Land use in LCA

CML-SSP Working Paper 02.002

Leiden, July 2001

Authors: Ester van der Voet.

Section Substances and Products, Centre of Environmental Science, Leiden University (CML-SSP)
P.O. Box 9518
2300 RA Leiden, The Netherlands
Tel +31 71 527 7477
Fax +31 71 527 7434
email: philips@rulcml.leidenuniv.nl
http://www.leidenuniv.nl/interfac/cml/ssp/

A slightly modified version of this paper has been published as Annex 2 of the report by E. Linderijer et al.: Improving and testing a land use methodology for LCA, including case studies on bricks, concrete and wood, Rijkswaterstaat-DWW report, May 2002.

Please refer to this published version when citing or quoting.

Table of Contents

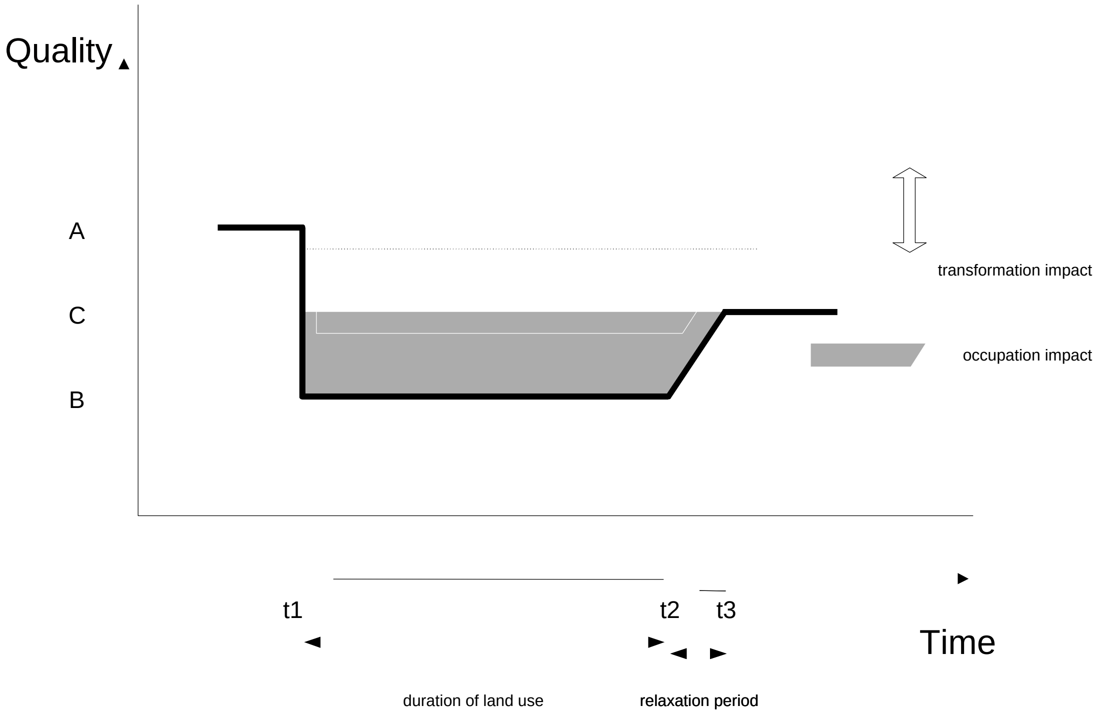
Land use in LCA

1 Introduction

Land use has large impacts on the natural environment. Despite this, the attention for this type of impacts within LCA circles has been lagging behind. Recently, some methods have been developed or rather are still in development to include land use impacts in the LCA framework. Three of these are discussed in this paper:

- the IVAM method (Lindeijer et al., 1998 and Lindeijer et al. in prep.)
- Köllner's method, as described in his PhD thesis and as included in the Eco-indicator 99 (Köllner, 2001 and Goedkoop & Spriensma, 2000)
- the LCAGAPS method of Weidema & Lindeijer (Weidema & Lindeijer, 2001).

The central figure used as a starting point for including land use impacts in LCA is the following (SETAC-WIA paper in preparation):



The figure is interpreted as follows: At time t1 land is being taken into use for a certain purpose. As a consequence, the quality of the area decreases from A to B. At time t2 the land use is terminated and recovery starts. At time t3 a new steady state has established itself which may differ from the original state; in this case the quality C is still lower than the original quality A.

It is not easy to operationalise this figure. This essentially dynamic picture must, as long as LCA still is an essentially static tool, be translated into static or steady state terms. This requires:

- a specification of the interventions in the LCA inventory
- the definition of indicators to measure "quality"
- the assessment of the impacts on the defined "quality" of certain types of land use
- the translation of these impacts into practical LCIA equivalency factors.

The methods treat these issues in different ways, as is discussed in the next sections.

2 The LCA inventory

In the Inventory, the process tree for the functional unit must be established. Two steps are required:

1. the definition of unit processes, to establish the interventions per unit of process output
2. the calculation of the required amounts of these unit processes for the functional unit.

If step 1 is made carefully, step 2 is relatively easy.

When dealing with land use, the interventions that must be linked to the unit processes will be in terms of the use of land area for certain purposes:

- extraction of raw materials (mining)
- production processes (agricultural land, area of industrial territory)
- transport (roads)
- use processes (residential area, recreational area)
- waste treatment processes (landfill sites, incineration plant area).

There is a difference between area already used by humans, or area newly extracted from nature. Generally, two types of interventions are distinguished:

- transformation: the conversion at the start from A to B
- occupation: the maintenance of quality B during a certain time period.

This implies that there are three possible situations:

1. Use of land area that already is being used for identical purposes
2. Use of land area that already is being used, but for other purposes
3. Use of land area that up to now was natural area.

A 4th situation could be: returning land that has been used up to now to natural area. In LCA studies, this will be an exceptional situation.
In the situations 2 en 3 there is transformation, a change in land use, that may be evaluated differently. It could even be argued that in situation 2 there is no transformation – the area was already added to the economic system and was no longer part of the environment. In all three situations the intervention occupation can be distinguished, that has a temporal as well as a spatial dimension (m^2.year).

Per unit process the following issues must be specified in the Inventory:

- the area transformed
- the nature of the transformation (from what into what), including irreversibility
- the area occupied
- the time of occupation
- the nature of the occupation.

When defining unit processes, we may encounter several problems:

- it can be difficult or even impossible to establish in practice what the previous use of the involved land area has been, and therefore whether or not transformation is an issue
- there may be problems in attributing a known transformation to the output of a unit process
- there may be allocation problems for occupation as well, in case of multi-functionality of land use.

The last problem is no different from the allocation required for emissions from multi-output processes. For this issue, rules have been established in ISO 14040 and a practical solution based on those rules may be found per case study.

The first and second problem related to unit process outputs are more difficult to handle. As in LCA we tend to abstract from time and location, we will find that it is impossible to link transformation to standardised, abstract processes. Transformation from nature (in figure 1 the jump for quality A to quality B) may have occurred in the distant past and may not be traceable. Even if we do know that in the real world the process of transformation is still going on, it is still not possible to attribute that to a unit process in a straightforward manner due to temporal problems: after transformation has taken place, the soil may be in use for many years to come and may deliver all kinds of outputs that are partly unknown and partly unknowable. In theory, there are two solutions for these problems:

1. Transformation could be attributed to the first activity after transformation, e.g. the first harvest or the first generation of houses. This is proposed by Guinée et al (LCA2 book) as a possible solution, equivalent to the solution for allocation of recycling of raw materials ("recycling of land": Heijungs et al., 1997). Guinée et al. do not elaborate this option. Problems arise especially in case of not directly production / consumption related land use, such as (rail)roads and other public facilities, where there is no apparent "first user" causing the transformation.
2. Transformation can be divided over the total output of the area involved, from transformation out of nature until the ending of human activity altogether. This involves the problem of the unknown past and unknowable future, as described above.

Both options are inconsistent with the LCA philosophy of abstraction from time and location, apart from practical data problems. The three methods discussed in this paper are remarkably silent on this issue. Lindeijer et al. (in prep.) are the only ones who enters this debate. They pose a solution by looking at the trend in land use changes over the latest years (decade?), and attributing the average yearly changes to the yearly outputs of various types of land use. They apply this solution to the Dutch situation. Although this method is applicable it has drawbacks:

- The Dutch situation is rather irrelevant from the LCA perspective and cannot be extrapolated easily to other parts of the world.
- The use of (net) trends in land use is irrelevant from an LCA perspective, and would lead to outcomes that are difficult to interpret. A negative trend, as is the case for agricultural soil in the Netherlands, would lead to a negative score for transformation into agricultural land, while a null trend would imply ignoring transformation.

The first problem could be evaded by using change on the global level, where there is no negative trend in any type of human land use at present. The second problem might be solved by using trends in changes instead of trends in land use. Not the yearly amount of square kilometres change in the total surface of agricultural soil, but the yearly amount of land being transferred from something else into agricultural soil then are the measure. The yearly amount of land transferred from agriculture into something else thus is out of the equation. It can be proven mathematically that this is identical to a generalisation of attribution to the first user:

A process delivering per unit of time a certain amount of products or services can be linked to transformation as follows:

transformation current process $T(P_t) = 0$
additional transformation at time t $T(\Delta P_t) = T_t$
with
T = transformation (units of transformation per unit product)
t = time t
P_t = production per unit of time
ΔP_t = increase in production per unit of time

In practice, it will hardly ever been known whether a unit product or service has actually caused any changes in land use, which means a generalisation must be made. If we want to generalise, a mix of newly transformed and already occupied area is in order. In equations:

$$T(P_t + \Delta P_t) = \frac{T(P_t)P_t + T(\Delta P_t)\Delta P_t}{P_t + \Delta P_t} = \frac{0 + T_t \Delta P_t}{P_t + \Delta P_t}$$

$$if \Delta P_t << P_t$$

$$T(P_t) = T_t \cdot \frac{\Delta P_t}{P_t}$$

This solution is workable and may stand up in further discussions.

The issue of allocation of transformation is clearly not resolved, and indeed has been given very little attention up to now. In this paper it will not be dealt with further. It is recommended that this issue is given more attention in circles of LCA methodology development such as SETAC and other platforms. Until then, a last possibility is to ignore the intervention of transformation, since at present it seems very difficult to deal with it adequately. This is not a very attractive option in view of the relevance of the issue, especially when dealing with transformation from nature to culture.

3 The LCA impact assessment

3.1 General structure

The general structure of the LCA impact assessment consists of classification, characterisation, normalisation and weighing.

Classification is a limited step, where interventions are being attributed to certain impact categories.

Characterisation means that the contribution per unit of intervention to each of the impact categories is established. The “unit of intervention” in this case refers to, for example, a square meter of a certain transformation, or a m^2.year of a certain occupation. The total contribution of a functional unit to a certain impact category is then calculated as follows:

$$\text{result}_{\text{impact category}} = \sum_{\text{unit process}} \text{characterisation factor}_{\text{impact category,type}} \times \text{intervention}_{\text{unit process,type}}$$

For each of the impact categories, indicators must be defined. The indicators then must be translated into characterisation factors that can be attributed to specific interventions. Two steps are required for this:

1. Per type of intervention, the contribution to certain impact categories must be made explicit. This involved some careful reasoning: as long as LCA is still primarily a static and non-site specific tool, time and location specific impacts must be abstracted into time and location independent terms.
2. Based on (1), characterisation or equivalency factors must be defined. When dealing with emissions, the approach is often used to define a reference emission and express the other emissions contribution to a certain impact category in relative terms (CO_2-equivalents, in the case of global warming). Whether or not to use such an approach for land use interventions as well is debatable. Strictly speaking there is no need for it. IVAM and Köllner do not use equivalency factors. LCAGAPS does by defining a reference ecosystem as unity and expressing its factors relative to this reference.

By multiplying interventions with characterisation or equivalency factors, the many different interventions connected to a functional unit can be added to a limited number of impacts.

The next step is normalisation by relating the result of the characterisation step somehow to the total present size of the impact category, or environmental problem. This ensures a certain harmonisation between the different problem categories: they are no longer expressed in their own units but relative to the total problem as-it-is.

Finally it is possible to assign weighing factors to the different impact categories to make a statement on their relative importance. This step is subjective by definition and is often not applied in LCA studies.

3.2 Models for estimating the impacts of land use

Land use has many different impacts. Starting from the “areas of protection” (WIA document), the following impacts can be distinguished:

1. availability of natural resources:
   - space as a natural resource: it cannot be depleted, but scarcity can occur, leading to competition over land
   - land use may cause a decrease of biodiversity, which in turn may decrease the availability of certain resources from biotic origins and of genetic information
2. life support services: certain types of land use may have adverse impacts on the regulatory functions of ecosystems
3. the intrinsic value of nature: land use may cause a decrease of biodiversity on the global or regional level (genes, species and ecosystems).

This document deals with the latter two impacts: the possible decrease of biodiversity (§ 3.2.1) and the possible impairment of life support services (§ 3.2.2) as a consequence of land use. The availability of natural resources is, although relevant, outside the scope of this project. The treatment of these subjects by the three different methods is discussed below.

3.2.1 Impacts on biodiversity

The possible impacts of land use on biodiversity

Decrease of biodiversity due to land use is caused by several mechanisms:

1. Impacts due to loss of natural area: by extracting land from nature, there is less space for natural ecosystems and the species dependent on those ecosystems. This may cause a loss of ecosystem, species and genetic diversity.
2. Indirect impacts:
   a. fragmentation: a loss of especially animal species due to the shrinking of the size of the undisturbed habitat, as well as the disturbance by human presence
   b. creating corridors: road shoulders and railway embankments can serve as refugia as well as connecting routes between natural areas, and thus may have a positive influence on the maintenance of species in cultural areas
   c. degradation of the landscape: eliminating structural elements in the landscape such as hedges, cops etc. implies a loss of habitat for smaller species of birds, insects and herbs
   d. change of the abiotic conditions and the microclimate (humidity, wind, nutrients, management regime) as a result of changed land use may lead to changes in the species composition, also of the microflora and -fauna.
3. Impacts of emanation:
   a. prevention of recovery: by occupying potential natural area, the natural situation cannot be reinstalled and the impact of space lost for natural ecosystems is extended
   b. knock-on effect: this occurs when, as is the case is Western Europe, large parts of the land are extracted from nature permanently. The remaining nature is

stressed to the point of loss of resilience, resulting in a higher sensitivity for disasters and a lower potential for recovery.

4. Impacts due to changes of land use within the economy: it can be argued that such changes are irrelevant from an LCA point of view – the land already is and will remain under human dominance. On the other hand, by ignoring such changes it becomes impossible to distinguish various forms of land use on their potential for joint use of the land by nature. Specific impacts within this category are:
    a. impacts on agro- / silvi- and industrial ecosystems
    b. impacts on tame species and species adapted to the human habitat.

    In order to be able to include this category of impacts, specific cultural ecosystems should be defined and specified.

It will not be possible to specify all impacts in such a manner that they fit within the LCA framework. After all, LCA aims at integrated evaluations of highly stylised product systems and not at providing an accurate picture of the impacts of certain types of land use on a specific location.

The impacts included in the various methods
In the IVAM-method the following biodiversity impacts are included:

- the impacts of loss of natural area on the vascular plant species diversity on the involved land area (1)
- the impacts of changes in land use within the economy on the vascular plant species diversity of the involved land area (4a)
- the impacts of prevention of recovery of the vascular plant species diversity on the involved land area by occupation of potential natural area (3a).

The impacts included by Köllner are rather similar. The details of the elaboration are different, see below. In addition, Köllners regional score is related to

- the knock-on effect,

but in a somewhat distant manner, treating cultural ecosystems in the same way as natural ones. In the derived Ecoindicator 99 this impact is included in a more direct manner (for details, see § 3.3).

Weidema & Lindeijer include:

- the impacts of prevention of recovery of the natural ecosystem diversity and the concurrent species diversity on the global level by occupation of potential natural area (3a)
- the knock-on effect (3b).

All methods are incomplete. IVAM and Köllner are more or less alternatives for the same impacts: differences in (vascular plant) species density dependent on the type of land use of the area involved. Weidema & Lindeijer indicate something different. On the one hand they are more encompassing: (1) they explicitly include ecosystems, (2) the impact assessment is related to the global problem of biodiversity loss. In some areas they are less developed: it is not possible to evaluate land use changes within the economy.

The use of vascular plant species diversity as a proxy for species diversity in general
All three methods use vascular plant species diversity as a proxy for species diversity in general. This seems a sensible choice, based on practical arguments of data availability. The question is whether vascular plant diversity is a good indicator for total species diversity. On the one hand the assumption is that more plant species means more species in general – this seems to be defendable. On the other hand the assumption is that impacts of land use on plant species diversity also have an impact on other species. This is clearly not always true (for example, fragmentation and disturbance have impacts especially on animals and much less on plants), but in many cases it is, if only because of the dependence of animals on plants. For the future the LCA community might consider expanding the indicator to total species diversity, or to compose indicators for plants, (different groups of) animals, and micro-organisms. At the moment, this does

not seem possible. Using plant species diversity, it is clear that a distinction must be made between different types of ecosystems, natural as well as cultural, based on their typical species diversity. How many types are defined is a matter of debate. In view of the purpose – including land use impacts in LCA – it would seem advisable to define a limited number. The IVAM method (1998) distinguishes roughly 10 types of ecosystems (they call it "physiotopes") on the global level, based on climate zones and abiotic factors, each with their own characteristic average, estimated species density. In later publications more are added, especially cultural ecosystems for the Dutch situation (Lindeijer et al., in prep.). Köllner defines about 30 ecosystems, both cultural and natural, for the Swiss situation. Weidema & Lindeijer use "biomes" on the global level and distinguish roughly 15 ecosystems, all natural.

Species diversity and ecosystem diversity
All three methods contain a combination of species and ecosystem diversity. The IVAM method and the method of Köllner both work with species density per type of ecosystem. The LCAGAPS method bases its impact assessment on the global scarcity, the species richness and the vulnerability of ecosystems. One question is, whether to separate species from ecosystem diversity. These two variables are linked but indicate different aspects: the global pool of species wherever they may occur, and the global variety in ecosystems apart from the number of species included in them. An ecosystem based indicator has, from the point of view of including land use changes in LCA, some clear advantages. It connects smoothly to the inventory since ecosystems have spatial dimensions. Aspects such as irreversibility and recovery time belong to ecosystems rather than species and might be included there in a more straightforward manner. The LCAGAPS method is the only one of the three that includes aspects of (global) ecosystem diversity. Oddly enough, LCAGAPS is also the only method addressing – be it indirectly – global species diversity by weighing ecosystems based on their natural species richness. Both the IVAM method and Köllners method weigh local changes in species density relative to the species density of the (theoretical) natural or desirable state of the location. There is no link to either ecosystem scarcity or the global species pool. Köllner does include a possibility to deal with species diversity on the regional level by applying his method to rare species. Since these are rare Swiss species the relevance for the global level is limited.

All this would imply that the LCAGAPS proposal theoretically is the best candidate. Problems related to this methods are (1) the choice made within LCAGAPS not to deal with changes within cultured land, and (2) the limitation of LCAGAPS to the occupation intervention. Either IVAM or Köllner may be used to supplement LCAGAPS to be more complete, or the other way round, the weighing procedure of LCAGAPS may be used to increase the relevance of either IVAM or Köllner.

The ecological models used in the three methods
The crucial issue in the IVAM method is the species density under various land use regimes. The ecological model behind that is a function describing the relation between surface area and number of species, as inspired by the island theory: a larger area contains a larger number of species, but with decreasing returns. Lindeijer et al. choose a logarithmic function to describe this relation. The formula is $S = \alpha \log A$, with S the number of species and A the surface area. The differences between ecosystems (both natural and cultural) are expressed in the α constant, which is taken as the measure for defining characterisation factors (see § 3.3).

Köllner too uses a function describing the relation between the number of species and the surface area. The function is different from the one used in the IVAM methods: $S = aA^b$, or the logarithmic variant $\ln S = \ln a + b \ln A$, with S the number of species, A the surface area, a a constant representing the typical species richness and b the "species accumulation rate". Köllner also discusses other functions but selected the one he uses as the best fit to his data. S is then specified for 30 ecosystems, for a standard surface of 100 m^2 and compared to a reference, being the Swiss situation in 1850. Species density for various types of land use is calculated as S_{occ} / S_{ref}. The inverse $(1 - S_{occ} / S_{ref})$ is called S_{lost}, or species potentially lost.

Stating a preference for either of the functions describing the relation between number of species and area is not possible without extensive ecological research. For the time being, Köllner seems to have dedicated most attention to this issue and put most effort in validating his equation. It seems therefore advisable, also in the light of harmonisation, to use the exponential function.

Weidema & Lindeijer propose a method to include impacts on ecosystems in LCA. At first sight this seems satisfactory: (1) it has a clear connection to the inventory because of the spatial dimension of ecosystems, which is lacking when dealing with species, and (2) ecosystems are more encompassing: they include species but also interspecies relations, structural aspects etc. In principle, a good ecosystem measure could make it superfluous to define a separate species indicator. Weidema & Lindeijer propose to weigh natural ecosystems according to the following characteristics:

- their biodiversity, expressed by the number of (plant) species they contain
- their inherent scarcity
- their vulnerability.

For the biodiversity characteristic, Weidema & Lindeijer also use a function describing the relation between area and number of species: $S = cA^z$, with S the number of species, A the surface and c and z "fitting parameters". Essentially this is the same equation as Köllner uses.

3.2.2 Impacts on the life support function of the biosphere

The life support function of the biosphere
The biosphere provides society with goods (fish, wood etc., included in the LCA problem area Depletion of biotic resources), but also with services: a.o. climate regulation on the micro and macro level, regulation of water quantity as well as quality, soil fertility, prevention of erosion, regulation of pests and diseases etc.. These services are connected to different aspects of the biosphere:

- the presence and maintenance of natural biogeochemical cycles (C, N, P, S, O, H_2O). These cycles play an important role in climate regulation and other basic requirements for sustaining human (and other) life and are maintained by organisms. Micro-organisms, plants and animals all have their part in these cycles. The magnitude of these cycles depends on the amount of biomass available to process the substances in question.
- the structure of ecosystems (the presence of layers in the vegetation, soil covering, colour etc.). This structure is determined by the vegetation. It is very important especially for the regulation of water streams and the water storage capacity of the land.
- the presence of specific species, such as predators, reducers, pollinators etc. required to keep certain pests in check, keep soil processes going, or to take care of pollinating crops.

Life support for humans or for nature?
In the WIA discussion paper section 4.4.3 this issue is raised. Obviously, life support is provided for both human and other species. Long discussions on this issue have led to the conclusion that it is not possible to define a life support system for non human species in general. The reason for this is that every species has its own demands. We like a high humidity, but desert plants do not. We like an atmosphere with oxygen, but for sulphur bacteria this is different – they like hot water with a lot of S and do not care for oxygen. Also if specific life support functions are discussed, in practice this will often be from a human perspective – climate, erosion, soil fertility etc. In accordance with (Dutch) environmental policy (Ministry of the Environment, 1992) defining life support functions for humans would seem most appropriate.

Which life support functions are relevant?
In the WIA document WIA three life support functions are mentioned:

1. the closing of substance cycles
2. climate regulation
3. a properly functioning soil quality

These three issues do not seem to be covering the issue: incomplete, overlapping and partly irrelevant. A (still not complete but less incomplete) list of life support functions for humans, depending on the three aspects of the biosphere, is the following (from Van der Voet et al., 1997):

Maintenance of natural cycles:
- climate regulation (temperature and humidity)
- air purification (CO_2/O_2 management and O_3 / NO_x filtering)
- Soil fertility (for wood and low tech agriculture), a.o. by N fixation
- Soil buffering (by degradation of pollutants)
- Water purification

Structure of ecosystems
- climate regulation, by wind breaking and albedo
- air purification a.o. by dust filtering
- protection against flooding by regulating water streams (providing delays and buffers)
- protection against erosion, a.o. by evaporation, allowing for infiltration and reduction of runoff
- soil structure, by bioturbation

Specific species
- pollination of agricultural species by insects
- regulation of pests and diseases by natural predators and parasites.

The relation between biodiversity and life support functions – can life support be measured by a biodiversity indicator?

The relation between the functioning of the life support system and biodiversity is complex. The life support system functions when ecosystem processes function well. Ecosystems are composed of species which keep the processes going. As may be clear from the above, in most cases functioning is not dependant on the presence of individual species but on functional groups: photosynthesisers, high vegetation, nitrogen reducers, pollinators, the presence of all links in a food chain etc. This implies there is a great redundancy of species in most ecosystems, and the disappearance of one or even many may not make much of a difference in the performance of life supporting ecosystem processes. On the other hand, this redundancy is not without meaning: it makes ecosystems more resilient against threats and disasters and better able to cope with changing circumstances.

In all, it would not seem advisable to measure life support services by a biodiversity indicator, but rather by one or more separate life support indicators. A biodiversity indicator for life support, if wanted for whatever reason, should not be directed at species diversity per se but rather at diversity between and within functional groups, with special emphasis on micro-organisms.

The impact of land use on life support functions

Different types of land use may have impacts on the life support services of the biosphere:
- biomass impacts: by removing natural ecosystems and replacing them by human made ecosystems there may be a loss in biomass production. This is a gradual loss – in agriculture, biomass is produced as well, and even cities have a certain amounts of green zones, but generally biomass production will be lower in human dominated zones.
- structural impacts: by removing the vegetation and especially by covering the surface the water management of a region is seriously altered. This may lead to an increased occurrence of flooding and erosion and a decreased availability of water for both natural and cultural ecosystems. (NB In the Dutch situation the water management system is for a large part man made (drainage, pumps etc.) which means that the natural system can be replaced by a human system, in this case. However this is expensive and may be less effective, especially in future in view of the rising sea level. Official water management policy now goes in the direction of more freedom for rivers, creating overflow polders for high waters etc.)
- species impacts: problems have been known to occur when certain species disappear through human intervention. By making land use changes this may happen due to the loss of suitable habitats like hedges and cops. Enlarging the scale of the landscape may be the key process here.

Indicators for life support functions
WIA proposes to focus on substance cycles and soil quality as indicators. For substance cycles, biomass indicators are proposed: the net primary production (NPP) per unit of surface. An ongoing discussion refers to whether to use the "free NPP" (fNPP), biomass production by nature only, or to include the human-regulated biomass as well. Which one to choose depends on the point of view; when life support for humans is the subject, then obviously the all-including NPP is the most appropriate. Ecosystem functions for nature may be indicated better by the fNPP, although even in this case this is debatable – conversion of carbon, useful for both human and other species, is done just as well by agricultural crops. The NPP, as a measure for biomass, indicates the maintenance of the biogeochemical cycles and connected life support functions. WIA further proposes that soil compaction and soil organic content should be translated into indicators. These indicators measure the quality of the soil and its ability to sustain crop production. They are also implicitly but obviously aimed at human life support – ecosystems sometimes have very poor soils, which is why the recovery may take such a long time, and still are able to maintain a large standing stock of biomass. A good example of such an ecosystem is tropical forests.

In addition, indicators could be added
- for ecosystem structure – one could think, perhaps, of (1) an indicator for metalling, and (2) an indicator for vegetation cover (0, 1, 2, 3 or more layers). This especially indicates the water retaining capacity of the area, but is also of relevance for albedo and air filtering.
- for life support species – perhaps an indicator aimed at micro-organisms or functional groups.

For the issue of life support, the developments have not progressed very far. For the time being it seems advisable to confine ourselves to biomass. For the future, a further operationalisation seems indicated. In this respect, the method proposed by Baitz et al. (1998) seems very interesting. They worked out a system for including the influence of land use on a number of life support functions (including erosion protection, wind protection, water storage capacity, soil buffering capacity and a number of others) in LCA studies. There is an indicator in development at RIVM aimed at measuring soil fertility / soil quality, which consists of an index based on the presence of functional groups of soil flora and fauna (micro-organisms, earth worms, mites, tiny insects etc.) (Schouten et al., 2000). This indicator does not refer to LCA but perhaps could be used as a starting point. These and possibly other proposals could be discussed and worked out further within the WIA or other LCA discussion platforms.

3.3 Using the models in the LCA framework: characterisation

In section 3.3.1, the characterisation procedure of the various methods is discussed. Since life support indicators are still in the first stages of development, the discussion is limited to the proposals on including loss of biodiversity. In 3.3.2, some issues of general importance as they emerge from the discussion surrounding the methods will be treated in more detail.

3.3.1 Characterisation procedures in the different methods

IVAM-method:
The characterisation factors are derived from the equation describing the relation between species density and area. Not the species density S but the constant α, the species accumulation rate, is used. The factors are calculated as follows:
- for transformation: $(\alpha_{ini} - \alpha_{fin}) / \alpha_{ref}$
- for occupation: $(\alpha_{ref} - \alpha_{occ}) / \alpha_{ref}$

For each case study therefore 4 α's must be established: (1) the reference situation α_{ref}, representing the potential natural ecosystem, (2) the situation before the transformation α_{ini}, (3) the situation during occupation α_{occ} and (4) the situation after termination of human activity α_{fin} which may or may not be equal to the reference situation, depending on the irreversibility of the damage done by human intervention. The α's are taken out of a database containing characteristics of a number of natural and cultural ecosystems. For the most part they still need to be determined. Lindeijer proposes to use the Floron database to determine α values for especially cultural ecosystems for the Dutch situation (Lindeijer et al., 2001). The result is possibly useful for the Netherlands but has a limited relevance for the rest of the world. Extrapolation of Dutch data to other areas of the world will be attempted later (oral communication, Lindeijer).

Köllners method
The measure used by Köllner for characterisation is called EDP – Ecosystem Damage Potential for species diversity. This measure is used in two ways: to assess local damage and to assess regional damage. The distinction Köllner makes between the two levels is not very clear to me, it is the same indicator: changes in species density on the area involved. The EDP values for local and regional impacts are derived from the S values (and not, as in the IVAM method, from the coefficient – which seems to make sense since S closer to what we're interested in than an abstract α). Four different formulae are presented: a linear and a non-linear one for local damage, and a linear and a non-linear one for regional damage. The local linear function bears most resemblance to the IVAM formula for occupation: $EDP_{local} = 1 - (S_{occ} / S_{region})$. The regional function includes the land use pattern already established in the region. The linear function is: $EDP_{region} = dS_{lost} / dL_i = b$ (a constant to be established empirically), L_i being the fraction of land already used for this purpose. The non linear functions are more precise but also include a value judgement: Köllner points out that a parking lot in an already species poor area comes out worse than the same parking lot in a species rich region. The choice is thus made to give a heavier weight to interventions in already stressed areas. The argument may also go to another direction: interventions in undisturbed sites might be considered more undesirable since the loss is larger than in already spoiled areas. When adopting this characterisation method, one must be aware of and agree with this choice.
Köllner then adds the local and regional scores to one total EDP score, based on equal weighting factors. EDP factors are used for both transformation and occupation. Köllner treats transformation as a specific type of occupation by using a "transformation time" to express it in m2.year units. Next to that a "restoration time" is used for the land to get back to the original state after termination of the activity, also leading to a m2.year occupation. NB the recovery is assumed to be complete, i.e. de situation before equals the recovered situation. For both transformation and restoration an EDP is used which is halfway between the original and occupied one. Thus, transformation and occupation are made into one intervention. Theoretically there is nothing against this, it even has certain advantages as discussed above. In this case however, Köllner ignores the allocation problem, which makes it highly questionable: the whole of the transformation as well as restoration are implicitly allocated to the functional unit under study.

Eco-indicator 99
Köllners method is, at least partly, integrated in the Eco-indicator 99. The area-species relationship from Köllner is used but not the EDPs. Instead, Goedkoop & Spriensma define PDFs (Potentially Damaged Fraction), as a counterpart of the PAFs they use for assessing damage to biodiversity by emissions. Köllners the distinction between the local and regional level is adopted, as is his expression of transformation in terms of m^2.years – only not a "transformation time" is used but a "restoration time". (NB It seems that in the SimaPro software, as opposed to the manual, the transformation score is expressed in m2 only and cannot be added to the occupation score. The manual in this respect is not quite up to date (oral communication Lindeijer)). As a result, there are four characterisation factors. The general equation is: $PDF = (S_{ref} - S_{use}) / S_{ref}$. S_{ref} is then defined differently for the four situations. The local factor for transformation includes the species density of the "situation before" as a reference, the local occupation factor that of the natural situation. On the regional level, the impacts on the (remaining) natural area are the issue. The reference for transformation then is the species density in the natural are in the region before transformation, and S_{use} is the same after transformation. By transformation, natural area has been lost and the number of species thus has become lower. For regional occupation, S_{ref} is the potential natural situation in the region as a whole, while S_{use} is identical to the S_{use} for regional

transformation. The surface area A also means different things. On the local level, A means area transformed or occupied, while on the regional level A is the area of natural territory within the region. By using different definitions for the same variable, Goedkoop & Spriensma succeed in giving the impression that they use just one formula, thereby preserving an image of simplicity. The complexity however is merely hidden, not eliminated, which is also a pity because Goedkoop & Spriensma offer a valuable contribution to the confusion around the issue of the reference situation (see below).

LCAGAPS
For species richness, S is used. The derivative of the equation, $S' = caA^{z-1}$, is used as an approximation of ecosystem vulnerability: the idea is that the steepness of the slope indicates the characteristic species loss per ecosystem for a (marginal) occupied unit of land. Ecosystem scarcity is measured as the inverse of the potential area per ecosystem type. The scores on the three criteria are multiplied to produce one indicator. This is the equivalency factor which is used to assess the impact of land occupation on natural ecosystems.
Although the idea is attractive there are still some details to worry about:

- the first characteristic could overlap with a species diversity indicator; if a species diversity indicator is used in addition to the ecosystem indicator, it requires some fine tuning
- the vulnerability of ecosystems is expressed as a function of the fraction that is already occupied: the more of the natural ecosystem area has disappeared, the more pressured and therefore vulnerable the remainder will be. This can be regarded as an operationalisation of the knock-on effect. Although this is relevant information, it seems incomplete. Vulnerability is also a characteristic of the ecosystem itself. An arctic, species poor ecosystem is more vulnerable than a temperate wetland: it is much more sensitive to interventions and recovers much more slowly. This could be a good argument to include the ecosystem specific natural recovery time in the vulnerability score, next to the already existing pressure on ecosystems.
- the method is limited to natural ecosystems and cannot be used for changes within cultured land.

3.3.2 Discussion of some issues of general importance

In summary, the IVAM method and Köllner's method attempt to achieve more or less the same: to specify (changes in) species density per type of ecosystem, related to a reference based on the (potential) natural ecosystem. There are some differences in the details of the approach. The LCAGAPS has a different starting point. Some issues causing confusion are discussed below:

1. the equation describing the relation between the number of species and the size of the area
2. the treatment of transformation and recovery
3. the difference between the local and regional level
4. the definition of transformation and occupation and the relation between the two
5. the use of references.

Area – species relationship
Two equations are proposed to describe the relation between area size and species density. Both are derived from literature. It is not possible to state a preference for either out of hand. However, Köllner dedicated an important part of his PhD to validating the different equations and selected his one as the best fit. This could be an argument to change to the $S = aA^b$ in the IVAM method as well (see § 3.2.1). Another difference is that both LCAGAPS and Köllner use S, the number of species, itself for deriving his EDP factors, while in the IVAM method the coefficient α is used. Either one seems valid but since S is closer to what we really are interested in it may be a good idea to conform to this proposal.

Transformation and recovery
In the IVAM method, transformation and occupation are strictly separated and are expressed in different units. The Köllner method integrates transformation, occupation and recovery into one

intervention: transformation and recovery are multiplied by a transformation resp. recovery period, thus creating an occupation-like measure in m^2.year units which is directly added to the score for occupation. Although the idea is attractive, it is also questionable since Köllner ignores the required allocation or attribution of transformation as well as recovery. To attribute the whole of the transformation and recovery to the functional unit under study leads to double counting and an implicit (very) heavy weighing factor, and therefore seems inadvisable.

Scale levels

Köllner and concurrently also Goedkoop & Spriensma make a difference between land use impacts on the local level and on the regional level. The local level refers to the area involved in the functional unit; here the transformation and occupation is absolute. The regional level refers to Switzerland, here the marginal impact of transformation / occupation on the Swiss biodiversity is the issue. The IVAM method does not make this distinction. Its characterisation factors bear a great resemblance to Köllners factors for the local level.

An argument for including the regional level is that it allows for a marginal approach, in accordance with general LCA philosophy. This puts the intervention in perspective. Also it opens possibilities to deal with “already stressed areas”. If we follow this line of thought it is then the question whether we are still interested in the local level – what does this add? Köllners reasoning is not very convincing here – he states, without much supporting argument or evidence, that the local level score indicates a proper ecosystem functioning, while the regional level indicates the nature conservation value. It is not clear why this should be so, nor why ecosystem functioning is added to a loss of biodiversity impact category.

On the other hand, the choice for any specific regional level is arbitrary. Köllner chooses Switzerland which is hardly relevant for LCA in general. Such a choice should somehow be derived from the global level: the world divided in a limited number of areas relevant for biodiversity issues, for example the biomes as defined by Weidema & Lindeijer.

Weidema & Lindeijer's method operates on the global level and defines its “areas” from that level. Comparable to Köllners regional level, it also deals with the present state of stress of the natural ecosystems. In that sense, the method is superior to both IVAM and Köllner: it allows for a marginal approach, without falling into the trap of having to define a regional level. However LCAGAPS has its limitations as well: it is not possible to evaluate changes within the area already in human use, which is an important part of both Köllner’s method and the IVAM method. As stated before, it could be argued that changes within already colonised land are irrelevant compared to the original change from the natural situation. However in Western Europe there is hardly any natural area left. Nature has to survive in corners of the domesticated area, and differences between the possibility of co-use by nature are relevant indeed.

The definition of transformation and occupation

On the issue of occupation the methods agree. In all three, the occupation indicator measures the (continuing) discrepancy between the actual and the natural situation, and thus for the deviation from the potential optimum with regard to biodiversity.

Transformation however is treated differently in all three or rather four methods, as described below. Köllner treats it as a part of occupation. By doing that, transformation is implicitly limited to transformation from nature into culture only, since the starting point is always his reference of Switzerland in 1850. In the Eco-indicator the two are separated although expressed in identical units. Although transformation is defined as change, the transformation impact refers to the loss of (species within the) natural area only. In the IVAM method it is stressed that transformation is different from occupation and should be treated as a separate issue, and the units are also different. Here it is explicitly stated that transformation is about change, and that change within the already cultural area is included as well. In LCAGAPS transformation is not elaborated but it is described as the irreversible change caused by an intervention, thereby again implicitly limiting it to transformation from nature into culture.

Various issues need to be resolved to clarify what “transformation” is all about, and thus be able to decide which treatment it should get in LCA:

1. Does transformation refer to extraction of land from nature only, or does it include changes of land use within the economy as well?
2. Is recovery included, if so, why and how?
3. What is the difference, or the relation, between transformation and occupation?

Ad 1. The methods disagree on this issue, although often implicitly. In fact, this is a normative choice. If we choose to apply transformation only to conversion of land from nature to culture, as most methods do, we are blind for changes within the cultural area. This may be regarded as problematical, but on the other hand it could be argued that the changes within the economy are irrelevant compared to the conversion from nature, and that this last issue is really the relevant one. Another problem when assessing transformation from nature to culture only is the distinction with occupation impacts: occupation, too, is a measure for the discrepancy with the natural situation.
If the choice is made to include all changes in land use, changes within the cultural area can be evaluated as well, but the question then becomes what to compare it to. The use of the natural situation as a reference then is questionable: the change is from the situation now, not from nature (see below). The Ecoindicator method perhaps has the most subtle solution for this, by defining transformation on the regional level different from transformation on the local level. On the regional level, only conversion from nature into culture is evaluated while on the local level the changes as they occur, also within the cultural area, are the issue. If we choose to include changes within the cultural area, the problem of allocation as mentioned in section 2 becomes even more pressing. The problems mentioned referring to the allocation of transformation apply to the transformation from nature to culture. It seems irrelevant to allocate every transformation within the economy – a certain piece of land may have had dozens of destinations during its history, all of them irrelevant for the functional unit in question. The argument for allocating change only to the changer becomes even stronger.

Ad 2. Recovery is implied to mean: reinstatement of the original natural situation. Recovery is included by Köllner in the same way as transformation is: by integrating it together with occupation into the one intervention land use. Köllners assumption is that every transformation is completely reversible. In the Ecoindicator 99 method, derived from Köllner, a recovery period is used likewise for translating the regional transformation measure into m^2.year units, although no integration with occupation follows. In LCAGAPS recovery is not an issue, but the related concept irreversibility pops up in their definition of transformation. Transformation is defined as the irreversible part of the land use change as compared to the natural state. In the IVAM method the recovered situation is used to compare with the “situation before”, instead of the situation during use. In the IVAM method, too, the recovery may not be complete, i.e., there is irreversibility. LCAGAPS and IVAM are essentially identical in this respect. All four options are debatable. Köllner and the Ecoindicator 99 use recovery time as a unit conversion trick, while it remains unclear what exactly it is they express by it. Under their own starting point of including land use changes within the economy, the IVAM treatment of recovery seems only logical in exceptional cases, when recovery is so to speak part of the intervention. This may be so in the case of extraction of surface resources such as clay or sand, where the occupation is short and there is an agreement beforehand to re-arrange the area as a natural area. In cases where this is unclear or unlikely, using the recovered situation clouds the issue. In fact, the not-recovered situation is used in the IVAM method in most cases (Lindeijer et al., 2001) – this is not regrettable, but as it should be. Although reversibility certainly is relevant it may be better not to hide it in a transformation indicator but give it an explicit, specific place in the procedure.

Ad 3. The relation between transformation and occupation is, sometimes implicitly, made differently in the surveyed methods. When Figure 1 is taken as the starting point, it is as follows: A certain area is transformed, then occupied, then released and recovered. The total time line then can be broken down into occupation and transformation (or not, as is essentially Köllners solution). The difficulties and methodological tangles of translating this figure are discussed in Section 2 and will not be repeated here. Regarding the Impact assessment, the methods nearly agree on occupation. About transformation there are basically two schools. One sees transformation as change, i.e. the change from the original situation to a different one, brought about by the functional unit or at least by human influence. The other does not look at the change itself, but at the lasting impact of the change: it may be that a certain change cannot be reversed completely, even if human occupation ended forever, for example when land is converted to water due to sand extraction. The irreversible part of the conversion then is the transformation impact.

In all, the distinction of a separate measure for transformation as is done in the IVAM method certainly is defendable. It seems that some clarification is required in the definition of the impact of transformation. From the above, it could mean a number of different things:

- the transformation impact is the change in species density due to changes in land use caused by the functional unit, compared to the situation before
- the transformation impact is the change in biodiversity due to the conversion of natural into cultural land caused by the functional unit
- the transformation impact is the irreversible change in species density due to changes in land use caused by the functional unit
- the transformation impact is the irreversible change in biodiversity due to the conversion of natural into cultural land caused by the functional unit

Regarding the choice for the situation we want as a comparison, it seems most logical not to take the natural situation but the situation as it was before the conversion. In that case, there is the least possible overlap with occupation, which (also) is a measure for the difference with the natural situation. Regarding the other choice, i.e. defining transformation as either the change itself or the irreversible consequences of the change, the matter is less clear. Both provide relevant information. It seems simplest and most straightforward to go for the change itself, but in that case the reversibility of the intervention is a forgotten aspect. A possibility is to compose a transformation indicator out of the two aspects: the change itself, corrected for a factor for the reversibility of this change. On a geological time scale, everything is reversible so the time period involved in a complete recovery could be a measure. In that case, this factor will probably become completely dominant and we have to ask ourselves whether we want to attach so much weight to this aspect.

References in land use

The use of references is the cause of much confusion. To clarify, a number of different references, popping up at different places in the LCA framework, can be distinguished:

- In the Inventory, a reference for the intervention comes from the “less is better” LCA philosophy. Less land used is better, so the reference is zero square meters of land used. In the Impact assessment, the reference is the basis for comparison, the reference as a yardstick for the impact of the intervention. Since more than 1 impact is distinguished, more than 1 reference is required.
- For the impact category Occupation the reference, meaning the difference with the natural situation, can also be derived from “less is better”. Less in this case means less impact, the reference being zero impact, i.e. zero “species potentially lost” as Köllner puts it, therefore the natural situation. In all methods discussed here, the species density of the natural situation is the reference used to compare with the situation in use, except for Köllner who uses Switzerland 1850. Köllners choice therefore seems not to be in line with the above reasoning.
- The IA reference for transformation of course depends on its definition. In case transformation is regarded as change, the situation before the change is the reference. When transformation is seen only as change from nature to culture, then once again the natural situation is the reference. Also including change within the economy means that the situation before the change, be it nature or culture, is the reference. In case transformation is regarded as the irreversible part of the impact of transformation, the natural situation automatically becomes the reference. Köllner solves the reference problem neatly by defining transformation (from nature to culture) as a part of the one intervention land use, combined with occupation and recovery. The natural situation thus is automatically the reference. In Ecoindicator 99, two references are used in accordance with the two types of transformation: the natural state for the regional level, and the situation before the intervention for the local

level. In LCAGAPS, transformation is not elaborated. The IVAM method is most problematical in this respect. Two references appear in the equation for the transformation indicator: the situation before (ini) as well as the natural situation (ref). Dividing by α_{ref} or S_{ref} serves the purpose of enabling to add different interventions to one transformation score. This purpose could be served just as well through dividing by α_{ini} or S_{ini}, thereby enabling to evaluate changes within the economy as well and clearly making the choice for assessing changes within the economy as well.

- A final place for a reference to appear is when defining equivalency factors. When doing this for emissions, a reference substance is used (for example CO_2 for global warming) and the factors for the other substances are given relative to this reference (in CO_2 equivalents). There is no need to do this but it is possible, and is actually done by Weidema & Lindeijer. They use a reference ecosystem, the one with the lowest natural species density, to derive equivalency factors for the characterisation regarding other ecosystems. They prefer to call these “scaling factors” but they are essentially identical to the reference substances.

3.4 Normalisation and weighing

Not much is stated on these issues in either of the methods. Weidema & Lindeijer provide a table with global normalisation factors referring to their ecosystems. In the Ecoindicator 99 normalisation procedure is described, and normalisation factors for land use interventions are provided for woods, “urban”, and different types of agricultural land. Köllner and IVAM are silent on this matter.
On weighing there are some scattered remarks in all methods:

- Ecoindicator 99 uses a weighing factor of 10 to add PAFs to PDFs;
- Köllner proposes equal weighing between the regional and local level, implicit and (therefore?) quite complicated weighing between transformation and occupation (depends on allocation which he does not specify, also a factor 4.1 is mentioned);
- IVAM takes the point of view that no weighing between transformation and occupation should be attempted at present;
- LCAGAPS offers no statement on weighing, but weighing takes place within the equivalency factors – all three areas of interest are included with equal weight.

4 Conclusions and recommendations

As is clear from the above, the inclusion of land use impacts in LCA is by no means finished. The issue has come up only during the course of LCA development and relatively little attention has been paid to the issue compared to the impacts arising from emissions. Land use impacts differ from emission impacts in many ways. Therefore the lines of thought that have to be followed are also different. In recent years there has been more attention for land use related impacts, as a result of the pressure arising from the obvious importance of such impacts. This has led to the development of several methods, none of which is “finished”. Some unfinished business is discussed in this paper in the previous sections.

A first conclusion is, that in all of the methods studied most attention has been paid to the Impact Assessment part of LCA. The LCA Inventory has had relatively little attention, despite the fact that a very important subject resides there: the rules for allocation. The allocation choices made in case studies have a large, sometimes even decisive influence on the outcomes. The combination of relative importance and relative neglect leads to a first, rather obvious conclusion that this issue is most unresolved and required most urgent attention.

For the LCA Impact Assessment there are various proposals which all have their merits and drawbacks. Below, the most important are discussed and some recommendations are made, both for the short term and for the long term.

LCA Inventory
Guinée et al. (in press) recommend – and make a start with – writing out neatly and clearly the whole Inventory procedure. This may clarify some issues and make apparent which discussions belong in what stage, what needs be resolved first and how to proceed from there.
The main problem in the Inventory is, as stated above, the Allocation, especially of the Transformation intervention. Solution of this subtle and complicated issue requires discussion within the broader LCA community. The SETAC group on LCA Inventory seems the appropriate platform, but there may be others as well. For the time being, there are several possibilities:

1. Exclude transformation as an intervention until this issue has been resolved
2. Include transformation only if it can be directly related to the functional unit. This may be the case for example when extracting clay or other raw materials for building. The transformation then can be attributed as a whole to the f.u.
3. The only concrete proposal available at present is Lindeijer's proposal to use trends. Despite the signalled problems (Section 2) this could be used until something better becomes available. A proposal is made in this paper to amend Lindeijer's proposal by not using the trend in land use itself, but in the changes therein (see Section 2). This can be regarded as a generalisation of the principle "transformation is attributed to the process causing the change".

LCA Impact Assessment
A first issue to be addressed is defining which of the impacts of land use can or should be included in LCA. All methods now available are incomplete in the impacts they consider. Partly, this could be amended, but partly, it will be beyond the scope of LCA. This issue cannot be resolved within the present project but could be subject of discussion in the SETAC-WIA taskforce on land use, or other such platforms.

Impacts considered in this paper are (1) impacts on biodiversity and (2) impacts on life support services. Some specific recommendations on these issues are made below.

<u>Impacts on biodiversity</u>
Biodiversity is linked to the two interventions transformation and occupation. All methods agree on these two interventions. They also more or less agree on the definition of occupation, which could be summarised as follows: *the impact category occupation refers to the difference with the no-impact, i.e. natural, situation of the land as caused by the intervention linked to the functional unit.* However there is a major difference between the methods regarding the treatment of transformation. They disagree on two main issues:

- the impact category transformation refers to the change in land use, vs. the irreversible part of the change in land use, caused by the functional unit
- transformation refers to a (irreversible) change from nature into culture, vs. refers to all (irreversible) changes in land use, caused by the functional unit.

In order to progress in the LCA Impact Assessment, a clear choice must be made, which must crystallise further in the LCA community. Such a choice also has its implications for the Inventory and the problems of allocation. For now, a proposal is made to define transformation as change, not the irreversible part of change, and to make it refer to changes in general, not just from nature into culture. The reasons are both practical (it is generally difficult to determine irreversibility) and to avoid double-counting (the difference with the natural situation is already indicated by the occupation impact category). This implies that the irreversibility of the impact is out of view, and that the natural situation cannot be used as a reference. In future some way must be found to deal with irreversibility.

The following recommendations are made regarding the applicability of *occupation* in this project:

- Use Köllners formula to describe the relation between area and number of species, since he has put in most effort in validating

- Use S and not α, since S is closer to what we are interested in
- Use LCAGAPS as a starting point, since this method fits best to general LCA framework requirements: an ecosystem indicator derived from the global level, no need for a further distinction between the local and regional level.
- Make additions to this method especially to be able to include the remaining species during occupation, by using the procedure out of the IVAM method instead of the LCAGAPS species richness factor nSR. The SR is identical to S_{ref}, and nSR is obtained through dividing by the species density of the ecosystem with the lowest species density S_{ref} / S_{min}. The nSR in LCAGAPS just weighs the intervention based on the natural species richness, implying that all gets lost; the IVAM procedure then must correct for the remaining biodiversity, S_{occ}. The higher S_{occ}, the lower the characterisation factor should be, since less species are "potentially lost". The equation for nSR then would be:
  $nSR = [(S_{ref} – S_{occ}) / S_{ref}] * [S_{ref} / S_{min}] = (S_{ref} – S_{occ}) / S_{min}$.
- It is also recommended to add recovery time to the Ecosystem Vulnerability factor. The recovery time in this case is an ecosystem characteristic, a general measure for how quickly a natural ecosystem recovers from disturbance, regardless of the exact nature of the intervention.

Further discussions to streamline this issue and harmonise the different methods, or to end up with a number of methods with different value choices, are indicated.

Recommendations regarding the application of *transformation* within this project are:

- Leave transformation out altogether until basic discussions have been solved
- If this is for some reason unacceptable, then use the Ecoindicator 99 PDFs but within the IVAM framework, i.e. do not add the recovery time to convert the score into m^2.year. When transformation is to include changes within the economy, the local PDFs are indicated.

For the future, the issue of transformation must be clarified profoundly. The different methods have different definitions, making them incomparable. Unless this is resolved, it hardly seems useful to elaborate on detailed Impact Assessment characterisation factors. When it is, it could be worthwhile to expand the LCAGAPS method with a transformation mode.

<u>Impacts on the life support function of ecosystems</u>:
Although some interesting proposals exist, there is even less agreement on this issue than on the treatment of biodiversity loss. Even the starting points are still under discussion. The one point of general agreement seems to be that biomass production is a valid indicator. For this project, it seems advisable to limit characterisation of life support functions to biomass, either NPP or fNPP. It also seems advisable to link this to Occupation, in view of the time dimension of biomass production. For the future, it is recommended:

- to decide whether LSF for humans or for other species are indicated; defining LSF for humans is politically accepted as well as more straightforward
- to define a more complete list of life support functions and decide which ones are relevant to include in LCA
- to make the link between land use, occupation and transformation, and damage to life support functions
- to elaborate characterisation factors for the different (categories of) life support functions.

<u>Normalisation en weighing</u>:
There is little attention for these issues in the currently available methods. Since it is important that land use impacts can be evaluated in the same framework as the other interventions, it seems that no method is really applicable without such a list.
Weighing is a subject that is no different for land use than for the other impact categories. There seems no need for special attention here.

5 Acknowledgements

The issue of land use in LCA is a very complicated one. This paper may hopefully serve to clarify some of the issues giving rise to debate and controversy. Significant contributions were made by Joris Broers for his suggestions regarding the Allocation procedure, by Sangwon Suh and Arjan de Koning regarding the use of references, by Reinout Heijungs and Gjalt Huppes on the general LCA framework, and by Erwin Lindeijer making available his knowledge and experience in the area of Land use in LCA.

6 References

Baitz, M., J. Kreissig & C. Schöch (1998). Methode zur Intergation der Naturraum-Inanspruchname in Ökobilanzen. IKP Universität Stuttgart report, version February 1998.

Goedkoop, M. & R. Spriensma (2000). The eco-indicator 99. A damage-oriented method for Life Cycle Impact Assessment. Methodology report, 2nd edition, 17 arpil 2000. Pré Consultants, Amersfoort.

Guinée, J.B. (ed.) (in press). Life Cycle Assessment. An operational guide to the ISO standard. Volume 3: Scientific Backgrounds.

Heijungs, R., J. Guinée & G. Huppes (1997). Impact categories for natural resources and land use. Leiden, CML report 138.

Köllner, Th. (2001). Land use in Product Life Cycles and its Consequences for Ecosystem Quality. Dissertation der Univ. St. Gallen, defended March 2001.

Lindeijer, E. & A. Alfers (2001). Project Toetsing beoordelingsmethodiek landgebruik. Concept tussenrapportage, concept A screening. TNO Industrie, draft.

Lindeijer, E., R. Müller-Wenk & B. Steen (eds.) (in prep.). Impact assessment of resources and land use. SETAC WIA-2 Taskforce on Resources and Land.

Lindeijer, E.W., M. van Kampen, P.J. Fraanje, H.F. van Dobben, G.J. Nabuurs, E.P.A.G. Schouwenberg, A.H. Prins, N. Dankers & M.F. Leopold (1998). Biodiversity and land use indicators for land use impacts in LCA. Ministerie V&W. Publicatiereeks Grondstoffen 1998/07, rapportno. W-DWW-98-059.

Ministry of Housing, Spatial Planning and the Environment (1992). Environmental Policy Plan 2. Staatsdrukkerij, Den Haag.

Schouten, A.J., J. Bloem, A.M. Breure, W.A.M. Didden, M. van Elsbroek, P.C. de Ruiter, M. Rutgers, H. Siepel & H. Velvis (2000). Pilotproject Bodembiologische Indicator voor Life Support Functies van de bodem. Bilthoven, RIVM rapport no. 607604001.

Voet, E. van der, F. Klijn, W.L. Tamis & R. Huele (1997). Regulatiefuncties van de biosfeer. Aanzet tot een operationalisatie van de life supportfuncties van de biosfeer, toegespitst op de rol van soortenrijkdom. Ministerie VROM, publikatiereeks SVS no. 1997/33.

Weidema, B.P. & E. Lindeijer (2001). Physical impacts of land use in product life cycle assessment. Final report of the Eurenviron-LCAGAPS sub-project on land use. Dpt of Manufacturing, Engineering & Management, Technical University of Denmark.