circumstances. In the following two sections, we will have a further look at these factors:

- the natural productivity of the land,
- the production method and the input of resources.

4.1.2.1Differences in natural productivity

Natural productivity for crops

The natural productivity of land is a function of several factors such as climate (rainfall, temperature etc.) and the quality of the soil and geography. The variation in natural productivity in different regions and countries can be shown by using data from the IMAGE 2.1 model (Alcamo et al., 1998). The IMAGE 2.1 estimates current yields for different crops in 13 global regions in relation to a theoretically-feasible production rate based on climate and soil conditions. Next, 'management factors' are derived to represent agricultural management, technology, agricultural inputs and know-how, indicating the ratio between actual and theoretically-feasible yields.

By combining actual yields and the management factor of the IMAGE 2.1 model, we can obtain a very rough indication of the theoretically-feasible production under optimal management conditions in each of the four countries. Since the model only includes information on management factors at the level of global regions, for Benin current yields have to be compared with natural production of Africa, for Bhutan South Asia, for Costa Rica Latin America and for the Netherlands Western Europe. *Table 4.2* shows the real yields per hectare and maximum feasible yields per hectare according to the IMAGE model for cereals, pulses and roots & tubers.

Table 4.2: Real and theoretically-feasible yields per hectare

	Pulses (tonne/ ha)	*Roots & tubers (tonne/ ha)*	*Cereals (tonne/ ha)*
Real yield (1994)			
Benin	0.6	10	1.0
Bhutan	1.0	11	1.2
Costa Rica	0.6	21	3.4
Netherlands	4.3	42	7.3
Indication max. feasible yield			
Africa	1.0-1.5	25	3.5-4.0
India region	3.0-4.0	15-20	3.0-4.0
Latin America	3.0-4.0	20-30	6.0-7.0
Western Europe	5.0	40-45	7.0-8.0

Source: FAO, 1996; Alcamo *et al*., 1998.

Table 4.2 shows that there are large differences in the maximum theoretically possible yields per hectare. Although the information in this table should be interpreted with great care, Western Europe (the Netherlands) seems to have the most favourable natural conditions of these regions for the crops mentioned.

The natural productivity of pasture lands
The yields (and land use) for the production of animal products as calculated in this report are strongly influenced by the amount of pasture land recorded by FAO per country. Pasture land is classified by the FAO as *'land used permanently (five years or more) for herbaceous crops, either cultivated or growing wild (wild prairie or grazing land)'*. FAO adds, however, that the dividing line between this category and the category 'forest and woodland' is rather indefinite, *'especially in the case of shrubs, savannahs, etc., which may have been reported under either of these categories'*.

Exactly the question, whether savannahs and comparable land use types should be regarded as pasture land or partly as undomesticated land, strongly influences our results. A large amount of pastures in Benin, Bhutan and also in Costa Rica is used very extensively such as savannahs in Benin, alpine pastures in Bhutan and grass areas in the mountains in Costa Rica. Following the FAO data, in our assessment these (extensively used) pasture lands are completely attributed to 'animal products'. It should be noted that often these types of 'pasture lands' are already used with a maximum intensity in view of their high vulnerability. More intensive grazing on the savannah or in the mountains can result in soil erosion and overgrazing. One could also argue that these areas are not used for grazing only, but also have important functions for keeping up biodiversity and production of wood. This provides a second argument to only partially attribute these 'pastures' to meat and dairy production.

4.1.2.2 Differences in production methods

Production of crops
Differences in yields per hectare are also actively influenced by agricultural management, knowledge and inputs. For instance, in the Netherlands vegetables are grown both in greenhouses and on the open field. The yields per hectare in greenhouses are, on average, four times higher than the open field yield per hectare. Ideal growth conditions can be created in greenhouses allowing multiple harvests per year resulting in a yield per hectare of 114,000 kg per ha. for an average mix of vegetables, while the global average yield is about 14,000 kg per ha. This higher productivity, however, implies increased inputs such as fertilisers, pesticides and in particular energy. The total energy requirement of food in the Netherlands lies between 13.5 and 19.1 GJ per person per year (Gerbens-Leenes, 1999) – which is about 10% of the total energy required for consumption of the population of the Netherlands. In comparison, the *total* energy consumption of Benin and Bhutan is about 10 GJ per person per year. In particular in the Netherlands, substitution of land by other inputs has been an attractive strategy to deal with relatively scarcity of land. *Chapter 5* further discusses energy consumption, but does not pay attention to food as a separate category.

The differences in intensity of production can be illustrated in terms of the use of fertilisers and the number of tractors. *Figure 4.4* shows the use of fertilisers and the use of tractors per hectare arable land in the four countries between 1980 and 1994.

The use of fertilisers and tractors in the Netherlands is much higher than in Benin and Bhutan. According to FAO data, Costa Rica is currently at about the same level as the Netherlands with regard to fertiliser use per hectare of arable land. The use of tractors and fertilisers in Benin, Bhutan and Costa Rica increases. In the Netherlands, their use decreases but despite this, the yields per hectare have increased. The main reasons for the increase in yield in the Netherlands include the use of new types of cereals, more optimal use of fertilisers and taking out of production of low productive areas during the current period of agricultural restructuring (Ko et al., 1998). In addition, in the Netherlands up to 60% of the total cropland is irrigated in 1994, compared to ca. 27%, 1% and 40% of the total cropland in respectively Benin, Bhutan and Costa Rica (these percentages have all increased between 1980 and 1994).

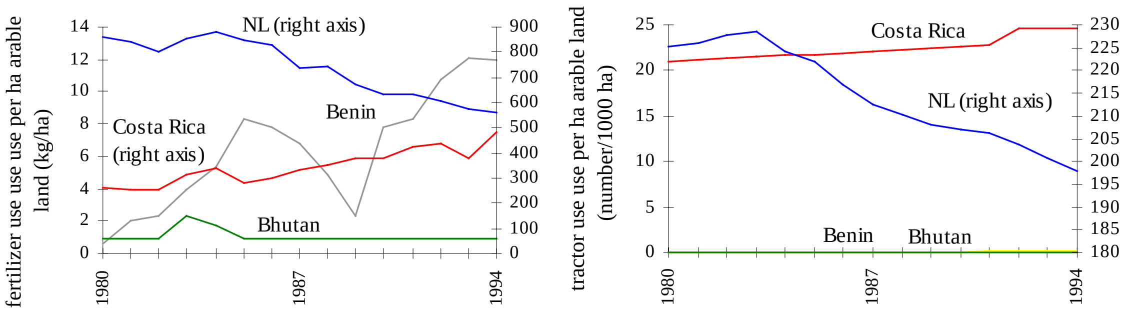

Figure 4.4: The use of fertilisers and tractors per hectare arable land
Source: FAO, 1998.

Animal production
Large differences exists between the land use per unit of animal product consumed (*Figure 4.3*). In Benin and Bhutan, animal husbandry is mainly done in the form of naturally grazing animals on small scale (domestic) farms or by nomadic herders, without the use of animal feed and high productive breeds. In contrast, in the Netherlands, animal products are produced with 'high yields per hectare' by using large amounts of animal feed. The nutritional value per hectare is for maize (used as feed) about 30% higher than for fresh grass. This means that the stable-based production methods (using animal feed) can be more land efficient than using production based on pasture lands. Moreover, stable-based production allows for increasing production by means of controlled environment. The consequences of this type of production in the Netherlands, however, are a relatively high environmental pressure in terms of manure production, the need for feed imports and unnatural living conditions for animals.

In addition, differences exists between the meat and milk production per animal. The production of fresh milk per cow per year, according to FAO statistics, in Benin, Bhutan and Costa Rica and the Netherlands are 120, 257, 1334 and 6404 kg per year, respectively. Similarly, carcass weight of beef and veal in these countries are 110, 85, 212 and 245 kg. FAO statistics also indicate an increasing production efficiency (in terms of production per animal) in Costa Rica and the Netherlands. Beef and veal average carcass weight in Costa Rica and the Netherlands increased between 1980 - 1994 with respectively 4% and 24%; the production of cow milk per animal increased with respectively 24% and 28%. This could (partially) be an explanation for the decreasing land use per kg milk and meat in these two countries.

4.1.2.3 Trends in global average yields
World-wide a trend can be observed towards the use of new varieties, new technologies and better management resulting in intensifying land use, increasing yields and cropping intensities (RIVM/UNEP, 1997). *Figure 4.5* shows the world average yield per hectare for a number of crops and the milk supply and carcass weight for animals.

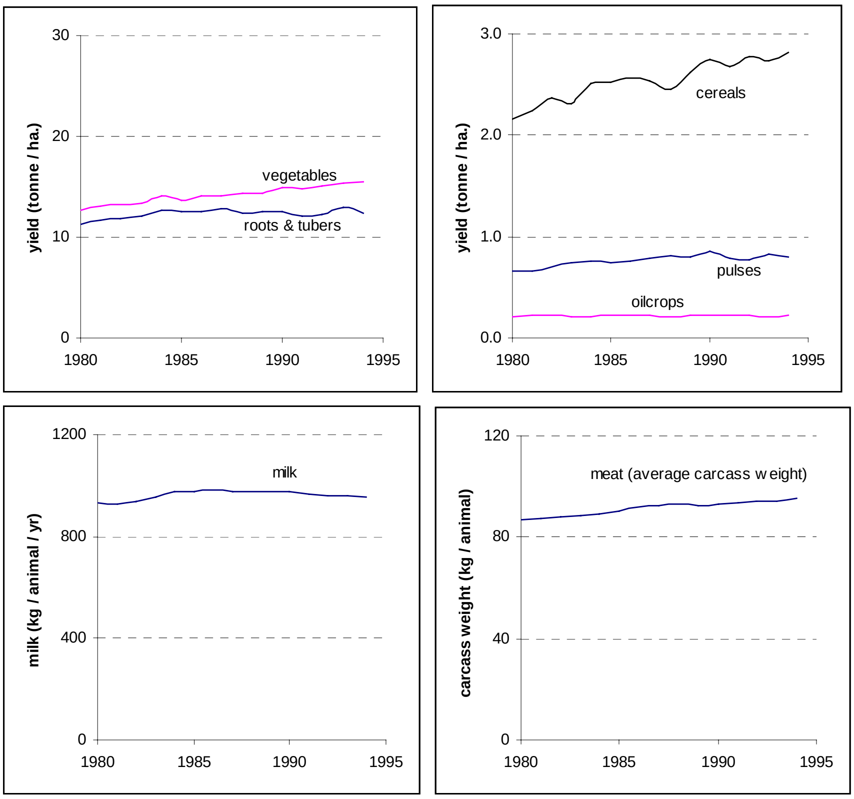

Figure 4.5 Global average yields per hectare for main agricultural crops and animal products
Source: FAO, 1998.

Also at the global level, the main reason for increasing yields per hectare are more intense production patterns, using new varieties, know-how and other inputs. For example, the irrigated area in the world has increased by 22% between 1980 and 1994 (FAO, 1998), the world number of tractors and harvesters has increased by 16% and the world total fertiliser consumption has increased by 6% (FAO, 1998).

4.1.3 Consumption patterns

The type of consumption also influences land use. An important aspect here is the share of animal products in total human food consumption. The biotransformation of grass and animal feed by animals into animal products (such as dairy products and milk) results in considerable losses. Thus, the production of animal products is in terms of land less efficient than the production of non-animal products (UNEP, 1997). In the Netherlands about one third of the daily calorie intake comes from animal products. In Costa Rica, less than 20% of the calorie intake comes from animal products. In Benin, the consumption per capita of animal products is low and more than 50% of the daily animal protein intake comes from fish (which is not included in this study). In Bhutan, the per capita consumption of meat and milk is very low; and the daily calorie intake mainly comes from cereals, starchy roots and vegetable products.

4.2 Land use for consumption of wood products

Wood products account for a considerable amount of land use, depending on the specific country.

4.2.1 Consumption of wood products

The consumption of wood is shown in *Figure 4.6*. In Benin, Bhutan and Costa Rica wood consumption consists mainly of fuelwood (heating, cooking, baking etc.). In the Netherlands almost no wood is used as fuelwood, as almost all energy is based on fossil fuels, and virtually all wood is used as industrial roundwood (mainly for paper production). Differences between the four countries should therefore be partly accounted to strategic choices in fuel (Benin and Bhutan have less access to substitutes for fuelwood and charcoal as an energy source).

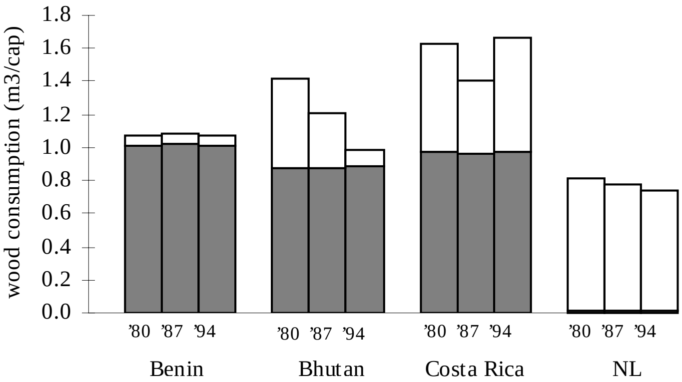

Figure 4.6: Consumption of wood products

Note: Solid part of the bars indicates fuelwood consumption. Open part indicates industrial roundwood consumption.

Source: FAO , 1998.

4.2.2 Production of wood products

In the calculations, natural production of usable m^3 roundwood per hectare forest has been used to assess the total area of wood land needed for the wood products consumed. In the Netherlands, most of the wood is imported. Therefore, the origin of the wood and the natural production of that particular part of the world have been included in the calculations (mentioned as 'average for imports' in *Table 4.3*). For the other three countries, estimates have been made of the local average yields (see *Table 4.3*).

Table 4.3: Average yields used in calculations

	Natural production (m^3 / ha. forest)
Benin	3.2
Bhutan	5.0
Costa Rica	4.1
Netherlands (domestic production)	6.5
Netherlands (average for imports)	3.5

Source: based on Stolp and Eppenga, 1998

The productivity of forests as used in the calculations is based on production of wood from more or less 'natural forests' (instead of plantations). Wood production in plantations -with the use of fast growing tree species, irrigation and optimum live cycles- gives much higher yields per hectare (up to ca. 20 - 25 m^3 non-coniferous roundwood per hectare versus the present 3-5 m^3 per hectare; Stolp and Eppenga, 1998). However, biodiversity is lower.

4.3 Built-up area

Table 4.4 shows the estimated built-up area of the four countries, both in hectares per capita and in total hectares and in percentage of the total land area. The area built-up land per capita is the largest in The Netherlands. In the Netherlands built-up land per capita slowly increases in the 1980-1994 period (+6%). For the other three countries trends are uncertain due to unreliability of the data.

Table 4.4: Area built-up land

	year	% of total land area	total area (1000 ha)	ha/cap
Benin	1980	0.3	35	0.01
	1987	0.4	42	0.01
	1994	0.5	52	0.01
Bhutan	1980	0.1	3	0.01
	1987	0.1	4	0.01
	1994	0.1	5	0.01
Costa Rica	1980	0.3	15	0.01
	1987	0.4	19	0.01
	1994	0.4	23	0.01
The Netherlands	1980	6.5	272	0.02
	1987	7.0	291	0.02
	1994	7.5	313	0.02

4.4 Total land use

4.4.1 Total land use

Figure 4.7 shows the total amount of land used for consumption of food, animal and wood products and built-up land in Benin, Bhutan, Costa Rica and the Netherlands for 1980, 1987 and 1994 on the basis of FAO data. The total net land use increases for all countries. *Figure 4.7* shows that for the four countries the largest shares of net land use (for those included in the study) can be attributed to the consumption of wood (25-50% of land use) and animal products (20-55% of land use). In Bhutan and Costa Rica, use of pasture land for low-intensity husbandry explains the large amount of land attributed to these categories (see also *Table 4.5*).

Comparison of the national footprints to the area of land actually available reveals to what extent the country relies on resources outside its own territory. The Netherlands uses much more land than domestically available; this was to be expected in view of the high population density. By means of international trade, the Netherlands has historically been able to use additional land in other countries - for instance, by importing cassava as fodder. The country is thus strongly reliant on land outside its territory.

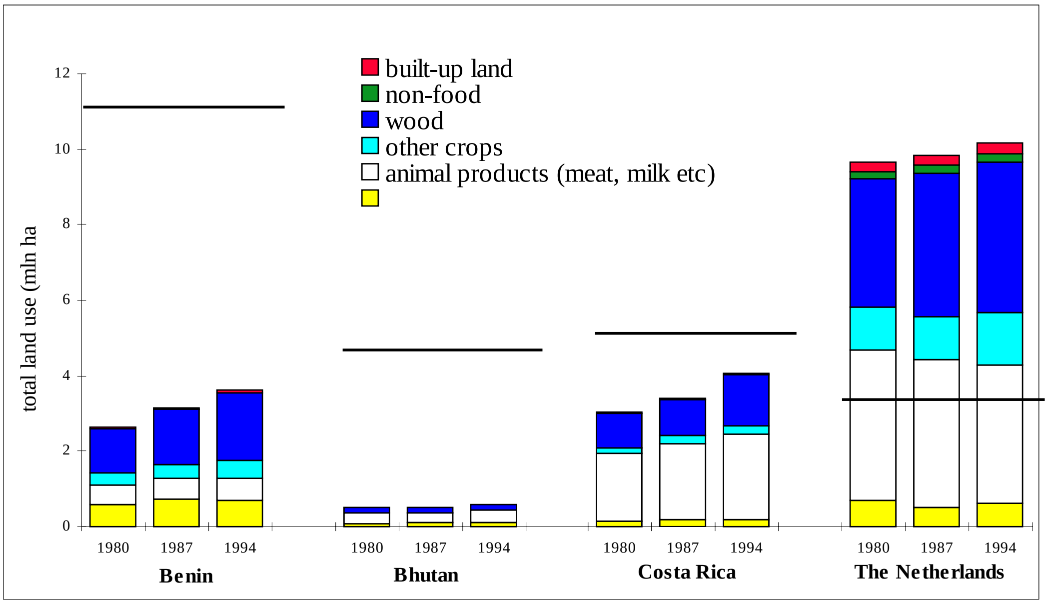

Figure 4.7: Net land use for agricultural products and wood

Note: The horizontal line indicates the actual size of each country; non-food includes land use for cotton and rubber.

Table 4.5: Share of different categories in total net land use

	Benin (%)	*Bhutan (%)*	*Costa Rica (%)*	*Netherlands (%)*
Cereals	19	19	4	6
Animal products (meat, milk etc.)	17	33	56	36
Other crops	13	2	5	13
Wood	50	23	34	39
Non-food	0	0	1	2
Built-up land	1	1	1	3

The surplus of domestically available land and land used for human consumption in Benin, Bhutan and Costa Rica is mainly brought about by relatively large areas which are still undomesticated. Also for Costa Rica, a sizeable amount of land is allocated to exports of fruit and coffee. At first glance, the surplus of land in all three countries might indicate that they still have the ability to increase the amount of land used within their own territory (although at the expense of biodiversity). However, in Bhutan, in particular, the potential for agricultural expansion is severely limited due the lack of arable land.

According to an earlier assessment (comparable methodology, focusing more on national data but with the same results), the gross land use, i.e. land used for the Netherlands' economy for food, animal feed and wood production inside and outside its borders was, in 1995, equal to 3 to 4 times its land surface (RIVM, 1997). By subtracting the land use for the Netherlands' exports to other countries, the net land use is found to be about 2 to 3 times the total land surface of the Netherlands. The largest share of land outside the Netherlands used for Dutch consumption is land for timber from Canada, Scandinavia and other parts of Western Europe. Food production also claims an important share, in particular, in North and South America, and Africa. Finally, land is used for the production of animal feed in Western Europe, North America, South America and Southeast Asia (Thailand).

4.4.2 Land use per capita for consumption of agricultural and wood products

Figure 4.8 shows the per capita land use for Benin, Bhutan, Costa Rica and the Netherlands. The comparison - as discussed before - is strongly influenced by differences in agricultural productivity. Possibly surprisingly, *Figure 4.8* shows that real net land use per capita is lowest for the Netherlands as a result of the high agricultural productivity of this country. For Costa Rica, the real net land use per capita is highest, mainly due to extensively used pasture lands (which are often marginal lands cleared from forest over the last decades). *Figure 4.8* also shows that in all four countries, the amount of land used per capita declines.

We argued that it might be possible to calculate a 'corrected' land use using 'natural yield factors' but this would require a large set of assumptions. Here, we have simply included the land use based on global average yields as a reference - thus not only nullifying differences in natural circumstances but also management factors (also Wackernagel et al., 1997 calculate their figures on the basis of global yields). The combination of real yield and global average yields figures indicates how important differences in yield are: for the Netherlands, for instance, land use increases from 0.7 ha. to almost 3.0 ha. per capita.

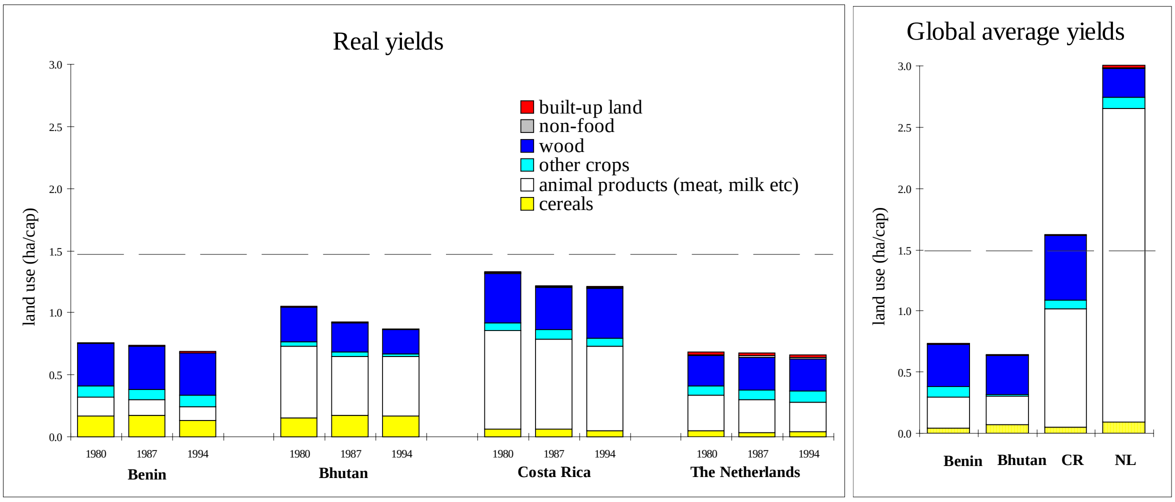

Figure 4.8: Net land use per capita based on actual and global average yield (1994)
Note: The horizontal line indicates global productive land per capita in 1994 - including forest, agricultural and built-up land (Wackernagel et al., 1997).

In terms of net land use based on global average yields, obviously land use of the Netherlands is largest - indicating the high level of consumption in this country. In particular, the consumption of meat and diary products represents a large share of the land use of the Netherlands if accounted for on the basis of global yields. Both the Netherlands and Costa Rica use a larger amount of 'global average yield land' than is actually available. On this measure, land use of Benin and Bhutan are lowest, being directly related to the low consumption level in these countries. The contrast between the left and right parts of *Figure 4.8* demonstrates the influence of both natural and humanly influenced factors determining agricultural yield.

In time, per capita use of land in Benin, Bhutan and Costa Rica decreases - while the per capita use of land in the Netherlands is almost stable. The most important reason for this are changes in productivity as discussed in the next section. In general, in Benin and Bhutan the consumed products have been produced with yields lower than the world average. In Costa Rica and especially in the Netherlands local yields are higher than global average yields per hectare.

4.5 Time trends in land use

Four trends could be held responsible for changes in the total real net land use for agricultural products:
1. changes in population;
2. changes in the level of consumption;
3. changes in yields per hectare;
4. changes in composition of consumption patterns.

Table 4.6 shows the contribution of each of these factors but limited by the reliability of the data; the figures should be seen as rough indications. In all four countries, increasing population has caused an important upward pressure on land use (about 10% increase in the Netherlands and 40-50% increase in the other three countries). The land use per capita, on the other hand, has decreased in all four countries by 10-17%. Increasing yield per product has been the most important factor behind the decrease in per capita land use in Benin, Costa Rica and the Netherlands - while in Bhutan, available data suggest a (further) shift away from land-intensive dairy products, also contributing to a lower land use per capita. Data for Bhutan are, however, relatively poor.

Table 4.6: Trends in net land use driving forces (1980-1994)

	Benin (% change)	*Bhutan* (% change)	*Costa Rica* (% change)	*Netherlands* (% change)
Consumption per capita	15	0	5	-1
Changes in consumption pattern	0	-10	5	-1
Increase in productivity	-30	-5	-25	-9
Land use per capita	*-15*	*-12*	*-15*	*-11*
Population	50	40	45	9
Land use	*25*	*20*	*25*	*-3*

The effect of consumption per capita, changing consumption patterns and productivity increase have been estimated by keeping the other two factors constant at 1987 level and thus analysing the influence of each factor separately.

4.6 Uncertainty of the data

We calculated the highest and lowest estimate for land use in each country on the basis of available (mostly national) data on consumption, yields or actual land use. These estimates, although strongly influenced by the presence of alternative data, gives some indication of the uncertainties involved in the land use assessment. For the Netherlands, these respective estimates are about 100% higher and 20% lower than the central estimate. The high estimate is mainly based on the study of Harjono et al. (1996). Other important factors are uncertainty in the estimates on the productivity of forests and the allocation of land to exports of dairy products and meat. For Costa Rica, the high and low estimates differ by 60% and 30% respectively from the central estimate. The most important factors here are the consumption of wood products (high estimate based on Wackernagel et al. (1997c), the productivity of pastures and amount of land attributed to other crops and non-food product. For Benin, the spread around the central estimate is about 30%. For Bhutan, the highest estimate is about 80% higher than the central estimate. Again, the productivity attributed to forests dominates the differences found.

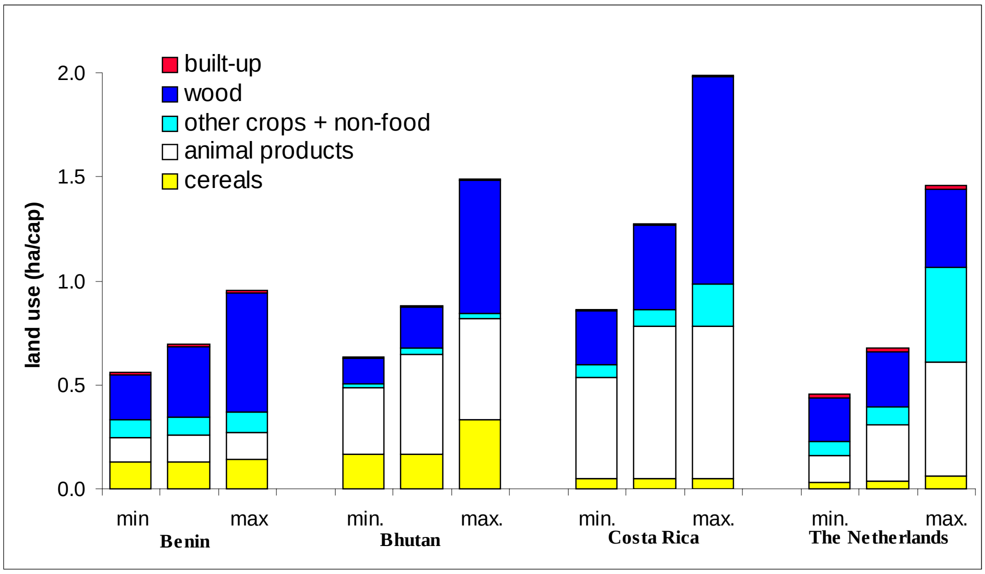

Figure 4.9: Highest and lowest estimate for net land use based on actual yields

5. Ecological Footprint for carbon dioxide emissions

The EF approach to carbon dioxide emissions is to determine the total amount of emissions related to consumption patterns within a certain region, thus including emissions related to imports and subtracting emissions related to exports. 'Regular' carbon dioxide statistics focus on the amount of energy and carbon dioxide emitted within a certain region, independent of where produced goods are finally consumed. Therefore, for assessing the EF for carbon dioxide emissions, it is necessary to adapt these statistics on the basis of observed imports and exports.

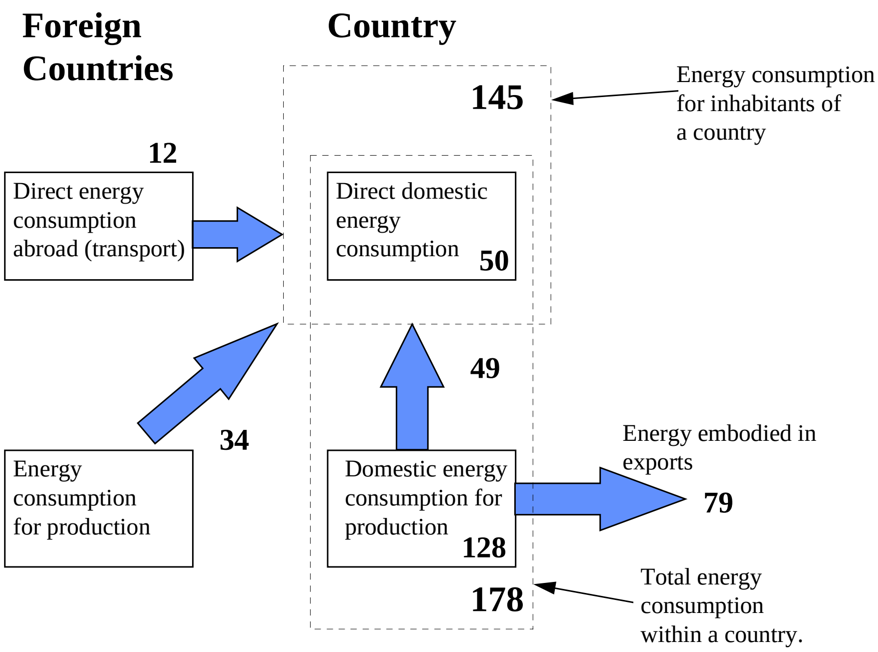

Figure 5.1: Ecological Footprint for carbon dioxide emissions - General approach and examples for the Netherlands
Note: numbers are in Mtonnes per year
Source: RIVM, 1998

For the Netherlands, this approach had been applied in earlier calculations as shown in *Figure 5.1*. Energy statistics, concentrating on the energy consumption within the Netherlands, show an emission of about 180 Mtonnes carbon dioxide in 1995 (=10.5 tonne per person). However, part of these emissions can be attributed to exports to other countries, while abroad emissions are caused for consumption of inhabitants of the Netherlands. The net 'emission balance of trade' for the Netherlands result in a lower emissions, about 145 Mtonnes (= 8.5 tonne per person). The main reason for this is that Netherlands has a relatively energy-intensive heavy industry, which produces goods (chemicals, steel etc.) for a large number of other countries.

In the following sections, we first discuss domestic energy consumption in each of the four countries. After this, we will discuss the actual carbon dioxide emissions which have been attributed to the four countries (EF). Next, we will look at land use for sequestering carbon dioxide emissions according to the methodology of Wackernagel and Rees (1996). Finally, we will discuss time trends in some of the underlying factors.

5.1 Energy consumption

Table 5.1 shows energy consumption per capita in Benin, Bhutan, Costa Rica and the Netherlands. Not surprisingly, *Table 5.1* indicates that far more energy is used in the Netherlands than in Costa Rica (60% less) and Benin and Bhutan (more than 90% less). Moreover, energy consumption in Costa Rica, Benin and Bhutan is based less on fossil fuels. Most of the commercial energy consumed in these countries is based on hydropower (thus zero emissions)[12]. In addition, a lot of fuelwood is consumed[13]. Resulting carbon dioxide emissions per capita are, thus, very low.

Table 5.1: Energy consumption per capita in 1994

	Oil GJ/cap	*Coal GJ/cap*	*Natural gas GJ/cap*	*Fuelwood GJ/cap*	*Hydro GJ/cap*	*Nuclear GJ/cap*	*Other GJ/cap*	*Total GJ/cap*
Benin	1.3	0	0	9.9	0.2	0	0	11
Bhutan	0.1	0	0	8.7	1.1	0	0	10
Costa Rica	22.3	0	0	9.5	3.7	0	0.5	36
Netherlands	65.4	23.3	91.6	0.1	0	2.6	1.9	185

Source: Van Vuuren and De Kruijf, 1997; CBS, 1996.

5.2 Carbon dioxide emissions

For EF assessment, carbon dioxide emissions within each country should be corrected for the energy embodied in the imported or exported goods. The total surplus (+) or deficit (-) of the trade balance is in all the four countries is less than 10% of total GDP: for Benin, Costa Rica and the Netherlands respectively +8.4, +3.0 and -5.6 % of the GDP in 1994 (see Van Vuuren and De Kruijf, 1998; data for Bhutan is less reliable).

Figure 5.2 shows domestic carbon dioxide emissions in the Netherlands and net emissions for consumption of the population of the Netherlands for the 1985-1997 period (same data as *Figure 5.1* but now as time series). The net emissions include emissions for persons from the Netherlands travelling abroad (air transport and cars). Earlier, Suri and Chapman (1998) reported that one factor behind the decreasing elasticity of energy to GDP in industrialised countries, as a group, is an increased import of manufactured goods from developing countries. This would imply - in terms of the EF - that net emissions grow faster than domestic emissions (since the former would also include the increased emissions in developing countries). The available data for the Netherlands, however, does not provide evidence for such a shift for this particular country. The Netherlands, however, has a large positive balance of trade; increasing exports in the same period may have offset increasing imports from developing countries.

[12] The use of land for hydropower has not been included in this study. Wackernagel et al. (1997) estimate the global average area occupied by hydropower dams is equal to 0.001 ha/GJ per yr. Using this world average figure for each of the four countries suggests per capita use of land for hydropower as negligible.

[13] Carbon dioxide emissions from fuelwood are normally not included in carbon dioxide emission inventories. In Benin and Bhutan, energy consumption of fuelwood is about 10 GJ per person per year in comparison with the 180 GJ per person of commercial fuels consumed in the Netherlands. Land use needed for fuelwood consumption has been included in Chapter 4.

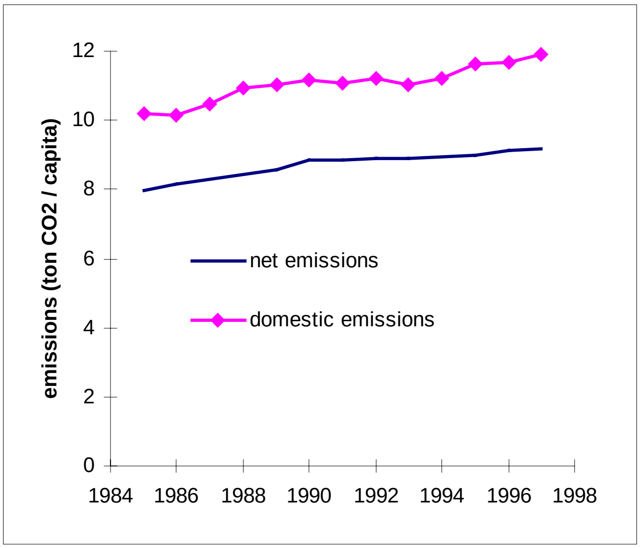

Figure 5.2: Trends in carbon dioxide emissions of the Netherlands
Source: RIVM, 1998 based on CBS,1998.

Based on the balance of trade in monetary terms - and the composition in type of products, it can be expected that Benin, Bhutan and Costa Rica have a (small) net import of energy embodied in products. For the purpose of this report, we have tried to correct the national energy statistics on the basis of the UN Trade Statistics for Benin, Bhutan and Costa Rica. However, results proven to be unsatisfactory due to uncertain and insufficient data and have not been used. For Costa Rica, we have used the results of Wackernagel et al (1997.

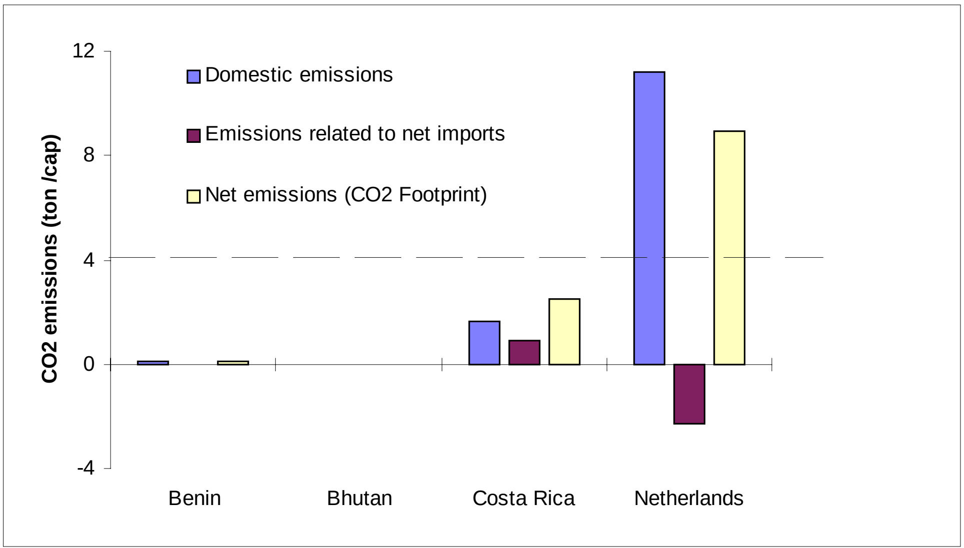

Figure 5.3: Ecological Footprint for carbon dioxide emissions in 1994
Note: The net effect of imports and exports is shown in *Figure 5.3* as negative emissions for the Netherlands. The effects of trade for Benin and Bhutan have not been included, since the data are highly uncertain. These two countries are expected to have a small net import of energy taken up in products. The horizontal line indicates global average emissions per capita in 1994.

In *Figure 5.3* the final EFs for carbon dioxide emissions for Benin, Bhutan, Costa Rica and the Netherlands are shown. For Costa Rica net carbon dioxide emissions are slightly higher than domestic emissions as a result of import of manufactured products. As for land use, the level of carbon dioxide emissions is also influenced by differences in natural circumstances (a cold climate will increase heating requirement), although these influences will be limited to a few per cent of carbon dioxide emissions only.

5.3 Land use for sequestering carbon dioxide emissions

Wackernagel and Rees (1996) express the amount of carbon dioxide emissions in terms of the amount of land needed for sequestering these emissions – in order to facilitate aggregation with other indicators. In *Chapter 2,* we indicated that this 'conversion' has also considerable disadvantages – including creating a virtual type of land use. Nevertheless in this section we will follow their proposal to allow comparison of our results with those of other studies.

In our calculations, we take into account differences in amount of carbon dioxide per GJ for each fuel type as expressed in *Table 5.2*.

Table 5.2: Emission factors used in this study

	Emission factor (kg CO_2 / GJ)
Coal	93
Oil	73
Natural gas	56

A diverse array of estimates for the sequestration rates per hectare can be found in literature – depending for instance on forest types, forests management, the time period considered and socio-economic criteria. Nabuurs et al. (1999), for instance, mention sequestration rates for different countries ranging from 2.2 to more than 10 tonne CO_2 per ha. per year. Nillson and Schopfhauser (1995) estimate that the global mean carbon flux rate is about 11 tonne CO_2 per ha. per year. Also Wackernagel and Rees (1996) reviewed different rates for temperate, boreal and tropical forests and indicate that average forest can accumulate approximately 6.6 tonne of carbon dioxide per year. In the latest publication, however, Wackernagel et al. (1997c) use a sequestration rate of 5.2 tonne CO_2 per ha. per year. Obviously, the sequestration rate used strongly influences the total amount of land attributed to energy consumption. In this report, we use both a sequestration rate of 5.2 tonne CO_2 per ha. per year (low estimate – but consistent with Wackernagel et al. (1997c)) and 11 tonne CO_2 per ha. per year (estimate of Nillson and Schopfhauser (1995)).

Figure 5.4 shows how much land would be required to sequester industrial emissions per capita of the four countries. The Netherlands would require the largest forests per capita to absorb the carbon dioxide emission. In Costa Rica the required area forest per capita to absorb the carbon dioxide emissions is about three times lower than in the Netherlands. In all the four countries, carbon dioxide emission (and thus the sequestration area) have increased between 1980 and 1994. Using the lower sequestration rate of Nillson and Schopfhauser reduces land use by a factor two. Currently, land really used for carbon dioxide sequestering is only very limited. However, current negotiations under the Framework Convention on Climate Change seem to lead to allowing sequestering as a method for fulfilling the 'obligations' under this convention (potentially in combination with carbon trading). This could lead to sharp increases in the land used for carbon sequestering.

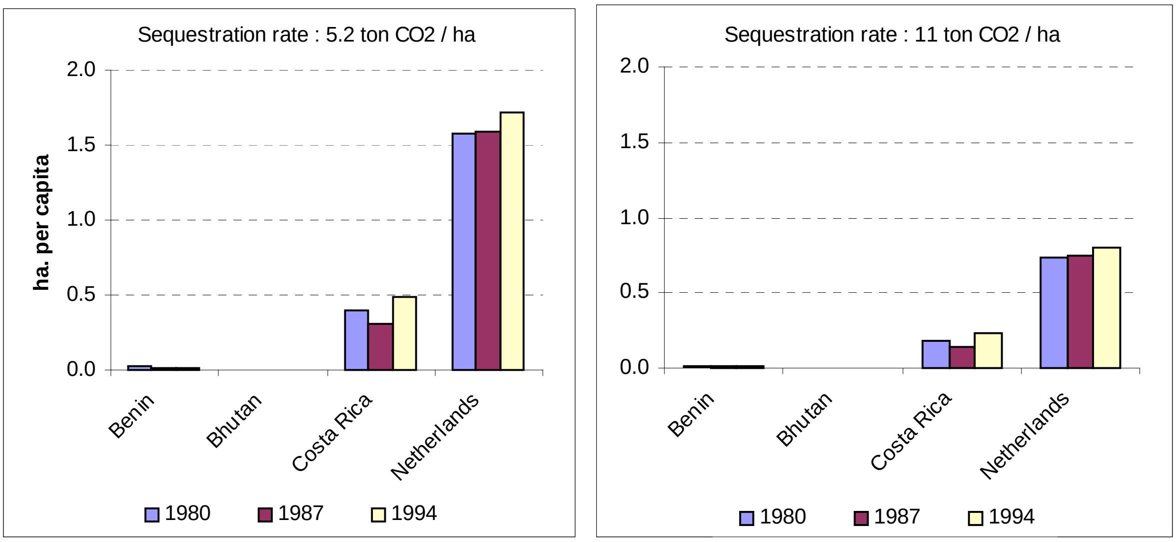

Figure 5.4: Land required to absorb all carbon dioxide emissions (commercial fuels)

Consumption of fuelwood already causes use of 'real' land. This type of land use has already been discussed in the section on wood products in *Chapter 4*. Alternatively, one could also include fuelwood in this section as a form of energy. Thus, different calculation methods could be used to compare the countries:

- fuel wood consumption multiplied by global average yields per hectare for wood products;
- fuel wood consumption multiplied by local average yields per hectare for wood products;
- fuel wood consumption multiplied by the emission factor for fuel wood and the global average absorption rates of carbon dioxide (to compare with other forms of energy).

The methods lead to differences in land attributed to fuel wood consumption. *Figure 5.5* shows the results of the last method.

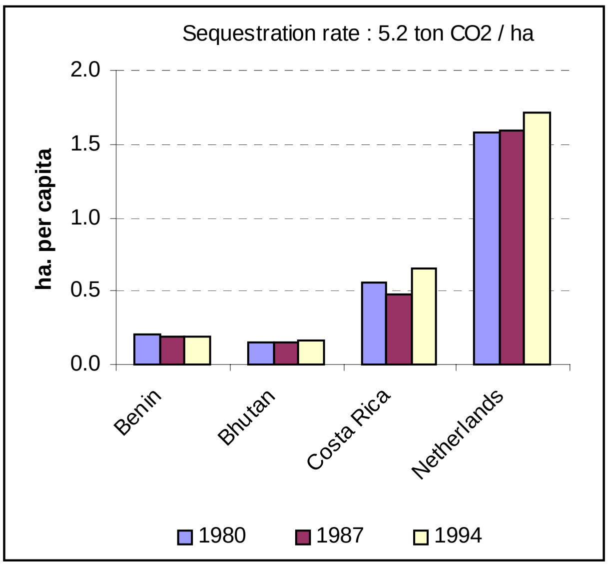

Figure 5.5: Land required to absorb carbon dioxide emissions, including fuel wood

5.4 Trends in carbon dioxide emissions

Trends in carbon dioxide emissions can be discussed vis-à-vis changes in population size, per capita income and carbon intensity (the so-called Kaya identity; Kaya, 1989). Although the Kaya identity does not provide an explanatory model, it offers a simple and transparent accounting framework which can assess the contribution of different factors to the overall change in carbon dioxide emissions. The factors included here are:

- population
- GDP per capita
- carbon intensity (carbon dioxide emissions per unit of GDP)

Table 5.3: Trends in carbon dioxide Ecological Footprint driving forces (1980-1994)

	Benin (% change)	*Bhutan* (% change)	*Costa Rica* (% change)	*Netherlands* (% change)
Population growth	52%	40%	34%	9%
GDP per capita (ppp 1987$)	-15%	76%	2%	20%
Carbon intensity (ktonnes CO2/ppp 1987$)	-10%	-	31%	-9%
Carbon dioxide emissions (Mtonnes)	15%	-	80%	18%

Note: '-'indicates no reliable data.

Sources: Carbon dioxide emissions are calculated as described under methodology; population growth and GDP in purchasing-power parity dollars per capita are taken from World Bank, 1998 (data for Bhutan from Van Vuuren and De Kruijf, 1998).

Table 5.3 shows the changes of the three different factors. In all four countries, population growth can be identified as an important upward pressure on carbon dioxide emissions. In addition, in the Netherlands and Bhutan GDP per capita has increased strongly over the 1980-1994 period (less so in Benin and Costa Rica as a result of strong economic recessions during the period of study). The remaining factor, carbon intensity (carbon dioxide emissions per unit of GDP), is a function of energy efficiency, structural changes in the economy and the type of fuel used. World-wide, carbon intensities decrease over time for industrialised countries while for developing countries trends are country-specific. Carbon intensity has decreased in the Netherlands and Benin, but increased in Costa Rica as result of an increased share of commercial fuels.

6. Aggregated Ecological Footprint

In the EF as defined by Wackernagel and Rees (1996) different types of resource use are finally aggregated into one single Ecological Footprint. *Figure 6.1* shows the EF that would result from calculations based on the definition of Wackernagel and Rees, i.e. including land for carbon sequestration ('energy land') - based either on real yields or global average yields. Real yields do reflect the actual land use of countries, but differences in natural circumstances the results strongly.

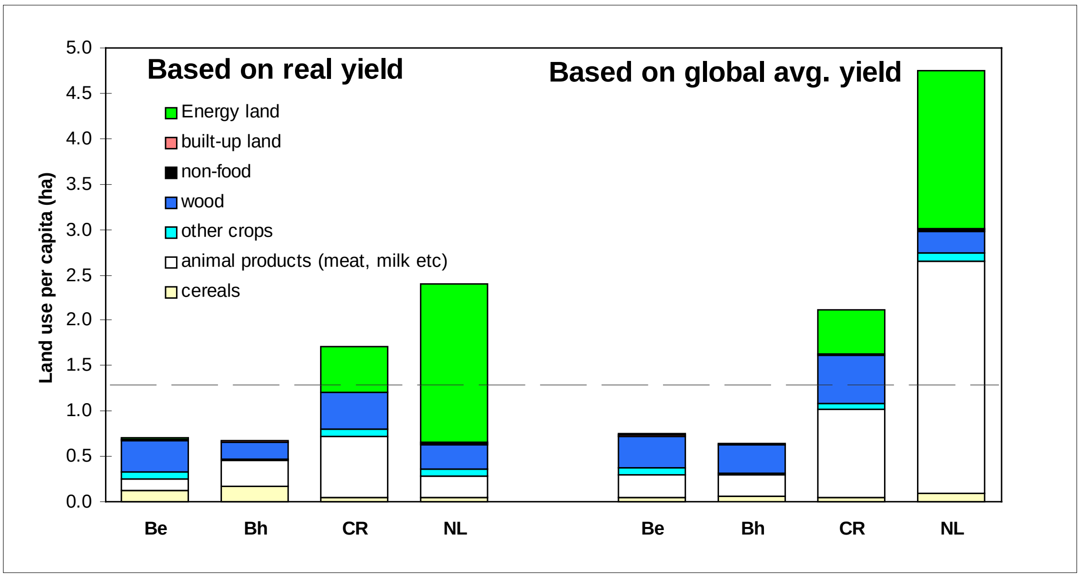

Figure 6.1: Ecological Footprint - definition Wackernagel and Rees (1996)
Note: Land use is included using real land use and global average yield as a base. The horizontal line indicates the level considered to be sustainable on the global scale by Wackernagel et al. (1997).

'Energy land' now becomes an important part of the EF of the Netherlands – and to some degree as well the EF of Costa Rica. As discussed in *Chapter 5*, the size of 'energy land' depends strongly on the assumed sequestration rates. Here, those of Wackernagel et al. (1997c) are used. The calculated figures can be compared with the 1.31 ha. per capita considered sustainable at global level by Wackernagel et al. (1997)[14]. The Netherlands and also Costa Rica are considerably above this level on a global average yield basis. In *Chapter 7*, results are compared to those of Wackernagel et al. (1997c).

[14] Wackernagel et al. (1997) mention that on global scale, 2.1 ha. per capita was available in 1993 - including 0.56 ha. sea. After subtracting the sea area, setting aside 12% of the land area for biodiversity, and recalculating available land on the basis of 1994 population data, 1.31 ha. per capita remains..

7. Comparison with other studies

7.1 Comparison of final results with those of Wackernagel et al. (1997)

The land use based on global average yields as calculated in this study can be compared to the earlier calculations of Wackernagel et al. (1997c). For comparison, we combined the equivalence factors of Wackernagel et al. (1997c) with our results. Moreover, we subtracted the use of sea area for fish from the results of Wackernagel et al. (1997c). The aggregated EFs of this study for the Netherlands and Costa Rica are somewhat lower than the earlier results (4.6 ha. per capita versus 5.2 ha. per capita, and 2.1 ha. per capita versus 2.4 ha. per capita, respectively). The main underlying differences are a smaller area attributed to forest use and carbon dioxide emissions for both countries and a larger area attributed to pasture land for Costa Rica.

Figure 7.1 shows the results of this study in comparison with the 52 countries included in the study of Wackernagel et al. (1997). Both the carbon dioxide emissions and land use component of the EF do more-or-less correlate with GDP per capita. At the same time, however, the spread of individual countries is large.

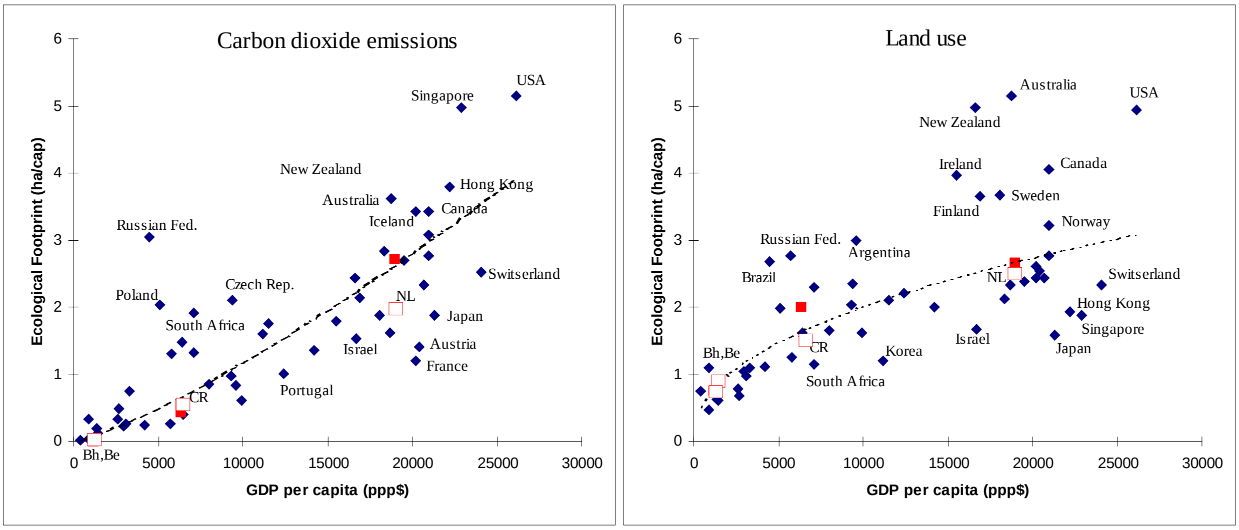

Figure 7.1: Wackernagel and Rees' EF on the basis of this study and earlier results
Source: EF data from Wackernagel et al. (1997) (closed diamonds) and this report(larger open squares) – the Netherlands and Costa Rica data from Wackernagel et al. (1997) are indicated by closed squares; GDP per capita in purchasing-power-parity dollars from World Bank, 1998.
Note: Dashed lines indicates best fit found on basis of linear, exponential and logarithmic fitting of the data.

The discussion in this article gives some idea of the causes of the spread, including consumption patterns and the overall level of consumption, local agricultural and climatic agricultural practices, influence of environmental policies and uncertainty in data and calculation methods. In case of land use, the available data seem to suggest a slow saturation at higher income levels. Within the Netherlands, a study looking at land use of different income groups made a similar observation. The countries above the 'average curve' are all large, scarcely populated countries - perhaps caused by the fact that land efficiency in these countries is less of a need. The carbon dioxide component shows that in addition to countries with high domestic emissions, such as the USA and the Russian Federation, also affluent, importing countries can, in EF terms, be identified as having a large per capita contribution to global emissions. This includes, for instance, countries like Hong-Kong, Iceland and Singapore.

7.2 Comparison of results for the Netherlands

Several studies have looked at the use of land for consumption in the Netherlands. Interestingly, the results of these studies differ considerably. Several factors are responsible for these differences:

- differences in comprehensiveness of the study (which crops and products are taken into account);
- differences in consumption, import and export data;
- differences in calculation methods (for instance, animal husbandry produces several products such as meat, milk, cheese, leather etc. Due to the fact that these products are imported and exported in various amounts, final land use of country depends on the allocation method used to allocate land to these different products);
- differences in yields assumptions (for instance, due to imports from different countries).

Table 7.1 summarises the studies that have looked explicitly at the total land use for consumption. *Table 7.2* summarises the studies that have focussed on the total land use for imports (thus excluding domestic land use and exports). Obviously, land-use assessments of Wackernagel et al. (1997c) cannot be compared directly to the other studies, since they use global average yields instead of local yields.

Studies overviewing land use for consumption (Table 7.1)

Several studies have tried to assess land use that can be attributed to consumption of the Netherlands. Most of these studies have paid attention to the land use of food consumption – which represents a considerable share of total land use (the only other large category is land use for consumption of wood products). Rietveld (1985) assessed the land use for food consumption of the Netherlands' population to be between 4 and 6 million ha. in 1985. Most of the more recent studies produced estimates within this range: 4.7 million ha. in 1994 (RIVM, 1997) and 4.5 million ha. in 1994 (RIVM, 1998b). The current study estimated this category of land use to be 5.5 million ha. All these studies used a combination of national and international (FAO) production and consumption statistics. Here, consumption is defined as apparent consumption, i.e. the difference between production, import and export flows. A study of the University of Groningen recently found a considerably lower figure, on the basis of consumption survey statistics: i.e. 2 to 3 million ha. The reason for the differences between the latter and the studies mentioned above is still unknown.

The studies for which more detail were available have been mentioned in *Table 7.1.*Below we discuss the most important differences identified in this table.

- The large differences in total consumption of cereals between Wackernagel (1997c) and the other three studies is probably caused by the fact that the former also partly covers cereals used as animal feed (although also a separate category 'animal feed' is included in their study). The final amount of land attributed to consumption of cereals of the other three studies differs between 0.33 and 0.61 Mha.
- Land use for grapes for wine production has been included in only one study, but does not seem to be significant for the final land use.
- Sugar consumption in RIVM (1997) and this study are expressed in terms of sugar crop equivalents. Wackernagel et al. (1997c) record their consumption rates (most probably) in

sugar equivalents, explaining the factor 10 difference. The differences in land use attributed to this category are, in absolute numbers, relatively small.

- As Wackernagel et al. (1997c) do not distinguish systematically between fruit and vegetables, their category has been mentioned under vegetables. The category in Wackernagel et al. (1997c) most probably also covers roots and tubers used as feed for animals. This explains the factor 3 to 4 difference between this study and the other three studies in terms of consumption rates. The final land use in this category lies between 0.1 Mha. (RIVM, 1997) and 0.3 Mha. (RIVM, 1998b).
- The differences in the category of oil and oil products are relatively large, in particular, in terms of consumption rates (high rates in RIVM, 1998b; very low rates in this study). This is caused mainly by methodological differences. First of all, since the cakes remaining after pressing oil out of oil seeds are used as animal feed part of the oil crops, they have, in this study, been partly contributed to this category. Secondly, consumption rates can refer to the weight of oils or to the weight of the original oil seeds.
- The category stimulants covers consumption of coffee, tea and cacao. Despite some differences in consumption rates, the land use in this category is fairly comparable between the four different studies.
- The category animal products shows the largest differences in land use. In RIVM (1998b) this category has only been included in terms of land required for production of animal feed. A very important factor is formed by the exports of all kind of different products to other European countries. Assumptions with regard to land attributed to different products can result in considerable differences. Final land use differs from 1.3 Mha. to 3.7 Mha. for the three studies using local yields and 19 Mha. for Wackernagel et al. (1997c). Again it should be noted that in some studies part of the land use for animal feed (oil seeds, vegetables) has been covered under other headings (cereals, oil crops).

Table 7.1: Total land attributed to consumption in the Netherlands according to different studies (data for 1994 or 1995)

	RIVM, 1998b			RIVM, 1997			This study			Wackernagel (1997c)		
	cons.	yield	Land	Cons.	yield	land	cons.	Yield	land	cons.	yield	land
	mln kg	kg/ha	mln ha	Mln kg	kg/ha	mln ha	mln kg	Kg/ha	mln ha	mln kg	kg/ha	mln ha
Cereals	3,000	7,000	**0.4**	2,122	6,506	**0.3**	3,069	5,064	**0.6**	8,046	2,725	**3.0**
Wine				278	6,780	**0.0**						
Sugar (products)				9,273	59,527	**0.2**	7,399	65,478	**0.1**	770	4,862	**0.2**
Vegetables	1,100	16,667	**0.1**	2,954	38.364	**0.1**	3,283	15,172	**0.2**	13,410	8,115	**1.7**
Fruit	3,225	11,367	**0.3**	732	31,826	**0.0**	2,308	27,249	**0.1**	n.a.	n.a.	**n.a.**
Oil / oil seeds	4,450	2,171	**2.1**	1,454	2,879	**0.5**	438	1,795	**0.2**	4,022	1843	**2.2**
Stimuli	174	545	**0.3**	382	1,174	**0.3**	341	665	**0.5**	211	536	**0.4**
Animal products	-	-	**1.3**	12,440	3,845	**3.2**	10,445	2,836	**3.7**	6,381	336	**19.0**
Rubber,cotton etc	7	167	**0.0**			**0.0**			**0.2**	279	279	**1.0**
Fish										193	29	**6.7**
	mln m3	m3/ha	mln ha	mln m3	m3/ha	mln ha	mln m3	m3/ha	mln ha	mln m3	m3/ha	mln ha
Wood	14	4	**3.3**	14	4	**4.0**	11	3	**4.0**	12	2	**6.0**
			7.8			**8.7**			**9.7**			**40.4**

- Differences in the category ‘natural rubber, cotton etc.’ are mostly caused by the comprehensiveness of coverage of this category.
- 'Surface' use for fish consumption has only been covered by Wackernagel et al. (1997c). For the Netherlands this amount of land use covers less than 3% of the total amount of land attributed to consumption.
- Wood and wood products represent an important part of total land use. Consumption rates vary between 11 and 14 million m^3. The final amount of land use between the three studies based on local yields complies very well (3.3 – 4.0 Mha). It should be noted that

the RIVM studies and this study use similar sources for their yields. Stolp and Eppenga (1998) indicate that the total land attributed to consumption of wood could be estimated at 3.4 Mha. and 6.0 Mha, depending on assumptions regarding yields and origin of production, imports and exports.

Studies overviewing land use for imports (Table 7.2)

The land attributed to imports has been mentioned as separate numbers in RIVM (1998b), Harjono et al. (1996) and RIVM, 1997. The total numbers differ considerably. The study of Harjono et al. (1996) shows higher figures than any of the other studies (including the total land use for consumption of this study). One reason is that the study identifies more consumption categories than the other studies, in particular, within the more aggregated categories mentioned here (for instance, leather, minerals and even drugs). The total land covered by most of these categories, however, is very limited (around 1 Mha). The main differences are actually caused by differences for the categories oil and oil seeds, animal products, feed, sugar and wood (products), which are also covered by the other studies.

For feed, differences in the land attributed to imports of soybeans cakes are responsible for 3.8 Mha. Harjono et al. (1996) use a very high import figure and low yields for these cakes. For wood products, estimates for yields partly offset differences in import rates between the studies.

Table 7.2: Total land use attributed to imports according to different studies

	RIVM, 1998b			Harjono et al. (1996)			RIVM, 1997		
	import	yield	Land	import	Yield	land	import	Yield	land
	mln kg	kg/ha	mln ha.	mln kg	kg/ha	mln ha.	mln kg	kg/ha	mln ha.
Cereals	770	6,814	**0.1**	6,800	6,834	**1.0**	7,400	6,981	**1.1**
Wine and beer	222	5,414	**0.0**	379	6,768	**0.1**			
Sugar				1,207	2,187	**0.6**			**0.0**
Vegetables	1,145	39,482	**0.0**	3,299	14,343	**0.2**	1,440	16,000	**0.1**
Fruit	355	32,272	**0.0**	1,853	10,528	**0.2**	6,690	11,503	**0.6**
Stimulants	381	530	**0.7**	728	696	**1.0**	663	475	**1.4**
Oil / oil seeds	1,454	2,874	**0.5**	8,573	1,869	**4.6**	6,320	2,221	**2.8**
Animal products				2,593	7,499	**2.6**			**0.0**
Feed	12,470	11,035	**1.1**	16,674	2,854	**5.8**	10,750	7,847	**1.4**
Rubber, cotton etc.	6		**0.0**	353	-	**0.3**	13	167	**0.1**
Tobacco				125	2,717	**0.0**			
Minerals				33,276	0	**0.0**			
	mln m3	**m3/ha**	**mln ha.**	**mln m3**	**m3/ha**	**mln ha.**	**mln m3**	**m3/ha**	**mln ha.**
Wood (products)	13	3.4	**3.8**	11	2	**5.7**	17	4	**4.0**
			6.4			**22.2**			**11.5**

Overall conclusions

The discussion indicates that even for the Netherlands, a country with relatively high data availability, considerable differences can be found between studies that consider the land that attributed to consumption and imports. Most of these differences could be explained by looking at categories covered and yield assumptions. Comparison of the studies show the results of this study to be well within the range in earlier studies: results are found to be relatively close to RIVM (1997) and RIVM (1998b) despite differences in the main data source used (FAO versus national sources) and detail. The studies of Wackernagel et al. (1997) and Harjono et al. (1997) indicate a much higher land use. For the former, this is completely due to the use of global average yields and not local yields.

8. Conclusions

8.1 The Ecological Footprint concept

The first objective of this study was to review the EF concept as an indicator for environmental pressure resulting from different consumption/production patterns. In methodological terms, the two innovating aspects of the EF concept are:

- the EF focuses on the environmental consequences resulting from the final consumption of a certain defined population. This not only includes domestic environmental effects but also (indirect) pressures generated outside the region (related to imports);
- the EF aggregates data on the consumption of different resources into one single indicator.

On the basis of the available literature, we concluded in *Chapter 2* that the EF has several appealing attributes but that there are also several obstacles in using the EF. As a concept, the EF covers simultaneously several issues relevant for sustainable development such as reallocation of environmental pressure to other countries, squandering of resources and the equity issue in resource use, as well as impacts of the use of renewable resources, trade and changes in consumption patterns. However, as well as support, the EF has also received criticism, particularly related to the high level of aggregation. Aggregation of different types of resources into one single indicator (land and carbon dioxide emissions) - as done by Wackernagel and Rees (1996) – is based on a weighting system, which unavoidably include subjective choices.

Adapted method versus original method

In this report, we adapted the EF calculation method of Wackernagel and Rees (1996) on several points. Specifically, we disaggregated the EF into separate footprints for individual resources, thus avoiding the controversial topic of combining real land use and land equivalents for carbon sequestration, while holding on to the more attractive attributes of the EF concept. In addition, we calculated land use on the basis of local yields to show the real land use of countries (a parameter that is more policy relevant at the national level). It was shown that for international comparison, however, use of local yields *only* can lead to results that are difficult to compare unambiguously. Obviously, what is best depends on the objective of the comparison. In general, the present study makes a case for simultaneous use of local and global average yields calculations. We conclude that the disaggregated presentation used in this article increases the applicability of the indicator in policy-oriented assessment (we will return to this later).

The EF (calculated in this report) includes the consumption of agricultural products, wood, built-up area and fossil fuels. Earlier studies indicated that for land use, the first three categories are the most important categories. The EF can, in principle, be calculated for the Netherlands from data included in the Environmental Balance and CBS statistics. For the other countries, FAO data extended with national information makes EF estimates possible. Estimates should however be used realising the uncertainty in data.

8.2 Results of calculations

Agricultural land use

The results of this study suggest that the total land use of all four countries is increasing - or in other words in none of them does absolute de-materialisation takes place in terms of land. In contrast, land use per person is decreasing in all four countries (but is too slow to offset the increasing population). Theoretically a further growth of the need for agricultural and forest land could be prevented by either exploiting the opportunities for increasing agricultural yields in a sustainable way or by changing consumption patterns - otherwise land conversion will lead to a further decline of natural areas and therefore biodiversity.

The EF component (per capita) due to the consumption of agricultural products and wood consists of four important land use categories: cereals, meat and other animal products, wood and other crops.

Both differences in consumption per capita and differences in the yields per hectare have a large impact on the calculated land use per capita. The efficiency is (actively) influenced by agricultural knowledge, technology, crop types and agricultural methods, but also (passively) by natural circumstances. In the Netherlands for instance, average yields per hectare are high due to the intensive production methods, considerable agricultural experience, but also favourable natural circumstances.

In 1994, the calculated EF per capita due to the consumption of agricultural products on the basis of **local yields** (for imports, the yields of the country of origin) is smallest for the Netherlands. Per capita land use of the Netherlands is 0.7 ha. while land use of Benin, Bhutan and Costa Rica are 0.7, 0.9, and 1.2 hectares per capita, respectively. The countries with the highest consumption (Costa Rica and the Netherlands) have the highest yields per hectare resulting in relatively little land use for the countries with high consumption levels; the land use per capita for Benin and Bhutan is compared to consumption much higher.

The Netherlands – as a densely populated country – is strongly dependent on use of land in foreign countries for its food and timber products consumption. The country uses a total amount of land in other countries for imports of food, animal feed and wood equal to 3 to 4 times the surface area of the Netherlands. After subtracting exports the total amount of land used is 2 to 3 times the surface area of the Netherlands. The other three countries use a total land area smaller than the surface area of their country.

In all four countries, increasing population has caused an important upward pressure on land use (about 10% increase in the Netherlands and 40-50% increase in the other three countries). On the other hand, increasing yield per product has been the most important factor behind the decrease in per capita land use in Benin, Costa Rica and the Netherlands – while in Bhutan, available data suggest a (further) shift away from land-intensive dairy products, also contributing to a lower land use per capita.

If, instead of local yields, **global average yields** were used, the results would be lowest for Bhutan, followed by Benin, Costa Rica and the Netherlands at 0.6, 0.7, 1.7 and 3.0 ha. per capita, respectively.

Carbon dioxide emissions

The EF for carbon dioxide emissions gives a better representation of the emissions resulting from different consumption patterns than traditional carbon dioxide statistics.

The EF of the Netherlands in terms of carbon dioxide emissions is about 8.9 tonne per capita. This is much higher than the global average (4.0 tonne per capita), but considerably lower than the approximately 11.2 tonne per capita carbon dioxide emitted in the Netherlands. This is due to the large exports of (energy-intensive) products from the Netherlands. The EF in the other three countries is below the global average. For Costa Rica, emissions are ca. 60% less than those in the Netherlands. For Benin and Bhutan, emissions are less than 10% of those in the Netherlands.

For carbon dioxide emissions, not only absolute emissions but also per capita emissions, are increasing in all four countries.

Using the Kaya formula, different important factors behind increasing emissions in the four countries can be identified in 1980-1994 period. In Benin, population growth played an important role. In the other three countries, in addition, economic activities per capita have grown strongly. Improvements of energy efficiency in the Netherlands offset increasing demand for energy services to a large extent. In contrast, Costa Rica became more fossil fuel intensive in that period.

Comparing results with other studies

The study of Wackernagel et al. (1997) can be used to discuss our results in a somewhat broader context. There seems to be some relationship between land use (based on global average yields) and per capita income and between EF for carbon dioxide emissions and per capita emissions. In case of land use, the available data seem to suggest a slow saturation at higher income levels. Despite this general relationship, there is a strong divergence of country positions caused by for instance country size, consumption patterns but also by energy efficiency.

A more detailed comparison of existing studies on land use for consumption in the Netherlands shows that for a country with a relatively high data availability, considerable differences can be found between studies looking at the land use that can be attributed to consumption and imports. Most of these differences can be explained by looking at categories covered and yield assumptions. Comparison of the studies shows the results of this study to lie well within the range in earlier studies: results lie relatively close to RIVM (1997) and RIVM (1998b) despite differences in the main data source used (FAO versus national sources) and detail. The study of Harjono et al. (1996) assessed land use for imports of the Netherlands to be much higher than any of the other studies. The study includes more consumption categories – but the differences are, in fact, caused mainly by differences for the categories included in all studies (thus consumption rates and, most importantly, yields assumed).

8.3 Potential use of the Ecological Footprint

We will discuss the potential of the EF as an indicator for sustainable development on the basis of policy relevance, measurability, analytical soundness and communication to a broader public. In particular, we will consider the adapted EF methodology here, although most observations are also valid for the original EF.

Issue and policy relevance

Obviously, the use of the EF as the sole indicator for sustainable development is very limited: the EF only covers some of the environmental topics and does not contain any information on economic and social development. Consequently, it should be part of a larger set of indicators. Moreover, EF (like many other indicators) is simply what it says: an *indication* of the current situation; its results should form a basis for further discussion. Policies can only be formulated after further analysis and taking into account more considerations. But, no indicator should ever replace decision-making processes, since it will not be able to give sufficient insight in the underlying processes and might encourage leaning on only those parameters included in it (while a lot of criticism directed to the EF seems to be misguided by the idea that the EF is meant to do so).

The strong point of the EF (and thus its relevance) is its metaphor and the way it focuses on several issues directly related to sustainable development in an integrated way: impacts of consumption and consumption patterns, reallocation of pressures, squandering, impacts of renewable resources, distribution of available resources and the impacts of trade. At the same time, weak points are false concreteness (certainly, if aggregated) and some issues related to analytical soundness discussed further in this chapter.

The results of this assessment indicate that the EF (i.e. land use and carbon dioxide emissions related to consumption of people, regardless of where the consequences occur) could be an additional assessment framework to production or domestic pollution oriented approaches. Specific questions that EF indicators - in principle - could address are:

- What is the current use / environmental pressure of a specific population on key resources for sustainable development to support its current consumption? How does use change in time?
- How does resource use - in per capita terms - of this population relate to the average global use or a level considered to be more sustainable?
- Does environmental pressure of industrialised countries shift to industrialising countries from which goods are imported? What consequences does the consumption of a specific population have on the environment in other parts of the world?
- Does international trade result in lower or higher overall environmental pressure (see Proops et al., 1999)?
- How is the current resource use distributed among different countries? What could this mean for future resource use - either unabated or based on redistribution of the environmental space in a more equitable way?

In general, results of EFs can be interpreted more unambiguously for a specific country than for international comparison (e.g. as result of differences in land use potential).

With regard to policy relevance, it is helpful to distinguish between **direct** and **indirect** environmental pressures as indicated in *Figure 2.1***.** For the first type of pressures, the question of responsibility is relatively clear – in the second case (environmental pressures within an exporting country as a result of consumption in the country in study), moral responsibility and engagement can be leading principles. Such responsibility is even more important if:

- The socio-economic, technical or institutional circumstances in the exporting country do not allow for tough environmental management. Obviously, this is strongly related to distribution of financial resources.
- Multinationals take up their responsibility for preserving the global environment. In many countries, multinationals have a very large share in total economic activities – and thus, a large influence on production methods and standards (e.g. coffee, cotton and bananas).
- Investment and trade flows are influenced by perverse subsidies (Sips and Brieskorn, 1999).

Policy measures aimed at reducing EFs will in most cases go in the same direction as current environmental policies such as: 1) improving agricultural production, if necessary to prevent degradation of natural areas; 2) changing material consumption patterns and levels (in affluent societies) to a more sustainable level; and 3) reducing fossil fuel emissions by energy efficiency and use of renewable energy. In addition, however, the EF might encourage policies that take into account the consequences in other countries, in particular, for carbon dioxide emissions. Obviously, distribution of environmental resource use is related to the distribution of financial resources – and thus akin to much broader policy themes (see Davidson et al., 1997).

Measurability
UN.CSD earlier decided not to include the EF in their set of consumption indicators, since it might be to difficult to measure (UN.CSD, 1999). However, this study (and that of Wackernagel et al., 1997) shows that EF-type indicators can be calculated on the basis of available data such as FAO data and data from national statistical sources. Estimates should, obviously, be used while acknowledging the many uncertainties and inaccuracies in these data. For international comparison, definition of EF indicators should be further defined, as this still seems to create confusion about the comparability of earlier studies.

Analytical soundness
Despite the adaptations proposed in this report, analytical soundness is currently the most troubling criterion in accepting the EF as an indicator for sustainable development.

- The topic of aggregation deserves further discussion; although the aggregated EF might be useful in communication to a broader public, we are of the opinion that analytical soundness improves if the EF is elaborated as a set of resource indicators.
- An important limitation is still the issue of agricultural productivity. We have first of all used local yields, but this method suffers from the fact that productivity is not only a function of management but also of natural circumstances. For international comparison, it should be good to distinguish the influence of these two factors. The solution of Wackernagel and Rees (1996) to calculate land use on the basis of global average yields rules out the possibility of countries reducing their EF by improved agricultural management. An alternative solution would be the introduction of equivalence factors, however, this requires more insight into the different underlying factors.

- A similar problem still exists with regard to multifunctional land use. In the EF, only one function is given to a certain amount of land. However, in reality, land can have, to a certain degree, more than one function e.g. forests can simultaneously produce timber and fuelwood, support biodiversity, support recreational use and sequester carbon dioxide.
- The most important obstacle at the moment is handling unsustainable resource use in the context of the EF. For example, no distinction is made in sustainable and unsustainable land use – which might lead to the paradoxical situation that unsustainable agricultural production methods (contributing to soil degradation) decrease EF due to higher productivities. The wealth-of-nations work of the World Bank has exactly the same problem. Improvements here hinge on the development of indicators for sustainable land use – which is still an area under development (see World Bank, 1996).
- It might be interesting to try to link the EF more directly to 'biodiversity' – another key resource for sustainable development. This would also significantly increase policy relevance of the EF. A first step could be to include an estimate for the ecological value of the land converted into agricultural land into consideration. A global assessment of biodiversity pressures, in fact, indicated that sheer conversion of ecosystems to agricultural land or wood plantations is the most important pressure on biodiversity (RIVM/UNEP, 1997).
- Finally, the EF is a macro-indicator which cannot indicate the situation for more specific issues or (still) other important aspects of environmental sustainability not included in the indicator, such as the use chemicals or water consumption. Macro-indicators, in general, are more useful as indicators of an *un*sustainable than a sustainable situation.

Table 8.1: Overview of attractive attributes and limitations and obstacles

Attractive attributes	*Limitations / obstacles*
• Metaphor • Focus on consumption • Focus on key resources (at present implicitly land and carbon dioxide) • Connecting environmental problems and distribution of material wealth (built-in references) • Communication • Aggregation • Consistent accounting scheme	• Aggregation / false concreteness • Agricultural productivity • Multifunctional land use • Unsustainable land use • Does and will not include all relevant resources

Communication to a broader public

Based on its popularity, the EF is among the most effective tools for providing an indication of the human impact on nature and for conveying this analysis to a broader public - an area where not many other indicators exist.

In particular, the concept and the accounting system have already proven to be useful in communicating the concept of sustainable development and related issues to scientists, policy-makers and school youth. The per capita EF seems to be more useful for this, than the absolute numbers. Although far from perfect, the EF can be concluded to provide a basis for discussion, for example, in the cause for differences among countries, the equity issue and available means to reduce the present ecological footprint of man on earth - both at the individual and global levels.

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