Biodiversity and Land Use

A Search for Suitable Indicators for Policy Use

Report
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CE Delft's solutions are characterised in being politically feasible, technologically sound, economically prudent and socially equitable.

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Executive Summary

Main message:
The goal of this study is to combine the knowledge of life cycle assessment (LCA) and biodiversity scenario scientists to build a global and accurate biodiversity indicator for resources policies
Our search for accurate global indicators for biodiversity in material and energy policy has led to the main conclusion that a better cooperation between LCA scientists (ReCiPe) who investigate the environmental aspects of products and materials, and biodiversity scenario analysts (MSA) who investigate the biodiversity trends in regions, could lead to a biodiversity indicator that is accurate, global, simple and easy to use in LCA studies. Until these MSA and ReCiPe indicators are integrated, the ReCiPe indicator with extra data for tropical regions is most suitable to use for life cycle analyses.

Biodiversity important in many policy issues

Land use for production of biotic raw materials (food, feed, wood, biofuels, biomass for heat and power) has an increasing impact on the world's ecosystem and climate. Governments try to mitigate these impacts with policies. Land use and its impact on biodiversity is a significant issue in several policy files, such as:

- Bio-based economy incentives policies concerning implementation of biofuels, biomass for heat and power and biomass for other applications in which it substitutes fossil fuels.
- Waste treatment and recycling policies, especially waste paper and waste wood related policies and associated packaging taxes.
- Global food consumption – especially global protein consumption – and the relationship between biodiversity and agricultural productivity.
- Deforestation and sustainable wood/timber policies.
- Natural conservation policies.

For all these policies global biodiversity effects of production, trade and use are important and governments want to include these effects in policy design.

In many of these policy files, biodiversity is not yet included as a quantitative aspect to be taken into account. In other files different methodologies are applied for monitoring. The Dutch government has asked CE Delft to investigate if for all relevant resources policy issues one biodiversity indicator could be applied.

Requirements in view of policy issues

The indicator should ideally be helpful in assisting policy makers (and economic actors) in making choices where the following comparisons are required:

1. Between different intensity of land use and land use development variation.
2. Between two different locations in different regions for cultivation of the same or comparable crop or tree.
3. Between a biotic and a fossil product for the same service.
4. Between different products from different regions, in order to focus a general biodiversity policy of a country.
5. Between more intensive production (entailing less biodiversity on the production area) and less intensive production (more area needed, but leaving more unharmed area outside), including the indirect land use change issue.

List of studied indicators

From a long list of indicators we selected the following indicators:
MSA, ReCiPe, TNO, CML2, PAS2050, Living Planet Index, Red List Species, VROM Biodiversity Assessment Framework, Ecological Footprint, Bioscore tool, IBIS and CBD indicators.

Three useful biodiversity indicators for material policy

From the long list of indicators, three methods were selected which were considered suitable in view of the purpose, as well as scientifically based:

- MSA
- ReCiPe
- TNO

All three selected methods are based on the scientific work of Arrhenius. In 1921, Arrhenius postulated a so-called *species-area curve* describing the relationship between the number of different kinds of vascular plants and the size of the natural area in which they grow[1]. In general, the number of different vascular plants seems to be a good indicator for biodiversity. According to the postulated relationship, the number of vascular plants is asymptotic with increasing area size, reaching a maximum or - in biodiversity jargon – climax for large areas.

Mean species abundance Indicator

The Mean Species Abundance or MSA methodology has been developed by PBL and WUR in the Netherlands specifically for monitoring and modeling biodiversity and for use in a scenario context.
It is applied in several UNEP projects conducted within the TEEB[2] project in which scenario studies based on integrated modeling have been performed. In these projects a set of integrated computer models is used for estimating pressure on biodiversity globally, based on scenarios for e.g. global population, economic growth, fossil fuel consumption and food consumption. These pressures are then translated into impact on biodiversity with the MSA methodology.

The MSA has been developed for scenario analyses to study the biodiversity developments in large regions (EG Europe). For scenario analyses the MSA indicator is very suitable. A plus of the MSA is the global approach of the indicator and the global coverage of data. For life cycle and material assessments the MSA indicator is not yet suitable as:

- Because of its relative measure for the biodiversity for a specific location – distinguishing between two different locations is not possible.
- In the current shape it cannot be combined with other environmental impacts and types of damages – such as impacts on human health - and cannot be combined with local pressures impacting biodiversity such as water shortage.
- The methods have no restoration time included for return of biodiversity.

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[1] For a better explanation of the concept of species-area curves we include following citation from the Wikipedia website:

> "In ecology, a species-area curve is a relationship between the area of a habitat, or of part of a habitat, and the number of species found within that area. Larger areas tend to contain larger numbers of species, and empirically, the relative numbers seem to follow systematic mathematical relationships. The species-area relationship is usually constructed for a single type of organism, such as all vascular plants or all species of a specific tropic level within a particular site. It is rarely, if ever, constructed for all types of organisms if simply because of the prodigious data requirements."

[2] The Economics of Ecosystems and Biodiversity.

ReCiPe

The ReCiPe 2008 methodology is a harmonised LCIA methodology developed in the Netherlands and commissioned by the former Ministry of Environmental Affairs. It was developed by a consortium of science organisations, such as Radboud University, CML Leiden, CE Delft and RIVM.

The goal for developing ReCiPe 2008 was development of a harmonised and consistent methodology for as many environmental impacts as possible. In addition to land use and its impact on biodiversity, it includes 17 other environmental issues, both well-known issues such as acidification and climate change and less frequently considered issues such as mineral and fossil fuel consumption. The methodology allows aggregation and weighing of the different impacts into one environmental damage figure. The methods include a restoration time for biodiversity. The ReCiPe method is suitable for life cycle material analyses. However, the ReCiPe method is not perfect, because

- In its current shape it is not applicable on a global scale because of a lack of data the methodology does not give indications which allow for quantifying different approaches in landscape design, such as the inclusion of ecological corridors or landscape elements.
- The methodology does not consider the uniqueness of a biome in the analyses.

These shortcomings can be remedied by transforming and including MSA data, by including corridors and landscape elements; and by borrowing the biome-uniqueness factor from the TNO method.

TNO method

In order to integrate land use in LCA, the Road and Hydraulic Engineering Institute (DWW) has initiated the development of a new method. The original reason to start the development of the land use methodology was that the theme ‘degradation of ecosystems and landscapes’ as mentioned in the CML guideline (1992) was not operational and that this theme is relevant for LCAs within the working field of several environmental policies, e.g. sustainable building and the Structure Plan on Surface Raw Materials. The focus was to develop a general method which can be used for all types of processes all over the world, just like other characterisation methods in the CML guideline.

The methodology elaborated by TNO for Rijkswaterstaat has been based on previous work, LCACAP, by Weidema and Lindeijer for the EU Commission.

Its status and the extent of its use are not clear. Yet, the methodology is interesting, because it contains a number of methodological choices not included in both other considered methodologies. Especially the uniqueness factor for biomes could be used to improve the ReCiPe/MSA indicator.

In Table 1 the three methods and their aspects are summarised.

Table 1 **Overview of match of the considered methodologies with desired specification (X=Yes)**

	MSA	ReCiPe	TNO
Methodological differences			
– Applicable in LCA?	Theoretically	X	X
– Considers impact of land use on surrounding area?		X	
– Accounts for long-term decrease of biodiversity for land use change?		X	
– Weighing factors for representing uniqueness and remaining area?			X
– Considers fragmentation, impacts of roads?	X		
Data set issues, applied dataset allows for considering:			
– Differences in land use intensity	X	X	X
– Differences in landscape design			Partly
– Differences in affected biomes			Partly
– Ecosystems outside EU?	X		

The differences are mainly related to the aim the indicators were developed for. The MSA methodology is designed for scenario analyses, the ReCiPe land use indicator for LCA and product analyses.

Cases
The three indicators were tested with cases for the policy questions.
The cases considered with the three indicators learn that:
– In most cases all three indicators favour the same option only the differences between the scores differ.
– Organic farming (less extensive, more biodiverse) is a complicated case. Two indicators favour conventional farming, one organic farming.
– Land destruction and restoration is emphasised in the ReCiPe method.
– In the ‘bio versus fossil’ cases adding a biodiversity factor lowers the gain of biofuels/materials versus fossil alternatives.

Conclusions
For application in policies, the ReCiPe indicator would be the most suitable methodology in the current situation, mainly because of its integration in LCA methodology. This would allow weighing biodiversity impacts with other environmental issues, e.g. climate change. Its value - and that of the other two indicators - would be improved by improving extensiveness and level of detail of the underlying datasets. Combining the different methodological features of the three identified indicators would improve their value in policy applications. For example, combining:
– The restoration factor of the ReCiPe indicator.
– A modified factor for scarcity of biomes from the TNO indicator would result in an indicator that would discourage land use change, especially in unique ecosystems of which little of the original area has remained.

Position and use of the proposed ideal indicator
This report gives recommendations for developing an ideal indicator which would address the policy questions more adequately.

Even such an indicator would not be a magic panacea, and would still have its limitations, partly as a result of currently available data.

First, the indicator only allows for monitoring of biodiversity and changes in biodiversity as a result of changes in land use and land use intensity. It has no relationship to underlying mechanisms that determine land use and land use intensity, e.g.:

- Factors determining total land use, such as food demand or energy policies.
- Landscape design and factors influencing landscape design.

In order to influence these factors, additional policies should be implemented, e.g. the creation of protected natural areas.

Secondly, in reporting the level of naturalness the considered methodologies do not distinguish between different kinds of species. As a consequence it is impossible to monitor and estimate the effect of land use and land use intensity on specific kinds of species, e.g. red-listed species. Protecting red-listed species requires additional instruments and policies.

Thirdly, the datasets describing the naturalness of different kind of land uses and land use intensities are currently limited in their level of detail.
For example:

- The datasets do not include natural grasslands.
- The datasets do not allow for distinguishing between different levels of grazing on natural and agricultural grasslands.
- Only the dataset applied for the TNO indicator allows for taking into account landscape elements such as hedgerows, ponds or edges of woods.
- The datasets and indicators do not allow for taking into account of regional landscape policy planning, as implemented under e.g. the EU Natura 2000 program and Dutch Rural Development.
- The datasets do not include quantification of the effects of certification on land use.

As a consequence, the indicators considered in this report can only be used for a broad estimation of impacts on biodiversity related to land using activities and chains of materials and products. The situation may be compared with a TIER I approach as considered under the IPCC methodology for reporting greenhouse gas emissions. Prolonging the comparison:

- The European Bioscore model may be considered an example of a TIER II analysis.
- A TIER III level of detail analysis for biodiversity impact would be a local and regional analysis as conducted in an EIA.

The Bioscore tool is a computer model using quantitative and global relationships between pressures and biodiversity, including land use, fragmentation and presence of power lines for 8 different categories of species and for 11 different biomes. It considers a number of different categories of organisms and dozens of specific species within each category. For example, 20 different individual species of amphibians are distinguished.

In an EIA the number of different species and the size of their population in the area that is likely to be influenced by an activity is determined in detail. Next to this the area, specific factors and pressures influencing biodiversity are determined and relationships between land use and species abundance and population sizes specific for the considered region are estimated.

1 Questions and Answers for Policy Makers

What is biodiversity?
Biodiversity can be defined in terms of species diversity. Biologists most often define biodiversity more broadly as the "totality of genes, species, and ecosystems of a region". An advantage of this definition is that it seems to describe most circumstances and presents a unified view of the traditional three levels at which biological variety has been identified.

Why is biodiversity important?
Biodiversity is a key natural resource which is strongly linked with the ability of an ecosystem of providing ecosystem services. Ecosystem services and biodiversity are interlinked by the necessity of retaining adequate biodiversity in an ecosystem for retaining ecosystem reproductivety and stability. As the well-being of the human population is fundamentally and directly dependent on ecosystem services (see Figure 1) biodiversity decline is undesirable.

For which policy issues is biodiversity important?
Biodiversity is an important aspect for all policies which are directed either at protection of nature, or at agriculture and other land-based production.
The production of products like wood, biofuels, meat, coffee or milk all have an impact on biodiversity; and policies for these bio-materials have to take into account biodiversity effects.

What role can a biodiversity indicator have in biodiversity policies?
It can be used for estimating impacts of policies and economic developments on biodiversity by conducting scenario studies for land use and land use intensity and translate these into levels of biodiversity. It can also be applied in determining the impact on biodiversity of production chains and material chains, and for analysing how this impact could be reduced.

Do businesses support biodiversity policies?
Both individual companies like DSM and Unilever as organisations of companies like the WBCSD strongly support the protection of biodiversity. They are busy with projects themselves and also ask governments to introduce policies to protect biodiversity.

Why do we need an indicator for biodiversity
In many policy issues Life Cycle Accounting or Carbon Footprinting is used to determine what should be chosen as policy. An indicator for biodiversity effects can help to add the biodiversity view in this decision process. The ReCiPe indicator makes it also possible to aggregate both the GHG effect and the biodiversity effect into one figure.

Is focussing on climate policies not enough, does climate policy not automatically also help biodiversity?
If fertile land use is no issue for a product or a material than in general the biodiversity effect of this product or material correlates with other environmental effect like GHG emissions and acidification. But if fertile land use is involved the GHG effect and the biodiversity effect are not correlated at all.

How do I integrate biodiversity in LCA studies?
The ReCiPe indicator (eventually with extra data from the MSA indicator) makes it possible to add biodiversity effect into LCA studies.

When will the proposed MSA/ReCiPe indicator be available?
Defining the indicator seems as much a political process as a scientific process. In fact, the basic science is already available. Choices need to be made on which weighing factors are to be included.
After that the indicator would be operational and could be applied. It could next be refined by adding more information on the relation between land use and land use intensity on one hand and level of naturalness and level of biodiversity on the other.

What role can a biodiversity indicator have in biodiversity policies?
It can be used for estimating impacts of policies and economic developments on biodiversity by conducting scenario studies for land use and land use intensity and translate these into levels of biodiversity.
It can also be applied in determining the impact on biodiversity related to production chains and material chains and for analyzing how this impact could be reduced.

How can a biodiversity indicator help biodiversity?
In many cases different products and materials can deliver the same service. Information on the biodiversity effect of these products makes a more biodiversity-friendly choice possible. Government can also introduce policies to steer to these biodiversity-friendly options.

Can I choose better materials/resources with a biodiversity indicator?
With ReCiPe or with the indicator proposed in this report, it is possible to determine the impact of the production materials or products or the use of resources on biodiversity, allowing stakeholders to choose.

How do I combine my climate and biodiversity goals?
In the ReCiPe LCA indicator both climate and biodiversity are integrated. This indicator can be used as a general environmental indicator.

How does this indicator connects to the TEEB process?
The Economics of Ecosystems and Biodiversity (TEEB) study is a major international initiative to draw attention to the global economic benefits of biodiversity, to highlight the growing costs of biodiversity loss and ecosystem degradation, and to draw together expertise from the fields of science, economics and policy to enable practical actions moving forward.
The indicator proposed in this project allows relating activities that require land use with the associated biodiversity loss. Such an indicator would thus allow allocating costs related to biodiversity losses to specific activities and in making the concept of converting biodiversity into economic value ready for use.

The significance of an indicator as proposed in this project may be illustrated by the fact that one of the indicators considered in this report – the MSA indicator – has been adopted under the TEEB initiative.

Are bioenergy and biofuels good for biodiversity?
First generation biofuels grown on existing fertile land are in general not very effective on climate change policies and in general also not good for biodiversity. On the other hand biofuels from unused waste products or produced on degraded land can be friendly for biodiversity.

2 Introduction

2.1 Why this study?

Land use for production of biotic resources (food, feed, wood, biofuels, biomass for heat and power) has an increasing impact on the world's ecosystem and climate.
Land users have on one hand created valuable cultural landscape, some of which has achieved protected status under UNESCO. On the other hand, the increasing requirement for land results in deforestation, soil degradation, increased greenhouse gas emissions and reduced biodiversity.

Land use and its impact on biodiversity is a significant issue in several policy files, such as:
- Incentives policies concerning implementation of biofuels, biomass for heat and power and biomass for other applications in which it substitutes fossil fuels.
- Waste treatment policies, especially waste paper and waste wood related policies and associated packing taxes.
- Global food consumption – especially global protein consumption – and the relationship between biodiversity and agricultural productivity.
- Deforestation and sustainable wood/timber.
- Natural conservation and species loss.

In some of these policy files, biodiversity is not yet included as an aspect to be taken into account. In other files different methodologies are applied for monitoring biodiversity (living planet index, red lists for species, ecological footprint) and – as far as implemented – linking land use with biodiversity (MSA, ReCiPe, etc.).

Biodiversity is a key natural resource which is strongly linked with the ability of an ecosystem to provide ecosystem services. Ecosystem services and biodiversity are interlinked: in order to retain ecosystem reproductivety and stability, it is necessary to maintain adequate biodiversity in the ecosystem. As the well-being of the global human population is fundamentally and directly dependent on ecosystem services (see Figure 1), biodiversity decline is undesirable.

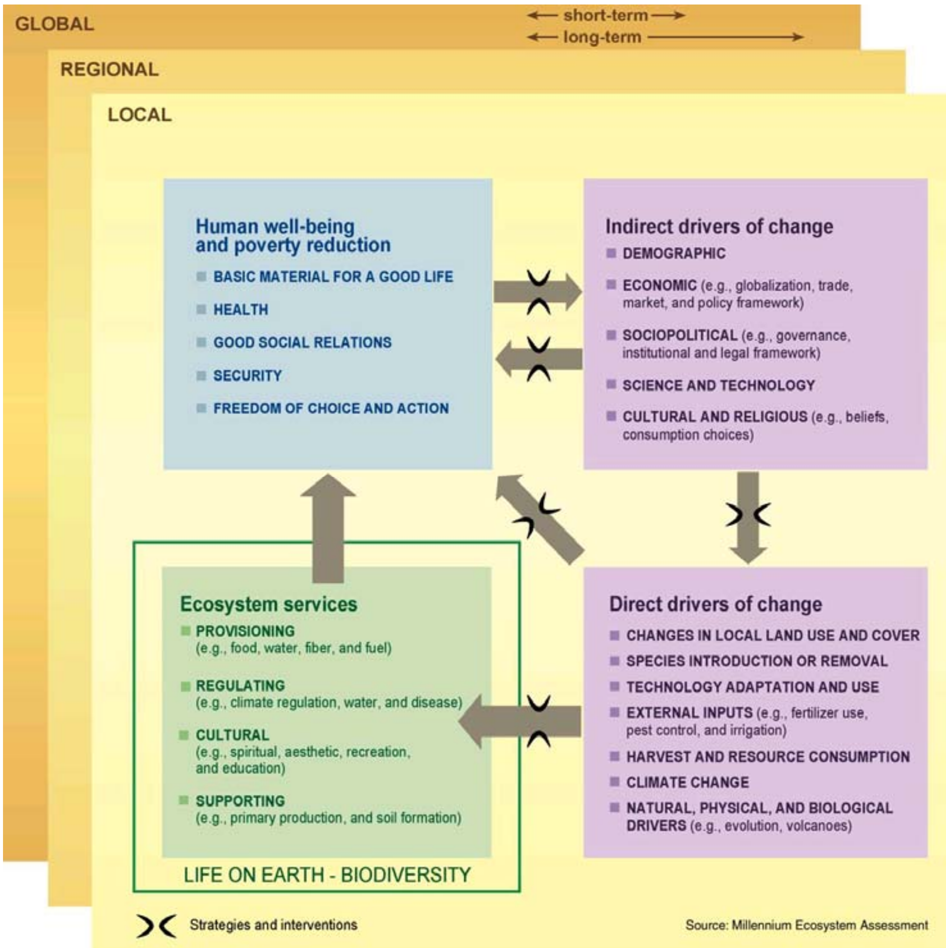
Governments have become increasingly aware of the importance of biodiversity and are trying to find ways of including biodiversity into the different policy files.

In view of the requirements of the different policy files the Dutch Government would like to identify an indicator which focuses on land use, biodiversity and their interaction.

2.2 Biodiversity is important for both industry and NGOs (too)

Biodiversity is important for both industry and NGOs too. The importance of biodiversity for NGOs is not surprising, given their focus on preservation of natural habitats and reduction of the impact of human activities on the environment (for a complete analyses of the opinions of industry and NGO on biodiversity see Annex I).

Figure 1 **A schematic image illustrating the relationship between biodiversity, ecosystem services, human well-being, and poverty**



Source: Millennium Ecosystem Assessment (2005).
The illustration shows where conservation action, strategies and plans can influence the drivers of the current biodiversity crisis at local, regional, to global scales.

But multinationals too view biodiversity and land use as an important issue. A review of the policy statements of leading Netherlands based multinationals - in particular petrochemical multinational Shell, the biochemical company DSM and the food company Unilever – indicate that many have made strong statements on the necessity of protecting biodiversity and have integrated biodiversity as an important issue in their business strategies. For these multinationals biodiversity and land use are either a business risk that should be mitigated or aspects that are essential for the provision of the required resources.

In the words of Shell:

> *“Helping to protect biodiversity makes business sense for Shell. We must meet legal and regulatory requirements. But it also reduces our operational and financial risk by ensuring we get our projects right. It helps to build trust with regulators and third parties so our projects can win approval and acceptance, it can make us the first choice for business partners, and can attract and motivate staff.”*

Unilever has made biodiversity a very important factor in its strategy:

> *Around half the raw materials we buy come from agriculture and forestry, measured by volume. We are among the world's largest users of agricultural raw materials such as tea, vegetables and vegetable oils. Growing our business – while conserving biodiversity – is a substantial challenge. We seek to ensure that our agricultural activities have minimal adverse effects on the number and variety of species found in a particular area or region. Protecting biodiversity is central to our Sustainable Agriculture Programme. Sustainable agriculture is ultimately about sustainable use of biological resources. One of four principles in Unilever's Sustainable Agriculture Programme is: "Ensuring any adverse effects on… biodiversity from agricultural activities are minimised and positive contributions are made where possible". Biodiversity is one of the 11 core indicators used to measure sustainable farming practices."*

In view of the importance of biodiversity conservation for NGOs and multinationals, these stake holders too would welcome methodologies that can be applied for monitoring land use and associated impacts on biodiversity.

2.3 A search for suitable indicators for policy use

The search is for methodologies that relate land use or land use transition with biodiversity and changes in biodiversity and can be applied in developing and analysing policies.

Methodological requirements

The indicators associated with these methodologies should (see e.g. PBS 2010[a]):

- Be applicable on a global scale.
- Be applicable in a scenario context.
- Be relatively simple.
- Be based on sound scientific principles.
- Allow for combining the impact of land use (change) on biodiversity with the impact of other pressures on biodiversity – e.g. acidification, eutrophication and eco-toxicity.
- Allow for combining with other types of environmental impact and types damages – e.g. damage to environmental health and impacts on water quality.

These characteristics will allow predicting impacts of policies on biodiversity in scenario studies on any relevant scale (on the spot to global) and will allow comparing impacts on biodiversity from different pressures.

Requirements in view of policy issues

The indicators should ideally also allow for taking into account following main policy related issues, comparisons and policy choices:

1. Comparison between different intensity of land use and land use development variation, e.g.:
   a The intensity of tillage and the use of fertilisers and pesticides.
   b The presence of ecological corridors, buffer zones and landscape components (e.g. hedgerows).
2. A comparison between two different locations in different regions for cultivation of the same or comparable crop or tree.
3. A comparison between a biotic and a fossil product for the same service.

4. Comparing different products for different regions for focusing a general biodiversity policy of a country.
5. Comparing more intensive production (less biodiversity on the production area) and less intensive production (more area needed) including the indirect land use change issue.

Comparison between different intensity of land use and land use development variation

The first issue is relevance in relation to the implementation of land use planning and biodiversity policies or in relation to increasing sustainability of agriculture and forestry.
It is also relevant for evaluating the sustainability of cultivation of feedstock crops for biofuels. In the certification scheme attached to the Renewable Energy Directive (RED)[3] and other certification schemes, qualitative and generic basic demands have been included in relation to biodiversity.

Comparison between two different locations in different regions for cultivation of the same or comparable crop or tree

The second issue refers to for example comparing different options for meeting biodiesel feedstock demand. Is it from a biodiversity perspective more desirable to use rape seed from temperate climate zones or to use tropical crops (e.g. soy or oil palm).

A comparison between a biotic and fossil product for the same service

The third issue is relevant in relation to for example:
- Biofuels policy and RED – at what biodiversity costs.
- The ambitions concerning bio-based economy and 'greening' of chemical
- Sector and other industrial sectors currently relying on fossil fuels.
- Comparing recycling versus energy utilisation of biotic materials such as wood in furniture or paper.
- A fossils plastic versus a bio plastic.
- Paper versus plastic.

Comparing different products for different regions for focusing a general biodiversity policy of a country

For focusing in a general biodiversity policy the ranking of products and materials on a biodiversity indicator is helpful.

Comparing more intensive production

The fifth issue refers to the question what is environmentally more beneficially, intensive agricultural practices that require a minimum area for production or more environmentally agricultural practices that may require more land.

[3] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:en:PDF

2.4 Activities conducted in this project and report structure

In this report we first broadly introduce the phenomena biodiversity and the relationship between biodiversity and ecosystem services in Chapter 3. We also use this chapter for a further definition of the scope of the report and the relevance of the methodologies studied. E.g.:

- How do these methodologies relate to other policy instruments and to monitoring instruments?
- What is the scope of the monitoring and regulating instruments with respect to the considered area and how does the scope compare with the different impacts influencing biodiversity?

In conducting this study we first made an inventory of the various methodologies applied for monitoring biodiversity and linking land use and biodiversity. From the inventory we selected those methodologies which, in our view meet the requirements defined in previous paragraph best. We next studied the different selected methodologies in more detail and considered the basic assumptions and subjective weighing factors introduced in the methodology. This analysis is described in Chapter 3.

In Chapter 4 we compared the different selected methodologies.

In Chapter 5 conclusions can be found about a suitable indicator for the five different policy issues.

In the Annexes all considered indicators are described in detail.

3 Biodiversity and Ecosystem Services

3.1 Biodiversity defined

Biodiversity can be defined in a variety of ways. A very narrow definition is to focus on genetic diversity (which occurs within species, e.g. subspecies/forms) or species diversity, perhaps taking into account the functional role different species play. A broader definition is to focus not just on species[4]. Biologists most often define biodiversity as the "totality of genes, species, and ecosystems of a region". An advantage of this definition is that it seems to describe most circumstances and presents a unified view of the traditional three levels at which biological variety has been identified:

- Species diversity
- Ecosystem diversity
- Genetic diversity

Here, varied landscapes, uplands, lowlands, wetlands and coastal areas all contribute to the diversity of the natural environment. This broader version follows the standard Convention on Biological Diversity definition (see http://www.biodiv.org).

Biodiversity is said to be “too complex to be fully quantified at scales that are policy relevant” (EASAC, 2005). Baseline values for biodiversity are also indicated to be difficult to set. Very little is known about even recent trends in the abundance of most species apart from some insects in restricted parts of Europe and, more generally, birds.

3.2 Aspects influencing biodiversity

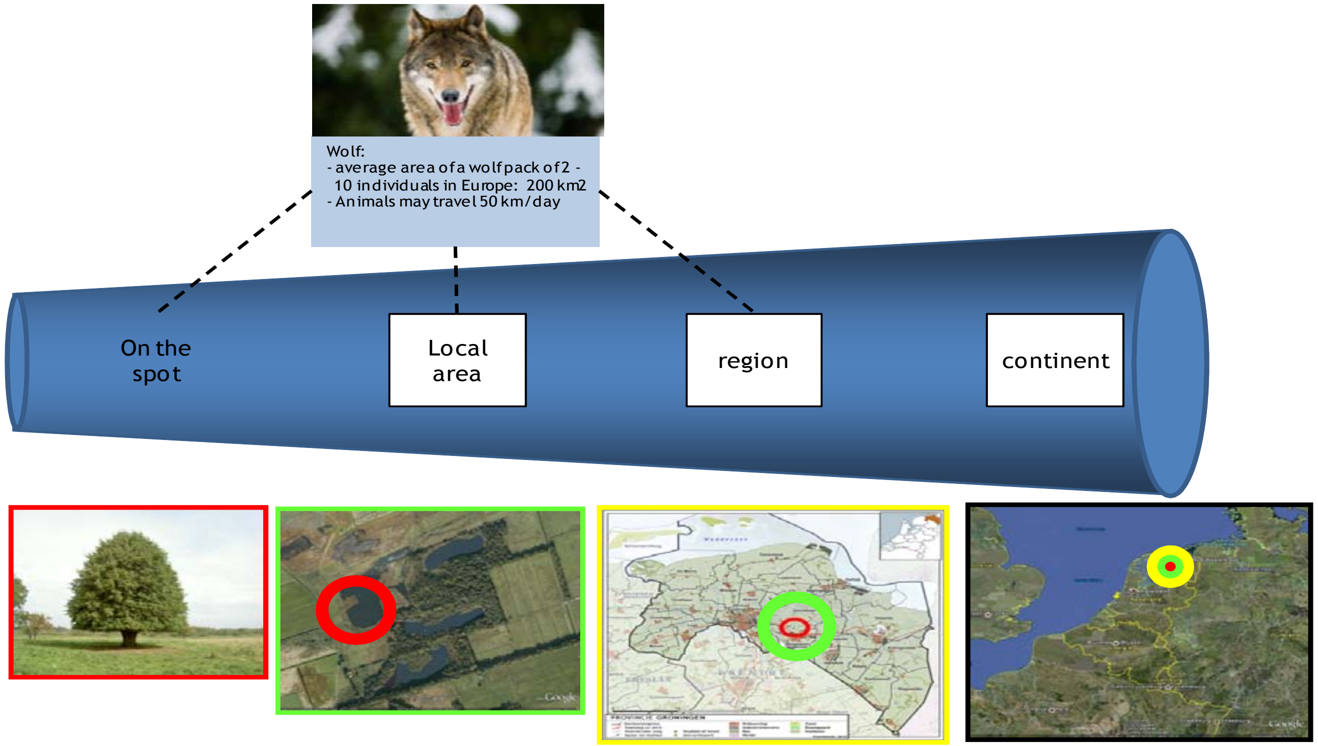
Biodiversity at a certain location (‘on the spot’) is influenced by a variety of micro, meso and macro aspects, ranging from the type and intensity of land use on a micro scale to the flow of oceanic currents and the migration of birds on a continental scale (see Figure 2).

The involvement of different aspects on both micro, meso and macro levels in the ‘on the spot’ biodiversity is logical if one considers the fact that:

- Large mammals, such as wolves, occupy territories of tens or hundreds of square kilometres.
- Migrating birds use breeding grounds and overwintering grounds situated many thousands of kilometres apart.
- Seeds of mussels travel tens or hundreds of kilometres before they settle and grow into mussels.

[4] The 1992 United Nations Earth Summit in Rio de Janeiro defined "biological diversity" as "the variability among living organisms from all sources, including, 'inter alia', terrestrial, marine, and other aquatic ecosystems, and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems". This definition is used in the United Nations Convention on Biological Diversity.

Figure 2 **Factors influencing biodiversity on a specific location**



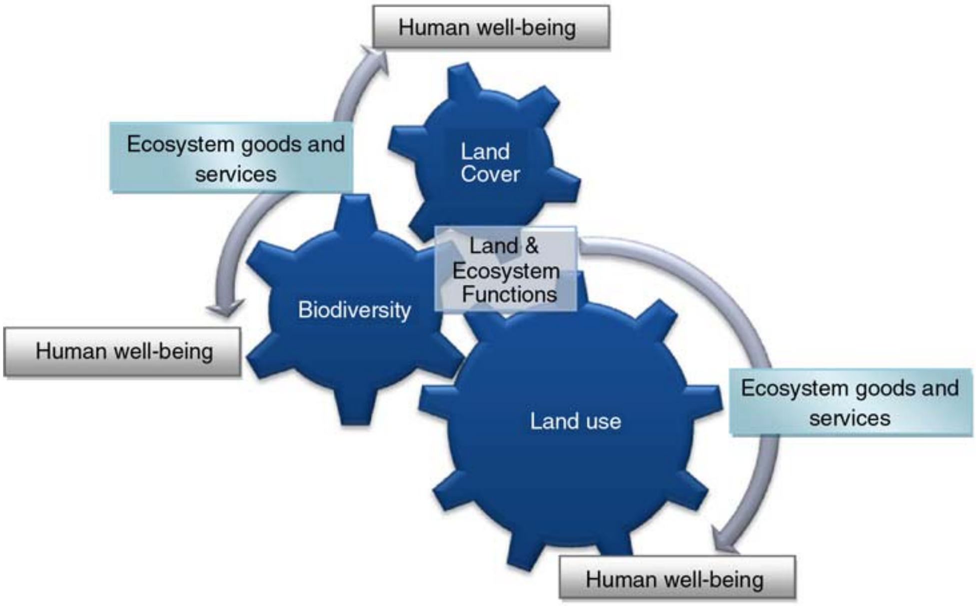
Biodiversity influencing aspects			
- Type and intensity of land use - Presence of landscape components (hedgerow, bushes, pools, …) - soil fertility - Nitrogen deposition and other forms of soil pollution	- Infrastructure - Encroachment - Fragmentation and size of patches of biotopes	- Regional land planning - Level of natural area's being linked, natural corridors natural corridors	- Climate change - Invasive species
	-------- Level of protection of high biodiverse area's -------		
		sea and oceanic currents	
----------- geographical and temporal availability of water -------------			

Westerbroek natural area near Hoogerzand Sappermeer in the province of Groningen in the Netherlands

As indicated in many sources land use (and land cover), biodiversity and ecosystem services are partially intertwined:

- Biodiversity can be regarded an indicator of the capacity of an ecosystem for providing ecosystem services. However, this capacity not just depends on biodiversity, but on for example soil structure as well.
- Biodiversity on a certain spot is determined by, among other things:
  - The use of the land at that location and the surrounding region.
  - The level of fragmentation of natural areas in the region.
  - Closeness of infrastructure.
  - Other land use related features.

Figure 3 The relationships between land use, land cover, biodiversity and the output of ecosystem services



Source: Haines-Young, 2009.

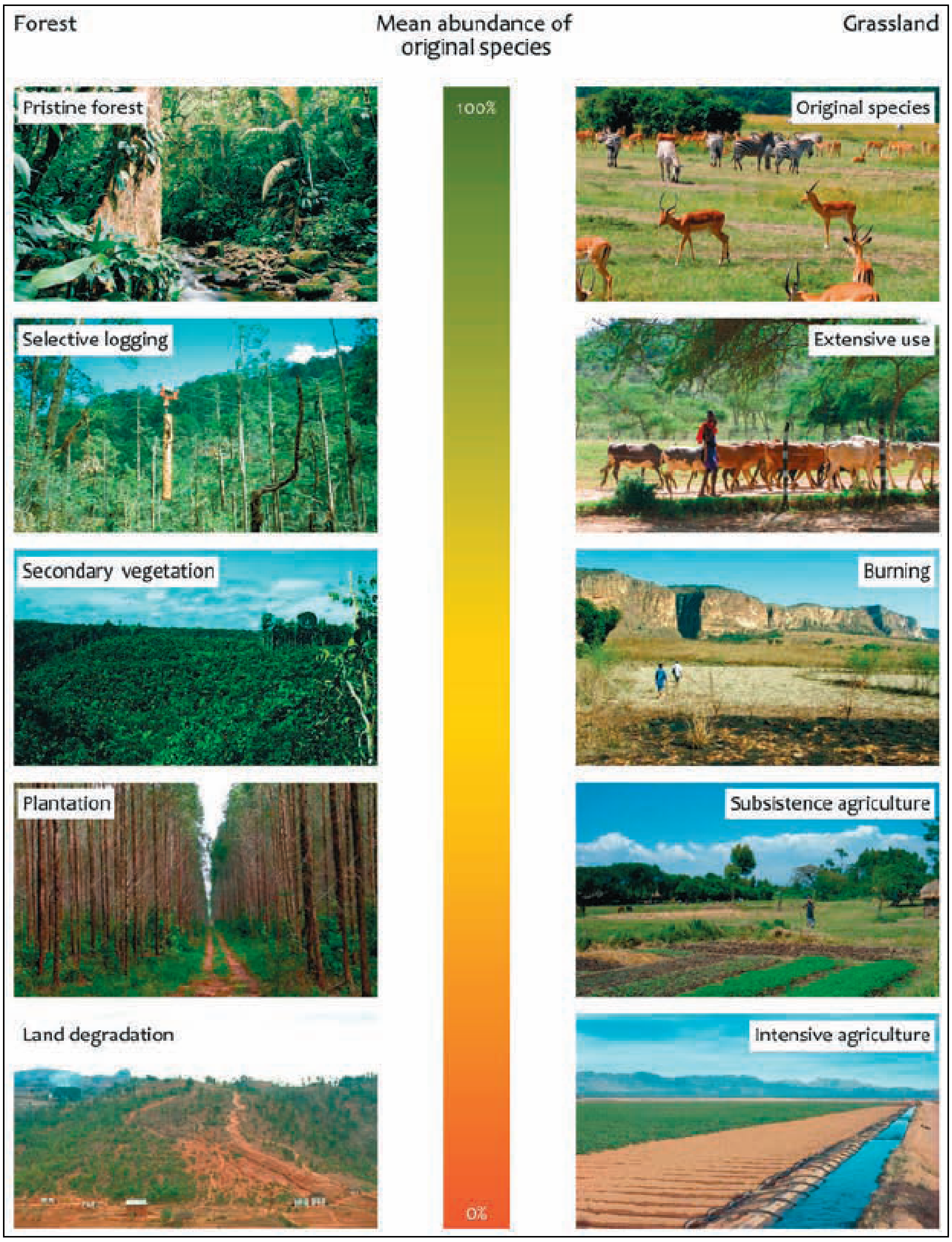
Biodiversity is, however, just as well determined by a whole set of other pressure (or their absence), such as water scarcity, deposition of toxic and eutrophicating substances, invasive species, etc. (see e.g. Haines-Young, 2009).

The effects of land use intensity on biodiversity and the naturalness of a landscape for example is illustrated in Figure 4.

3.3 Biodiversity and ecological services

Humanity receives countless benefits from the natural environment in the form of goods and services such as food, wood, clean water, energy, protection from floods and soil erosion (TEEB, 2008) – see Figure 5. Natural ecosystems are also the source of many life-saving drugs as well as providing sinks for our wastes, including carbon. Human development has also been shaped by the environment, and this inter linkage has strong social, cultural and aesthetic importance. The well-being of every human population in the world is fundamentally and directly dependent on ecosystem services.

Figure 4 Naturalness of landscape as a function of land use intensity



Source: PBL (2010a).

Figure 5 Ecosystem services as identified in the Millennium Ecosystem Assessment

Provisioning services
Products obtained from ecosystems

- Food
- Fresh water
- Fuelwood
- Fiber
- Biochemicals
- Genetic resources

Regulating services
Benefits obtained from regulation of ecosystem processes

- Climate regulation
- Disease regulation
- Water regulation
- Water purification
- Pollination

Cultural services
Nonmaterial benefits obtained from ecosystems

- Spiritual and religious
- Recreation and ecotourism
- Aesthetic
- Inspirational
- Educational
- Sense of place
- Cultural heritage

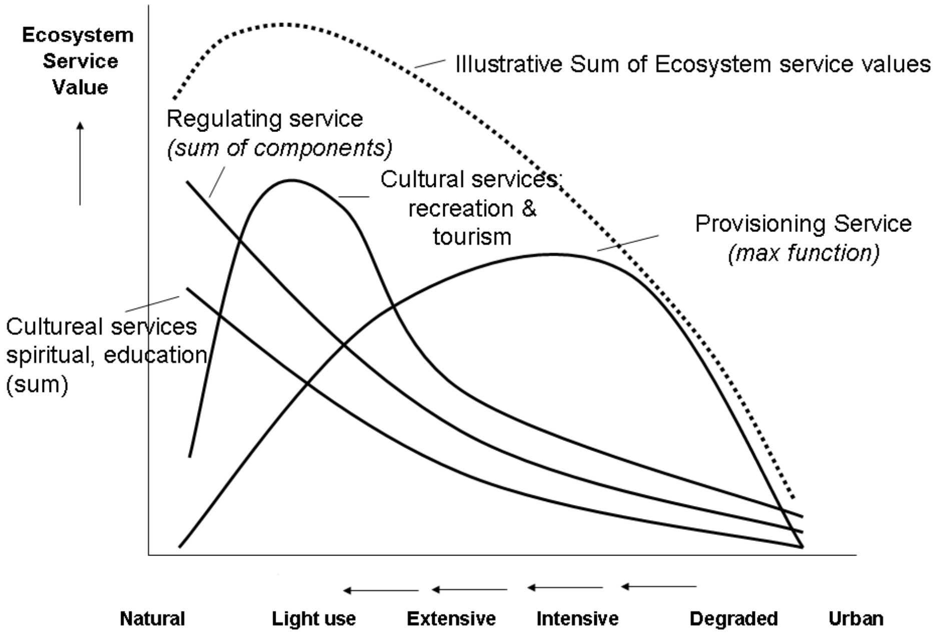
Supporting services
Services necessary for the production of all other ecosystem services

- Soil formation
- Nutrient cycling
- Primary production

Source: Ranganathan, 2008.

Ecosystem services and biodiversity are interlinked by the necessity of retaining adequate biodiversity in an ecosystem for retaining ecosystem reproductivety and stability (Haines-Young, 2009; COPI, 2008), as illustrated by Figure 6.
An ecosystem may become disrupted when a critical amount of biodiversity has been lost or a level of nutrient inputs exceeded (see text box).

Figure 6 **Generalised and fictional relationships between land use/biodiversity and ecosystem services**



Source: COPI, 2008.

Ecological tipping points

Ecological systems can become disrupted up to the point that it collapses and can no longer supply (certain) ecosystem services or even any form of live. Infamous examples are:

- The Aral Sea environmental disaster.
- The ‘Dust Bowl’ in the USA and Canada in the 1930’s.
- The Great Sparrow campaign and the following Great Chinese Famine, resulting partly because of locust population explosion due to absence of sparrows.
- Invasive species – e.g. rabbits, rats and mice – in Australia and New Zealand.

But even before such a tipping point or threshold is reached, disturbance of ecosystems can cause disastrous damage, e.g. flood disasters as the recent disaster in Pakistan.

Ecological tipping points are difficult to predict because their approach may be accompanied by slow, subtle changes, in contrast to the rapid, drastic changes that occur when a tipping point is reached.

Additional information:

- Examples of thresholds can be found in the Resilience Alliance database (http://www.resalliance.org/index.php/database?st=26#N).
- In the EU a threshold program has been running under the EU Sixth Framework Programme, focussing on thresholds for water pollution in coastal areas and algae explosions (see e.g. http://www.thresholds-eu.org/public/Thresholds_brochure_web.pdf).
- Mathematical theory behind estimating thresholds can be found on: http://www.ecologyandsociety.org/vol1/iss1/art7/

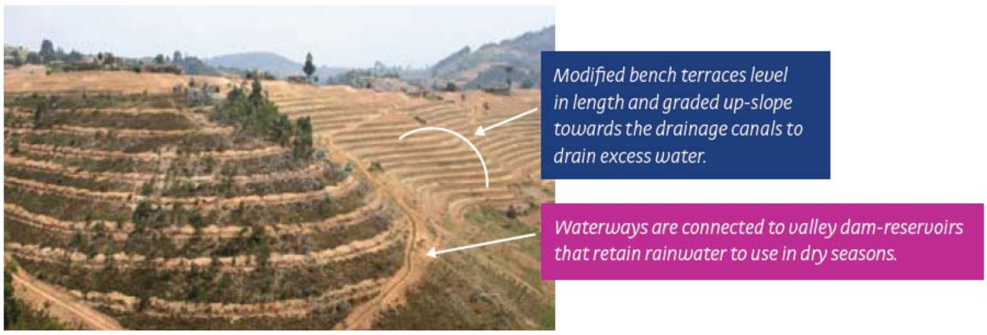
Though it is clear that:

– Ecosystem functioning is not equally affected by all species. And
– Ecosystem services can partly be regulated and maintained by measures that do not directly relate to biodiversity (see measures illustrated in Figure 7).

Ecologists presently have no way of reliably predicting which species are of no value now and in the future. History shows that new utilitarian values of biodiversity are constantly discovered, and species that were previously thought to be of no benefit at all have turned out to provide significant or even crucial benefits. These are also known as option values.

The precautionary principle suggests that biodiversity losses should be minimised to minimise the risk of sudden loss of stability and ecosystem function. Taking into account that the cost of protecting biodiversity at an adequate level is modest in comparison with many other expenses, protection of biodiversity can be seen as an essential component of sustainable development.

Figure 7 Examples of measures for increasing water availability on arable land

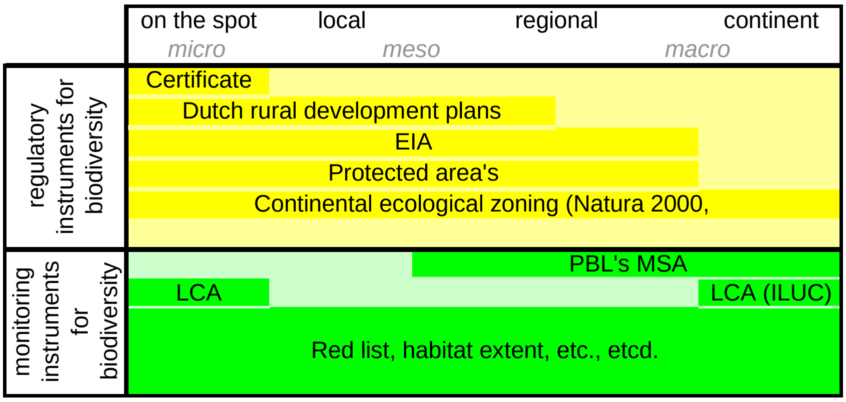


Source:
http://www.worldwaterweek.org/documents/WWW_PDF/Resources/2010_05sun/3R_brochure_First_Issue.pdf

3.4 Biodiversity conservation, instruments for monitoring and preservation

A wide variety of instruments exists for monitoring and regulating biodiversity and ecosystem services (see Figure 8). No instrument covers all aspects of biodiversity since the focus of the instruments is limited to a certain perspective.

Figure 8 **Existing regulatory and monitoring instruments for biodiversity and ecosystem services**



Given the fact that processes and aspects at different geological scales influence biodiversity, biodiversity loss cannot be stopped if biodiversity policies are implemented in at only one level of geographical scale.

Given the impacts of aspects such as land use in the surrounding region on local biodiversity and of aspects such as the level of fragmentation of natural areas in the region and closeness of infrastructure, biodiversity cannot be regulated solely on a micro geographical level and in isolation from other policies, such as those on the economy, urban and infrastructure development, and climate change.

Below the different regulatory instruments are discussed briefly in order to provide some indication of the applied approach in maintaining biodiversity. Given the goal of this report, the focus of the reminder of the report is on monitoring instruments and their applicability in relation with the policy issues mentioned in Paragraph 2.2.

Certification

Certification is a voluntary, market driven approach, whereby producers agree to comply with a widely recognised standard drawn up by an independent body, and to be assessed against this standard by an accredited auditor (the Certification Body). Certified companies can label their products and make certain claims about their management and/or performance. Certification is one way of setting voluntary rules for management for forests, according to FAO (2009) approximately 8% of global forest area has been certified under a variety of schemes and it is being estimated that one quarter of global industrial round wood now comes from certified forests (FAO, 2009). Most certification is found outside the tropics and less than 2% of forest area in African, Asian and tropical American forests are certified. Most certified forests (82%) are large and managed by the private sector (ITTO, 2008). The scope of forest certification is forest management within a production unit (Forest Management Unit). It plays virtually no role in the combat against the most important threat to biodiversity: the conversion of natural forests.

Two types of certification systems[5] can be distinguished, each with its own way of biodiversity/land use verification[1]:

- Source oriented: Systems that focus on the management of the area where a product or service is coming from (e.g. forest management certification systems). These systems focus on the management or exclusion of the entire production unit (cut-off date).
- User-oriented: Systems that focus mostly on the product/service itself (e.g. carbon storage, biomass for energy, vegetable oil, soy, timber plantations). These systems tend to exclude areas from production, e.g. as a result of their biodiversity values (spatial dimension). They usually do not address biodiversity very specifically within productive areas once the production site has been identified. There is a stricter separation between production and biodiversity conservation.

Two types of sustainability criteria/indicators can be distinguished;

- Performance-based: These criteria give specific minimum requirements for verification and monitoring. Criteria/indicators are measurable.
- System-based: Criteria/indicators are procedural and refer to procedures to be followed in order to increase sustainability.

Main elements of performance-based criteria for biodiversity/land use are the following:

- Biodiversity:
    - Species inventories.
    - Monitoring.
    - Protected areas and HCVA's (high conservation value areas.
- Land use:
    - Land conversion. Setting rules (cut-off dates) prevents a management unit from getting a certification after clear-cutting HCVA (glossary).
    - Land use rights.
- General:
    - Some principles can be considered performance-based when supported by a measurable monitoring system.
    - Compliance with applicable laws and regulations can be performance-based, depending on the specific situation. Actually, certification requires legal status of management.

Recent research suggests that forest management certification in the difficult tropics is beneficial for biodiversity: "Forest certification has certainly done more to improve tropical forestry than any other intervention with similar intentions (e.g., the Tropical Forestry Action Plan, the Montreal Process and the ITTO's many outstanding efforts). At the same time, we are unable to quantify the full extent of these benefits" (Roderick J. Zagt, Douglas Sheil and Francis E. (Jack) Putz, 2010).

[5] See Erik Lamerts van Bueren, 2009.

4 Methodologies for Relating Land Use and Biodiversity

4.1 Biodiversity and area size – some theoretical background information

Relationships between biodiversity and land use have been developed in the field of ecology. In ecology, the biodiversity – expressed as species richness, the number of species per unit of area – has been described as a function of the size of that area of a habitat, or of part of a habitat in so-called species-area curves.

The challenge of this project is identifying and evaluating methodologies utilising these relationships in a shape that allows for meeting the requirements defined in the previous paragraph.

For a better understanding of the theory behind these methodologies and the evaluation of these methodologies, a brief introduction into the theory of species-area relationships – as far as relevant for this study – is given in this paragraph.

The theory of species-area relationships

Larger areas tend to contain larger numbers of species, and empirically, the relative numbers seem to follow systematic mathematical relationships[6]. The species-area relationship is usually constructed for a single type of organism, such as all vascular plants or all species of a specific trophic level within a particular site. It is rarely, if ever, constructed for all types of organisms if simply because of the prodigious data requirements.

Arrhenius in 1921 was the first to develop a mathematical relationship between area and species richness[7]. All methodologies for linking land use and biodiversity are based on his the area-species relationship, expressed as:

$$S = a * A^b$$

In which:

S =	Species richness for the considered area A
a =	Species richness factor, species richness for an area of the considered biome of infinite size
A =	Area (m^2)
b =	Species accumulation factor – a measure for the tempo with which the number of species increases with area size

The relationship indicates that biodiversity *S* in a specific biotope increases with increase in area *A*. The parameter *b* indicates how quickly biodiversity increases with area size.

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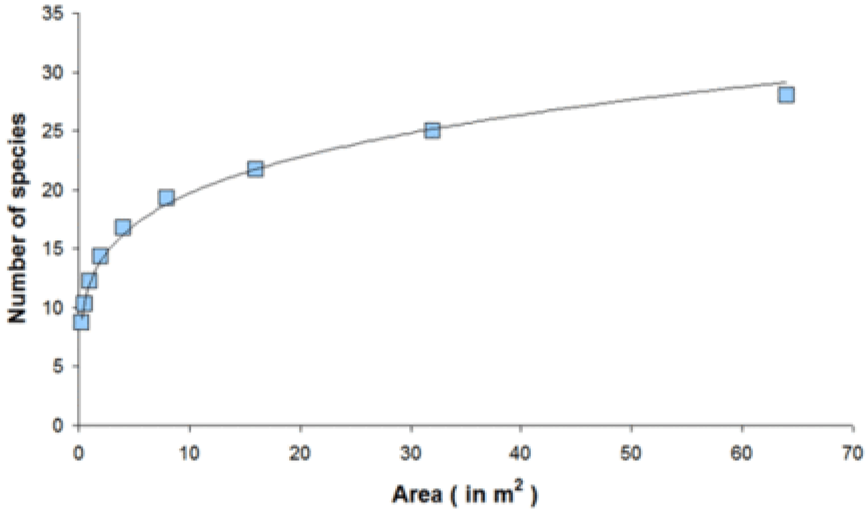
6 Preston, F.W. 1962. The canonical distribution of commonness and rarity: Part I. Ecology 43:185-215 and 431-432, as cited at http://en.wikipedia.org/wiki/Species-area_curve

7 See http://www.ime.unicamp.br/sinape/sites/default/files/Resumo_gSARModel.pdf for more information.

Figure 9 Illustration of a species-area relationship



Alternative formulations of his relationship have been proposed by e.g. Gleason (1922) and Plotkin et al. (2000). Alternative relationships have been postulated by e.g. Ulrich & Buszko or Conceicao et al., but as far as can be deducted these variations or alternatives are not applied.

The PDF parameter

In addition to Arrhenius' relationship, impacts on biodiversity are often expressed in Potential Disappeared Fraction of species (PDF). The PDF parameter is a measure for the relative **change** in biodiversity, relative to the biodiversity of a reference situation. This reference may be:

- For land occupation: the natural, pristine biome that would be present without any human interference.
- For transformation or land use change: the land use in the situation after land use change.

Both situations are mathematically expressed below. The parameters *S* and *a* in these relationships are the same as in Arrhenius' species-area relationship. The difference between *S* and *a* is that the *S* refers to the species richness of a standardised unit or area, e.g. 10,000 ha.

For occupation:

$$PDF_{nature \rightarrow occ.} = \frac{S_{nature} - S_{occupation}}{S_{nature}} \quad \text{or} \quad PDF_{nature \rightarrow occ.} = \frac{a_{nature} - a_{occupation}}{a_{nature}}$$

For transformation:

$$PDF_{1 \rightarrow 2.} = \frac{S_1 - S_2}{S_2} \quad \text{or} \quad PDF_{1 \rightarrow 2} = \frac{a_1 - a_2}{a_2}$$

Another option of expressing changes in biodiversity is expressing the relative **level** of the species richness for a considered situation, relative to the species richness in a reference situation: the Mean Species Abundance.

For this methodology of reporting the reference as a rule is the natural, pristine biome that would be present without any human interference.
The mathematical formulation is:

$$MSA = \frac{S_{occ}}{S_{nature}} \text{ or } MSA = \frac{a_{occ}}{a_{nature}}$$

As can be seen from both types of relationships, MSA and PDF can easily be calculated from one another as for example:

$$PDF_{nature \to occ.} = \frac{S_{nature} - S_{occupation}}{S_{nature}} = 1 - MSA$$

4.2 A selection of relevant methodologies

In the search for indicators fulfilling the requirements defined in the previous chapter, a first selection of relevant methodologies was made. The selected methodologies all allow for relating land use or land use transition with biodiversity and changes in biodiversity and thus meet the basic requirements for the indicators searched for.
The selected methodologies are broadly described in the next paragraphs.
A more detailed description is added in the Annexes to this report.

For comparison, other methodologies for monitoring biodiversity which do not refer to the relationship between land use (change) and biodiversity are also mentioned.

Table 2 Overview of considered and selected (bold) biodiversity related methodologies

	Midpoint aspects		End point aspects		
	m^2 area	Population	PDF/m^2	MSA	Estimated impact
Selected methodologies					
a MSA (by PBL)				X	
b ReCiPe			X		
c TNO			X		
Not selected					
– Midpoint monitoring methodologies – (Land occupation, land use transition) – E.g. CML2 methodology, PAS 2050	X				
– Monitoring methodologies for biodiversity – E.g. living planet index (WWF), Red list species		X			
– VROM biodiversity assessment framework					
– Carbon footprinting methodologies – E.g. Ecological footprint, IPCC					
Bioscore tool					X
IBIS methodology (CREM)					X

Not selected categories of methodologies

Categories of methodologies not further considered were:

- Midpoint methodologies
- Monitoring methodologies
- Carbon footprinting methodologies

Midpoint methodologies such as applied by CML or PAS 2050 consider and quantify land use related to a specific activity such as mining or agriculture. They do, however, not include a relationship between land use and biodiversity and thus do not allow quantifying impacts of these land using activities on biodiversity.

Monitoring methodologies on the other hand, present methodologies for monitoring trends in regional or global biodiversity. The Living Planet Index, for example, is generated by averaging three separate indices for the forest, freshwater, and marine biomes. Each index describes the average trends in populations of vertebrate species from around the world since 1970. Each index is set at 100 in 1970 and given an equal weighting. The index is currently based on nearly 3,000 population time series for over 1,100 species. All species in the index are vertebrates.
Monitoring methodologies however do not include mechanisms that directly relate the observed trends with aspects such as types of land use, intensity of land use and extent of different areas of land use. This makes them unfit for linking a land-requiring activity with the impact of that activity on biodiversity.

In carbon footprinting methodologies, it is not biodiversity, but emissions of greenhouse gases that are considered. The considered emissions result from e.g. use of fossil fuels and also from land use related changes in natural carbon stocks in the biosphere. However, since greenhouse gas emissions have no direct relationship with biodiversity these methodologies do not allow for linking biodiversity and land use.

WWF's Ecological Footprint Methodology combines aspects of monitoring methodologies and carbon footprinting methodologies. The Ecological Footprint uses yields of primary products (from cropland, forest, grazing land and fisheries) to calculate the area necessary to support a given activity. Greenhouse gas emissions and waste are included and are translated into land area by calculating the amount of biologically productive land and sea area required to absorb these emissions and wastes. Greenhouse gas emissions are, for example, translated into land area by considering the area of growing forest required to absorb and sequester the emitted greenhouse gases or an equivalent amount of CO_2.

Other methodologies

Next to the above mentioned categories several specific methodologies were discussed in the early stages of the project, which upon further consideration show to be assessment methodologies for analysing whether impacts on biodiversity have been considered sufficiently in e.g. EIA's and biodiversity impact reporting (e.g. the VROM Biodiversity Assessment Framework).

The IBIS methodology on the other hand can be used for estimating the scale of negative and positive impacts of an activity on biodiversity.
The methodology however does not allow for estimating absolute impacts of land use (change) on biodiversity.

Bioscore
The Bioscore tool developed by EnCN and partners was also not selected. This tool is a computer model using quantitative and global relationships between pressures and biodiversity, including land use, fragmentation and presence of power lines for 8 different categories of species and for 11 different biomes. This level of detail with respect to biomes and categories of species makes the methodology too elaborate to allow discussion in this report. It is not ‘simple’ enough.
As an analogue with the different levels of detail and precision in the IPCC Greenhouse Gas Monitoring methodology, one could say that the methodologies considered in this report are at a TIER I level, while the Bioscore tool is at a TIER II level.

Another reason for not considering the Bioscore tool was that it considers a number of different categories of organisms and for each category considers dozens of specific species. For example, for amphibians, 20 different individual species are distinguished.
The methodology would require a weighing of changes in population or species richness of the different categories relative to each other to allow expressing changes in biodiversity in one single value that can be included in an LCA.

4.3 MSA

4.3.1 Relevance of the MSA methodology

The Mean Species Abundance or MSA methodology has been developed by PBL and WUR in the Netherlands specifically for monitoring and modeling biodiversity and for use in a scenario context.
It is applied in several UNEP projects conducted within the TEEB[8] project, in which scenario studies based on integrated modeling have been performed. In these projects a set of integrated computer models is used for estimating pressure on biodiversity globally based on scenarios for e.g. global population, economic growth, fossil fuel consumption and food consumption. These pressures are next translated into impact on biodiversity with the MSA methodology.

4.3.2 Methodology

The Mean Species Abundance (MSA) is an index which calculates the mean trend in population size of a representative cross section of the species, in line with the CBD 2010 indicator for species abundance.
As indicated in Paragraph 4.1, the MSA index represents the relative level of biodiversity, compared with the natural biodiversity of pristine nature:

$$MSA = \frac{S_{occ}}{S_{nature}} \quad \text{or} \quad MSA = \frac{a_{occ}}{a_{nature}}$$

In the MSA methodology *a* is considered.

The Mean Species Abundance indicator (MSA-indicator) - was developed at the European and global levels, using a number of proximate drivers (or pressures) as a crude measure for ecosystem quality. These relationships between pressures and species abundance (dose-response relationships) are based on

8 The Economics of Ecosystems and Biodiversity.

extensive literature reviews. The MSA addresses homogenisation by dealing only with the original species in a particular area. This avoids the increase in the opportunistic species masking the loss in the original species.

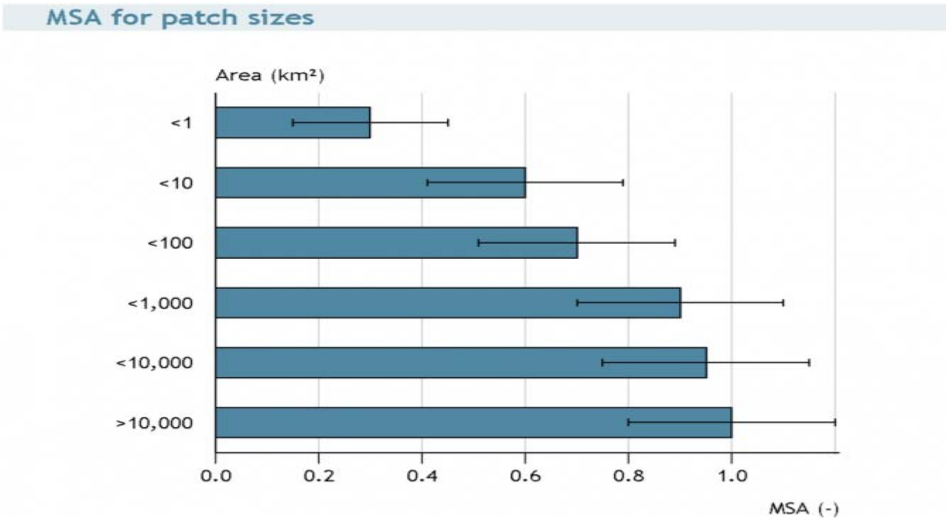
The driving forces (pressures) incorporated in the model are:
- Land use - e.g. forest and built up area - and land use intensity (MSA_{LU})
- Infrastructure development (MSA_{I})
- Fragmentation (derived from infrastructure) (MSA_{F})
- Climate change (MSA_{CC})
- Nitrogen deposition (MSA_{N})

Assuming no interaction among the drivers, for a specific location *I*, the overall MSA is calculated by multiplying the MSA's related to the different drivers:

$$MSA_i = MSA_{LU(i)} \cdot MSA_{N(i)}\, MSA_{I(i)} \cdot MSA_{F(i)} \cdot MSA_{CC(i)}$$

For connecting land use and biodiversity, only land use and land use intensity (MSA_{LU}), infrastructure development (MSA_{I}) and level of fragmentation (MSA_{F}) are relevant.

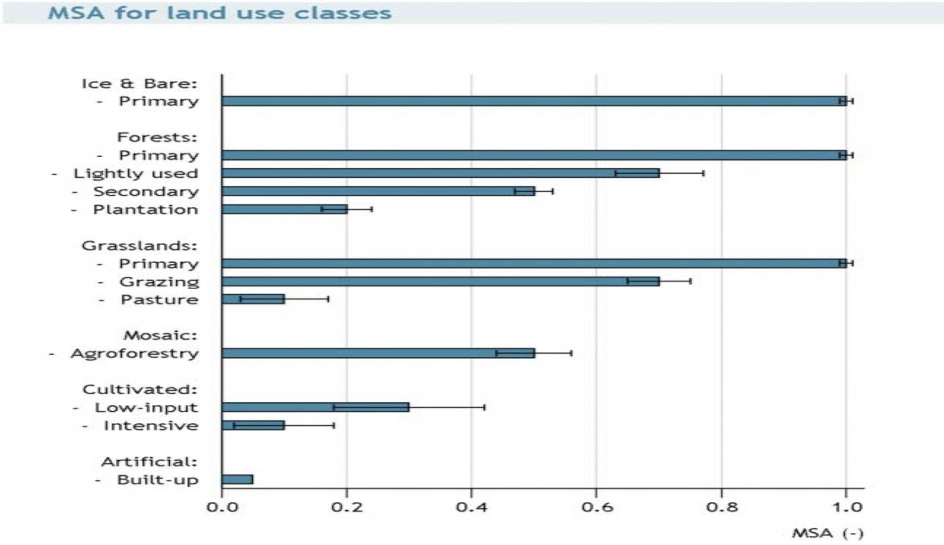
Figure 10 MSA values for patch sizes



Source: http://www.globio.info/what-is-globio/science-behind-globio/land use

The different land use types mentioned in the considered studies were categorised into six globally consistent groups – see also Figure 4:
- Primary vegetation
- Lightly used primary vegetation
- Secondary vegetation
- Pasture
- Plantation forestry
- Agricultural land, including cropland and agro-forestry systems

Figure 11 MSA for land use classes



Source: http://www.globio.info/what-is-globio/science-behind-globio/land use

Different agricultural land use intensity classes can be distinguished. A gradual increase in external inputs in agricultural systems forms the basis for different intensity classes. Each intensity class carries a specific biodiversity value.

The methodology contains no relationship with the critical amount of biodiversity lost or the level of nutrient inputs exceeded at which an ecosystem becomes disrupted and incapable of supplying ecosystem services.

4.3.3 How well does the MSA methodology fit the requirements?

Summarising the ins and outs of the methodology as in Table 3 below, the MSA methodology meets a number of the requirements defined earlier in the report (Section 2.2).

- The methodology has been designed specifically for use in modeling.
- The fact that it is applied in UNEP projects may be seen as an indication of the level scientific soundness.
- Other pressures than land use related pressures (nitrogen deposition, climate change) can be taken into account. This however refers to regional or globally uniform pressures. More local pressures such as water depletion/draught, eutrophication and deposition of toxic substances cannot be taken into account.
- In the methodology different levels of land use intensity are distinguishes. The number of different categories of intensity are however limited, especially for arable farming.

Table 3 **Overview of match of methodology with desired specification**

	Score
Methodological requirements	
– Be applicable on a global scale	X
– Be applicable in a scenario context	X
– Be relatively simple	X
– Be based on sound scientific principles	X
– Allow for combining with other pressures on biodiversity	Partly
– Allow for combining with other types of impacts and damages such as human health	Theoretically
Policy issues to be considered	
– Differences in land use intensity	(X)
– Differences in landscape design	No
– Differences in affected biomes	No
– Comparing fossil and bio	No

On the other hand, because of its nature – being a relative measure for the biodiversity for a specific location – distinguishing between two different locations is not possible.

The methodology does not give indications which allow for quantifying different approaches in landscape design, such as including ecological corridors or landscape elements. This probably is because data allowing for such a differentiation was not available.

In its current shape, the methodology cannot be combined with other environmental impacts and types of damages – such as impacts on human health - and cannot be combined with local pressures impacting biodiversity such as water shortage. However, in its current shape it is quite comparable with the PDF factors applied in LCAs (see next two sections). It therefore seems that it would allow combination with LCA methodology.

4.4 ReCiPe LCA methodology for land use (change) impact on biodiversity

4.4.1 Significance of ReCiPe methodology

The ReCiPe 2008 methodology is a harmonised LCIA methodology developed in the Netherlands and commissioned by the former Ministry of Environmental Affairs. It was developed by a consortium of science organisations, such as Radboud University, CML Leiden and RIVM.

The goal for developing ReCiPe 2008 was developing a harmonised and consistent methodology for as many environmental impacts as possible. In addition to land use and its impact on biodiversity it includes 17 other environmental issues, both well-known ones such as acidification and climate change and less frequently considered issues such as minerals and fossil fuels consumption. The methodology allows aggregation and weighing of the different impacts into one environmental damage figure.

The ReCiPe methodology can be considered an updated version of the Eco-indicator 99 methodology and is used in a somewhat different version in the Ecoinvent LCA tool[9].
As far as we know it is a quite authoritative methodology system within the field of LCIA, but it has not (yet) be applied in scenario studies and other types of policy supporting studies.

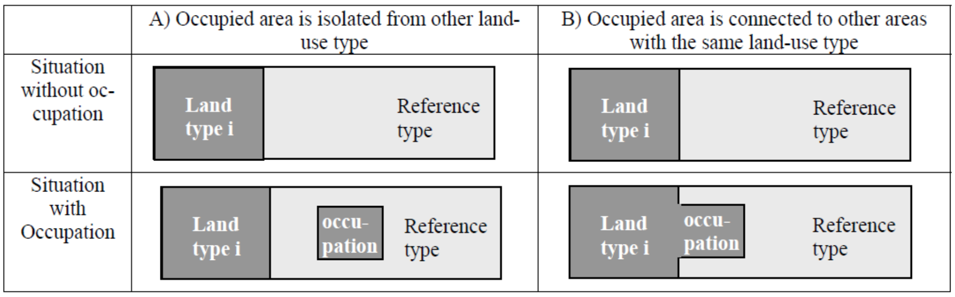
The land use and biodiversity impact methodology applied in ReCiPe 2008 is also an updated version of the methodology applied in Eco-indicator 99.
Its geographic focus is Europe.

4.4.2 Outline of the calculation rules

In the ReCiPe methodology, two different situations regarding a used plot of land are considered:
– Situation A: an isolated plot, surrounded by land applied for some other use.

or
– Situation B: a plot, attached to land used for a similar use.

Figure 12 Illustration of the unconnected and the connected form of changing a reference land use type into land use type i



Source: ReCiPe (2009).
"Reference type" refers to pristine natural biome.

For these situations following generalised relationships have been derived for the environmental damage (ED) due to occupation and transformation.

$$ED_{occ.,sit.A} = (b_{ref} + PDF_{nature \rightarrow occ.}) * A_{occ} * t_{occ}$$

$$ED_{occ.,sit.B} = (b_{nature} - b_{occ} + PDF_{nature \rightarrow occ.}) * A_{occ} * t_{occ}$$

$$ED_{trans.,sit.A} = (b_2 + PDF_{1 \rightarrow 2}) * A_{occ} * t_{restoration}$$

$$ED_{trans,sit.B} = (b_2 - b_1 + PDF_{1 \rightarrow 2}) * A_{occ} * t_{restoration}$$

In these relationships ED = Environmental Damage.
The parameters **a**, **S** and **b** refer to the Arrhenius relationship. **ED** is expressed in terms of percentage of species lost.

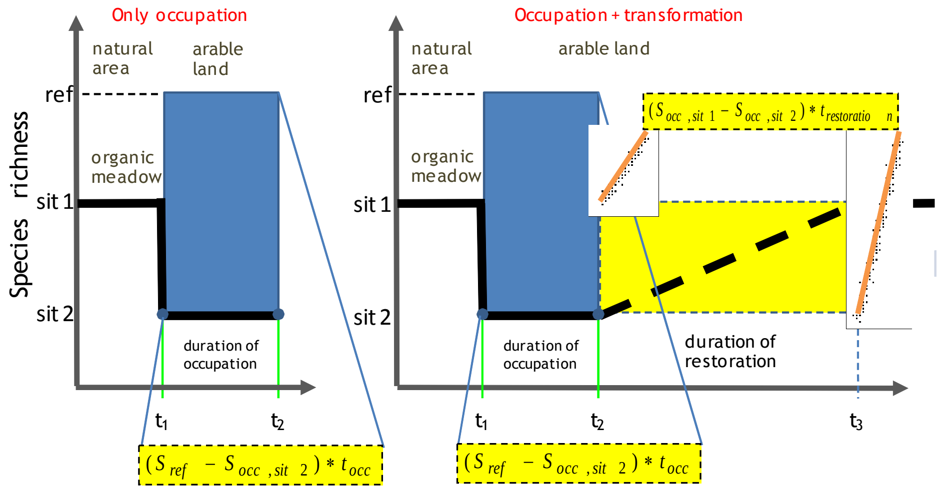
[9] The difference between both methodologies concerns the methodology for land transformation. For land transformation two reference types are distinguished in Ecoinvent - tropical rainforest and other natural areas - while in the ReCiPe methodology itself no distinction is made between different types of old forests.

PDF is based on *S* in the Arrhenius species-area relationship, not on *a*. Species density scores have been standardised to 10,000 ha. The considered species concerns vascular plants.

The essence of these relationships is illustrated by both graphs in Figure 13:

– Biodiversity impact due to occupation is expressed as the product of:
  - The relative change in biodiversity compared to the biodiversity of the pristine natural biome representative for the region, where the land use (change) occurs.
  - Time period of occupation.
– Biodiversity impact related to land use change from one type of land use to another (e.g. from organic meadow to intensively used arable land) is expressed as the product of:
  - The relative change in biodiversity compared to the level of biodiversity after transformation.
  - The time required for the area to return to its previous level of biodiversity as during the former type of land use.

Figure 13 Essence of the relationships applied in ReCiPe for quantifying impact of land use on biodiversity



In both cases (occupation and transition), the methodology makes the land user accountable for the whole burden of biodiversity that is absent during occupation time or restoration time.

For absence of biodiversity due to transition a worst case scenario is assumed, in which the biodiversity is assumed to remain at the level directly after transformation for the whole period of restoration. In practice, biodiversity will increase gradually during natural restoration, as illustrated by tree growth and measured (see Figure 14).

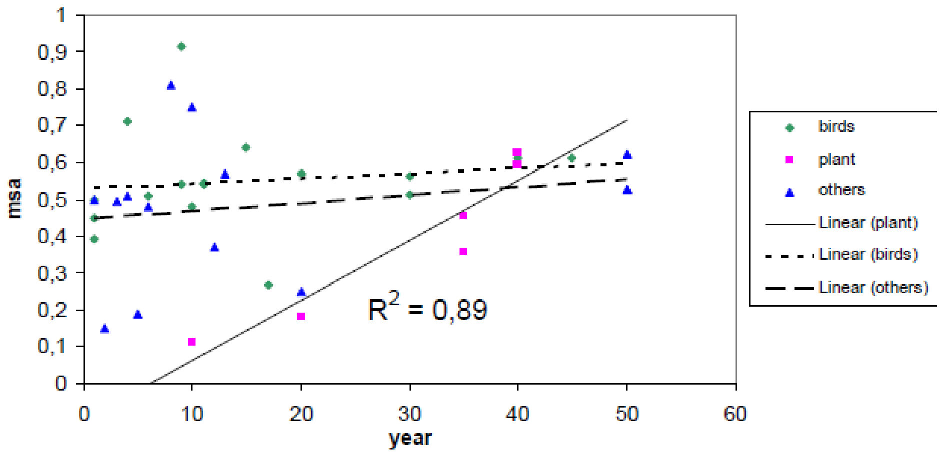
Impacts to biodiversity in the region, in which the occupied or transformed area is situated, is accounted for by adding the factors $\mathbf{b_{nature}}$, $\mathbf{b_{occ}}$, $\mathbf{b_1}$ and $\mathbf{b_2}$. As a result of these factors the total decrease in biodiversity can be > 100%, compared with the original biodiversity at the considered occupied area. The methodology applied for taking into account regional impacts concerns a mathematical elaboration of the Arrhenius curve. In the ReCiPe methodology manual, no data is presented supporting the mathematical approach. Information from other sources indicates that land use change on a certain spot can have a significant impact on biodiversity in the surrounding area, for example in case of land use around nature reserves[10].

For arable farming and forestry, $\mathbf{t}_{occupation}$ can be considered to be 1 for any annual crop and the economic life of the plant or length of rotation (for a tree) for perennial crops.

The way in which transformation is into account is not explained in the ReCiPe manual.

Hypothetically, in a case in which a specific area of old grow forest or some other very biodiverse biome is transformed into arable land for cultivation of annual crops, the whole burden of biodiversity decline could theoretically be allocated to the first yield produced on that area.

Figure 14 Biodiversity values (as MSA) for different species during recovery after forest clearance



Source: Lysen, 2008.

It is, however, not very likely that the transformation is realised just to farm one year on that area. As illustrated by farming practices in Europe, transformed natural area may be used for agriculture for centuries.
An approach more in line with this fact and in line with methodological choices in e.g. greenhouse gas emission balance methodologies, would be considering a specific time for 'depreciating' the loss in biomass. In IPCC methodology, for example, greenhouse gas emissions due to land use change, are depreciated over a period of 20 years.

10 See e.g. http://www.currentconservation.org/issues/cc_2-4-12.pdf

In the methodology, different levels of land use intensity are distinguished, e.g.:
- Monoculture Crops/Weeds
- Intensive Crops/Weeds
- Extensive Crops/Weeds
- Monoculture Fertile Grassland
- Intensive Fertile Grassland
- Extensive Fertile Grassland
- Monoculture Infertile Grassland
- Extensive Infertile Grassland

Fragmentation and disturbances such as power lines and infrastructure are not taken into account.

The methodology contains no relationship with the critical amount of biodiversity lost or the level of nutrient inputs exceeded, at which an ecosystem becomes disrupted and incapable of supplying ecosystem services.

4.4.3 Perspectives on midpoint impacts and their influence on endpoint impacts

In the ReCiPe methodology, three different perspectives are distinguished, representing different views on the damages caused by environmental impacts:
- Egalitarian Perspective E is the most precautionary perspective, taking into account the longest timeframe, impact types that are not yet fully established but for which some indication is available, etc.
- Individualist Perspective I, which is based on the short-term interest, impact types that are undisputed, technological optimism as regards human adaptation.
- Hierarchist Perspective H, which is based on the most common policy principles with regards to timeframe and other issues.

These different views are reflected in the restoration times assumed for land use transition and in the assumed geographic embedding of the occupied or transformed area (A - isolated or B – connected).

Table 4 Selected restoration time and geographic embedment in different perceptions

	Range	Egalitarian	Individualist	Hierarchism
Assumed geographic embedment		A - isolated	B - connected	A - isolated
Restoration time (years)		Maximum restoration time	Mean restoration time with maximum of 100 years	Mean restoration time
– Arable land – Pioneer vegetation	< 5	5	2.2	2.2
– Species poor meadows and tall-herb communities – Mature pioneer vegetation	5-25	25	11	11
– Species poor immature hedgerows and shrubs – Oligotroph vegetation of areas silting up – Relatively species rich marshland with sedges – Meadows	25-50	50	35	35

	Range	Egalitarian	Individualist	Hierarchism
– Dry meadows and heath land				
– Forests quite rich in species – Shrubs and hedgerows	50-200	200	100	100
– Low and medium (immature) peat bogs – Old dry meadows and heath land	200–1,000	1,000	100	500
– High (mature) peat bogs – Old grow forests	1,000-10,000	10,000	100	3,300

Source: ReCiPe, 2008.

4.4.4 How well does the ReCiPe methodology fit the requirements?

Summarising the ins and outs of the methodology as in Table 5, the ReCiPe methodology meets most of the requirements defined earlier in the report (Paragraph 2.2).

– The methodology has been designed specifically for use in LCAs. Its quantitative nature means it can be applied in scenarios.
– It has been developed by a consortium of science organisations. One would assume that this means the methodology is scientific sound.
– The methodology is specifically aimed at taking different pressures on biodiversity into account and combining them into one overall impact.
– The methodology is also specifically designed for combining and aggregating different kinds of environmental impacts and damages. However impacts of landscape design aspects such as vicinity of roads and fragmentation can not be accounted for.
– In the methodology a limited number of different levels of land use intensity are specifically distinguishes.
– LCAs are specifically developed for comparisons such as between fossil fuels and biofuels.

Table 5 Overview of match of methodology with desired specification

	Score
Methodological requirements	
– Be applicable on a global scale	No
– Be applicable in a scenario context	X
– Be relatively simple	X
– Be based on sound scientific principles	X
– Allow for combining with other pressures on biodiversity	Partly
– Allow for combining with other types of impacts and damages	X
Policy issues to be considered	
– Differences in land use intensity	(X)
– Differences in landscape design	No
– Differences in affected biomes	Partly
– Comparing fossil and bio	X

In its current form, the ReCiPe methodology is not applicable on a global scale.

The methodology does not give indications which allow for quantifying different approaches in landscape design, such as including ecological corridors or landscape elements.

The methodology would allow taking into account differences in affected biomes, as long as these are of a different category – e.g. grassland and forest. However, if two biomes of the same category would be affected there would be no difference in the outcome, although the biome may be quite different.

4.5 TNO Methodology

4.5.1 Significance of the TNO methodology

In order to integrate land use in LCA, the Road and Hydraulic Engineering Institute (DWW) has initiated the development of a new method.

The original reason to start the development of the land use methodology was that the theme 'degradation of ecosystems and landscapes' as mentioned in the CML guideline (1992) was not operational and that this theme is relevant for LCAs within the working field of several environmental policies, e.g. the Structure Plan on Surface Raw Materials. The focus was to develop a general method which can be used for all types of processes all over the world, just like other characterisation methods in the
CML guideline.
The methodology elaborated by TNO for Rijkswaterstaat has been based on previous work, LCACAP, by Weidema and Lindeijer for the EU Commission.

Its status and the extent of its use are not clear. The methodology is, however, interesting because it contains a number of methodological choices not included in either of the other considered methodologies.

4.5.2 General methodology outline

As in Eco-indicator 99 and in ReCiPe, both environmental damage due to occupation (ED_{occ}) and to transformation of land use (ED_{trans}) are distinguished in the TNO methodology. Both are again expressed as the percentage of species lost.

For occupation the impact is determined using:

$$ED_{occ} = A * t * EQ_i * ES_i * EV_i * PDF_{nature - occ.}$$

With ecosystem level factors:

- EQ_i (Ecosystem "Quality" of biome i) = S_i / S_{min} (SR ≥ 1).
- ES_i (Ecosystem Scarcity of biome i) = $A_{pot,max}$ / $A_{pot,i}$ (ES ≥ 1).
- EV_i (Ecosystem Vulnerability of biome i) = $(A_{exi}/A_{pot,i})^{b-1}$ (EV ≥ 1).

Where

- S_{min} = the species richness in the least species rich biome in the world.
- $A_{pot,i}$ = the global potential (natural) area of biome i.
- $A_{pot,max}$ = the globally largest value for A_{pot} (to render scores ≥ 1).
- A_{exi} = the existing global ecosystem/biome area left.

For land transformation, the same approach as for land occupation is chosen: using three ecosystem level factors and one species level factor:

$$ED_{trans} = A * EQ_i * ES_i * EV_i * PDF_{1\rightarrow 2}$$

The relationships combine local changes in biodiversity with global relative ecosystem scores (based on Weidema, 2001). In this manner, the global perspective and the local details are both assessed. The global factors have following underlying significance:

- The “Eco Quality” factors represent a measure for the relative species richness of the considered biome, relative to the biome with the lowest species richness (tundra). In other words, the higher the species richness, the more ‘quality’ the biome has.
- The “Ecosystem Scarcity” indicator is a measure for the natural occurrence of the considered biome. Intertidal zones such as the Wadden Sea or mangrove forests are quite rare globally. According to the TNO methodology impacts on such ecosystems should be weighted higher than impacts on more extensive ecosystems. The weighing factor is expressed relative to the potential global area of boreal forest.
- The “Ecosystem Vulnerability” is a measure for how much of the ecosystem has already disappeared.

In the relationship for impacts due to occupation, PDF is based on *S* in the Arrhenius species-area relationship, not on *a*. Species density scores have been standardised to 0.01 ha. The considered species concerns vascular plants.
In the methodology, a distinction between different levels of land use intensity is made for arable land and grassland, but not for forestry. Considered types of agricultural land use are:

- Conventional arable
- Integrated arable
- Organic arable
- Fibre/energy crop kenaf
- Fibre/energy crop hemp
- Fibre/energy crop Chinese reed
- Organic orchard
- Intensive meadow
- Less intensive meadow
- Organic meadow
- Agriculture fallow + hedgerow

As illustrated by this overview, several different types of crops are also considered as separate categories. Fragmentation and disturbances such as power lines and infrastructure are not taken into account.
On the other hand, specific species densities for hedgerows and forest edges are included, which makes it theoretically possible to take into account differences in landscape design.

The methodology contains no relation to the critical amount of biodiversity lost or the level of nutrient inputs exceeded at which an ecosystem becomes disrupted and incapable of supplying ecosystem services.

Methodological choices have been summarised in Table 6. The values of EQ_i, ES_i and EV_i are given in Table 7.

Table 6 **Overview of methodological choices made in TNO methodology**

Subject	Choices made
Biodiversity levels included	Ecosystem and species level
Species included	Only vascular plant species included; equal weighting of all species
Relationship of actual state to reference state for occupation	1 - {actual state/reference state} or (reference state – actual state}/reference state
Species diversity reference state	Maximum or average score for regional biome
Species diversity standardisation	To 0.01 ha via Arrhenius formula using a = 4.1 and b = 0.2
Reference state data	Taken from Barthlott, 1997
Relationship between initial and final state for transformation	1 - {final state/initial state}, or {initial state - final state}/initial state
Biome definition for ecosystem level	Taken from Leemans et al., 1998
Ecosystem quality aspects	Scarcity, vulnerability and value/quality
Ecosystem scarcity factor	Largest potential biome area/potential area of biome i
Ecosystem vulnerability factor	{Existing are of biome i/potential are of biome i}$^{b-1}$
Ecosystem value/quality	Species richness$_i$/minimum biome species richness

Table 7 **Overview of aggregated ecosystem level factors**

Biome	Ecosystem scarcity	Ecosystem vulnerability	Ecosystem quality	EsxEVxEQ Min	EsxEVxEQ Max
Ice	3.80	1.00	0	0	0
Tundra	2.80	0.96	1	3	3
Wooded tundra	8.22	0.85	2-2.5	14	17
Tundra total	4.19	0.93	1-2.5	6	7
Boreal forest	1.00	1.17	2-5	2	6
Cool conifer forest	5.36	1.70	5	45	45
Temp. deciduous forest	4.08	4.26	7.5-10	174	220
Temp. mixed forest	3.29	3.32	5-7.5	55	82
Warm mixed forest	5.32	3.81	15	304	304
Mixed forest total	4.07	3.49	5-15	140	158
Grassland/steppe	1.47	1.67	2-7.5	5	19
Savanna	2.19	1.84	2-15	8	61
Grassland total	1.77	1.74	2-15	6	34
Hot desert	1.78	1.18	1	2	2
Scrubland	3.12	2.80	5-20	44	175
Tropical woodland	3.73	1.45	10-15	54	81
Tropical forest	4.41	1.40	15-45	93	278

4.5.3 How well does the TNO methodology fit the requirements?

Summarising the ins and outs of the methodology as in Table 8, the TNO methodology probably meets all requirements defined earlier in the report (Paragraph 2.2).

– The methodology has been designed specifically for use in LCAs. Its quantitative nature means it can be applied in scenarios.
– It has been based on and developed by a consortium of science organisations. One would assume that this implies that the methodology is scientifically sound.

- As the methodology is specifically aimed at enabling to take into account land use impacts on biodiversity it should theoretically allow for the combination of land use with other pressures on biodiversity and the combination and aggregation of different kinds of environmental impacts and damages. Actually, the relationship for impact on biodiversity due to occupation and transition are basically the same as applied in ReCiPe, apart from some methodological differences. This does, however, imply that the resulting variable is the same as calculated in the ReCiPe methodology.
- In the methodology, different levels of land use intensity are specifically distinguished for agriculture.
- LCAs are specifically developed for comparisons such as between fossil fuels and biofuels.

Table 8 **Overview of match of methodology with desired specification**

	Score
Methodological requirements	
– Be applicable on a global scale	No
– Be applicable in a scenario context	X
– Be relatively simple	X
– Be based on sound scientific principles	X
– Allow for combining with other pressures on biodiversity	?/X
– Allow for combining with other types of impacts and damages	?/X
Policy issues to be considered	
– Differences in land use intensity	Partly
– Differences in landscape design	Partly
– Differences in affected biomes	X
– Comparing fossil and bio	?/X

The methodology is probably not yet applicable on a global scale.
The PDF values included only concern changes in biodiversity for Central European biomes, the Swiss Plateau being the natural reference.

5 Comparing Methodologies

5.1 Methodological variations

As described in previous chapter, the three methodologies selected as potentially applicable in this project have the same basis for expressing impacts of land use on biodiversity: all of them relate to relative changes in biodiversity as expressed by MSA or PDF.

The differences between them concerns differences in scope and availability and applied data and differences in methodological choices.

Table 9 Comparison of methodological specifications of the considered methodologies (X=Yes)

	MSA	ReCiPe	TNO
Methodological choices			
– Considered biodiversity basis	a	S	S
– Standardised area size (ha)	1,000,000	10,000	0.01
– Considers regional impact?		X	
– Considers restoration time?		X	
– Applies “quality”, “vulnerability”, “scarcity” or other weighing factors?			X
– Considers fragmentation, disturbances?	X	No	No
– Considers crop specific biodiversity?	No	No	(X)

These differences notwithstanding, all considered methodologies meet most of the requirements defined for the desired methodology and associated indicator(s):

Table 10 Overview of match of the considered methodologies with desired specification (X=Yes)

	MSA	ReCiPe	TNO
Methodological requirements			
– Be applicable on a global scale	X	No	No
– Be applicable in a scenario context	X	X	X
– Be relatively simple	X	X	X
– Be based on sound scientific principles	X	X	X
– Allow for combining with other pressures on biodiversity	Partly	Partly	Partly
– Allow for combining with other types of impacts and damages	Theoretically	X	X
Policy issues to be considered			
– Differences in land use intensity	X	X	X
– Differences in landscape design	No	No	Partly
– Differences in affected biomes	No	?	X/No-partly
– Comparing fossil and bio	No	X	X

There is one very important exception: none of the methodologies contains a relationship with the critical amount of biodiversity lost or the level of nutrient inputs exceeded at which an ecosystem becomes disrupted and incapable of supplying ecosystem services.

Next to this, since the three methodologies share the same basis, the MSA and PDF data applied in the different individual methodologies concerning changes in biodiversity can be applied in the other methodologies too.

In order to give more insight in the consequences of the different methodological choices, we will elaborate on a quantitative example calculation for the policy issues mentioned in the first chapter:

1. A comparison between different intensity of land use and land use development variation, e.g.:
   a The intensity of tillage and the use of fertilisers and pesticides.
   b The presence of ecological corridors, buffer zones and landscape components (e.g. hedgerows).
2. A comparison between two different locations in different regions for cultivation of the same or comparable crop or tree.
3. A comparison between a biotic and fossil product for the same service.
4. Comparing different products for different regions for focusing a general biodiversity policy of a country.
5. Comparing more intensive production (less biodiversity on the production area) and less intensive production (more area needed) including the indirect land use change issue.

5.2 Impact of land use intensity

As indicated in the previous section, the three methodologies all contain different PDF values for different levels of land use intensity. This is illustrated for arable farming (Table 11).

Table 11 Overview of PDF values for occupation of arable land of different usage intensities in Europe

	Occupation		
	PDF local	**PDF regional**	**PDF total**
MSA, cultivated land	Reference not differentiated		
– Intensive	0,90	0	0,90
– Low-input	0,70	0	0,70
ReCiPe - arable land	Reference European woodland		
A) Egalitarian perspective			
– Monoculture Crops/Weeds	0,95	0,44	1,39
– Intensive Crops/Weeds	0,89	0,44	1,33
– Extensive Crops/Weeds	0,85	0,44	1,29
B) Individualistic perspective			
– Monoculture Crops/Weeds	0,95	0,23	1,18
– Intensive Crops/Weeds	0,89	0,23	1,12
– Extensive Crops/Weeds	0,85	0,23	1,08
TNO - arable land	Reference forest Swiss plateau		
– Conventional	0,74	0	0,74
– Integrated	0,82	0	0,82
– Organic	0,35	0	0,35

Most PDF values for local biodiversity impact are comparable, with the exception of the PDF applied in the TNO methodology for organic farming. Taking into account regional effects in the ReCiPe methodology has a notable effect on the value of the PDF, especially for the egalitarian perspective.

For illustration purposes, the PDF values in Table 12 were applied in a comparison between conventional and organic farming of winter wheat on clay soils in the Netherlands. These two types of arable farming practices on average annually yield respectively 8.7 and 6.0 tonnes of cereals (KWIN, 2009).

Table 12 Estimation of impact on biodiversity for different land use intensities for wheat cultivation in the Netherlands

	Occupation			
	PDF Total (PDF/m^2/y)	Ha/tonne	Environmental damage	
			PDF	Relative
MSA, cultivated land	Reference not differentiated			
– Intensive	0,90	0,11	0,10	100%
– Low-input	0,70	0,17	0,12	113%
ReCiPe - arable land	Reference European woodland			
A) Egalitarian perspective				
– Monoculture Crops/Weeds	1,39	n.r.		
– Intensive Crops/Weeds	1,33	0,11	0,15	100%
– Extensive Crops/Weeds	1,29	0,17	0,22	141%
B) Individualistic perspective				
– Monoculture Crops/Weeds	1,18	n.r.		
– Intensive Crops/Weeds	1,12	0,11	0,13	100%
– Extensive Crops/Weeds	1,08	0,17	0,18	140%
TNO - arable land	Reference forest Swiss plateau			
– Conventional	0,7	0,11	0,09	146%
– Integrated	0,8	n.r.		
– Organic	0,4	0,17	0,06	100%

As the considered region is the same, the reference for the occupied land is the same and weighing factors as applied in the TNO methodology can be ignored.

As illustrated by the relative size of the damage, the TNO methodology gives a different result for both other methodologies as biodiversity for organic farming is assumed to be significantly higher compared with intensive farming in this methodology. In ReCiPe and MSA, the difference in biodiversity between both arable practices is less distinct.

The result primarily illustrates the impact of the datasets used in the different methodologies, indicating the importance of the dataset.

Comparing the results for the ReCiPe methodology and the MSA methodology illustrates the effects of taking into account (estimated) regional effects. Taking these into account makes the result more pronounced. However, as indicated in Paragraph 4.4, the scientific soundness of the way in which the regional effects are estimated is not clear.

5.3 Impact of landscape design

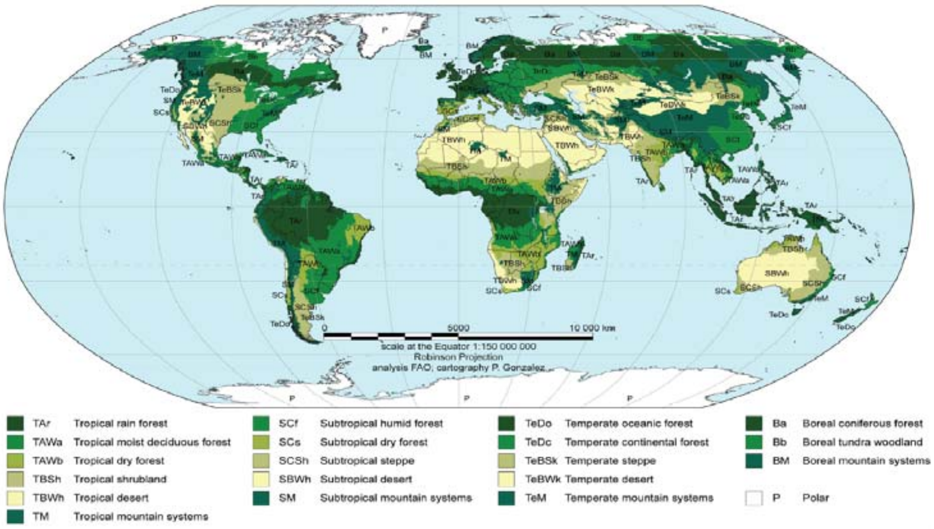
As stated in the previous section, only in the TNO methodology PDF values have been included for landscape elements such as hedgerows and forest edges.
A comparison between methodologies on a quantitative base is therefore not possible.

5.4 Biodiversity impacts for different regions and biomes

For illustrating the effects of comparing land use in different regions and biomes, a comparison was made between wheat cultivation in the Netherlands (clay soil) and Spain.

Because ReCiPe and TNO methodology only give PDF values for land use within a European context, the case study had to refer to a comparison between different European biomes. The natural reference (see Figure 15):
a For the Netherlands is temperate oceanic forest.
b For most of Spain subtropical dry forest.

Figure 15 Global ecological zones, based on observed climate and vegetation patterns



Source: IPCC, 2006.

Yields for conventional farming amount to 8.7 tonnes/ha/year in the Netherlands and to approximately 3 tonnes/ha/year in Spain. It was assumed that at both locations intensive, conventional agriculture occurs.

For all three methodologies it was assumed that the PDF values for occupation given in Table 13 are representative for both types of natural references.

In the TNO methodology these two natural biomes are valued differently. In this case study it was assumed that:
– The category ‘temperate oceanic forest’ considered in the IPCC methodology matches with the category ‘temperate deciduous forest’ considered in the TNO methodology.

– The category ‘subtropical dry forest’ considered in the IPCC methodology, matches with the category ‘warm mixed forest’ considered in the TNO methodology.

In accordance with the weighing factors given in Table 7, occupation of 1 hectare of ‘warm mixed forest’ would be valued as being (304 ÷ 174 = 1.75) to (304 ÷ 202 = 1.50) times more damaging as occupation of 1 hectare of ‘temperate deciduous forest’.

The resulting estimated biodiversity impact is illustrated in Table 13.

Table 13 Estimating impact of wheat cultivation in two different biomes

	Occupation				
	PDF total ($PDF/m^2/y$)	Ha/tonne	Relative weighing factor	Environmental damage	
				PDF	Relative
MSA, cultivated land	Reference not differentiated				
– Dutch wheat	0,90	0,11	1,00	0,10	100%
– Spanish wheat	0,90	0,34	1,00	0,31	295%
ReCiPe - arable land	Reference European woodland				
A) Egalitarian perspective					
– Dutch wheat	1,33	0,11	1,00	0,15	100%
– Spanish wheat	1,33	0,34	1,00	0,45	295%
B) Individualistic perspective					
– Dutch wheat	1,12	0,11	1,00	0,13	100%
– Spanish wheat	1,12	0,34	1,00	0,38	295%
TNO - arable land	Reference forest Swiss plateau				
– Dutch wheat	0,7	0,11	1,00	0,09	100%
– Spanish wheat	0,7	0,34	1,63	0,41	480%

Since the same PDF value for occupation is assumed to be representative for both locations, the ratio between the impacts on biodiversity at both locations is equal to the ratio of the areas required per tonne wheat at both locations for ReCiPe and MSA methodologies. The weighing factors considered in the TNO methodology give a more pronounced ratio and more strongly indicate that wheat cultivation in the Netherlands with its wetter climate and higher availability of water is more beneficial with respect to biodiversity.

In order to give an impression of the level of biodiversity of Spanish arable land required for giving the same occupation related environmental impact, the required PDF values for Spanish arable land are given in Table 14.

Table 14 Estimating impact of wheat cultivation in two different biomes

	Assumed PDF for Dutch arable land ($PDF/m^2/y$)	Required PDF for comparable impact ($PDF/m^2/y$)
MSA, cultivated land		
– Dutch wheat	0,90	
– Spanish wheat		0,30
ReCiPe - arable land		
A) Egalitarian perspective		
– Dutch wheat	1,33	
– Spanish wheat		0,45
B) Individualistic perspective		
– Dutch wheat	1,12	
– Spanish wheat		0,38
TNO - arable land		
– Dutch wheat	0,74	
– Spanish wheat		0,15

For comparison, the reader can refer to Figure 4 in Section 3.3. Comparing the required PDF values in Table 14 with the naturalness in Figure 4 indicates that the Spanish arable land should have a naturalness comparable with that of forest or grassland that is almost pristine or is selectively logged, extensively used. It is very unlikely that such a level of naturalness can be achieved for arable land.

5.5 Biodiversity impacts of similar crops

To illustrate this comparison, a case study was conducted for vegetable oil from rapeseed cultivation in the Netherlands and from sunflower cultivation in Spain. The oil is the most valuable product that can be derived from both of these crops. The protein-rich press cake is an attractive by-product, that is primarily sold as a protein-rich feed component. The two types of vegetable oil are largely interchangeable and are both used in cooking, as a raw material for margarine, etc.

As in the previous example, conventional intensive cultivation practices for rapeseed and sunflower were assumed.

Yields of rapeseed in the Netherlands amount to 4.0 tonnes/ha/year of oilseeds (KWIN, 2009). The seeds will yield approximately 43% oil and 57% cake (Biograce v3). According to the RED methodology, the environmental impact should be allocated according to energy content. This would mean an allocation factor for oil of 61%.
The yield of sunflower in Spain amounts to an average of approximately 1 tonne/ha/year, according to FAOSTAT. The seeds will yield approximately 47% oil and 57% cake (Biograce v3). According to the RED methodology, the environmental impact should be allocated according to energy content. This would mean an allocation factor for oil of 66%.

Assuming PDF values and – for the TNO methodology – weighing factors as given in Table 13, the resulting relative impacts on biodiversity are given in Table 15.

Table 15 Comparing rapeseed and sunflower cultivation

	Occupation				
	PDF total ($PDF/m^2/y$)	ha/tonne oil	Relative weighing factor	Environmental damage	
				PDF	relative
MSA, cultivated land					
– Dutch rape seed	0,90	0,58	1,00	0,32	100%
– Spanish sunflower	0,90	2,04	1,00	1,21	383%
ReCiPe - arable land					
A) Egalitarian perspective					
– Dutch rape seed	1,33	0,58	1,00	0,47	100%
– Spanish sunflower	1,33	2,04	1,00	1,79	383%
B) Individualistic perspective					
– Dutch rape seed	1,12	0,58	1,00	0,39	100%
– Spanish sunflower	1,12	2,04	1,00	1,51	383%
TNO - arable land					
– Dutch rape seed	0,7	0,58	1,00	0,26	100%
– Spanish sunflower	0,7	2,04	1,63	1,62	623%

As in the case study in previous subsection, the ratio between the impacts on biodiversity at both locations is equal to the ratio of the areas required per tonne wheat at both locations for ReCiPe and MSA methodologies. The weighing factors considered in the TNO methodology give a more pronounced ratio and more strongly indicate that cultivation should be concentrated in the Netherlands with its wetter climate and higher availability of water.

Again, the methodologies advocate maximum production per unit of area. This only differs when applying the TNO methodology, in which ecosystem vulnerability is taking into account: the relative size of the area of the biome that remains compared with the potential area it could occupy naturally.

But even when applying the TNO methodology, the area of 'temperate deciduous forest' has to become very small compared with the potential area of this biome before the weighted impact on biodiversity becomes similar to that caused by sunflower cultivation in Spain. This would require a vulnerability factor of 8.5, which means that the area of 'temperate deciduous forest' would have to be reduced to approximately 7% of its potential area. This implicates that the relative weight of the remaining proportion of a biome is not that important. The relative species density as expressed in the 'Ecosystem Quality' and the potential extent of the biome as expressed in the 'Ecosystem Scarcity' largely mitigate the weight of 'Ecosystem Vulnerability' for biomes with a high biodiversity. This in itself is quite significant, since a high-level of biodiversity is an important reason for wanting to protect such a biome in environmental conservation policy.

5.6 Intensification of cultivation, restoration effects included

To illustrate this effect, a hypothetical case was assumed, in which wheat cultivation in Spain is optimised such that yields can be doubled. Potentially yields of 3.5–8.0 tonnes/ha/year could be realised, but water stress and limited nitrogen availability result in a yield gap and limit yields to an average of the 3.0 tonnes/ha/year mentioned in Section 5.4. Specific annual yields can however be as low as 1.8 tonnes/ha/year in dry years (FAOSTAT).

Projects in sub-Saharan countries with limited and irregular rainfall, can on the other hand illustrate that water stress can be reduced by applying no till or reduced till practices and by maximising soil organic carbon by utilising green manure and crop residues.

By doubling the yield, the required area per tonne of wheat obviously reduces with 50%. Theoretically, the area no longer required could be allowed to return to its natural state.
ILUC effects and elasticity effects have been ignored in this case study.

The three considered methodologies treat this hypothetical restoration in a very different way:
- In the MSA the actual time-related MSA value will be registered and taken into account. In this case study it is assumed that the biodiversity slowly improves. In order to take this improvement into account, a biodiversity level comparable with that for extensive cultivation was assumed.
- In the ReCiPe methodology the slow restoration is valued by adding a transition factor to the 'environmental damage' consistent of:
  - The product of the PDF of the change in biodiversity between the original situation (intensive cultivation) and the situation after transition (natural forest).
  - The restoration time – assumed to be 200 years for an egalitarian perspective and 100 years for an individualistic perspective.
    The impact of transition is divided by 20 years, as is done for greenhouse gas emissions from land use change in the IPCC methodology and RED.

For the fallowing and restoring area, a biodiversity level comparable with that for extensive cultivation was assumed.
- In the TNO methodology the restoration is valued by taking into account the PDF for the changes in biodiversity. As for the ReCiPe methodology, the impact of transition is divided by a period of 20 years. For the fallowing and restoring area, a biodiversity level comparable with that for extensive cultivation was also assumed.

The resulting PDF values and impacts on biodiversity are given in Table 16.

Table 16 Estimating biodiversity effects of yield improvements and associated land restoration

	Occupation				
	PDF total ($PDF/m^2/y$)	Ha/tonne	Relative weighing factor	Environmental damage	
				PDF	Relative
MSA, cultivated land					
– Reference	0,90	0,34	1,00	0,31	112%
– Doubled yield	0,80	0,34	1,00	0,27	100%
ReCiPe - arable land					
A) Egalitarian perspective					
– Reference	1,33	0,34	1,00	0,45	100%
– Doubled yield	-5,34	0,34	1,00	-1,81	-402%
B) Individualistic perspective					
– Reference	1,12	0,34	1,00	0,38	100%
– Doubled yield	-1,70	0,34	1,00	-0,58	-152%
TNO - arable land					
– Reference	0,74	0,34	1,00	0,25	141%
– Doubled yield	0,53	0,34	1,00	0,18	100%

In this case study the ReCiPe methodology gives a very large bonus for land restoration because the methodology emphases changes in biodiversity. Because it takes the product of restoration time and change in biodiversity it – as it were – imposes a legacy on the land using and changing activity.

In the TNO methodology this effect is far less pronounced because the restoration time is not considered. In the MSA methodology, no 'legacy' is included.

To summarise, if a methodology that favours restoration discourages deforestation and other kinds of natural habitat loss is to be implemented, the ReCiPe methodology is the most appropriate.

5.7 Bio versus fossil

5.7.1 Considered methodologies and environmental issues

To illustrate this type of comparison, we compared rapeseed biodiesel and conventional diesel as included in the Ecoinvent database. Both types of transportation fuels were compared for all types of environmental impacts considered in the ReCiPe methodology:
– Climate change impacts on human health
– Ozone depletion
– Human toxicity
– Photochemical oxidant formation
– Particulate matter formation
– Ionising radiation
– Climate change impacts on ecosystems
– Terrestrial acidification
– Freshwater eutrophication
– Terrestrial ecotoxicity
– Freshwater ecotoxicity
– Marine ecotoxicity
– Agricultural land occupation
– Urban land occupation

– Natural land transformation
– Depletion of metal resources
– Depletion of fossil fuel reserves

The impacts were recalculated by the Simapro LCA software program to normalised and weighted total environmental impacts, aggregated over all the above environmental issues. Characterisation, normalisation and weighing have been done for the two extreme perspectives on environmental damage included in ReCiPe:

– Egalitarian Perspective E is the most precautionary perspective, taking into account the longest time-frame, impact types that are not yet fully established but for which some indication is available, etc.
– Individualist Perspective I, which is based on the short-term interest, impact types that are undisputed, technological optimism regarding to human adaptation.

The illustration has to be limited to the application of the ReCiPe methodology and the to integration of land occupation in this methodology.
As indicated in previous chapter, the MSA methodology does not yet allow for combination with other environmental impact categories. The characterisation factors, weighing factors and normalisation factors applied in the TNO methodology have not been included in the Simapro program and underlying Ecoinvent database.

5.7.2 Considered biofuels

The rapeseed biodiesel considered in the database - 'Rape methyl ester, at regional storage/CH U' - consists of a 80% of conventional rape seed cultivation and 20% organically farmed rapeseed, cultivated in Switzerland. Associated yields amount to respectively 3 tonnes/ha/year and 2 tonnes/ha/year of seeds.
For the biodiesel case, potential indirect land use change effects have been ignored. These effects could significantly increase GHG emissions related to biodiesel.

The considered ‘diesel case’ ('Diesel, low-sulphur, at regional storage/RER U') refers to low-sulphur diesel as produced and marketed in Switzerland.

5.7.3 Results bio versus fossil with the ReCiPe indicator

The resulting aggregated normalised and weighted contributions are shown in Figure 15 and Figure 17, expressed relative to the total aggregated impact for RME, applying normalisation factors and weighing factors associated with the egalitarian perspective on environmental damage and damage to human health.

For illustration of the applied perspective on environmental damage, the aggregated normalised and weighted contributions are also given for an individualistic perspective.

Figure 16 **Normalised contributions per GJ of RME or conventional diesel for egalitarian and individualistic perspectives of environmental damage**

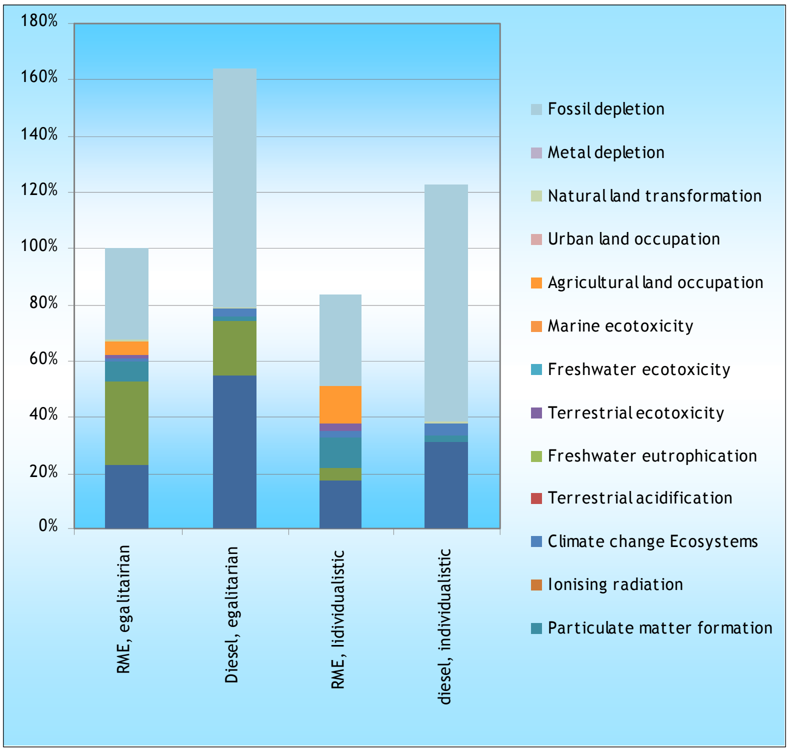
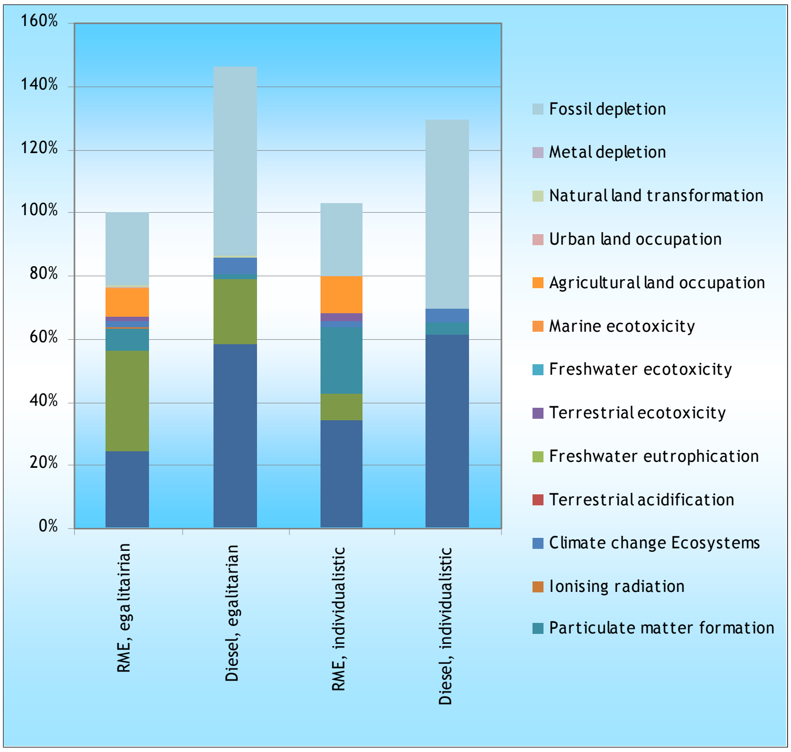


Figure 17 **Weighted contributions per GJ of RME or conventional diesel for egalitarian and individualistic perspectives of environmental damage**



The main contributions to total normalised and weighted scores concern greenhouse gas emissions, depletion of fossil reserves, human toxicity and particulate matter formation.

As indicated by the two figures, consumption of conventional diesel gives a higher total impact, mainly because of depletion of fossil fuel reserves and of higher direct greenhouse gas emissions for conventional diesel.
The picture would change if depletion of fossil fuels was not considered an environmental issue. In that case, the aggregated normalised and weighted contributions for RME and diesel would become more comparable. Arguments in favour for not taking into account fossil fuel reserves depletion could be that it concerns an economic problem rather than an environmental problem and that the consumption of non-renewable resources is undesirable and should not take occur in the first place.

Land occupation – the issue considered in this project - for rapeseed cultivation is not negligible, but its normalised or weighted contribution is clearly not a deciding factor, which change the outcome of the comparison between fossil diesel and biodiesel.

The effect of an individualistic or egalitarian perspective is limited because the perspective on the environmental issues with the highest contribution to total normalised or weighted scores (greenhouse gas emissions and depletion of fossil reserves) are relatively insensitive for the applied perspective.
The effect of regarding environmental impacts from either of the two considered perspectives is best illustrated by the difference in the contributions of human toxicity for biodiesel – as long-term effects are less important in the individualistic perspective, total contribution of human toxicity is smaller.

5.7.4 Bio versus fossil compared with the MSA indicator

Although the MSA indicator is not directly suitable for a product/material analyses, a study from PBL with a biomass energy scenario can function as an example of how the MSA indicator treats a comparison between fossil and bio energy. In the MNP (2007) study, PBL considered a scenario with bioenergy and biofuels (first generation) and energy savings. The direct negative effects on biodiversity by land use were compared with the indirect positive effect on biodiversity by lowering the global warming effect (less GHG) effect. This combination of 60% energy efficiency and 40% biofuels with the assumption that the emission of biofuels are zero leads to the conclusion that the gain of this combined scenario equals the initial loss in 50 years. If we separate the energy efficiency part (no biodiversity loss) and the bio energy part in the scenario, the payback time for the bioenergy part is approximately 100 years. If we also take into account that most bio options do not reduce the GHG emissions with 100% but between 20 and 90%, then this payback time could grow to 200 years.

This example with the MSA indicator shows that in the MSA approach, the biodiversity loss of biomass production is of the same magnitude of the biodiversity gain on the long-term by lowering the GHG effect. The net results depend on the timeframe that is chosen.

5.8 Conclusions from the cases

The cases considered with the three indicators teach us that:
- More production from existing production land is favourable.
- In most cases all three indicators favour the same option only the differences between the scores differ.
- Organic farming (less extensive more biodiverse) farming is a complicated case. Two indicators favour conventional farming, one organic farming.
- Land restoration and destruction is emphasised in the ReCiPe method.

The MSA methodology is designed for scenario analyses, the ReCiPe methodology for LCA and product analyses. The MSA methodology has a larger dataset with data from all over the world. Because of the similar background these data could be transformed for use in the ReCiPe indicator.

The ideal indicator would be a hybrid system with:
- The dataset behind the MSA indicator.
- The restoration factor of the ReCiPe indicator.
- A modified factor for scarcity of biomes from the TNO indicator.

Until this ideal indicator has been developed, the MSA indicator is suitable for cases in which restoration is no issue, and the ReCiPe indicator is suitable for other cases. The dataset of the ReCiPe indicator has to be expanded with data for regions outside Europe.

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