THE FINNISH ENVIRONMENT 24 | 2011

Land use in life cycle assessment

ENVIRONMENTAL PROTECTION

Tuomas Mattila, Tuomas Helin, Riina Antikainen, Sampo Soimakallio, Kim Pingoud and Helena Wessman

Finnish Environment Institute

THE FINNISH ENVIRONMENT 24 | 2011

Land use in life cycle assessment

Tuomas Mattila, Tuomas Helin, Riina Antikainen,
Sampo Soimakallio, Kim Pingoud and Helena Wessman

Helsinki 2011

FINNISH ENVIRONMENT INSTITUTE

THE FINNISH ENVIRONMENT 24 | 2011
Finnish Environment Institute

Cover Photo: Päivi Tahvanainen
Layout: Liisa Lamminpää

The publication is available only in the internet:
www.ymparisto.fi/publications

ISBN 978-952-11-3926-0 (PDF)
ISSN 1796-1637 (verkkoj.)

PREFACE

The ongoing competition between forestry, agriculture, infrastructure and natural ecosystems has made land a limited resource. Land use and land use change have also negative environmental impacts, thus being interesting topic from the perspective of sustainable consumption and production and life cycle thinking. Currently, land use related terminology is diverse, and the methodologies to assess the impacts of land use and land use change are still partly under development. The aim of this study was to discuss how land use induced environmental impacts can be taken into consideration in the life cycle assessment (LCA). This study was conducted as a part of the FINLCA project (Life Cycle Assessment Framework and Tools for Finnish Companies) in two tasks (WP 2.1 land use and WP 5.2 biomaterials). The study was conducted in co-operation with the Finnish Environment Institute (SYKE): Tuomas Mattila and Riina Antikainen and VTT Technical Research Centre of Finland: Tuomas Helin, Sampo Soimakallio, Kim Pingoud and Helena Wessman.

The Life Cycle Assessment Framework and Tools for Finnish Companies –project (FINLCA) started in 2009. The project identifies problems and obstacles in the use of life cycle methods, especially from a corporate perspective, and develops knowledge and know-how on LCA and related methods. A network of research institutes and companies was established to create a national roadmap on how life cycle methods can be promoted in Finnish industries. The project aims at developing life cycle approaches and a framework to help companies determine which are the most feasible methods and best practices. The aim is also to improve the environmental competiveness of Finnish companies. The research project consists of a theoretical part and several case studies. The theoretical part focuses on recent developments in life cycle methods. Case studies and information from companies is used to support the theoretical findings. SYKE acts as the coordinator of the FINLCA –project, other partners being VTT, Åbo Akademi, The University of Oulu, and The School of Science and Technology, Aalto University. The project has been financed by Tekes, and Finnish Forest Industries, Finnish Plastics Recycling Ltd, Scandinavian Copper Development Association, Outotec Oyj, Metals Industry, Neste Oil Oyj, the Federation of Finnish Technology Industries and Tikkurila Oyj.

The authors gratefully acknowledge the financiers of the project, the reviewers of the text, and all the persons who gave useful comments during the work.

CONTENTS

Extended summary and recommendations

- **The ongoing competition between forestry, agriculture, infrastructure and natural ecosystems has made land a limited resource.** As human population is continuously increasing, productive land is becoming even more limited resource for biomass production. Land is needed for the production of food, feed, fibres and fuels, but also, along with viable soil, for several ecosystem services such as clean air and water. It is estimated that some 12% of the global land area that is not covered with ice is reserved for agriculture at the moment. It has been proposed that if this land area is to exceed 15%, agricultural production would need to expand to less productive areas, which would lead to a significant intensification of deforestation. The competition is not restricted only to land use as there is also a competition for biomass use between different products and the natural ecosystems. Lately the discussion has concentrated on the land use impacts caused by cultivation of biofuels, but this discussion should be expanded to cover all land use intensive product chains. These are all production chains that include food, feed, fibre or fuel production from biomass raw materials, as well as activities that are linked to mining and community building and services. (Chapter 1)

- **Land use and land use change as terms refer to several aspects and are used in different meanings in different disciplines and fields, which sometimes leads to misunderstandings and confusion.** Different meanings include, inter alia, i) land use and land use change in policy context and reporting schemes (e.g. reporting according to IPCC, the EU Renewable Energy Directive (RED) and the PAS 2050 carbon footprint scheme), ii) a phenomenon intensifying climate change, widely interesting for environmental scientists, policy makers, NGOs and other interest groups, iii) a phenomenon being a threat for biodiversity hot spots, being relatively widely interesting for environmental scientists, policy makers, NGOs and other interest groups, and iv) as a phenomenon affecting ecosystem services including productivity of land and equal and fair possibility to use land, which is of interest to relatively few interest groups. In addition, land use and land use change can be considered from the viewpoint of spatial planning. In this report, we do not consider the last meaning. (Chapter 1 and 7)

- **The land use related terminology is diverse, and it is often difficult to know what the exact meaning of a certain term is in various contexts.** Two basic definitions, land cover and land use, are often mixed or used as synonyms. Land cover refers to the physical material on earth's surface, while land use most often refers to the functional dimension and describes how the area is used for urban, agricultural, forestry and other uses. In LCA, land use generally covers both these aspects. Land use change or land transformation means, for example, the change from forestry to agriculture, but also from one agricultural purpose, e.g.

from meadow to field. Several data sources on land use and land cover exists, including national, European Union (Eurostat) and global (FAO) agricultural and forestry statistics (see Appendix 1). These, however, only indicate the areas, but not the driving forces behind any changes. Moreover, often the data received from general statistics is very coarse and any detailed analysis requires additional information. This report will give an overview and explanations on the most commonly used terms. (Chapter Terms and definitions)

- **Land use causes various environmental impacts.** At the moment the focus is on land use related greenhouse gas emissions, but changes in carbon cycles and storages, soil quality and soil net productivity, and loss of biodiversity are growing in importance. Additionally, changes in land use and land cover also affect water quality and availability. The IPCC has estimated that the land use change is the second most important source of GHG emissions, right after the use of fossil fuels. Land use and land cover change, especially clearing of forests to agricultural areas, release carbon from long-term storages. Land cover affects the climate through changes in biogeophysical and biogeochemical changes, such as albedo and various chemical compounds. In addition to climate change, land use and land use change has significant effects on the environment. For example, the Millennium Ecosystem Assessment identified land use change as one of the main reasons for biodiversity loss. Biodiversity loss differs from many other environmental problems due to the fact that after a certain threshold the loss is irreversible. When a species is extinct, it will not return even if the surrounding system would recover to the reference status. Increasing demand for land and its impacts are therefore connected to several environmental problems and should be measured and assessed using a relevant and wide enough set of indicators. (Chapter 5)

- **Many international and national agreements and guidelines have recommendations or instructions on how to take land use and land use change into account from the GHG perspective. However, often other environmental impacts or indirect impacts are not taken into account.** The European Community directive on the promotion of the use of energy from renewable sources (RED) defines sustainability criteria for biofuels and bioliquids that need to be fulfilled in order to be taken into account when measuring compliance with the requirements of the directive. Biomass from land with high biodiversity value, land with high carbon stock or peatlands should not be used to produce raw materials for biofuels. Annualised emissions from carbon stock changes caused by land use change shall be calculated by dividing the total emissions equally over 20 years. The carbon footprint specification by British Standards Institution, PAS 2050:2008, also gives guidance on how to consider land use. According to PAS 2050:2008 the GHG emissions arising from direct land use change shall be assessed for any input to the life cycle of a product originating from agricultural activities. The assessment of GHG emissions occurring as a result of direct land use change shall be done in accordance with the relevant sections of the IPCC Guidelines for National Greenhouse Gas Inventories. The total emissions arising from the land use change shall be divided for each year over the period of 20 years following the change in land use. PAS 2050:2008 states that methods and data requirements for calculating the GHG emissions arising from indirect land use change are not fully developed, and therefore, the assessment of emissions arising from indirect land use change is not yet included in the carbon footprint specification. However, the inclusion of indirect land use change will be considered in future revisions of the specification. The influences of occupation and transformation on land use and land cover can be combined depending on the indicators and the impact categories relevant for the study in question. (Chapter 2)

- **When should we consider land use and/or land use change – and how do we choose the reference status?** Some environmental indicators, such as the ecological footprint or the forest footprint, focus only on the impacts of either land use (occupation) or land use change (transformation). In LCA, land use occupation is measured as area time (m^2a) and transformation is measured as area from and to (e.g. m^2 from coniferous forest to sand extraction area). In the impact assessment, these separate inventories have to be combined and made comparable to other environmental impacts considered. The generally recommended method for this is to integrate the impacts of transformation over time by using estimates of natural restoration rates. Transformation is therefore considered as a series of occupation impacts occurring in different points of time. The suitability of the recommended approach depends on several issues and the choice of a suitable reference status is of crucial importance. Unfortunately little guidance is given in the scientific literature for choosing such a reference status. In addition the guidelines for combining the impacts of transformation and occupation are given based on the more traditional attributional approach to life cycle assessment. A consequential approach might require considerably different reference levels and the treatment of transformation.

  Our recommendation is to include both land use occupation and transformation in the inventory stage. In the impact assessment stage these can be combined, if the generally proposed combination method is applicable to the goal and scope of the life cycle assessment study. If the method is applied, care should be taken to make sure that also the reference status chosen is in line with the goal and scope of the study. (Chapter 3)

- **Indirect effects through market mechanisms are one of the most difficult and controversial issues to be dealt with in LCA.** Any change in resources such as land, feedstock, other auxiliary inputs or products demand and supply causes indirect effects, which are typically always related to land use. As land resource for various human actions, in particular food, feed, fibre, and fuel production, is a limited natural resource, which is in addition under increasing competition, land-use changes also take place. In the worst case, land-use changes result in the loss of large carbon pools and biodiversity through deforestation of natural rainforests.

  The indirect effects may be very far reaching in space and time, including possibly a number of complicated positive and negative feedback mechanisms. General scientific consensus exists about using an economic approach to address indirect land use changes, but the methods are widely controversial. Due to the difficult cause and effect relation of market mechanisms it is probably impossible to objectively attribute a certain iLUC to a certain single product. However, it is important that companies recognize the connections and risks of their processes on indirect land use and land use changes. Competition for resources should not raise the risk for environmentally harmful indirect effects. Furthermore, as rapid actions are required in climate change mitigation and in reducing deforestation, some compromise solution in accounting iLUC impacts is probably required to manage and significantly reduce the environmentally harmful iLUC in one way or another. (Chapter 4)

- **Land use and land use change cause environmental, social and economic impacts. There is a need to develop indicators to fulfil requirements of more holistic, sustainable use of land.** Land use is included in life cycle assessment as a unit process, as an intervention and as several impact indicators. For example cultivation of crops (unit process) occupies a certain piece of land (land use occupation) and may expand to other regions (land use transformation). The land use of crop cultivation affects soil quality, biodiversity, productivity and groundwater recharge (impacts). Most of the developed impact indicators connect a certain land area to the loss of productive land available for other uses. A multitude of indicators has been developed to model land quality through net primary productivity, energy flows, food production capacity, soil quality changes, species density and natural state of the landscape. In addition methods for assessing the emissions from land use processes (e.g. water use of crops, nutrient emissions from fields and greenhouse gas emissions from land cover changes) have been developed. However the developed indicators fail to include some of those aspects of land use, which are relevant for sustainable development and therefore additional indicators are needed.

  Biodiversity can be damaged quite considerably by a small land use change, which fragments existing populations or removes one subpopulation. At its current state, life cycle assessment cannot take this into account, but focuses on the total land area affected instead. The loss of so-called keystone species will result in the loss of the ecosystem function as a whole. The connection between the studied system and the status and threats to biodiversity should at least be made clear qualitatively. Several lists of biodiversity indicators exist and they have been introduced in this report.

  In addition to impacts on ecosystem quality and function, land use influences also social and economic sustainability to a considerable degree. For example tropical deforestation is a complex process involving many groups of people. Accordingly, land use operations in these regions are likely to affect many of these groups simultaneously. The impacts to the economic status and social equality of different groups of people may be positive or negative, but it is important that they are transparently documented. Therefore external certification plans and expert judgments may be preferable to life cycle assessment, when giving statements about the overall sustainability of a land using system. (Chapter 5)

- **How to deal with the carbon dynamics of direct land use.** Use of biomass as a renewable source of energy and materials is an important option in climate change mitigation. However, in some cases it can cause substantial emissions from terrestrial carbon stocks – even without change in land-use category, e.g. final felling in forestry – compensated by the re-growth of biomass only in the long term. Ambitious climate targets such as the 2°C stabilization target, which requires that global GHG emissions peak within one decade, has lead the timing of net GHG emissions to become an important indicator for evaluation of bioenergy systems. Thus the true climatic consequences of land use change as a function of time should be considered, but there is no clear choice for the optimal time frame, related to the success of global climate policy in general. An illustrative indicator for the warming impact over time is the cumulative radiative forcing (CRF) of the emissions. Calculating CRF for the emissions annualized (=amortized) over 20 years (PAS 2050, RED) clearly underestimates the climatic impacts compared with the calculation of CRF for the actual instant land-use-change emissions. Moreover, another challenging task is to estimate the actual baseline land use over time, i.e. the development of terrestrial C stocks without biomass use, needed in a consequential climate impact analysis of specific biomass use cycles. PAS 2050 and RED assume that the baseline is constant, but in reality forests could continue sequestering carbon for a long time, e.g. far beyond their economically feasible rotation lengths. (Chapter 5.1)

- **A case study proves that it is currently possible to make land use impact assessment with LCA. However, limited coverage of land use related data reduces the reliability of the results**. Indicators are available for all the three identified land use impact categories (resource depletion, soil quality, and biodiversity) and it is possible to carry out an LCA with the goal and scope being land use environmental impact assessment. Part of the land use LCI data can be found in public databases (e.g. Ecoinvent) and the characterization factors for land use LCIA have been presented within the LCA framework. However, the impact category ‘land use‘ currently included in some of the most widely used LCIA methods (e.g. ReCiPe, CML or EI99) cover only one aspect of land use induced environmental impacts and thus cannot be considered comprehensive. Additionally, some of the land use indicator results are difficult to understand and communicate to third parties unfamiliar with environmental and conservation ecology. Only the indicator results for land occupation and transformation (i.e. LCI results), ecological footprint, and also changes in soil organic matter measured with SOC and changes in biodiversity indicated by using EDP or PDF are relatively easy to communicate and comprehend. In future, better understanding of land use related impacts and characterization factors on a regional level is needed instead of global or generic level assessments. (Chapter 6)

- **Land use related aspects are important also from company perspective.** Therefore, we consider accounting of land occupation (m^2a) and transformation (m^2 from and to) to be a good starting point together with the relatively simple ecological footprint indicator for productive land occupation (resource depletion). A more comprehensive and challenging approach to land use impact assessment in LCA is to include all three impact categories. The SOC/SOM indicator can be suggested for soil quality impacts and EDP or PDF for biodiversity. These indicators are considered applicable to LCA, possible to communicate but the availability of reliable data for characterization models remains uncertain. In case no quantitative assessment can be done, we propose, that companies would do a mapping of their raw materials' origins and a qualitative assessment related to their products' life cycles to map if there is any potential land use or direct and indirect land use change risks. (Chapter 6.1)

Terms and definitions

Land use related terminology is numerous and often ambiguous. Many definitions are often mixed or used as synonyms, for example, land cover and land use. Hence, it is essential to have exact definitions on some land use related terms used later in this report.

Land cover is the physical material on earth's surface, meaning the trees and other vegetation, water, soil, asphalt and so on.

Land use refers to the functional dimension (i.e. use) and corresponds to the description of areas in terms of their socio-economic purposes – how the area is used for urban activities, agriculture, forestry etc. Another approach to land use is termed sequential, and it refers to a series of operations, particularly in agriculture, carried out by humans in order to obtain products and/or benefits through using land resources. Contrary to land cover, land use is difficult to "observe". For example, it is often difficult to decide if grasslands are used or not for agricultural purposes. By the definition of IPCC (2007a) **land use** refers to the total arrangements, activities and inputs undertaken in a certain land cover type (a set of human actions). The term land use is also used in the sense of the social and economic purposes for which land is managed (e.g., grazing, timber extraction, and conservation).

Land use is further divided into two separate categories in LCA terminology: land *occupation* and land *transformation.*

Land occupation refers to a continuous use of land area for a certain human-controlled purpose, e.g. agriculture, forestry or buildings.

Land transformation refers to the change from one land use category to another; for example plantation of forest on land previously used for agriculture. Land transformation can be caused both by human activities and by nature's processes. A widely used synonym for land transformation is **land use change** which, using the definition by IPCC (2007a) refers to a change in the use or management of land by humans, which may lead to a change in land cover. Land cover and land use change may have an impact on the surface albedo, evapotranspiration, sources and sinks of greenhouse gases, or other properties of the climate system and may thus have a radiative forcing and/or other impacts on climate, locally or globally. Land use categories are defined by e.g. the IPCC (International Panel on Climate Change) and land cover categories by e.g. the CORINE (Coordination of information on the environment) Programme of the European Commission.

Direct land use change (dLUC) is the land transformation that is caused directly by the expansion of a certain land use activity; i.e. drainage of peat land to forestry area.

Indirect land use change (iLUC) refers to the land transformation that is caused indirectly by land competition outside the studied product system boundary and that is attributable to the studied activity. For example, taking the land producing feed into biofuel production results in indirect effects, if the need for feed production does not decrease simultaneously somewhere else. Then raw material production for feed needs to replace land area used for production of a third product or service, e.g., food, fibre, or natural ecosystem services.

Natural restoration (synonymous to natural relaxation) refers to a spontaneous land transformation due to forces of nature, i.e. slow recovery process of abandoned agricultural land to a natural habitat.

Carbon stocks of terrestrial ecosystems refer to the biogenic C stocks in vegetation, soil and detritus of the land ecosystems.

1 Introduction, goal and scope

The purpose of this report is to discuss how land use induced environmental impacts can be taken into consideration in the life cycle assessment (LCA). LCA is considered as the best methodology for holistic assessment of environmental impacts of a certain activity but it has its limitations. Raw material acquisition, manufacturing, refining or processing, the use phase of the studied product, the transport, and the possible end use options are included in the cradle-to-grave LCA studies. But the environmental impacts caused by land use are often excluded from the calculations for e.g. raw material cultivation. This leads to the omission of several impact categories in LCA studies, such as impacts on biodiversity and soil net productivity. Furthermore, the omission can lead to misinterpretations in greenhouse gas (GHG) balance calculations of land use and biomass intensive products or services. This can lead to conclusions that differ significantly from the real environmental impacts of the studied activity.

With the expansion of human population, land area is becoming a limited resource. First, there is a competition of land use between forestry, agriculture, community building and services, and natural ecosystems. Second, there is a competition of land and biomass use between different products (food, feed, fibre, fuel etc.). Some 11.7% of the global land area (that is not covered with ice) is in agricultural use at the moment. It has been proposed that this should not exceed 15%, because it is estimated that the agricultural activities would need to expand to less productive areas if this limit is exceeded. This would lead to intensification of deforestation, which would have an adverse impact on the essential ecosystem services. (Rockström et al. 2009)

One major challenge related to the inclusion of land use in LCA is that there is no commonly agreed international standard available on land use impact assessment in LCA. The LCA practitioners are relatively free to adopt any approach on land use impact assessment they consider suitable. Therefore the claims made on the land use aspects of any products or activities are difficult to verify or compare to competing activities. The ISO 14040 standard series for life cycle assessment does not provide adequate guidelines on the impact assessment of land use induced environmental impacts. As a consequence, the companies that are currently determined to carry out environmental impact assessment of land use with LCA need to prepare to defend and justify the approaches that they have adopted. This report aims at assisting Finnish actors in such a task by providing sufficient scientific background.

This report summarises the results of the FINLCA project's (Life Cycle Assessment Framework and Tools for Finnish Companies) two tasks (WP 2.1 land use and WP 5.2 biomaterials). The aim is to clarify the terms, definitions and practices of how the land use and land use change have been included in life-cycle assessment. This is further illustrated with a practical example related to beer and wine production systems. Finally, the aim is to make recommendations on how Finnish industry should consider land use in life cycle assessment as part of their environmental management work. There is a need not only to define a methodology to calculate the impacts of land use, but also to test the land use related indicators in the context of LCA in a case study. The land use methodology approach, especially with the indirect land use impacts, needs a systematic approach and rules for how to define the system boundary. Although land use has environmental, social and economical dimensions, this report concentrates mainly on the environmental impacts according to the original scope of LCA. The focus is set on the perspective of Finnish companies with activities in Finland or abroad.

Activities of interest from a Finnish perspective

Are land use related environmental impacts significant for a large or a limited group of activities? In Finland, and also globally, public discussion on land use impacts has lately focused mainly on the cultivation of biofuel raw materials. This focus is quite narrow as in reality there is a need to assess all product chains that cause significant land use impacts, not only some of them. To find out which human activities and product chains are of interest from a Finnish perspective, the first step is to identify the present land cover and land use in Finland (Figure 1).

Forests represent the largest share of Finland's land cover (Figure 1 A), while the share of the urban fabric (roads, households, industrial sites etc.) land cover category is some 3% in Finland. The inland is allocated to economic activities in Figure 1 B in order to identify different land uses induced by different groups of economic activities. The land area covered by the infrastructure and buildings (i.e. the direct land area needed for industrial production sites) is rather small in terms of land area occupation. As the LCA methodology was originally designed and mostly implemented for the needs of environmental impact assessment of traditional industrial production value chains (e.g. metal, machining and packaging industries) this is probably one of the reasons, why land use induced environmental impacts have been omitted in such a large extent for so long in the methodology. The most important contributors to land cover and land use in Finland are all the areas that produce biomass: forests, shrubs and bogs (either in natural or managed state) as well as all the agricultural lands. Therefore it is important to include the assessment of impacts of land use especially in the LCA studies on the activities that use biomass as a raw material. These are all

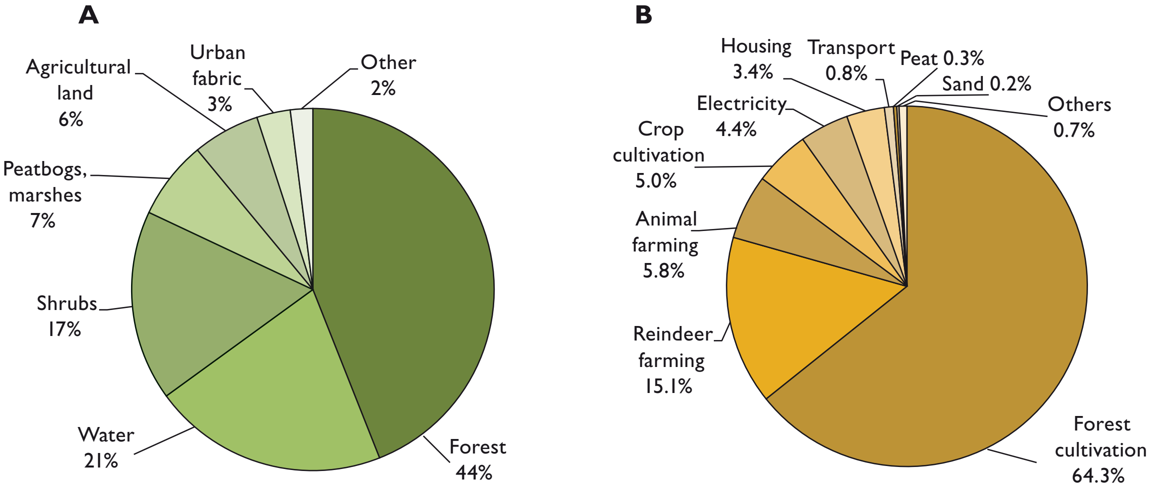

Figure 1. Total land cover in Finland divided into different categories (A) and allocation of the inland area to different economic activities (B) Source: Mattila et al. 2009.

the production chains that include food, feed, fibre or bio-based fuel production. In Finland this means especially forest industry and the bioenergy sector. In addition, agriculture and new bio-based products are of interest. It needs to be kept in mind, however, that Figure 1 includes information only on the relative share of land occupation (m^2a), not on the relative share of environmental impacts of each activity. Land occupation for e.g. extensive reindeer farming leads to very different environmental impacts than the occupation of the same amount of land area for intensive mining operations. Therefore activities such as mining, community building, and services should not be cut off in land use related LCA studies without proper justifications. These issues are discussed in detail in Chapters 3, 5 and especially with the case study presented in Chapter 6.

System boundaries of land use and land use change cannot be restricted only to Finland. The Finnish companies are international actors and the trade of biomass products takes place in both directions across the country's borders (see Haberl 2009, Mattila et al. 2009). For example, over 90% of all the land use intensive forestry products made from Finnish pulp wood are exported from Finland. Hence a large share of current land use in Finland is caused by foreign consumption. On the other hand, many biomass-based raw materials or products are imported to Finland. These biomass importing sectors include forest, foodstuff, and biofuel industries. Roundwood that was imported to Finland from Russia was responsible for the majority of the "imported" land use (Mattila et al. 2009). Food and feed were the other significant contributors to the foreign land use. At the moment, Finland is a net exporter of biomass products (Haberl 2009) because of the vast exports of Finnish forest products. However, this does not automatically mean that the balance of biomass imports and exports is similar for Finnish-based companies with production sites all around the world.

At the European level, according to EEA (2005), the expansion of artificial areas and related infrastructure are the main causes of the increase in the coverage of land. The development of artificial surfaces leads to disappearing agricultural zones and, to a lesser extent, forests and semi-natural and natural areas, which further affects biodiversity since it decreases habitats, the living space of a number of species, and fragments the landscapes that support and connect them. This indicates that the land use problem is very different in Europe in general than in Finland.

Introduction to land use related environmental impacts

Both land occupation and land transformation cause environmental impacts by occupying and transforming the land. In addition, agricultural, forestry, industrial and other processes cause direct emissions to air, water, and soil and cause changes in soil quality and in the use of natural resources. The complex cause and effect relations that lead to environmental impacts are described in Figure 2.

The main environmental impacts include changes in biodiversity, resource availability and soil quality. The soil quality impacts include changes in net productivity and in natural carbon, nutrient and water balances of the land area. The impact on natural carbon stocks has a direct link to the impact category of climate change. Public discussion of the land use induced impacts is mostly focusing on GHG emission issues because climate change is often considered to be the environmental problem that needs the most immediate mitigation. Various national, European, and international policies, such as targets to use increasing amounts of biofuels, are leading to significant changes in land use. Even though the GHG emissions have been identified to have major importance, the majority of LCA studies have focused only on the direct GHG emissions caused by biofuel and bioenergy systems, not on all biomass use as would be necessary. Moreover, in recent bioenergy LCAs, only a small minority has included land use or the land use change category in their assessment, due to the fact, that there is no widely accepted methodology for including land use impacts in LCA (Cherubini & Strømman 2010). The indirect impacts have been taken into account even more seldom, because a satisfactory methodology to quantify all the indirect environmental impacts caused by the land use change of biomass cultivation is also lacking.

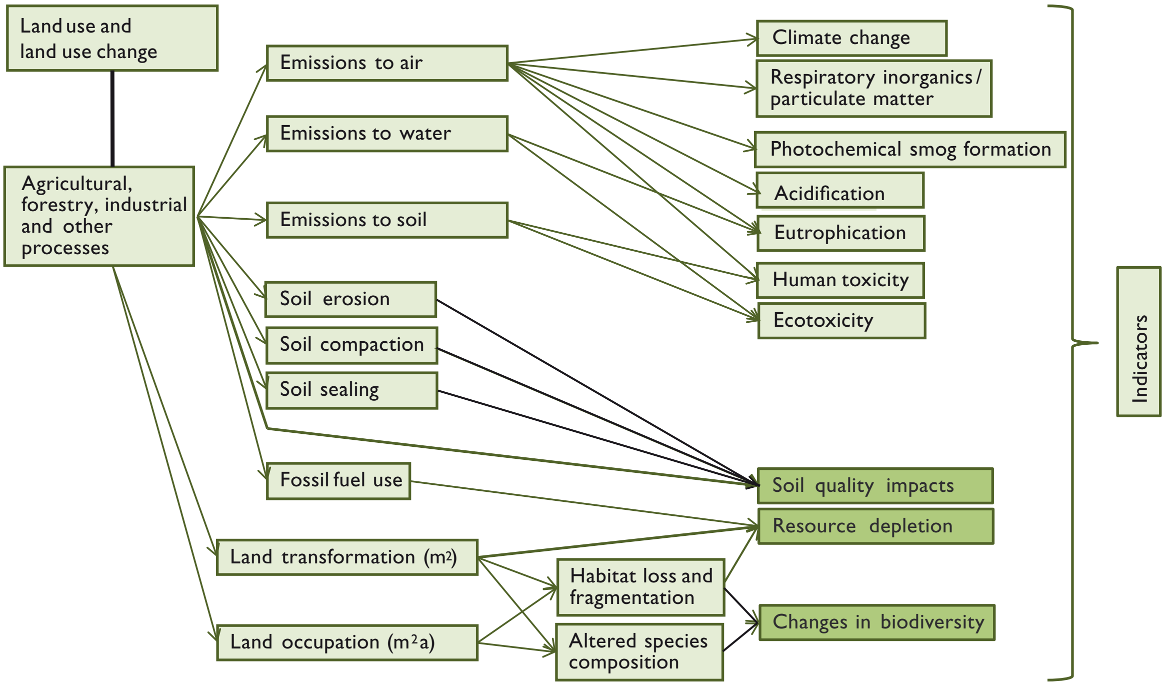

Figure 2. The causal relationship between land use and environmental impacts. The human intervention processes are presented on the left, the environmental interventions (e.g. emissions and immediate impacts on land) in the middle and the resulting environmental impacts on the right.

2 Review on existing guidelines

Different international and national agreements refer to land occupation and land transformation mainly in connection with the estimation of GHG emissions. Here we briefly present:

i) Guidelines in which land occupation and land transformation related GHG emissions are dealt with:

- the EU Renewable Energy Directive (RED),
- PAS 2050 (carbon footprint specification by BSI),
- California Low Carbon Fuel Standard (LCFS), and
- IPCC guidelines on land use in agriculture, forestry and land use (AFOLU) sector.

ii) Guidelines in which land use is dealt with in a broader LCA perspective:

- UNEP/SETAC Life Cycle Initiative,
- ILCD Handbook 2010, and
- existing LCIA sets, e.g. ReCiPe, CML, LIME.

EU Renewable Energy Directive 2009/28/EC (RED)

The European Community Directive 2009/28/EC on the promotion of the use of energy from renewable sources (RED) defines sustainability criteria for biofuels and bioliquids. The criteria need to be fulfilled in order to be taken into account when measuring compliance with the requirements of the Directive concerning national targets, measuring compliance with renewable energy obligations, and eligibility for financial support for the production and consumption of biofuels and bioliquids (European Union 2009). The reference date of the Directive is January 2008, and it is used as a reference for the criteria of land with high biodiversity value, land with high carbon stock and peatland (European Union 2009). Annualised emissions from carbon stock changes caused by land-use change shall be calculated by dividing total emissions equally over 20 years (European Union 2009). Guidelines for the calculation of land carbon stocks drawing on the 2006 IPCC Guidelines for National Greenhouse Gas Inventories - volume 4 are given in the Commission decision 2010/335/EU (COM 2010a). Indirect land-use changes are not considered in the land carbon stock accounting of the RED. However, in July 2011 the Commission shall publish an assessment of the indirect land-use change impacts of the renewable energy promotion policy and the options to consider them (COM 2010b).

Carbon footprint specification PAS 2050 by British Standards Institution (BSI)

The Carbon footprint specification PAS 2050:2008 by British Standards Institution (BSI) also gives guidance on calculation of land use (BSI 2008). This specification document defines the direct land use change as the conversion of non-agricultural land to agricultural land as a consequence of producing an agricultural product or input to a product on that land. Indirect land use change refers to the conversion of non-agricultural land to agricultural land as a consequence of changes in agricultural practice elsewhere.

According to the specification, the GHG emissions arising from direct land use change shall be assessed for any input to the life cycle of a product originating from agricultural activities. The GHG emissions arising from the direct land use change shall be included in the assessment of GHG emissions of the product. The assessment of GHG emissions occurring as a result of direct land use change shall be done in accordance with the relevant sections of the IPCC Guidelines for National Greenhouse Gas Inventories. The assessment of the impact of land use change shall include all direct land use change occurring on or after 1 January 1990. The total GHG emissions arising from direct land use change shall be included in the GHG emissions of products arising from this land. One-twentieth (5%) of the total emissions arising from the land use change shall be included in the GHG emissions of these products in each year over the 20 years following the change in land use. If the emissions from land use change occurred more than 20 years prior to the assessment being carried out, no emissions from land use change should be included in the carbon footprint assessment.

(BSI 2008) states that methods and data requirements for calculating the GHG emissions arising from indirect land use change are not yet fully developed, and therefore, the assessment of emissions arising from indirect land use change is not included in the carbon footprint specification. However, the inclusion of indirect land use change will be considered in future revisions of the specification.

Critique on the approach adopted in RED and PAS 2050

An illustrative indicator for the warming impact in time is the cumulative radiative forcing (CRF) of the emissions. Calculating CRF for the emissions annualized (=amortized) over 20 years according to both PAS 2050 and RED clearly underestimates the climatic impacts compared with the calculation of CRF for the actual instant land-use-change emissions. Moreover, another challenging task is to estimate the actual baseline land use over time, i.e. the development of terrestrial C stocks without biomass use, needed in a consequential climate impact analysis of specific biomass use cycles. PAS 2050 and RED assume that the baseline is constant, but in reality forests could continue sequestering carbon for a long time, e.g. far beyond their economically feasible rotation lengths. These issues are discussed in more detail in Chapter 5.1.

California Low Carbon Fuel Standard (LCFS)

The Low Carbon Fuel Standard (LCFS) is a part of current legislation of the State of California which calls for a reduction of at least 10% in the carbon intensity of California's transportation fuels by 2020. The LCFS has been effective since April 2010 and it is the first binding legislation for transport fuels that requires the inclusion of GHG emissions from indirect land use change. (ARB 2010a). It requires fuel providers to determine the carbon intensity and life cycle GHG emissions of the fuel they provide, including direct emissions and significant indirect emissions such as emissions from land use changes. The life cycle GHG emissions are defined for each fuel with the CA-GREET model and a specific LUC modifier obtained with a modified Global Trade Analysis Project (GTAP) model. It is required that the GTAP model will be used for the assessment of iLUC induced GHG emissions for all the yet undefined fuel chains as well. An expert workgroup will issue regulatory amendments or recommendations, if appropriate, on approaches on how to address and how to improve the land use and indirect analysis no later than January 2011. (ARB 2010a, ARB 2010b)

IPCC guidelines on agriculture, forestry and land use (AFOLU) sector for national inventories

The United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol set requirements on national annual GHG inventories and reporting. There is no baseline to which the emissions/removals are compared. In the annual inventory only the true emissions occurring in the reporting year are reported and no life-cycle perspective is taken.

Land use is divided in six categories being forest land, cropland, grassland, wetlands, settlements, and other land (IPCC 2003a, IPCC 2006). The inventory of GHGs concerns only the anthropogenic emissions and removals by sinks on ‘managed land’, which is defined as land where human interventions and practices have been applied to perform production, ecological, or social functions. All land definitions and classifications are specified at the national level, and they need to be described in a transparent manner, and be applied consistently over time. Even though the emissions/removals of greenhouse gases do not need to be reported for unmanaged land, according to IPCC, it is good practice for countries to quantify, and track over time, the area of unmanaged land so that consistency in area accounting is maintained as land-use change occurs.

The guidance and methods for estimating greenhouse gas emissions and removals for the AFOLU Sector include the following:

- CO_2 emissions and removals resulting from C stock changes in biomass, dead organic matter and mineral soils, for all managed lands;
- CO_2 and non-CO_2 emissions from fire on all managed land;
- N_2O emissions from all managed soils;
- CO_2 emissions associated with liming and urea application to managed soils;
- CH_4 emissions from rice cultivation;
- CO_2 and N_2O emissions from cultivated organic soils;
- CO_2 and N_2O emissions from managed wetlands
- CH_4 emission from livestock (enteric fermentation);
- CH_4 and N_2O emissions from manure management systems; and
- C stock change associated with harvested wood products.

The methods for analyzing the GHGs from the AFOLU sector are divided into three so called tiers.

- **Tier 1** methods are designed to be the simplest ones to use and for which equations and default parameter values (e.g., emission and stock change factors) are provided in the IPCC Guideline. Country-specific activity data are needed, but also for these there are often globally available sources of activity data estimates.
- **Tier 2** can use the same methodological approach as Tier 1 but applies emission and stock change factors that are based on country- or region-specific data, for the most important land-use or livestock categories.
- At **Tier 3**, higher order methods are used, including models and inventory measurement systems tailored to address national circumstances, repeated over time, and driven by high-resolution activity data that are disaggregated at sub-national level.

The accuracy increases and uncertainty of the emission estimates increases when moving from lower to the higher tiers. Data for the tier 3 can consist for example on GIS-based systems of age, class/production data, soils data, and land-use and management activity data.

Even though the IPCC guidelines are designed for national level inventories, their emission factors are often used also in LCA to estimate land use and soil GHG emissions, a typical example being the N2O emissions from soil.

Further, within the Kyoto Protocol (Articles 3.3 and 3.4) the accounting rules for emissions from LULUCF differ from the basic national inventory reporting under the UNFCCC. Accounted emissions/removals are those taken into account to fulfil the national obligations under the Protocol. For instance concerning forest lands, only Article 3.3 is mandatory, in which the terrestrial C stock due to deforestation, afforestation and reforestation are accounted on full C basis. The Article 3.4, whose inclusion is voluntary for the Kyoto Parties, is related to activities in lands subject to forest, cropland or grazing land management or revegetation. In case a Kyoto Party has elected forest management as a national activity, only a limited part of C sequestered into the forest is allowed to be taken into account because national caps on sinks were negotiated in the Kyoto Protocol.

In addition, to meet national obligations in the Kyoto Protocol it is possible to use LULUCF projects under Article 6 (Joint Implementation) and Article 12 (Clean Development Mechanism). Here the accounting is based on a kind of consequential analysis, where the C crediting is made with reference to forecasted baseline land-use scenario (business as usual). Only those emission reductions, which are a clear consequence of the project activity, are allowed to be credited.

UNEP/SETAC Life Cycle Initiative

UNEP/SETAC Life Cycle Initiative has formed a working group on natural resources and land use[1] with the aim of establishing a recommended practice and guidance for use for natural resources and land use categories, i.e.: water resources, minerals resources, energy carriers, soil resources and erosion, land use, salinisation and desiccation and biotic resources. It will address both midpoint categories and their relation to damage categories such as the biotic and abiotic natural environment. One of the main outputs from the working group is the Mila i Canals et al. (2007a) research paper

---

[1] http://www.estis.net/sites/lciatf2/, http://www.pes.uni-bayreuth.de/en/research/projects/LULCIA/ (visited February, 21, 2011)

“Key Elements in a Framework for Land Use Impact Assessment within LCA” which provides an overview on how to combine different temporal aspects and different indicators in LCIA of land use, as discussed in Chapters 3.1 and 3.2.

ILCD Handbook 2010

The recently published ILCD Handbook (EC 2010) stated that by the time the book was published, no established and globally applicable practice on land use occupation and transformation was available, but several approaches with either only regional applicability or lack of practice experience were being developed. Furthermore, it was commented that the different methodologies work with fundamentally different inventorying approaches. Therefore any specific recommendation or requirement on inventorying land use and conversion was not given. However, the handbook gives general guidelines on taking land use and transformation issues into account in LCA referring to the requirements of the LCIA method being applied, IPCC emission factors or case specific measurements or modelling. The general guidelines by the ILCD Handbook are as follows:

- **Land use (occupation) and transformation:** Direct land use (occupation) and land transformation shall be inventoried along the needs of the applied LCIA method (if included in the impact assessment)

- **Emissions from land use and transformation:** If land use and/or land transformation are modelled, carbon dioxide and other emissions and related effects should be modelled as follows:

  - **Soil organic carbon changes from land use and transformation:** For CO_2 release from or binding in soil organic carbon caused by land use and land transformation, the most recent IPCC CO_2 emission factors (IPCC 2003b, Chapter 3.3, 74-82[2]) shall be used, unless more accurate, specific data is available.

  - **Land use and transformation related CO_2 emissions from biomass and litter:** For virgin forests and for soil, peat, etc. all land uses shall be inventoried as "Carbon dioxide (fossil)". Emissions from biomass and litter of secondary forests shall be inventoried as "Carbon dioxide (biogenic)". This applies unless the selected LCIA method requires otherwise.

  - **Nutrient losses:** Emissions of nutrients shall be modelled explicitly as part of the land management process.

  - **Other emissions:** Other emissions as a result of land transformation (e.g. emissions from biomass burning, soil erosion etc.) should be measured or modelled for the given case or using authoritative sources.

---

[2] Available at: http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_files/Chp3/Chp3_3_Cropland.pdf

General LCIA method sets, e.g. ReCiPe2008, Ecoindicator 99.

Many well known general LCIA method sets include an impact category 'land use', e.g. ReCiPe2008, EPS 2000, LIME2, StepWise2006, Swiss Ecoscarcity, CML 2002 and Ecoindicator99. These land use impact categories cover only one aspect of land use, which most often is impact on biodiversity (ReCiPe2008, Ecoindicator99, Swiss Ecoscarcity, EPS 2000 and StepWise2006). LIME2 includes also resource depletion through impact on primary production. The approaches to land use related impacts cannot be considered comprehensive before all the three land use impact categories (depletion of productive land area, changes in soil quality and biodiversity) are included in the land use impact assessment. However, most interesting approaches in CML 2002 and ReCiPe 2008 are described with more details in Chapter 5. The Joint Research Centre will soon publish a yet unfinished report (as part of the ILCD Handbook) that will include a thorough review of the approaches on land use in these general LCIA method sets[3].

---

[3] By the time of writing (March 2011) a draft version of the ILCD Handbook document "Recommendations based on existing environmental impact assessment models and factors for Life Cycle Assessment in a European context" is under public consultation. It includes the preliminary results on approaches to land use impact assessment but the draft version for consultation shall not be cited. The final document can be eventually found from http://lct.jrc.ec.europa.eu/assessment/ (within the year 2011).

3 Direct land use

3.1

Land occupation and transformation

Before assessing impacts, the magnitude of land use has to be estimated. In the field of LCA this belongs to the life cycle inventory stage. The purpose of this chapter is to present an outline of how land use commonly is inventoried. Further information on data sources (together with the description of primary data collection tools) is presented in Appendix 1.

Traditionally life cycle assessment has focused on two different classes of land use: transformation (land use change) and occupation (land use). Transformation refers to changing one kind of land cover to another; occupation refers to the use of a land cover for a certain period (Figure 3). Incorporating both types of land use in an assessment is important for full analysis, but considerable difficulties persist in the interpretation and combination of the two classes.

In a suggestion for a framework of land use in LCA, Mila i Canals et al. (2007a) presented an outline for combining the impacts of land occupation and transformation (Figure 3). Transformation changes the land quality, which will then restore towards the reference state (Figure 3, top). The impact is then the integrated area between the reference state and the land quality development. The influence of occupation can be seen as a delay in the restoration process (Figure 3, bottom). Over time, if the area had not been occupied, it would have reached a better land quality sooner. Therefore the impact of occupation can be seen as the time integrated loss of quality.

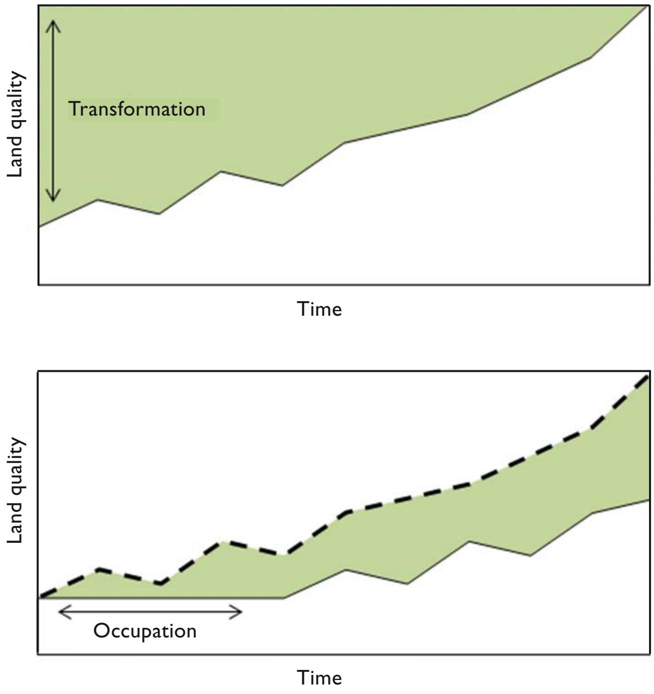

Figure 3. Land transformation can be considered as an occupation impact, which is required to restore the system to a natural state. Similarly occupation can be seen as a delay in the restoration towards a natural state (drawn from Milá i Canals et al. 2007a).

Other researchers express transformation as a series of occupations required to restore the ecosystem after the current use has ended. For example when a primary forest has been converted into a residential area, 50 years are needed to restore the area back to primary forest after the occupation has ended and 500 years to recover it into a completely natural state (Table 1, Koellner and Scholz 2007). It is clear that considerable uncertainties are not only in the times of recovery, but also in the probabilities of recovery even happening. For example, instead of the residential area being abandoned and allowed to recover to forest, the area might be converted into a highway.

The combination of transformation and occupation is not straightforward and there is no consensus in combining these impacts in LCIA. For example, what is the time period for integrating the impacts? And what should be done if the restoration is incomplete and land quality remains at a lower level permanently? Different solutions to these questions are presented in the current literature. Therefore a general suggestion of recording land occupation and transformation separately in LCIA is recommended. This does not limit the possibilities of using life cycle impact assessment models with differing time frames. Maintaining as much resolution as possible is also recommended at the inventory stage, i.e. using CORINE land classifications (EEA 2010). Occupation is recorded as m^2a and transformation as m^2 from and to a given land cover. As an additional suggestion, it is recommended that the location of the land use is recorded. Maintaining as much details as possible allows the use of up-to-date LCIA models, when they are developed.

As an additional possibility in the LCI, it could be beneficial to also record the modifications to the land use occupation. According to (EC 2001) the land transformation (or *land cover and land use change* as in EC 2001) is commonly divided into two broad categories: conversion and modification. *Conversion refers* to a change from one cover or use category to another (e.g. from forest to grassland). *Modification* represents a change within one land use or land cover category (e.g. from rain fed cultivated area to irrigated cultivated area) due to changes in its physical or functional attributes. The current LCI practice of recording only land area would be improved by the analysis of ongoing processes, such as intensification, extensification, afforestation, deforestation, development (a transformation of open land to urban, industrial or transport uses) or reclamation (a flow involving the creation of open land to areas previously developed (e.g. reclamation of mineral workings). These could also serve as additional qualitative statements in the final LCA report.

3.2

Reference status

In the previous section, the uncertainties in assessing recovery times after transformation are presented, especially when the land use is followed by other economic activities. Subsequent transformations also impose the problem of allocation: should the conversion of agricultural area to a highway carry some of the burden of the original conversion from woodland? This allocation problem is deeply rooted in reality, since most tropical deforestation in the Amazon occurs in a series of economic activities: timber harvesting, initial colonization, competition over land, conversion to cattle pastures, and consolidation of colonization in the original area and new colonization in more marginal regions[4] (Lambin et al. 2001). Given such a chain, how should environmental impacts be allocated to the activities? In the current biofuel

---

[4] This chain of activities applies only to Latin America. The reasons of deforestation are different for Amazonia, Central Africa and Southeast Asia (Lambert et al. 2001).

debate, much of the land transformation is allocated to the pastures, which relocate because of biofuel plantations, but other alternative allocations would be possible.

Several approaches to allocating land transformation to subsequent uses have been published (Lindeijer 2000), but there does not appear to be a clear consensus among researchers. For example in the Ecoinvent datasets for bioenergy, transformation is allocated to the first year of crop production and subsequent uses do not suffer from transformation impacts (Jungbluth et al. 2007). In contrast Brandão et al. (2010) have assumed a 100 year period, over which the transformation impacts should be allocated, and since many croplands have been transformed prior to that, they argue that land transformation can be ignored for many cases.

To a large degree, the differences in allocation stem from the different assumptions on the reference status. The aim of this section is to give an overview of the different alternatives in choosing a reference status.

Dynamic and static reference situation

Milà i Canals et al. (2007a) use the term *dynamic reference situation*, which defines the size of the land use transformation impact as the difference between effect on land quality from the studied case of land use and a suitable reference land use on the same area. The impact is dependent on the type of land use, referring to both land cover and land use intensity. In this methodology, the *occupation impacts* can be measured by the amount of area affected, multiplied by the difference in quality between current quality and the reference situation at each moment of the occupation process multiplied by the duration of the occupation process (Figure 3). *Transformation impacts* are measured as the permanent change in land quality (Figure 3).

After the occupation, the recovery of land quality may originate both in natural and human induced processes (natural relaxation and backup technology, including human induced relaxation). However, there may also be permanent land quality degradation. Milà i Canals et al. (2007a) identify three types of land use processes ending with different types of recovery:

A) After the occupation process, land quality is lower than in the initial phase,

B) If the land, after the relaxation time, transforms to the same quality as in the initial phase, there are no transformation impacts, and only reversible occupation impacts occur,

C) Land quality reaches a certain threshold limit value and recovery is not possible within the time frame of the assessment.

In each of the cases the analysis is based on the dynamic reference situation of the system, which would not have been affected, as discussed in the previous section.

While Milà i Canals et al. (2007a) proposed a dynamic reference situation, Koellner & Scholz (2007) proposed a static reference situation for calculating the occupation impact. A static reference situation is defined as the current regional status of ecosystem quality. According to Koellner & Scholz (2007), this allows one to assess whether a specific land use type is worse or better compared to the regional average land use mix. In their methodology, land use impacts are divided in three phases with different sizes of damages: transformation, occupation, and restoration, which are compared to the reference average land use. The total damage caused to ecosystems is the sum of these factors. Koellner & Scholz (2007) also propose estimated restoration times of different types of intensities of land use (Table 1). These estimates are clearly arbitrary and only a rough first approach, and depending on the initial and final quality of the land use type, the climate, and many other factors, restoration times may vary quite considerably. Additionally, some ecosystem types might never be restored again.

Table 1.Estimated time in years which is necessary to transform an initial land intensity to a final land intensity (Koellner ja Scholz 2007)

From: **Initial land use, including intensity (below)**	**To: Final land use, including intensity (top row)**						
	conventional arable, integrated arable, organic arable, fibre/energy crops, intensive meadow	less intensive meadow, organic meadow, organic orchard, natural grassland	built up land, continuous urban, discontinuous urban, sport facilities, industrial area – part with vegetation	green urban, rural settlement, rail embankments	forest plantations	semi-natural broad-leafed forest (either moist or arid)	heathland, hedgerows, peatbog
conventional arable, integrated arable, organic arable, fibre/energy crops, intensive meadow	-	10	<1	2	25	50	500
less intensive meadow, organic meadow, organic orchard, natural grassland	<1	-	<1	2	25	50	500
built up land, continuous urban, discontinuous urban, sport facilities, industrial area – part with vegetation	5	10	-	2	25	50	500
green urban, rural settlement, rail embankments	2	5	<1	-	25	50	500
forest plantations	1	2	<1	2	-	25	-
semi-natural broad-leafed forest (either moist or arid)	1	2	<1	2	10	-	-
heathland, hedgerows, peatbog	<1	<1	<1	2	10	25	-

4 Indirect effects of land use

Increased demand for biomass for fuels, food, feed, and fibre is generating changes in current land-use configuration. The limited biomass and land resources together with the increasing competition for the particular resources put pressure to harvest more land for biomass cultivation. Biomass utilisation has influences on land use and land-use changes both directly and indirectly, the latter being discussed in this chapter.

Indirect effects take place through various market mechanisms which influence resource utilisation. There are both positive (reinforcing the impact) and negative (diminishing the impact) feedback market mechanisms. Certain changes can lead both to positive and negative feedback mechanisms thus influencing the resource and land utilisation in both directions. For example, the increase in electricity consumption may increase the electricity price and decrease the consumption afterwards (negative feedback mechanism). On the other hand, the increase in electricity consumption may boost new investments lowering the electricity price and thus increase the electricity consumption afterwards (positive feedback mechanism). The term 'indirect' refers here to a factor that is outside the product system boundary set for the consideration but that can be attributed to the action occurring in the system.

When market mechanisms influence the utilisation of resources derived from the ground, land resources are influenced causing indirect land use. The most significant environmental impacts are typically caused when this indirect effect causes a land-use change. In order to meet a given demand for various biomass-based products, a certain amount of feedstock and land area is required. The increase in feedstock demand requires more land for biomass production if the increased demand cannot be satisfied by intensifying biomass production in current biomass production areas. The indirect land-use changes may take place due to increased competition for feedstock, land area or other auxiliary resource inputs (Figure 4). In addition, other changes in product systems like substitution effects may lead to transfers in production and thus also to indirect land-use changes. The environmental impacts of indirect effects are similar to those of direct land use or direct land-use changes, but the drivers are different.

Let us consider that a certain fixed amount of beer is produced in Finland using barley as a feedstock (see Figure 4). If this barley amount is, instead, used for some other purposes, the same amount of barley needs to be produced in some other area to satisfy the demand. Typically, the feedstock is purchased from the market, which means that the increased demand tends to increase the price and the production of the feedstock. In such a case, the increased demand (feedstock competition) would possibly be satisfied by increasing the barley or another grain crop (providing the desired demand) production in some other area. This effect can be called as a *production shift through feedstock competition* (pathway *(b)* in Figure 4). Even if the barley would not be otherwise produced, the particular land area might be used for some other purposes, for example turnip rape cultivation. If this would be the situation, turnip rape or some other vegetable oil production might shift to another area. This effect can be called as a *production shift through land area competition* (pathway *(a)* in Figure 4).

Besides feedstock and land area competition indirect land-use changes may take place also through market impacts related to main and co-product(s) produced. In the given example the beer production unit produces 'beer' and 'animal feed' as products. The key issue arising is what happens when this new amount of product is submitted to the market. The response is likely to depend on the market situation. It is possible that the particular products will partly participate in satisfying the increasing demand or will lower the price level of other products providing the same function. The latter option may result in a substitution effect: some product is replaced with a new product. In the case of beer the replaced product may be for example the same beer product, another beer product or another beverage. Similarly, the animal feed replaced may be produced for example from corn, wheat, or from vegetable oil plants like rapeseed, palm tree or soybean. If the substitution effect takes place, the production of co-products involved is also reduced. This may lead to a chain reaction which seems not to have any end. Anyway, land use patterns are also influenced through main product and co-product market impacts. The effect can be called as *production shift through product substitution* (pathway *(c)* in Figure 4).

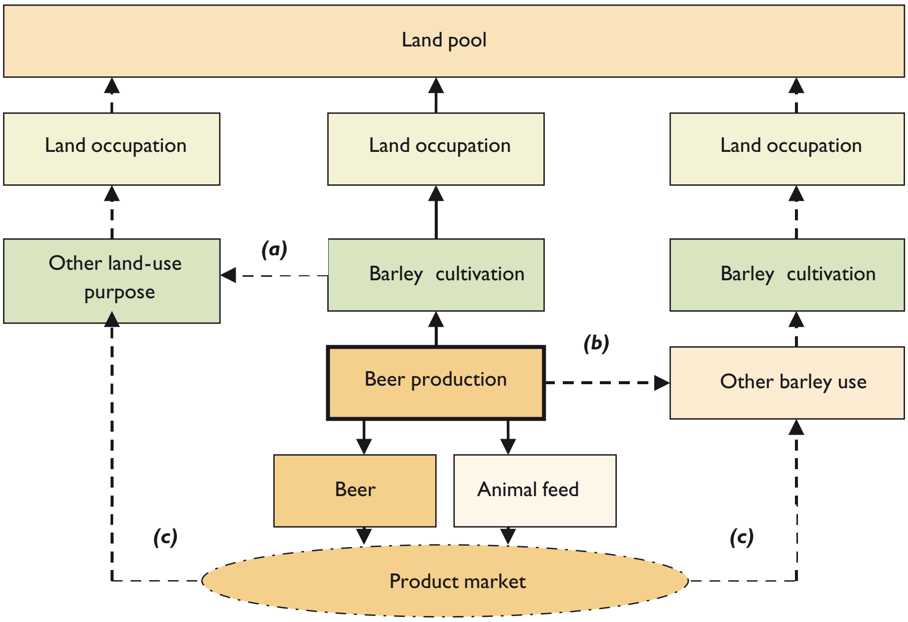

Figure 4. Illustration of impacts of beer production on land use through (a) land area competition, (b) feedstock competition, and(c) product substitution.

Production of any product requires a varying number and amount of auxiliary energy and material inputs. In the case of beer production, fertilizers, pesticides, diesel oil, electricity, yeast, water, and heat produced by fossil fuels are typical auxiliary inputs. Analogically to feedstock and land area requirements, these other inputs may also be subject to competition. The use of auxiliary inputs under competition increases their demand and thus likely also the supply of them. The use of resources to provide auxiliary energy and material inputs is likely to have influences on land use and may also cause land-use changes. When the effect takes place indirectly, it can be called as *production shift through competition of auxiliary inputs other than feedstock or land*.

Indirect effects of human actions are not a new issue but the term indirect land-use change (iLUC) has been established through a group of recent research papers emphasising the potential significance of iLUC in LCA of biofuels (Cramer Commission 2007a and b, E4Tech 2006, Delucchi 2004, Turner et al. 2007, Farrel and O'Hare 2008, Kloverpris et al. 2008a, b, and c, Hellman and Verburg 2008, Searchinger et al. 2008, Kim et al. 2009, JRC 2010). There is an extensive scientific agreement that iLUC related to emerging biofuel production may cause significant CO_2 emissions, but no common agreement on the methodologies for monitoring, modelling and quantification of the iLUC related impacts. The measures and data used to quantify the implications have been questioned for example by Liska and Perrin 2009. Currently, the research efforts are focused on how to identify and quantify iLUC, how to calculate GHG impacts from iLUC and how to include them in a LCA, and how to take iLUC into account in national GHG emission targets and reporting to the UNFCCC (United Nations Framework Convention on Climate Change).

The indirect effects may be very far reaching in space and time, including possibly a number of complicated positive and negative feedback mechanisms. As the indirect effects are driven by market forces, relevant market area needs to be considered when aiming to capture the implications. As many of the product systems affected by ‘the cause’ considered are connected to the global trade, a global economic approach is typically needed. Furthermore, as the implications do not take place immediately, timing issues should also be taken into account. General scientific consensus exists about using an economic approach to address indirect land-use changes (Gnansounou et al. 2008). However, the methods are widely controversial.

The recent aims to quantify iLUC impacts are related mainly to GHG impacts of expanding production of liquid biofuels. A few different models and approaches have been used. Searchinger et al. (2008) used the FAPRI[5] international partial equilibrium model of agricultural commodities to allocate displaced corn production for other purposes and soybean displaced from rotation in the same land. Kloverpris et al. (2008) used the GTAP[6] equilibrium model to evaluate land-use changes due to crops consumption. Kloverpris et al. (2009) modified the GTAP Model to predict global land-use changes caused by increased wheat demand in Brazil, China, Denmark, and the USA. Hertel et al. (2010) used the GTAP-BIO model[7] to assess impacts of maize ethanol on global land use and GHG emissions. These models used to estimate iLUC and associated GHG emissions are based on forecasting the economic effects of marginal changes in the use or output of cropped materials. Tipper et al. (2009), and Fritsche et al. (2008) have attributed CO_2 emissions from iLUC to biofuels based on statistics, and derived so called iLUC factors.

The selection of the approach and model together with specific assumptions (e.g. carbon pay back time) may have significant impact on the results. For example, iLUC-related CO_2 emissions from the production of maize ethanol have been estimated by Searchinger et al. (2008) and Hertel et al. (2010) to equal 104 and 27 g/MJ, respectively, if allocated over 30 years of production. US EPA (2010) and Tipper et al. (2009) also considered iLUC and present figures for maize ethanol between the above mentioned range. For comparison, GHG emissions from typical maize ethanol production excluding iLUC are about 60 to 65 g CO_2-eq. corresponding to some 80% of the life-cycle GHG emissions of fossil gasoline (CARB 2009). Consequently, the estimated CO_2 emissions from iLUC are remarkable according to all the above referred studies.

---

[5] http://www.fapri.iastate.edu/

[6] https://www.gtap.agecon.purdue.edu/

[7] https://www.gtap.agecon.purdue.edu/resources/download/3939.pdf

Gnansounou et al. (2008) characterized quantification of iLUC by separating the methods into following approaches:

1) economic modelling of demand for land in a general/partial equilibrium approach,
2) modelling of global iLUC by relocation of activities on a worldwide scale,
3) worst case assumptions,
4) subjective choice of land where to allocate displaced activities,
5) restricted to cropland relocation,
6) restricted to land use due to biomass-use substitution and avoided crop rotation,
7) modelling iLUC as decreased supply in producing country and increased production in other producing country of the same commodity, and
8) displaced land use is not currently modelled.

Various approaches have their specific pros and cons. Complex economic forward-casting models are typically very uncertain due to multiple degrees of freedom, feedback loops, complex interactions and limited resolution. However, together with geographical information and land-use-related statistics they can be used to carry out scenarios. Approaches based only on statistics are not necessarily well-suitable to describe the future development although, when data is well-available, they can be used to describe the historical development. Simple worst case or marginal analyses are useful to describe the possible risks that may be realized in the worst case but may overestimate the actual impacts.

The iLUC may take place due to very different factors related to changes in resource use. Any change in output or use of a crop includes indirect effects: for example reductions in cereal output in Australia resulting from drought, increased meat production resulting from higher meat demand in China, and reduction in agricultural output as a result of removal of subsidies (Tipper et al. 2009). Given the interlinked nature of global agricultural markets it is virtually impossible to determine precisely where one indirect effect ends and another begins (Tipper et al. 2009). Furthermore, due to difficult cause and effect relation, it is very difficult to attribute a certain iLUC impact to a certain single product on scientific basis. However, exclusion of iLUC-related CO2 emissions is not a solution towards reducing deforestation, which currently causes some ten percent of the global GHG emissions annually (Global Carbon Project 2011). As rapid actions are required in climate change mitigation and in reducing deforestation, some compromise solution in accounting of iLUC impacts is probably required.

The main problem in iLUC is the fact that deforestation mainly takes place in countries that are currently not committed to the binding targets for GHG emission limitations and reductions, such as Indonesia and Brazil (determined as non-Annex I countries in the UNFCCC). Furthermore, iLUC is mainly promoted by increasing global demand and trade of agricultural products caused by various industrial branches in developed and developing countries. The agreement of non-Annex I countries on binding GHG emission targets or reduction of deforestation could be a solution for the problem. However, as long as this kind of agreement is lacking, some other solution is required. One possible option is that LUC emissions from non-Annex I countries are attributed to the countries purchasing biomass from the country where the LUC took place. Then the purchasing country may again attribute the particular LUC emission burden to the economic actors by various measures.

Indirect impacts are relevant for many companies, but they cannot typically be assessed or controlled at the company level. However, it is very important that the mechanisms are recognised and that the magnitude of the impacts is known at the company level in order to plan strategies to reduce harmful indirect impacts. Such strategies may include for example reconsideration of raw material basis.

5 Land use impacts and indicators

There is a multitude of environmental indicators that can be used for land use impact assessment. A selection of promising indicators were grouped on the basis of three land use impact categories: resource depletion, changes in biodiversity, and soil quality impacts (Figure 5). Changes in carbon stocks are often considered as a part of soil quality, but is separated here as a climate change category.

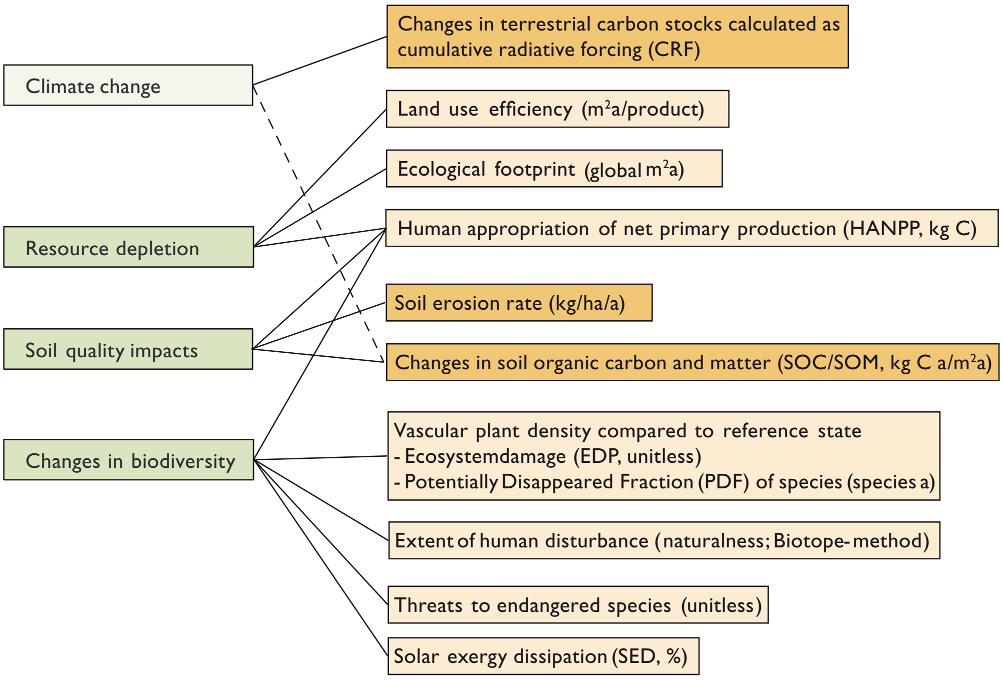

Figure 5. Set of environmental indicators (on the right) for land use impact categories(on the left).

These environmental indicators are presented and discussed in detail in the following chapters along with some indicators for impacts of land use on climate and water balances. Many of the indicators relate to multiple land use impact categories.

5.1

Climate impacts

Land use contributes to the balance of terrestrial carbon (C) stocks, which are an integral part of the global C cycle. The magnitude of terrestrial carbon stocks is substantial, of the order of 2000 Gt C. The global annual terrestrial C sink in the 1990s was roughly estimated at 2.6 Gt C/a and the C emissions from land use change at 1.6

Gt C /a when the global fossil C emissions were 6.4 Gt C /a on average (IPCC 2007a, p. 515). Both change in land use and management can lead to change in terrestrial C stocks and above terrestrial sink or emission fluxes. For example, a land use change due to land clearing and establishment of biomass plantations on lands with high initial terrestrial C stocks (such as indigenous forests) creates an instant emission to the atmosphere and a reduction of the terrestrial C stock. After establishment of such a plantation emissions from decomposing soil (e.g. from organic soils) might continue for long. The C balance of the soil is also dependent on the cultivation practices applied. On the other hand, by reforestation the terrestrial stocks could be restored. Further, a change in land management practices without any land use change can reduce the terrestrial C stocks. For example, intensified utilisation of forest harvest residues leads to declining stocks of dead wood and soil C at the landscape level (Repo et al. 2010) which should be taken into account in emission estimates.

From the point of climate change mitigation the dynamics of the terrestrial C is also an issue to be considered due to the urgency of emission reductions. In sustainable long-rotation forestry the C dynamics of terrestrial stocks are periodic and neutral over the cycle when the management practices are not changed, but there exists still C debt over time due to felling which is slowly compensated by re-growth of new forest biomass.[8]

Land use has also impact on other GHG emissions from land, i.e. methane and nitrous oxide. Nitrous oxide emissions are typically a result of fertilizer use on arable land. The emissions vary temporally and spatially and their climate impacts could be strong enough to jeopardize the climate benefits of fossil fuel replacement, for example, by cultivated bioenergy crops. Another important climate forcing agent is methane from wetlands and paddies.

Land use has also non-GHG related climate impacts due to surface albedo, which is lower for forested than open land. The difference between these land categories increase under snow cover.

Climate indicators in LCA

What would be the appropriate way of valuing the terrestrial C debt due to land use in LCA? There are basically two different types of climate indicators: ex-post and ex-ante. GHG inventories are an example of the first ones. The materialized emissions are reported afterwards, such as in the national emission reporting under the UNFCCC and the Kyoto Protocol. Crediting or GHG accounting to meet the national commitments is typically based on ex-post indicators. Similarly, in monitored or certified carbon footprints the emissions need to be monitored afterwards.

Ex-*ante* indicators are relevant in future-related LCA, where the impacts of some planned project activities or product lifecycles on global warming have to be estimated in advance. Timing of the future emissions is a key issue, because accomplishment of the 2°C degree stabilization target requires quick reductions in global GHG emissions, possibly peaking of emissions within one decade (IPCC 2007b, p. 15, Table SPM5). Thus, if there are changes in land use, or terrestrial C stocks in general, the dynamics of the stock changes must be considered in an ex-ante climate indicator. For the LCA methodology the description of the timing might be problematic, as the impacts are usually integrated over the whole lifecycle and presented by a single time-invariant number. In the case of climate change mitigation the appropriate time frame to be considered is also an open question.

---

[8] In the long term, the use of biomass plantations as a source of renewable energy and materials can still reduce net GHG emissions into the atmosphere, because emissions from permanent tectonic fossil C stocks can be avoided. To value the climate impacts, timing of the emissions of the whole biomass lifecycle must be considered, in addition to the changes in terrestrial stocks.

When estimating the impacts we have to consider climate impacts of land use change and management on C stocks, non-CO_2 GHG and particle emissions, and albedo with respect to the non-use baseline as a function of time in the projected future. One example is climate impact assessment of forestry. Estimating the impacts involves substantial uncertainties, because future scenarios of land both in projected and reference land use are required.

Some agreed guidelines such as PAS 2050 (BSI 2008) simplify the land use change impacts by amortizing the instant emission from the permanent C stock loss over a period of 20 years and provide thus one single emission number for the 20 year time period in the future. The amortization method can be criticized, but in this type of instant land use change the associated change in biogenic C stock can be verified without any predictions of the future stock development. For example, PAS 2050 (BSI 2008) is incapable of considering sustainable forestry at all, as there is no permanent C stock loss to be accounted for. Another simple way is just to consider the terrestrial stock C balance over time with respect to the reference scenario, but it does not provide any single emission number for the product LCA.

To be more realistic, the real warming impacts over time must be taken into account. One suitable and often applied measure for the impact is the cumulative radiative forcing (CRF), i.e., integrative warming impact over time. To estimate the warming impact at least a simplified model for atmospheric C cycle is needed (see e.g. Monni et al. 2003). To this measure it is also possible to integrate non-GHG climate forcing agents, such as changes in surface albedo. Further, the measure can be applied to value ex ante the climate impact of land use, biomass re-growth, and recovery of the terrestrial C stock. The integration interval should be relevant from the viewpoint of mitigation time frame, but there is no clear choice of the frame as mentioned. The amortization method of PAS 2050 (BSI 2008) clearly underestimates the true warming impacts described by CRF, as noted by Kendall et al. (2009), and this applies also to the indicator that reports just the C balance of terrestrial stocks.

GWP factors, commonly applied to non-CO_2 gases in order to transform them to CO_2 equivalent emissions, are a measure based on CRF. In national emission inventories the 100 year time interval is used when calculating the GWP factors. These factors could also be used to value the climate impacts of the terrestrial C debt (Cherubini et al. 2011). We consider this approach as a promising candidate in product LCA for describing the C footprint of land use change or management. In the approach the CRF of the terrestrial C debt, due to biomass harvest containing 1 t of biogenic C, is divided by the CRF of a permanent C emission pulse of 1 t of fossil C. The result is called the GWP_{bio} factor and it describes the relative climate impact of the terrestrial C emission with respect to a fossil C emission. By this method the time dependent terrestrial C debt can be transformed to a simple and single C emission figure in case the time frame of interest is chosen. However, as there is no unambiguous choice of the time frame T, it would be preferable also to consider the sensitivity of GWP_{bio} to T.

Example: Climate impacts of sustainable forestry

The rotation length of managed boreal forests typically varies from 60 years to far beyond 100 years. How should the spatial and temporal boundaries be considered in LCA and from the viewpoint of climate change mitigation?

1) A forest stand is a source of renewable biomass. The C stock has been sequestered from the atmosphere during preceding centuries. If we consider the whole lifecycle of wood biomass starting from growing forest and ending through product phase back to the atmosphere and we neglect the timing of sequestration and emission, the biomass stock change over the lifecycle is basically zero and the use of renewable biomass is thus C neutral.

2) We can also broaden the perspective spatially by considering forests at landscape or country level, but during a certain inventory year. In case the net C stock change in the forests is zero they can be considered C neutral. Thus a net growth in C stocks can be considered to be a C sink (or removal) and the net decrease an emission. There is no baseline to which the emissions/removals are compared. The national inventory reporting under the UNFCCC is made from this perspective.

3) In case the objective is to value the climatic impacts of harvesting forest biomass, we have to generate a reference scenario of not harvesting, i.e. without any activity, and estimate the difference of C balance over time between those two scenarios. From this perspective the harvest means always emissions with respect to the reference land use, at least in the short run.[9] The difference in C balance between above scenarios could be described over time, or more realistically, by the true warming/cooling impacts due to the emission difference or the C debt. We conclude that even sustainable forestry, where the C balance of forest land is basically neutral (or even positive) over the full rotation, cannot be considered climate neutral. This is due to the fact that the rotation length or re-growth time is typically much longer than the urgent timetable of emission reductions, thus creating a C debt with respect to the no-use baseline.

5.2
Resource depletion

Several life cycle impact assessment methodologies have been proposed for land use impacts. This is partially caused by the many values of land. Land can be seen as a limited resource for production similar to labour and capital. Therefore competition for land area limits the ability of other economic actors to maintain their production. In practice this may cause social issues, where animal herding is moved from rangelands, which are converted into plantations. In the CML2001 life cycle impact assessment method, competition is measured as occupied area * time (m^2a) (Guinee et al. 2002). In the ReCiPe midpoint method occupation is limited to urban and agri-

---

[9] To consider the whole lifecycle we have in addition to take into account the effect of wood use. As a consequence of using wood-based energy and materials higher emissions from competing fossil energy and materials could be avoided (i.e. with respect to the reference scenario) and besides part of the harvested biomass could be temporarily sequestered into wood products.

cultural land, and forestry is excluded (Goedkoop et al. 2009). The focus is therefore on the occupation of land area suitable for food production. In the ReCiPe Method, no attempts are made to combine the influence of occupying forest plantations and arable fields at the midpoint level.

The ecological footprint broadens the land use competition by taking into account the capacity of different land cover types to produce resources for humans (Wackernagel and Rees, 1996). This is used to combine arable, pasture, forest, urban, and coastal land occupation into an ecological footprint, measured in global hectares. Global hectares (ha_{global}) are productivity normalized hectares (hectare years), so that the average land cover productivity is 1 ha_{global}/ha. Pastures are not very productive, therefore they have an equivalence factor of 0.46 ha_{global}/ha. Forests are more productive, with an equivalence factor of 1.26 ha_{global}/ha and croplands are highly productive, with an equivalence factor of 2.51 ha_{global}/ha (Ewing et al., 2010a). Therefore from a resource competition viewpoint, occupying a hectare of cropland is on average more than five times as bad as occupying a hectare of marginal pasturelands. The productivity differences between countries are adjusted with a yield factor, which is applied in addition to the equivalence factors. The yield factor is the ratio of the local yield to the world average, therefore European croplands are more productive than the world average and rainforests are more productive than other forests. The aim of the ecological footprint is to measure the use of productive land to different purposes with a focus on human resource use. In addition to land use, the ecological footprint includes fossil fuel consumption as "carbon uptake land". The carbon uptake land can be interpreted in either the land area needed to sequester CO_2 emissions to growing biomass or as the area needed to replace the fossil fuels with biomass. Both approaches give roughly similar figures. As a result of fossil fuel use, humanity is using more resources than could be supplied by biological means, which is known as ecological overshooting. In 2007 humanity was estimated to require 1.5 Earths to supply its needs for food, fibre and fuels from biomass (Ewing et al. 2010b). Roughly half of this need was caused by global CO_2 emissions through "carbon uptake land" described above. This indicates the potential pressure to ecosystems if biomass would be used to replace fossil fuels on a large scale.

As described above, the ecological footprint method does not include the competition with other species, since it considers only biomass usable by humans. Another indicator has been developed to quantify the competition with also other heterotrophic (i.e. non photosynthetising) species. The indicator is called *the human appropriation of net primary production* (HANPP) and it includes both the reduced net primary production (NPP) due to land use change and the human used NPP due to harvesting. Therefore it describes the difference in the free NPP left for ecosystems between the current land use and a reference natural state (HANPP = natural state NPP – reduction in NPP – harvested NPP). The human appropriation of NPP is reported in carbon mass (kg C). This difference has been found to correlate well with species diversity, with more species found in places, which maintain as much of the net primary production as possible (Haberl et al. 2004). When using the HANPP indicator, care should be taken to understand the implicit weighting of biotopes by their productivity: a removal of one ton of biomass has the same value, irrespective of the productivity of the area where it is removed (i.e. removal of all biomass from a meadow has the same influence as removal of 15% of biomass from an intensive cropland). Only the aggregated ratio of biomass production and use is of relevance. On average, mankind is using one fourth of the terrestrial NPP, the main surplus being in the tropical rainforests, in the boreal zone, and in western United States (Haberl et al. 2007). In Finland, the remaining HANPP is in forest litter, logging residues, marginally productive lands, mires and bogs, and in grain straw and roots (Mattila et al. 2010).

When using the HANPP indicator to estimate biodiversity impacts, care must be taken in interpretation. The HANPP does not value different kinds of biomass. For example in the case of Finland, although biomass is available, there is a strong competition for wood biomass between the forest industry and the species dependent on deadwood (Rassi et al. 2001).

5.3

Soil quality

Soil organic matter (SOM) has been proposed as a soil quality indicator in LCA (e.g. Milà i Canals et al. 2007a, 2007b, 2007c, Brandão et al. 2010) as it is often reported and is closely related to many other soil quality indicators such as cation exchange capacity and soil life activity. The changes in SOM can be estimated using another indicator, soil organic carbon (SOC), which correlates well with SOM levels and changes. The changes in SOC have also a direct link to the climate change through changes in carbon sequestration and release caused by land use and land use changes. In order to quantify the soil quality and climate impacts, a calculation method for the SOC characterization factor has been proposed by Milà i Canals et al. (2007b) and Brandão et al. (2010). The following information is needed for the calculation:

- the land occupation due to an activity per functional unit (e.g. ha year/f.u.),
- he SOM value at the start and the end of land use (including the evolution of SOM levels during the occupation,
- the SOM value in the reference land use situation on the site, and
- the restoration rate of SOM levels during the natural relaxation process after the occupation.

The calculation of case and site specific SOC characterization factors is possible but time consuming. All the information on the SOC evolution of the studied activity and on the reference state needs to be collected from some reliable source and the availability of reliable site specific data can be limited. The other option is to use published SOC characterization factors from the literature. Some characterization factors for the SOC indicator are provided by Milà i Canals et al. (2007b), but they may not be applicable in all cases, because of, for example, their assumptions on the reference state may differ significantly from the true site specific situation.

The SOM indicator does not cover all the aspects of ecological soil quality. Soil erosion, compaction, build-up of toxic substances, acidification, salinisation, and depletion of nutrients and ground water are soil quality aspects that need to be covered with other indicators in LCIA (Milà i Canals et al. 2007b). These aspects, furthermore have impacts on functional properties of soil, and therefore also on the biodiversity of soil.

Soil erosion is another indicator proposed for soil quality in LCA. Main causes of soil erosion are water and wind. In Europe, water causes 92% of soil erosion (EEA 2003). Land use impact assessment on soil erosion has recently been reviewed by Podmanicky et al. (2011), and several models exist to assess the soil erosion rate. For example the Pan-European Soil Erosion Risk Assessment (PESERA) project has created a model that uses a process-based and spatially distributed model to quantify soil erosion by water and assess its risk across Europe (De Vente et al. 2008, Kirkby et al. 2008). Another established method for assessing soil erosion rate (kg/ha/a) is the Universal Soil Loss Equation (USLE) Model (Wischmeier and Smith 1978) with its revised versions RUSLE (Renard et al. 1997) and RUSLE 2 (Foster et al. 2002). Methodological development is going on to create LCIA characterization factors based on the modeling results.

5.4

Biodiversity

Biodiversity has both structural and functional properties. Structure is represented by the species and their interactions while function is represented by the capabilities of the ecosystem to store energy and nutrients and regulate the environment (Achten et al. 2008). LCIA indicators have been developed for both types of biodiversity, although most indicators still focus on the structural properties.

The major problem of including biodiversity in LCA is the limited amount of information collected in the inventory stage. Often only land cover and land cover change information is registered, thus limiting the amount of variables that can be used in the impact assessment models. In addition, the impact assessment models should be applicable to all kinds of environments (i.e. forest, agriculture, industrial). In comparison, the models of conservation biology are usually developed for a certain species group in a certain habitat and usually based on expert judgement. Examples are farmland birds in England (Butler, Vickery, and Norris 2007) or large mammals in Africa (Scholes and Biggs 2005). These indicators can predict the change in biodiversity following changes in management, but include parameters which cannot be monitored throughout the life cycle (e.g. the height of vegetation in the time period of bird nesting). This has led some researchers to doubt the possibilities of including land use impacts in life cycle assessment at all, and have suggested certification schemes to be used instead (Udo de Haes 2006).

In spite of these limitations a few impact assessment models have been developed and included in LCIA methodologies. The ReCiPe 2008 LCIA methodology (Goedkoop et al. 2009) includes land use as a midpoint indicator in occupied agricultural and urban land area as well as transformed natural land. In addition the method includes endpoint impacts for various land use classes and transformations. The endpoint impact level considers biodiversity damage as the Potentially Disappeared Fraction (PDF) of species in a given region. PDF is also affected by other midpoint categories, such as eutrophication, climate change and ecotoxicity. The damage caused by occupation is calculated as the difference in species richness in the occupied case compared to the reference state, which is considered to be woodlands for Europe. The method includes both the local impact to species richness as well as the regional impact caused by reducing the area of remaining biotopes. For commercial forests and orchards, the regional impact is of the same magnitude as the local. For agricultural crops the regional impact is considerably smaller than the local impact, due to the greatly reduced amount of species in intensively managed fields.

Transformation is combined with occupation by considering the restoration time necessary to restore the ecosystem back to the original state. Only transformation from natural ecosystems is considered and transformations between agricultural land and urban surfaces are ignored. This follows the logic of the policy objectives of nature conservation, where "wild" areas are prioritized.

A considerable problem in the evaluation of biodiversity impacts is the fact, that the response between occupied land area and species diversity is not linear. Very small areas (1-10 m^2) accumulate species slowly as do very large areas (> 100 km^2) (Crawley and Harral, 2001). As the land use occupation is reported in LCI as area multiplied by time, it is impossible to know the size of the occupied area (i.e. occupation of a small area for a long period of time gives the same result as a large area occupied for a short period of time). In the ReCiPe method, it was assumed that the occupied area would be close to one hectare. Deviating from this assumption will increase the uncertainty in the results for example in LCA of single houses or in national land use strategies.

The PDF approach of ReCiPe 2008 is based on the diversity of vascular plants (i.e. other land plants than mosses and algae). This is a common approach in most LCIA models due to better data availability of plant than animal and fungal diversity. However Lenzen et al. (2009) did a global regression between species endangerment and land use. The study resulted in broad correlation coefficients for land use occupation and threats to birds, mammals, plants, reptiles, and amphibians. The results could be used as an approximation for the threat to endangered species and presented in ready characterization factors. The method used is exceptional in both considering the global situation as well as including also threatened animals and not only vascular plants. As an overall result it was found that the main threats are caused by permanent crops, timber plantations, and large water surfaces (such as hydroelectric dams). Natural forests and build up land had a tendency to conserve biodiversity.

Vattenfall has developed the Biotope method (Kyläkorpi et al. 2005) to assess the impacts of land transformation to biodiversity. In the method, the affected land area is divided into four classes according to the presence of and threats to endangered species. The four classes are critical, rare, and general biotope as well as the technotope (built land). No characterization factors are provided for the method, but a case by case data collection system using GIS and threatened species counts is necessary. The method requires good knowledge of the local conditions, making it nearly impossible to quantify effects which occur far in the supply chain (e.g. coal mining in China for electricity used in steel used in metal structures), are distant in the future (e.g. restoration of mines), or are due to indirect land use change (e.g. expansion of agricultural land due to increase in global demand). Therefore the method would seem to be more applicable to local risk assessment than life cycle assessment.

Relatively few indicators have been developed to assess the functional biodiversity. Some authors have approached land use impact assessment from the viewpoint of theoretical ecology, starting from thermodynamic goal functions. Ecosystems can be seen as self organizing systems, evolving towards higher exergy storage (in biomass, species number and interaction complexity) and maximal exergy dissipation (inflowing solar radiation, water, material and species are processed as far as possible before leaving the system). This self organisation is limited by the local environmental conditions, thus preventing the succession to a universal climax state. For a review on the topic, see Dewulf (2008).

Wagendorp et al. (2006) developed a functional biodiversity indicator based on the extent of solar exergy dissipation. The idea behind the indicator is to monitor the surface temperature of different ecosystems in similar conditions. If the exergy input is the same, the ecosystem which emits less heat has dissipated more exergy (e.g. in growing biomass, transporting water and nutrients). For example a mature Douglas fir forest dissipates 90% of solar exergy, while a clear-cut forest dissipates 65% and a cereal crop 66% (Wagendorp et al. 2006). The influence of occupation to the capability of ecosystems to dissipate exergy can be seen as an indicator of the sustainability of the current occupation at landscape level.

Achten et al. (2008) proposed an operational set of indicators based on systems ecology (MASD, MAximum Structure and Dissipation). The indicator set follows the midpoint-endpoint categorization of LCIA: endpoints are ecosystem structure and ecosystem function. The midpoints in relation to structure are soil fertility, biodiversity and biomass production. The midpoints for functioning are soil structure, vegetation structure and area water balance. The indicators are compared to a reference state, which is different for land occupation and land transformation. Occupation is compared to the potential natural vegetation (taking into account disturbance, therefore it is not the climax vegetation), and land transformation is compared to the previous land cover.

The proposed indicators in MASD for soil fertility are cation exchange capacity (CEC) and base saturation (BS), which measure the capacity of the soil to store plant nutrients and the actual state of nutrient storage. Biomass production is quantified by total aboveground biomass (TAB) and the amount of unharvested net primary production (free NPP, fNPP). Species diversity is measured as the total amount of vascular plant species. For ecosystem functioning, soil structure is measured through soil organic matter (SOM) and soil compaction (measured as water infiltration rate). Vegetation structure is measured as leaf area index (LAI) and vertical structure (VS). The leaf area index describes the ability of the ecosystem to dissipate incoming solar radiation and rainfall, while the vertical structure describes resistance to wind and rain erosion. The water balance is measured as evapotranspiration as well as soil vegetation cover.

The proposed multi-indicator approach has been applied to various land uses, such as ancient forest management, short rotation coppice and eucalypt plantations. The indicator set has a strong foundation in systems ecology, which is a benefit of the set. However most indicators require on site measurement, which limits the application to cases where the majority of land use is in the studied foreground system. Even in these cases some land use impacts have to be cut-off due to data limitations (e.g. although most energy using processes are connected to natural gas pipelines in Siberia, it is nearly impossible to do a full impact assessment on them in a LCA study).

Overall several impact assessment methods for assessing biodiversity have been developed during the last few years. Some of them are ready for application in simple LCA studies (such as the PDF of the ReCiPe method), while others are more suitable for studies where land use is the main focus.

5.5
Water cycle

Water footprint is one of the newest calculation tools to assess the sustainability of products and services (see Appendix 2 and Mattila & Antikainen (2010) for further information). The water from the nature, i.e. green water in the water footprint, is strongly linked together with soil quality, biomass growth, evaporation and ground water circulation and furthermore with e.g. agriculture and forestry. Changes in land use (e.g. change in vegetation type or land coverage) will change regional water balance both in volume and quality basis. Therefore defining regional water stress both as volume and as quality is important. However, the regional data and models for the areal evapotranspiration or predicting the effects on water resources and land use change are lacking in most cases. It has been discussed widely to what extent the natural water cycle should be taken into consideration and how the natural reference status for water cycle could be defined. Green water plays a major role in the water footprint of biomass based energy production, e.g. bio-ethanol and other bio-fuels (Gerbens-Leenes et al. 2009). Pfister et al. (2008) have studied how the freshwater consumption should be taken into account in LCA. The results show the importance of regionalized inventory and impacts assessment compared to global average values generally used in LCA. In the near future, the environmental damages of freshwater use of products like food and bio-fuels needs more analysis of soil-related impacts especially in regions where water use could be more damaging than land use. Additionally, international standardisation is currently going on to establish a common methodology for water footprint assessment.

6 Case example: Land use impact assessment in LCA of beer and wine

The theoretical framework for land use induced environmental impact assessment in LCA was presented in the preceding chapters. In order to test and demonstrate the applicability of the framework in practice, an illustrative case is needed. To address this issue a comparative land use impact assessment with the LCA methodology for beer and wine production is presented.

6.1
Goals of the case study

In this case study we assess and compare the land use induced environmental impacts over the whole life cycle of Finnish beer and Spanish wine consumed in a Finnish restaurant with a set of land use related environmental indicators. The goal of this simple case study is to test and illustrate the applicability of the framework and set of indicators proposed in this report for land use impact assessment in LCA. Many questions would remain unclear without an illustrative example: Is it possible in practice for a LCA practitioner to include all or some of the proposed environmental indicators in a LCA study? What are the characterization factors for selected indicators and are these publicly available? Does the proposed set of land use related indicators cover the most important impacts caused by land use? Where can one find suitable data needed for the life cycle based land use impact assessment? How can the indicator results be interpreted, are the results of all the indicators consistent with each other and can third parties understand the results? Or what do the different indicators describe, what are their limitations, and do they provide useful information? Furthermore, more importantly do the indicator results provide means for choosing one product over another? These questions are further discussed and clarified with this case study, in order to give guidance and suggestions for the LCA practitioners that consider the inclusion of land use impacts in LCA studies.

The comparative LCA was based on the principles of attributional LCA. Only land use associated impacts are included. Therefore, the results represent the land "embodied" in the final product. Another option for constructing the LCA would have been to look forward at the consequences of the selection. This consequential LCA is frequently used in evaluating biofuels policies and is predominantly concerned with indirect land use change (iLUC) (ILCD 2010a, p 173). In this case study, the indirect land use changes were not considered, because it was assumed that the decision would have minimal influence on the overall land use. However, the iLUC approach is demonstrated for illustrative purposes in Chapter 4 (see Figure 4).

The attributional LCA case study focuses on the evaluation of the land use induced environmental impacts based on a selection to be made by a consumer: A consumer has an option to drink a glass of Spanish wine or a bottle of Finnish beer in a Finnish restaurant and the consumer considers land use related environmental impacts as the main selection criteria. Here we assess with the LCA methodology which of the two drinks would have smaller environmental impacts if only indicators related to land use and land use change are considered in the life cycle impact assessment (LCIA). This is a comparative LCA case study, but the purpose of the study is only to illustrate the use of the underlying methodology. The results obtained are only illustrative by nature and shall not be confused with a comparison of two existing product systems.

6.2

Case description

Functional unit. Selection of a fully comparable functional unit for the two alcoholic beverages is not straightforward. For example, the comparison of two alcoholic beverage product systems should not be made based on the volume of the drinks consumed, as for example one liter of wine does not represent a fully comparative function to one liter of beer. Hence, the functional unit is selected in the study as one portion[10] of alcoholic beverages served in a Finnish restaurant. This functional unit, one portion of alcoholic beverages, equals to 0.33 l of beer or 0.12 l of wine.
System boundary. The system boundary of the case study is presented in Figure 6.

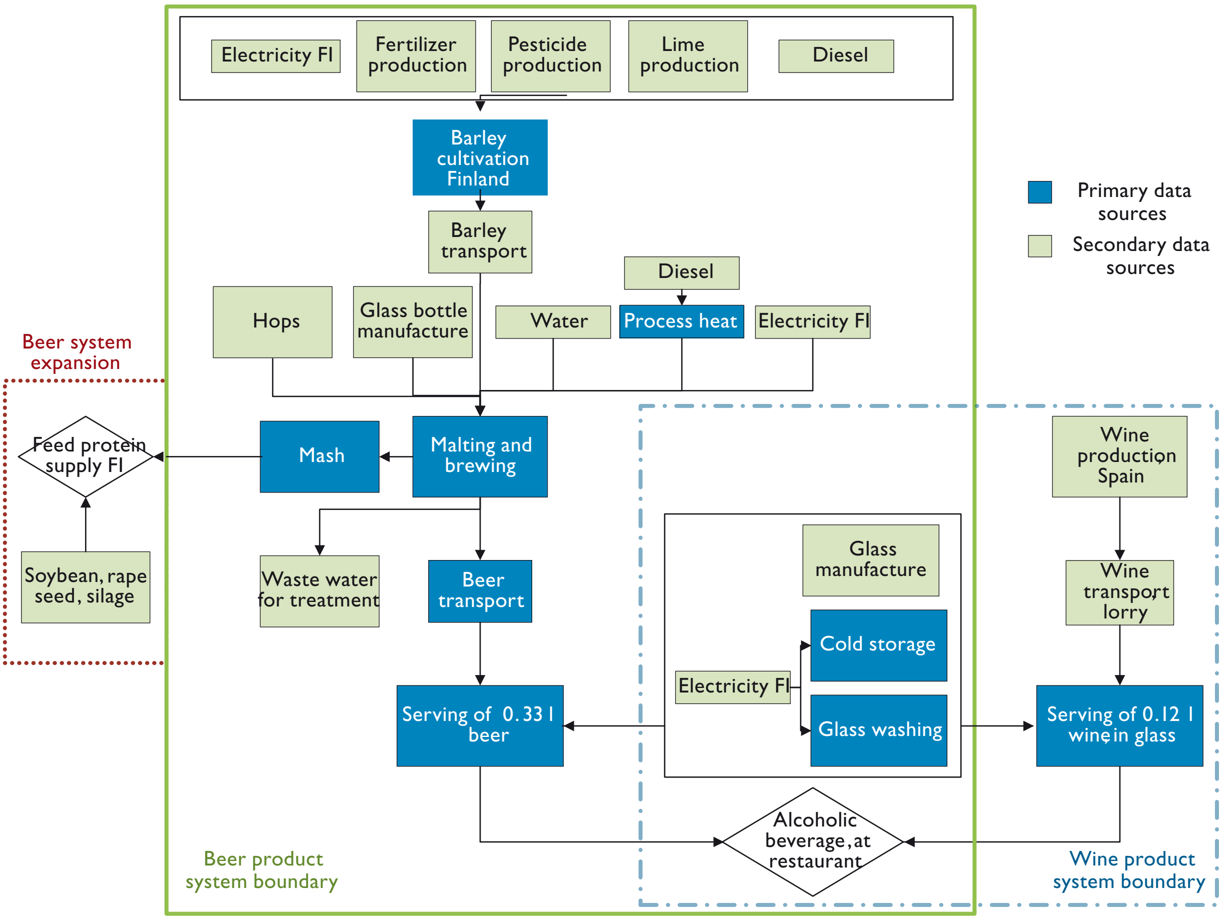

Figure 6. System boundary of the study. The green (uniform) line delimits the beer product system boundary, the red (dotted) line the system expansion for beer product system and the blue (dashed) line the wine product system boundary. Some processes belong to both the beer and wine product systems and therefore the system boundaries overlap. Note: The wine production process includes only the land use inventory data for grape cultivation (Gazulla et al. 2010).

---

[10] One portion of alcoholic beverages is a standardized measure in Finland and equals to 11-15 g of alcohol.

All the processes which were considered to potentially have noticeable land use impacts are included in this cradle-to-consumer study for the beer product system. These include all major raw material, co-product, energy and transport flows. It needs to be stressed that the processes that contribute significantly to land use related environmental impacts may be very different from the ones that cause the majority of impacts in other impact categories, e.g. climate change. Hydroelectric power plants (with water reservoirs), biomass production and quarries are examples of such processes. This has to be considered when cut-offs are made.

Inventory data selection and description. The main quality requirement set for the inventory data is that land occupation and transformation interventions have to be included in the source data. As the goal of the case study is illustrative to its nature no other systematic source data quality assessments are made. The beer product system is of primary focus in the study with as much primary data used as possible. The wine product system as well as the system expansion for mash co-product material substitution is based mainly on secondary data. The secondary data for the wine product system is based on Gazulla et al. (2010). Although their study covers the whole life cycle of wine production, the LCI data on land use includes only grape cultivation and omits the land use of upstream and downstream wine production processes. All the other secondary data is collected from the Ecoinvent 2.2 database (Ecoinvent 2010). The data sources for all processes included in the study are presented in Appendix 3. To our knowledge, Ecoinvent is the only LCI database suitable for the needs of the study at the moment, as it is the only one that includes upstream land occupation and transformation data for all the processes in the database. However, no LCI data is provided in Ecoinvent 2.2 for wine production. Land use data for each process (including upstream processes) is divided into 47 distinct classes for land occupation and land transformation (both from and to) based on CORINE (EEA 2010). The land use classes include e.g. intensive forest, extensive permanent fruit crop, rail network traffic area etc. See Appendix 4 for an example on all the land use intervention data included for brown packaging glass (including upstream processes).

For the land use associated with barley cultivation, yield statistics (3500 kg/ha) were used (FAO 2010). The inputs for barley cultivation were taken from Mäkinen et al. (2006). The industrial land occupation associated with malting and brewing, as well as with mash processing, were assumed to be insignificant (i.e. they were cut-off). The primary data for malting and brewing was based on the environmental reports of Carlsberg (Carlsberg 2005).

Finnish power supply mix (covers years 1992-2004 in Ecoinvent 2.2) is used for electricity use in Finland. All the secondary data collected from Ecoinvent includes built-in assumptions for upstream electricity production and respective land occupation and transformation for each process.

No recycling was assumed for beer and wine bottles as the secondary data for wine does not make such an approach possible. The impact of possible recycling is described only qualitatively.

Allocation procedures. Mash is a major co-product of the brewing process with an output of approximately 0.15 kg per 1 liter of beer bottled (Carlsberg 2005). In Finland, the mash co-product is sold to animal feed processing (Suomen Rehu 2010). Based on the composition of mash, it was assumed to replace primarily protein supplements in the feed. In the base case this is assumed to be soybean meal, but substitution of rape seed, silage or no substitution at all is studied with sensitivity analysis. According to Nerantziz & Tataridis (2006) there are many by-products from wine production, e.g.

vine prunings, grape stalks and grape pomace[11]. Many utilization options exist for these co-products, but the potential is currently not exploited on large scale. Therefore no material or energy substitution options for wine co-products were modeled in this LCA study.

The system expansion approach is selected to cover the mash co-product flow out from the studied beer production system. System expansion was applied instead of allocation, since it was the approach primarily suggested by the ISO14044 Standards and ILCD Guidelines (ILCD 2010a). Following the guidance for micro-level decision support with attributional LCA, the average technology was assumed to be supplemented. Since statistics of feed protein composition were not available a sensitivity analysis of four options was constructed. The average situation is a combination of the values presented.

6.3

Methodology description

LCA methodology is divided into four distinct phases: goal and scope definition, inventory analysis, impact assessment and interpretation (ISO 14040:2006). Some focal information needs in land use environmental impact assessment in LCA is presented in Figure 7.

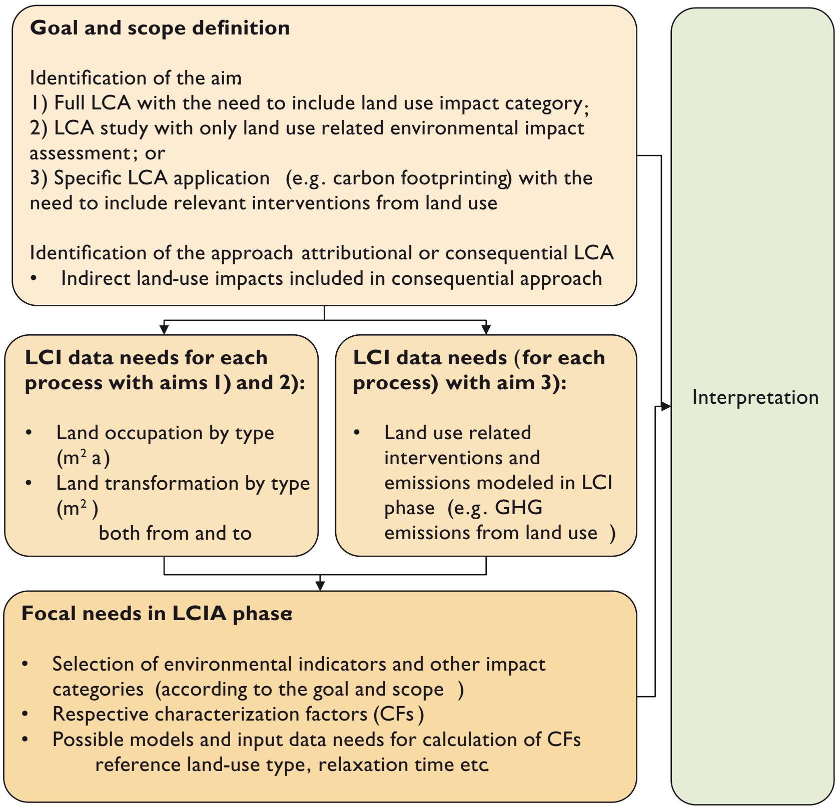

Figure 7. Examples of information needs in land use related environmental impact assessment divided into the distinct phases of LCA.

---

[11] Pomace is the solid remains of grape after pressing for juice. It contains the skins, pulp and seeds of the fruit.

The approach to land use related impact assessment depends on the goal and scope of the study. If land use related impacts are to be considered among all other potential environmental impacts (full LCA study), the LCA practitioner has to make sure that the approach for land use impact assessment is in full accordance with the selected impact assessment method (CML, EI99, ReCiPe etc.) that is modified. This approach calls for the formation of a land use impact category with principles in accordance with the other impact categories included in the selected LCIA method, e.g. EI99. Therefore the LCA practitioner needs to have an expert understanding of the structure of the selected LCIA method. If the goal is to study only the land use related environmental impacts of some activity, then the set of land use related environmental indicators (i.e. an own impact assessment method) can be selected freely. If the goal is to include land use related environmental impacts to a specific LCA application (e.g. carbon or water footprinting), then the land use related interventions and emissions have to be modeled already in the LCI phase. The specific LCA applications in general have preselected impact categories and commonly agreed characterization factors, such as GWP factors for a selection of GHG emissions. The land use related interventions need to be provided in a proper format in the LCI phase in accordance with the selected specific LCA application. For more information on the topic, see the ILCD Handbook (ILCD 2010a, p. 221).

The additional inventory data that needs to be included in the LCI phase for each process is land occupation (m^2a) and land transformation (m^2 both from and to) for all land types affected. The data collection process and data sources are described in more detail in Chapter 6.2. The selection of environmental indicators, respective characterization factors (CFs), and possible models and data needs for calculation of CFs are described below.

As the goal of this case study is to assess only the land use related impacts, the approach for land use impact assessment is the free selection of a set of land use related environmental indicators, i.e. formation of an own LCIA method for land use. A promising set of land use related environmental indicators was selected and presented in Chapter 5. The indicators that are tested and demonstrated in this case study are presented briefly in Table 2. The set of indicators can be divided into three groups by the respective impact categories: Resource depletion (including land occupation), soil quality, and biodiversity (see Figure 5).

Table 2. The selected land use related environmental indicators for the case study. Name and unit of the indicators, related impact categories and source of the documentation and characterization factors.

Land use related environmental indicator	**Unit**	**Land use impact categories**	**Source**
Land use efficiency	m^2a/ product	land occupation, (resource depletion)	e.g. Guinee et al. 2002, Ecoinvent 2.2 database (2010)
Ecological footprint	global m^2a	land occupation, resource depletion	Ewing et al. 2010a
Human appropriation of net primary production (HANPP)	kg C	resource depletion, biodiversity	Haberl et al. 2004, 2007
Ecosystem damage (EDP)	unitless	Biodiversity	Koellner and Scholz, 2006
ReCiPe endpoint hierarchic, Potentially Disappeared Fraction (PDF) of species	species a	Biodiversity	Goedkoop et al. 2009
Threats to endangered species	Unitless	Biodiversity	Lenzen et al. 2009
Solar exergy dissipation SED	%	Ecosystem function	Wagendorp et al. 2006
Changes in soil organic carbon SOC and soil organic matter SOM	kg C a/ m^2a	soil quality, climate change	Milà i Canals et al. 2007a, Brandão et al. 2010

All the characterization factors used in this study and their original sources can be found in Appendix 5. Most of the characterization factors are adopted directly from the source documents and some need to be calculated or modified based on the original publications. The characterization factors for Ecological footprint can be calculated based on Ewing et al. (2010a). Some characterization factors for SOC have been published in Milà i Canals et al. (2007b) and applied in this study, but the model for calculation of detailed characterization factors is presented in Brandão et al. (2010).

6.4

Land use data for life cycle inventory and characterization models

According to the framework of land use in LCA, the LCA practitioner needs to collect only the data for land occupation (m^2a) and transformation (m^2, both to and from) for each process in the studied system. This is all the land use LCI data that is needed from the LCA practitioner's perspective. The primary LCI data can be considered reliable as it describes the actual production processes studied. A large proportion of the land use LCI data, however, most probably needs to be collected from secondary sources, such as LCI databases. The secondary LCI data includes global average or country-level average land occupation and transformation data for the process. This leads to some uncertainty and may lead to wrong conclusions if the land use intensity of the actual process in the studied system differs significantly from the average. This uncertainty regarding the LCI data from databases is, however, a universal issue regarding the LCA methodology, and is not an issue that is specific for data on land occupation and transformation.

On the other hand, the underlying land use data used in the LCIA characterization models is probably one of the main sources of uncertainty in the assessment of land use induced environmental impacts. Usually the LCA practitioner is familiar only with the published characterization factors used in the LCIA phase and does not need to be in contact with the underlying land use data. At least this is the way the LCA methodology is built and actively carried out with traditional impact categories. Regarding climate change impact category, for example, the LCA practitioner uses the published global warming potential (GWP) factors for different greenhouse gases in the LCIA phase. One does not need to be well familiar with the underlying model and understand why e.g. methane has a GWP of 25. At least this is the ideal situation when there are no major differences in the impacts or underlying data in different geographic locations.

For land use related environmental impacts the situation with the underlying data is, unfortunately, very different. The global or regional average data may differ significantly from site specific characteristics, e.g. soil properties, annual primary production or species richness. An example of this is the terrestrial carbon stock data for vegetation and soil, which is needed in the assessment of land use related soil quality or climate change impacts with SOC and CRF indicators. Müller-Wenk and Brãndao (2010) have made a comparison of selected data sources that include global average data for carbon stocks in vegetation and in soil in several biomes, e.g. tropical forests, temperate forests, boreal forests and croplands. Their results indicate that there remains a significant difference in the global average data found for any single biome. The average data for boreal forests, for example, varies between 42-90 tC/ha for vegetation and 206-344 tC/ha for soils in the three data sources studied (Müller-Wenk and Brãndao 2010). Therefore caution needs to be taken when the published characterization factors for example for SOC indicator (Milà i Canals et al. 2007b) are applied in the LCIA phase or when the impacts of an activity on the terrestrial carbon stocks are estimated. The SOC levels and change rates may differ significantly from the estimated global averages in the actual sites of the studied processes. Regionalised characterization factors could provide a solution to this uncertainty, but those are not currently available. Such work is fortunately carried out by UNEP/SETAC life cycle initiative. In the meantime, a solution for minimising this uncertainty is to familiarise oneself with the underlying characterization models and build own characterization factors with the site specific data, if available.

6.5

Case results and discussion

6.5.1

System expansion has a significant impact on land use inventory results

Raw material cultivation is responsible for the majority of land occupation in the beer and wine product systems (Figure 8). Permanent vine crop cultivation for wine and arable land for barley cultivation for beer are the main land categories occupied. Note that the LCI data for wine production was limited to the land occupation in grape cultivation. Inclusion of up- and downstream production processes in wine production system would further increase the land occupation per portion of wine. Forestry forms a notable 35% of the land occupation for the beer product system, while 0.06 m^2a can be avoided in soy bean cultivation with feed protein substitution. The forest land use is connected to glass bottle and energy production (both including upstream processes). If the beer bottles would be recycled (as they often are in Finland), this would lower the forest land occupation significantly. However, the issues regarding bottle recycling and data coverage for the wine production process would not change the conclusion that the beer production system causes less land occupation per portion of drink than the wine prodution.

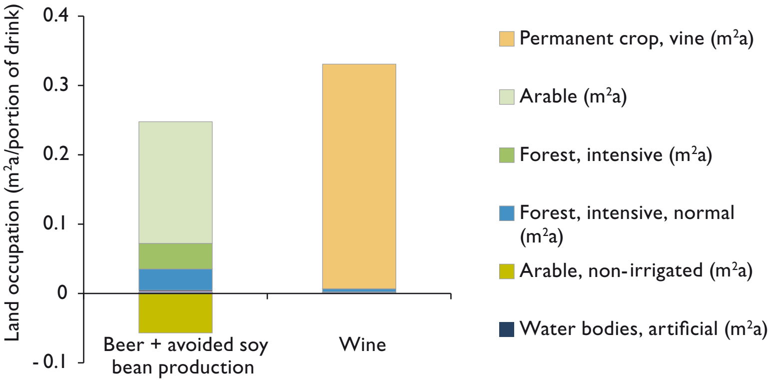

Figure 8. Land occupation of beer and wine product systems divided by land category. Avoided land occupation is the result of system expansion (avoided soy bean meal production by material substitution). Note: The system boundaries of the two systems are not fully comparable.

Regarding land use change, it can be seen from Figure 9 that the system expansion for substitution of soy bean production has a significant impact on the results of land transformation. The avoided soy bean production leads to the avoidance of clearance of tropical rain forest and sclerophyllous shrub land to arable land used for soy bean cultivation. The transformation of an area of approximately 30 cm^2 of shrub land and 20 cm^2 of tropical rain forest can be avoided per portion of beer because of the mash co-product from malting & brewing. It needs to be noted, however, that the data for wine does not include the animal protein use of co-products from wine processing. The direct land transformation impacts within beer and wine production systems (i.e. without system expansion) are much smaller and are therefore presented in a separate graph in Figure 10.

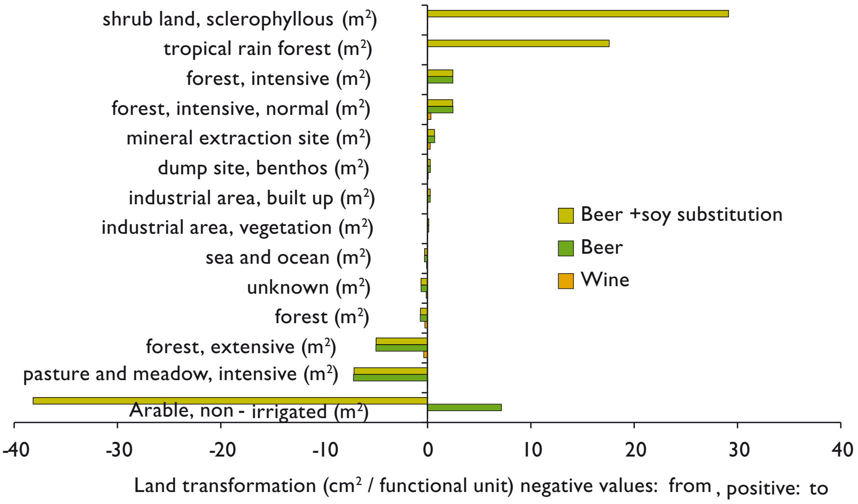

Figure 9. Land transformation impacts (direct) of beer and wine product systems divided by land category. Results for beer are presented with and without system expansion for soy bean production. Negative values indicate decrease in a certain land use category (i.e. from) and positive values an increase in a land use category (i.e. to).

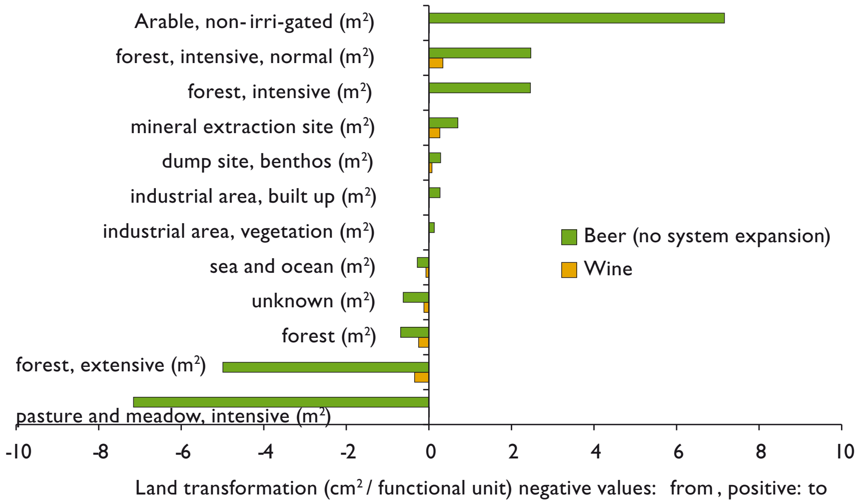

Figure 10. Land transformation impacts (direct) of beer and wine product systems divided by land category. The results for beer are presented without system expansion for substitution of soy bean production. Negative values indicate a decrease in a certain land use category (i.e. from) and positive values an increase in a land use category (i.e. to). Note: The system boundaries of the two systems are not fully comparable.

Virtually no information on land transformations are connected to the LCI data of the wine product system. For beer production (without system expansion) approximately 7 cm^2 pasture or meadow is converted to arable land and appr. 5 cm^2 extensive forests are taken into intensive silviculture per one portion of beer. However, the direct land transformations caused by the beer product system are small compared to the soy bean substitution impacts. System expansions have a significant impact on the results of land transformation.

6.5.2

System expansion has little influence on resource depletion

We will compare and discuss the quantitative indicator results one by one for wine and beer production below. As the soy bean meal system expansion seems to have a significant impact on the results of the beer production system, the results for beer are presented i) without system expansion, ii) with soy bean meal substitution and iii) with other animal feed sources (rape seed and silage) that could possibly be substituted. The results of land occupation for beer and wine production are compared in Figure 11.

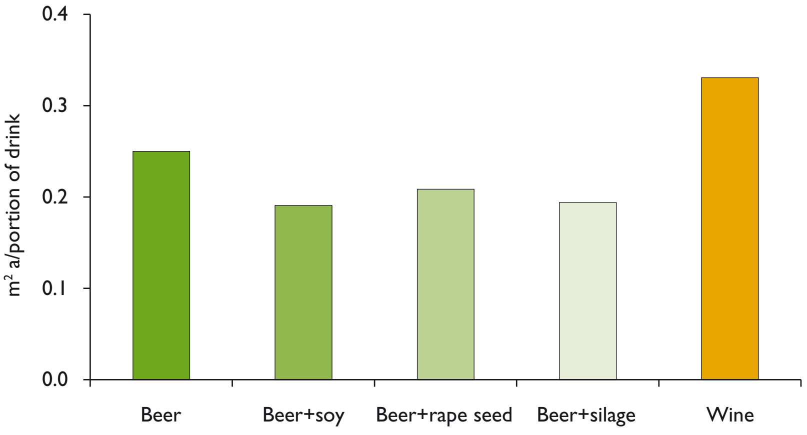

Figure 11. Comparison of land occupation between wine and beer. The results for beer are presented i) without system expansion and ii) with soy bean meal, rape seed, and silage substitution. Note: The system boundaries of the wine and beer production systems are not fully comparable.

It can be seen that Spanish wine production causes more land occupation than Finnish beer production irrespective of the occurrence of animal feed substitution in beer product system. The land occupation decreases only by 15-25% if the mash co-product is used to substitute some animal feed production and this does not change the conclusions based on land occupation between beer and wine. It needs to be remembered, however, that land occupation can be used only for the purposes of accounting of land area reserved. It should be considered only as a first step in land use impact evaluation as it is based solely on LCI results and does not include any weighted environmental impact assessment procedures based on different land use types (e.g. extensive forestry vs. landfill site).

Resource depletion related to land use can be examined with the results from ecological footprint (in Figure 12) and HANPP indicator calculations (in Figure 13).

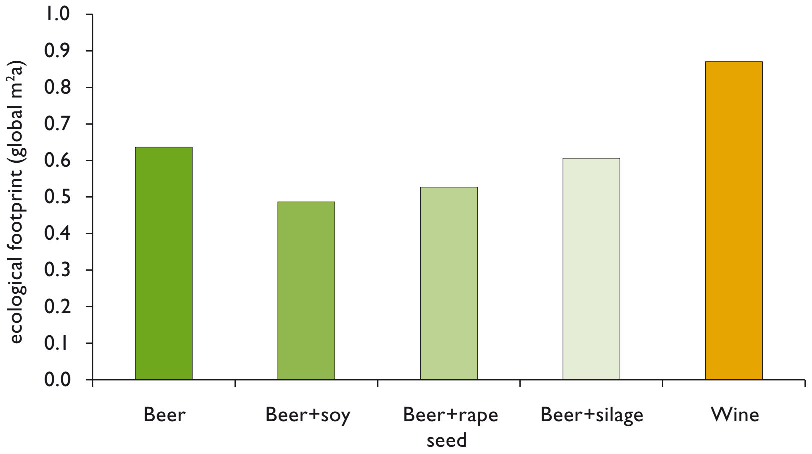

Figure 12. Comparison of ecological footprint indicator results between wine and beer. The results for beer are presented i) without system expansion and ii) with soy bean meal, rape seed and silage substitution. Note: The system boundaries of the wine and beer production systems are not fully comparable.

Figure 13. Comparison of Human appropriation of net primary production (HANPP) indicator results between wine and beer. The results for beer are presented i) without system expansion and ii) with soy bean meal, rape seed and silage substitution. Note: The system boundaries of the wine and beer production systems are not fully comparable.

These two indicators lead to contradicting results on land use related resource depletion between the two studied drink production systems. Wine production seems to have higher impact than beer production on resource depletion in the light of the ecological footprint indicator and the opposite result according to the HANPP indicator. The two indicators give consistent results for resource depletion only for the beer production system with different animal feed substitution possibilities, including the case of no substitution. One possible explanation for the difference between the two indicators is that HANPP is an indicator for both resource depletion and biodiversity impacts that includes the competition on human usable biomass with other heterotrophic (i.e. non photosynthetising) species. Vine is a perennial plant and only a small portion of the biomass (the grapes) are collected for wine production. This differs significantly from barley cultivation in which most of the net primary production is harvested annually. Moreover, the ecological footprint indicator gives similar results as land occupation (see Figure 11). This can be expected as it is one step further into impact assessment from land occupation with weighting of different land use categories based on the productivity of the individual land category.

6.5.3

No conclusions can be drawn based on soil quality

The soil quality impacts are measured with the SOC indicator. The SOC indicator result for wine production is approximately 1.5 kgC*a/m^{2}a (Figure 14). The results of the comparison of soil quality impacts between wine and beer production systems depend on the ocurrence of animal feed substitution with mash and on the type of animal feed substituted. If no substitution occurs or if mash substitutes mainly silage as a source of animal feed protein, then it can be concluded that wine production has lower impacts on the soil quality than beer production. On the other hand, if soy bean or rape seed production for animal feed is avoided, then the beer production system can be considered to have lower impacts on soil quality. It needs to be noted, however, that the SOC indicator results are sensitive to the very generalized assumptions made in the reference SOC levels as well as in the SOC loss rates. These parameters are very site specific but characterization factors based on average SOC parameter values have to be used in practice by LCA practitioners.

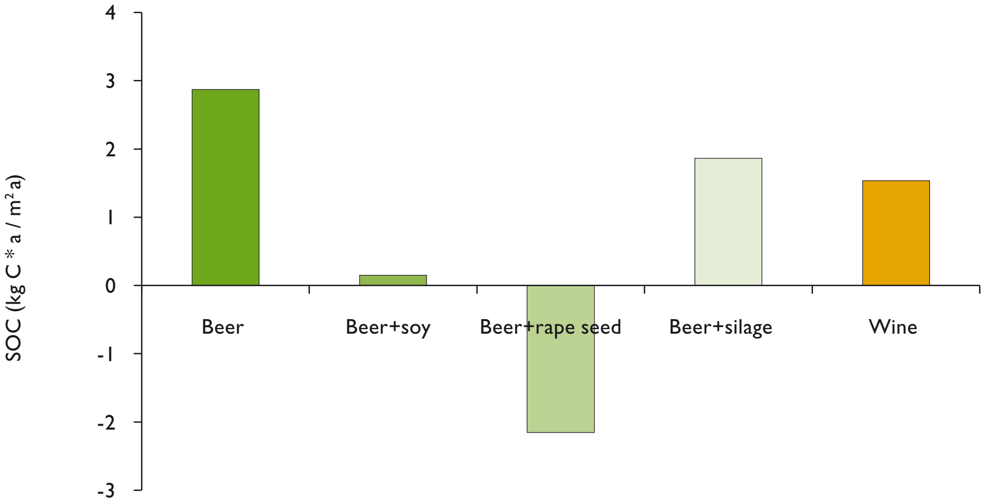

Figure 14. Comparison of SOC indicator results between wine and beer. The results for beer are presented i) without system expansion and ii) with soy bean meal, rape seed and silage substitution. Note: The system boundaries of the wine and beer production systems are not fully comparable.

6.5.4

Soy bean substitution has significant relevance in terms of biodiversity

Land use impacts on biodiversity are presented with three indicators: HANPP (see Figure 13), the Ecosystem damage potential (EDP) in Figure 15 and the ReCiPe endpoint indicator (Potentially disappeared fraction of species, PDF) in Figure 16.

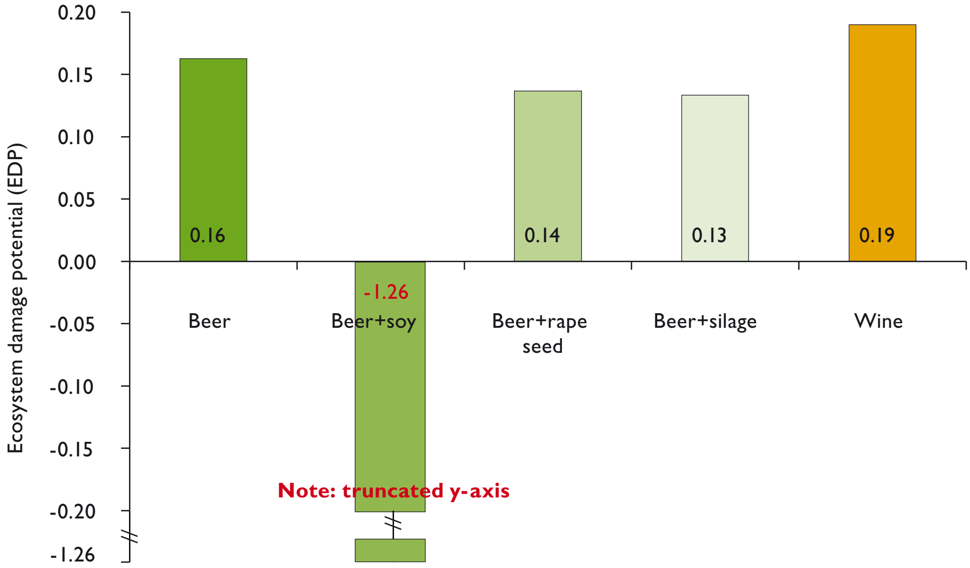

Figure 15. Comparison of EDP indicator results between wine and beer. The results for beer are presented i) without system expansion and ii) with soy bean meal, rape seed and silage substitution. Note: The system boundaries of the wine and beer production systems are not fully comparable.

Figure 16. Comparison of ReCiPe endpoint indicator (Potentially disappeared fraction of species, PDF) results between wine and beer. The results for beer are presented i) without system expansion and ii) with soy bean meal, rape seed and silage substitution. Note: The system boundaries of the wine and beer production systems are not fully comparable.

The EDP and ReCiPe endpoint indicators are consistent and give similar results for biodiversity impacts. There is no big difference in the biodiversity impacts between the two drink production systems if the feed protein substitution by the mash co-product is omitted. The beer production system has slightly lower biodiversity impacts than wine production if the avoided rape seed or silage production is considered and even positive impacts on biodiversity if the soy bean production is considered to be avoided by feed protein substitution. The reason for this is that the land transformation from high biodiversity tropical rainforests to soy bean production sites could be avoided. It is evident that the indicator results on biodiversity impacts are most sensitive to the system expansion for feed protein substitution in this case.

6.5.5

Synthesis of the indicator results

In order to identify hotspots of the wine and beer product systems on land use induced environmental impacts, the indicator results need to be examined by individual life cycle phases (i.e. processes). However, only the beer production system can be divided into separate processes with sufficient detail. The wine production process data (Gazulla et al. 2010) includes only grape cultivation in Spain. The contribution of each process on the beer product system is presented in Figure 17 as a relative share (%).

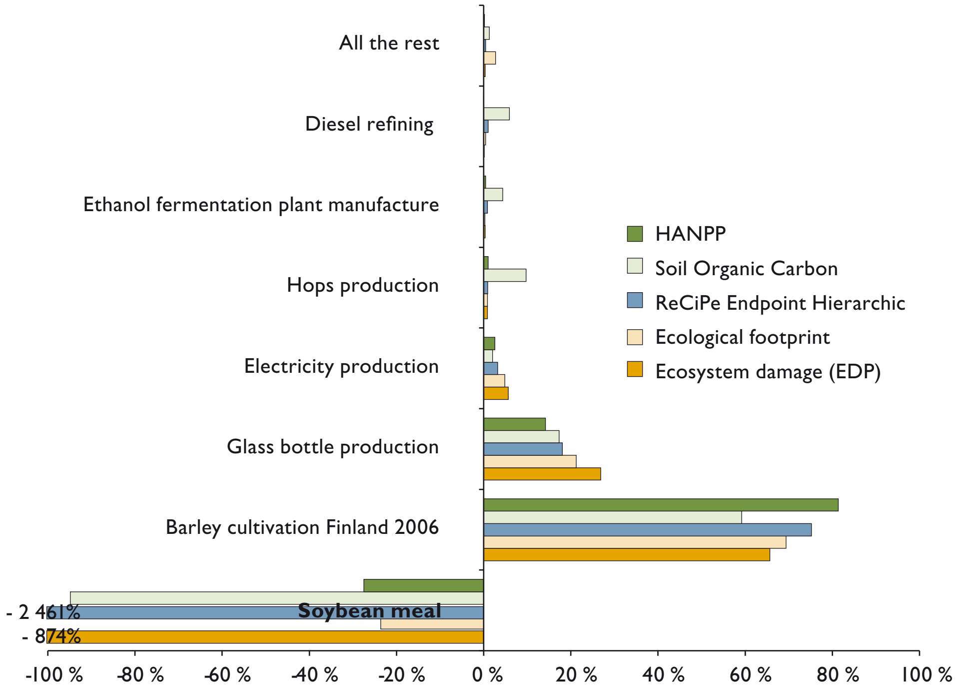

Figure 17. Contribution of individual life cycle phases (i.e. processes) on a selection of environmental indicator results for land use caused by the beer product system in [%] of the total indicator result with no system expansion. Regarding the system expansion (avoided soy bean meal production), a contribution of -100% would signify a net indicator result of zero.

It can be concluded that a relatively small amount of the processes form the majority of the land use induced impacts in the beer product system with all the indicators considered. Barley cultivation forms approximately 60-80%, glass bottle production 15-20%, and the rest of the life cycle ca. 10% of the land use related environmental impacts measured with the land use indicators. This result gives confidence that the cut-offs applied in the wine production system (data available only for the grape cultivation and wine transport processes) do not lead to a large underestimation of the land use results for wine. It is noteworthy that current electricity production in Finland is not in focus in terms of land use indicators. Usually energy production is the main contributor of environmental impacts in other impact categories. Avoided soybean meal production dominates the impact assessment results for beer with most of the indicators. The impact is lower for HANPP and ecological footprint indicator results, although the system expansion reduces these two notably as well (20-25% decrease). The reason for this is the avoided conversion of tropical rain forests to arable land (see Figure 10) when soybean meal production for animal feed is avoided. The SOC indicator results differ slightly from the other indicator results with less contribution from the raw material cultivation (barley or grapes) and impacts originating from a wider number of processes. For wine, almost all land use related impacts are from grape cultivation because of the limitations in the land use data coverage in Gazulla et al. (2010).

It would be anticipated that the land use indicators that describe one impact category (resource depletion, soil quality or biodiversity) should lead to consistent results with each other. It is possible on the other hand that one of the drink production systems has lower impact in some of the three different land use impact categories and higher in the rest (for example biodiversity saving practices can lead to higher erosion in the short term). The indicators for biodiversity (EDP and PDF) and the ecological footprint indicator for resource depletion give similar results for land use related environmental impacts as the LCI data for land occupation. In the light of these indicators, consumption of Finnish beer could be considered to have lower land use related impacts than consumption of Spanish wine. However HANPP, an indicator for both biodiversity and resource depletion, would lead to an opposite conclusion. The SOC indicator for soil quality impacts leads to favorable conclusions for either drink depending on the feed protein source that is considered to be substituted with the mash co-product. Although the majority of the indicators lead to the conclusion that beer production leads to lower land use related environmental impacts than wine production, still not all of the indicators tested lead to consistent results. Not even within a specific land use impact category (e.g. resource depletion).

It needs to be stressed that the system expansion in the beer product system, i.e. feed protein substitution, has a dominating effect on the quantitative results, especially in the soil quality and biodiversity impact categories. The reason for this is the reduced need for soy bean production, which leads to reduced need to land transformation of tropical rainforest to soy bean production fields. Care needs to be taken when the system expansions are introduced and assumptions are made for the products that are substituted in a LCA case study. The sensitivity analysis carried out for the feed protein substitution shows that results differ significantly if some other source of feed protein than soy bean is considered. It needs to be noted as well that wine production might have some co-products that were not identified here. Nevertheless, the results obtained show how important in terms of land use impacts it is to secure that the co-products are used in substitution of agricultural products in the real world production systems as well.

The ReCiPe endpoint indicator, i.e. the potentially disappeared fraction of species (PDF), is the only of the indicators examined above that is taken unmodified from the well known general LCIA method sets (e.g. ReCiPe, EI99, CML). The indicator describes mainly the biodiversity impacts of land use, although the indicator result is affected by other midpoint categories, such as eutrophication, climate change, and ecotoxicity. The depletion of productive land area resource and land use impacts on soil quality are omitted from the land use impact assessments in these well known LCIA methods. Hence it can be concluded that the impact category 'land use' included in some of the most widely used LCIA methods cover only one aspect of land use induced environmental impacts. Their approaches to land use related impacts cannot be considered comprehensively before all the three land use impact categories (depletion of productive land area, changes in soil quality and biodiversity) are included in the land use impact assessment.

No indirect land use impacts were considered in the case study. However, an illustrative presentation of the indirect land competition routes can be found in Chapter 4 (see Figure 4).

6.6

Case conclusions and recommendations

The goal of this case study was to test and illustrate the applicability of the framework and set of indicators proposed in this report for land use impact assessment in LCA in practice. Because of the illustrative nature of this case study, these results should not be confused with a comparison of land use impacts of two existing drink production systems, especially because the system boundaries for the two systems were not identical. It can, however, be concluded based on this case study that a set of indicators is available for all the three identified land use impact categories and it is possible to carry out an LCA in which the goal and scope is land use environmental impact assessment. The needed land use LCI data is available in public databases (at least in Ecoinvent) and the characterization factors for land use LCIA are available and applicable in the framework of LCA. It remains unclear, however, if the land use LCIA can be carried out comprehensively together with a commonly used LCIA method, e.g. ReCiPe, CML or EI99. The impact category 'land use' currently included in some of these most widely used LCIA methods cover only one aspect of land use induced environmental impacts and cannot be considered comprehensive before all land use impact categories are included.

The *possibility* to carry out land use LCIA does not mean, however, that *the results on land use impacts* are reliable, comprehensible, and consistent with each other and that they provide useful information for decision making or environmental communication.

Some of the land use indicator results are somewhat difficult to understand and communicate to third parties unfamiliar with environmental and conservation ecology, e.g. the Human Appropriation of Net Primary Production -indicator. Only the indicator results for land occupation & transformation (i.e. LCI results), ecological footprint and perhaps changes in soil organic matter measured with SOC could be considered somewhat easy to communicate and comprehend. The reliability of the results of these easily communicable land use indicators is difficult to assess and further research would be needed on this issue. It can be concluded that one source of unreliability is the availability of land use LCI data. The current situation is that the land use LCI data mainly originate from public LCI databases with global average data. This information might differ significantly from case specific regional land occupation and transformation taking place. Many of the characterization models would need regional data for reliable impact assessment, but a general level of data and characterization factors have to be used in LCA in practice. One example is the SOC indicator in which the selection of reference land use in the characterization model has a significant impact on the indicator results. Although site specific data could be used in the characterization model in theory, in practice the LCA practitioner with limited resources will use the general characterization factors with some preselected reference status. The inconsistency in the results of the indicators that describe the same impact category (i.e. HANPP & EDP for biodiversity) further raises questions on the reliability of the land use indicator results and on the possibility to draw solid conclusions.

Regardless of the uncertainties and open questions remaining, some suggestions can be made on the land use impact assessment in LCA:

- Accounting of land occupation (*m^2a*) and identification of land use efficiency (*m^2a/product*) can be considered as a good starting point. It is a simple and easily communicable indicator that describes the land use related resource depletion caused by the studied activity. This indicator is based solely on the LCI results on land occupation and should be used only for the purposes of simple accounting as no impact assessment of different land use types or land transformation impacts are included. To be able to provide more relevant information on the impacts on resource depletion, we suggest that the Ecological footprint indicator is applied in the LCIA phase. These indicators are easy to apply, the results can be considered easily communicable, and the results seem consistent and reliable. This approach covers the assessment of productive land area resource depletion.

- For a more comprehensive and challenging approach to land use impact assessment all the three land use impact categories should be covered. The SOC/SOM indicator can be suggested for soil quality impacts and the EDP or the PDF for biodiversity. These indicators are considered applicable to LCA and possible to communicate, but the availability of reliable data for characterization models remains uncertain.

- A variety of other land use indicators for LCIA exist, e.g. the HANPP, and the Solar exergy dissipation SED (Haber et al. 2004, 2007; Wagendorp et al. 2009), but they cannot be suggested without doubt. They seem to cover some land use environmental impacts well but the communication of these indicator results to stakeholders could be challenging as it is difficult to comprehend what they really describe.

- It is evident that there still remains a big need for indicator and LCI data development. Therefore far reaching decisions and conclusions should not be made based on currently available means for land use impact assessment in LCA.

- Carrying out an LCA land use impact assessment case has proved to be a resource consuming task. The assessment can be carried out by research organizations and large private companies, but we suggest preparing for intensive resource needs and for the presence of multiple yet unresolved uncertainties.

7 Discussion, conclusions and recommendations on how to approach land use in LCA

The ongoing competition between forestry, agriculture, infrastructure and natural ecosystems has made land a limited resource. As human population is continuously increasing, productive land is becoming even a more limited resource for biomass production. Biomass is needed for food, feed, fibre and fuels, but also, along with viable soil, for several ecosystem services such as clean air and water. It is estimated that some 12% of the global land area that is not covered with ice is reserved for agriculture at the moment. It has been proposed that if this land area is to exceed 15%, agricultural production would need to expand to less productive areas, which leads to a significant intensification of deforestation. The competition is not restricted only to land use, as there is a competition for biomass use between different products and the natural ecosystems. Lately the discussion has concentrated on the land use impacts caused by cultivation of biofuels, but this discussion should be expanded to cover all land use intensive product chains. These are all production chains that include food, feed, fibre or fuel production from biomass raw materials, as well as activities that are linked to mining and community building and services.

Land use and land use change as terms refer to several aspects and are used in different meanings in different disciplines and fields, which sometimes leads to misunderstandings and confusion. Different meanings include, inter alia, i) land use and land use change in policy context and reporting schemes (e.g. reporting according to IPCC, the EU Renewable Energy Directive (RED) and PAS 2050 carbon footprint scheme), ii) a phenomenon intensifying climate change, widely interesting for environmental scientists, policy makers, NGOs and other interest groups, iii) a phenomenon being a threat for biodiversity hot spots, being relatively widely interesting for environmental scientists, policy makers, NGOs and other interest groups, and iv) as a phenomenon affecting ecosystem services including productivity of land and equal and fair possibility to use land, which is of interest of relatively few interest groups. In addition, land use and land use change can be considered from the viewpoint of spatial planning.

Land use related terminology is diverse, and it is often difficult to know what the exact meaning of a certain term is in various contexts. Two basic definitions, land cover and land use, are often mixed or used as synonyms. Land cover refers to the physical material on earth's surface, while land use most often refers to the functional dimension and describes how the area is used for urban, agricultural, forestry and other uses. In LCA, land use generally covers both these aspects. Land use change or land transformation means, for example, the change from forestry to agriculture, but also from one agricultural purpose, e.g. from meadow to field. Several data sources on land use and land cover exists, including national, European Union (Eurostat) and global (FAO) agricultural and forestry statistics. These, however, only indicate the areas, but not the driving forces behind any changes. Moreover, often the data received from general statistics is very coarse and any detailed analysis requires additional information. This report gives an overview and explanations on the most commonly used terms.

Land use causes various environmental impacts. At the moment the focus is on land use related greenhouse gas emissions but changes in carbon cycles and storages, soil quality and soil net productivity, and loss of biodiversity are growing in importance. Additionally, changes in land use and land cover also have impacts on water quality and availability. IPCC has estimated that the land use change is the second most important source of GHG emissions, right after the use of fossil fuels. Land use and land cover change, especially clearing forests to agricultural areas, release carbon from long-term storages. Land cover affects the climate through changes in biogeophysical and biogeochemical changes, such as albedo and various chemical compounds. In addition to climate change, land use and land use change has significant effects on the environment. For example, the Millennium Ecosystem Assessment identified land use change as one of the main reasons for biodiversity loss. Biodiversity loss differs from many other environmental problems because after a certain threshold the loss is irreversible. When a species is extinct, it will not return even if the surrounding system would recover to the reference status. Increasing demand for land and its impacts is therefore connected to several environmental problems and should be measured and assessed using a relevant and wide enough set of indicators.

Many international and national agreements and guidelines have recommendations or instructions on how to take land use and land use change into account from the GHG perspective. However, often other environmental impacts or indirect impacts are not taken into account. The European Community Directive on the promotion of the use of energy from renewable sources (RED) defines sustainability criteria for biofuels and bioliquids that need to be fulfilled in order to be taken into account when measuring compliance with the requirements of the directive. Biomass from land with high biodiversity value, land with high carbon stock or peatlands should not be used to produce raw materials for biofuels. Annualised emissions from carbon stock changes caused by land use change shall be calculated by dividing total emissions equally over 20 years. The carbon footprint specification by British Standards Institution, PAS 2050:2008, also gives guidance on how to consider land use. According to PAS 2050:2008 the GHG emissions arising from direct land use change shall be assessed for any input to the life cycle of a product originating from agricultural activities. The assessment of GHG emissions occurring as a result of direct land use change shall be done in accordance with the relevant sections of the IPCC Guidelines for National Greenhouse Gas Inventories. The total emissions arising from the land use change shall be divided for each year over the 20 years following the change in land use. PAS 2050:2008 states that methods and data requirements for calculating the GHG emissions arising from indirect land use change are not fully developed, and therefore, the assessment of emissions arising from indirect land use change is not yet included in the carbon footprint specification. However, the inclusion of indirect land use change will be considered in future revisions of the specification. The influences of occupation and transformation on land use and land cover can be combined depending on the indicators and the impact categories relevant for the study in question.

When should we consider land use and/or land use change – and how should we choose the reference status? Some environmental indicators such as the ecological footprint or the forest footprint focus on the impacts of either land use (occupation) or land use change (transformation). In LCA, land use occupation is measured as area multiplied by time (m^2a) and transformation is measured as the area from and to a certain use (e.g. m^2 from coniferous forest to sand extraction area). In the impact assessment, these separate inventories have to be combined and made comparable to other environmental impacts considered. The generally recommended method for this is to integrate the impacts of transformation over time by using estimates of natural restoration rates. Transformation is therefore considered as a series of occupation impacts occurring at different points of time. The suitability of the recommended approach depends on several issues and the choice of a suitable reference status is of crucial importance. Unfortunately little guidance is given in the scientific literature for choosing such a reference status. In addition the guidelines for combining the impacts of transformation and occupation are given based on the more traditional attributional approach to life cycle assessment. A consequential approach might require considerably different reference levels and the treatment of transformation.

Our recommendation is to include both land use occupation and transformation in the inventory stage. In the impact assessment stage these can be combined, if the generally proposed combination method is applicable to the goal and scope of the life cycle assessment study. If the method is applied, care should be taken to make sure that also the reference status chosen is in line with the goal and scope of the study.

Indirect effects through market mechanisms are one of the most difficult and controversial issues to be dealt with in LCA. Any change in resources such as land, feedstock, other auxiliary inputs or products demand and supply causes indirect effects, which are typically always related to land use. As land available for various human actions, in particular food, feed, fibre, and fuel production, is a limited natural resource, which is in addition under increasing competition, land-use changes also take place. In the worst case, land-use changes result in the loss of large carbon pools and biodiversity through deforestation of natural rainforests.

The indirect effects may be very far reaching in space and time including possibly a number of complicated positive and negative feedback mechanisms. General scientific consensus exists about using an economic approach to address indirect land use changes but the methods are widely controversial. Due to difficult cause and effect relation of market mechanisms it is probably impossible to objectively attribute a certain iLUC to a certain single product. However, it is important that companies recognize the connections and risks of their processes on indirect land use and land use changes. Competition for resources must not raise the risk for environmentally harmful indirect effects. Furthermore, as rapid actions are required in climate change mitigation and in reducing deforestation, some compromise solution in accounting for iLUC impacts is probably required to manage and significantly reduce environmentally harmful iLUC in one way or another.

Land use and land use change cause environmental, social and economic impacts. There is a need to develop indicators to fulfil requirements of more holistic, sustainable use of land. Land use is included in life cycle assessment as a unit process, as an intervention, and as several impact indicators. For example cultivation of crops (unit process) occupies a certain piece of land (land use occupation) and may expand to other regions (land use transformation). The land use of crop cultivation effects soil quality, biodiversity, productivity and groundwater recharge (impacts). Most of the developed impact indicators connect a certain land area to the loss of productive land available for other uses. A multitude of indicators has been developed to model land quality through net primary productivity, energy flows, food production capacity, soil quality changes, species density and the natural state of the landscape. In addition methods for assessing the emissions from land use processes (e.g. water use of crops, nutrient emissions from fields, and greenhouse gas emissions from land cover changes) have been developed. However the developed indicators fail to include some of those aspects of land use, which are relevant for sustainable development and therefore additional indicators are recommended.

Biodiversity can be damaged quite considerably by a small land use change, which fragments existing populations or removes one subpopulation. At its current state, life cycle assessment cannot take this into account, but focuses on total land area affected instead. The loss of a so-called keystone species will result in the loss of ecosystem function as a whole. The connection between the studied system and the status and threats to biodiversity should at least be made clear qualitatively. Several lists of biodiversity indicators exist and they have been introduced in this report.

In addition to impacts on ecosystem quality and function, land use influences also social and economic sustainability to a considerable degree. For example tropical deforestation is a complex process involving many groups of people. Accordingly, land use operations in these regions are likely to affect many of these groups simultaneously. The impacts to the economic status and social equality of the people groups may be positive or negative, but it is important that they are transparently documented. Therefore external certification plans and expert judgments may be preferable to life cycle assessment, when giving statements about the overall sustainability of a land using system.

Use of biomass as a renewable source of energy and materials is an important option in climate change mitigation. However, in some cases it can cause substantial emissions from terrestrial carbon stocks – even without change in land-use category, e.g. final felling in forestry – compensated by the re-growth of biomass only in the long term. Ambitious climate targets such as the 2°C stabilization target, which requires that global GHG emissions peak within one decade, has lead the timing of net GHG emissions to become an important indicator for evaluation of bioenergy systems. Thus the true climatic consequences of land use change as a function of time should be considered, but there is no clear choice for the optimal time frame, related to the success of global climate policy in general. An illustrative indicator for the warming impact in time is the cumulative radiative forcing (CRF) of the emissions. Calculating CRF for the emissions annualized (=amortized) over 20 years (PAS 2050, RED) clearly undermines the climatic impacts compared with the calculation of CRF for the actual instant land-use-change emissions. Moreover, another challenging task is to estimate the actual baseline land use over time, i.e. the development of terrestrial C stocks without biomass use, needed in a consequential climate impact analysis of specific biomass use cycles. PAS 2050 and RED assume that the baseline is constant, but in reality forests could continue sequestering carbon for a long time, e.g. far beyond their economically feasible rotation lengths.

A case study proves that it is currently possible to make land use impact assessment with LCA. However, limited coverage of land use related data reduces the reliability of the results. Indicators are available for all the three identified land use impact categories (resource depletion, soil quality and biodiversity) and it is possible to carry out an LCA with the goal and scope being land use environmental impact assessment. Part of the land use LCI data can be found in public databases (e.g. Ecoinvent) and the characterization factors for land use LCIA have been presented within the LCA framework. However, the impact category ‘land use‘ currently included in some of the most widely used LCIA methods (e.g. ReCiPe, CML or EI99) cover only one aspect of land use induced environmental impacts and thus cannot be considered comprehensive. Additionally, some of the land use indicator results are difficult to understand and communicate to third parties unfamiliar with environmental and conservation ecology. Only the indicator results for land occupation and transformation (i.e. LCI results), ecological footprint, and also changes in soil organic matter measured with SOC and changes in biodiversity indicated using EDP or PDF are relatively easy to communicate and comprehend. In future, better understanding of land use related impacts and characterization factors on regional level is needed instead of global or generic level assessments.

Land use related aspects are important also from company perspective. Therefore, we consider accounting of land occupation (m^2a) and transformation (m^2 from and to) to be a good starting point together with the relatively simple ecological footprint indicator for productive land occupation (resource depletion). A more comprehensive and challenging approach to land use impact assessment in LCA is to include all the three impact categories. The SOC/SOM indicator can be suggested for soil quality impacts and the EDP or PDF for biodiversity. These indicators are considered applicable to LCA, and possible to communicate, but the availability of reliable data for characterization models remains uncertain. In case no quantitative assessment can be done, we propose, that companies would do a mapping on their raw materials' origins and a qualitative assessment related to their products' life cycles to map if there is any potential land use or direct and indirect land use change risks.

REFERENCES

Achten, W.M.J., Mathijs, E., Muys, B., 2008. Proposing a life cycle land use impact calculation methodology. Proceedings of the 6th International Conference on LCA in the Agri-Food Sector, Zurich, November 12-14, 2008. p. 22-33.

ARB California Environmental Protection Agency - Air Resources Board. 2010a. Background information on Low carbon fuel standard of the State of California, USA. Available online: http://www.arb.ca.gov/fuels/lcfs/lcfs-background.htm. [Accessed on 19.10.2010]

ARB California Environmental Protection Agency - Air Resources Board. 2010b. Low carbon fuel standard. Part of the effective legislation of the State of California, USA, since April 2010. Available online: http://www.arb.ca.gov/regact/2009/lcfs09/lcfscombofinal.pdf . [Accessed on 19.10.2010]

Benyon, R., England, J., Eastham, J., Polglase, P., White, D, 2007. Tree water use in forestry compared to other dry-land agricultural crops in the Victorian contexts. Report prepared for the Dept. of Primary Industries Victoria, Ensis, Technical Report 159, 50 p. ISBN 0643065350

Boulay, A-M., Bulle, C., Margni, M., Deschenes, L. 2009. Regional compensation impacts from water use: Methodology and application to the pulp and paper industry. Poster presentation in the ^{17}th International Biomass Conference in Hamburg, 2009

Brandao, M., Milà i Canals, L., Clift, R. 2010. Soil organic carbon changes in the cultivation of energy crops: Implications for GHG balances and soil quality for use in LCA. Biomass and Bioenergy (2010), doi:10.1016/j.biombioe.2009.10.019

Bringezu, S., Schütz, H., Arnold, K., Merten, F., Kabasci, S., Borelbach, P., Michels, C., Reinhardt, G.A, Rettenmaier, N. Global implications of biomass and biofuel use in Germany – Recent trends and future scenarios for domestic and foreign agricultural land use and resulting GHG emissions. Journal of Cleaner Production 2009; 17: S57-68

BSI. 2008. PAS 2050:2008. Specification for the assessment of the life cycle greenhouse gas emissions of goods and services. http://www.bsigroup.com/upload/Standards%20&%20Publications/Energy/PAS2050.pdf.

Butler, S. J., Vickery, J. A., Norris, K. 2007. Farmland biodiversity and the footprint of agriculture. Science 315, 5810: 381.

CARB, 2009. California Environmental Protection Agency, "Proposed regulation to implement the low carbon fuel standard," vol. 1 (EPA, Sacramento, CA, 2009); www.arb.ca.gov/fuels/lcfs/0304091cfs_isor_vol1.pdf.

Carlberg 2005. Environmen Report 2003 and 2004. Carlsberg Breweries, Denmark.

Cherubini, F., Peters, G.P., Berntsen, T. ,Strømman, A.H. and Hertwich, E., 2011, CO2 emissions from biomass combustion for bioenergy: atmospheric decay and contribution to global warming, GCB Bioenergy, doi: 10.1111/j.1757-1707.2011.01102.x.

Cherubini, F. & Strømman, A.H. 2010. Life cycle assessment of bioenergy systems: State of the art and future challenges. Bioresour. Technol. (2010), doi:10.1016/j.biortech.2010.08.010

COM 2010a. Commission Decision of June 2010 on guidelines for the calculation of land carbon stocks for the purpose of Annex V to Directive 2009/28/EC. 2010/335/EU, Official Journal of the European Union 17.6.2010.

COM 2010b. Report from the European Commission on indirect land-use change related to biofuels and bioliquids. COM(2010) 811 final. Brussels, 22.12.2010

Cramer Commission, 2007a. The greenhouse gas calculation methodology for biomass-based electricity, heat and fuels. Project group Sustainable Biomass. The Netherlands. Report from Working Group CO2 Methodology. January 2007. Pp. 39.

Cramer Commission, 2007b. Testing framework for sustainable biomass. Final report from the project group "Sustainable production of biomass". March, 2007. Pp. 62.

Crawley M.J., Harral J. E., 2001. Scale Dependence in Plant Biodiversity, Science 291, 5505: 864 -868.

De Vente, J., Poesen, P., Verstraeten, G., Van Rompaey, A., Govers, G. 2008. Spatially distributed modelling of soil erosion and sediment yield at regional scales in Spain. Global Planet. Change. 60: 393-415.

Delucchi M., 2004. Conceptual and methodological issues in life cycle analyses of transportation fuels. UCDITS-RR-04-45. Final Report. October, 2004. Pp. 23.

Dewulf, J., Van Langenhove, H., Muys, B., Bruers, S., Bakhsi, B.R., Grubb, G.F., Paulus, D.M., Sciubba, E. 2008. Exergy: its potential and limitations in environmental science and technology. Environmental Science & Technology 42, 7: 2221-2232.

E4Tech, 2008. Carbon reporting within the Renewable Transportation Fuel Obligation- Methodology. Final report, February 2008. Pp. 43.

EC. 2001. Manual of concepts on land cover and land use information systems. Luxemburg: European Commission. http://ec.europa.eu/eurostat/ramon/statmanuals/files/KS-34-00-407-__-I-EN.pdf.

EC. 2010. ILCD Handbook: General guide for Life Cycle Assessment - Provisions and action steps. 1st ed. European Commission, Joint Research Centre, Institute for Environment and Sustainability. http://lct.jrc.ec.europa.eu/pdf-directory/ILCD-Handbook-General-guide-for-LCA-PROVISIONS-online-12March2010.pdf.

Ecoinvent 2010. Ecoinvent life cycle inventory database v2.2. Swiss Centre for Life Cycle Inventories.

EEA European Environment Agency. 2003. Europe's Environment: the third Assessment. Environmental Assessment Report No. 10, Copenhagen.

EEA European Environment Agency. 2005. Land take assessment (CSI 014). Available online: http://themes.eea.europa.eu/IMS/ISpecs/ISpecification20041007131735/IAssessment1116504972257/view_content . [Accessed on 18.10.2010]

EEA European Environment Agency. 2010. Corine land cover inventory 2006. The European Topic Centre of Land Use and Spatial Information.

European Union. 2009. Directive 2009/28/EC (RED) of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:EN:PDF.

Ewing, B., Reed, A., Galli, J., Kitzes, J., Wackernagel, M., 2010a. Calculation methodology for the National Footprint Accounts, 2010 Edition. Oakland: Global Footprint Network.

Ewing, B., Moore, D., Goldfinger, S., Oursler, A., Reed, A., Wackernagel, M. 2010b. The Ecological Footprint Atlas 2010. Oakland: Global Footprint Network.

FAO. 2010. Agro-MAPS: Global Spatial Database of Agricultural Land-use Statistics. Version 2.5. User guide. Available at: http://www.fao.org/landandwater/agll/agromaps/interactive/doc/aglIDocs/uguide_en/index.htm, visited January 14, 2010.

Farrell, A. E. and O'Hare, M. 2008. Greenhouse gas (GHG) emissions from indirect land use change (LUC). Memorandum for the California Air Resources Board. Energy & Resources Group, University of California Berkeley, pp. 4.

Foster, G. R., Yoder, D. C., Weesies, G. A., McCool, D. K., McGregor, K. C., Bingner, R. L. 2002. Users guide — Revised Universal Soil Loss Equation Version 2 (RUSLE 2). USDA–Agricultural Research Service. Washington, DC. Available online: http://www.ars.usda.gov/Research/docs.htm?docid=6010 [Accessed on 4.4.2011]

Fritsche, U. et al: The ILUC factor as a means to hedge risks of GHG emissions from ILUC associated with bioenergy feedstock provision, Oeko Institute, 2008

Gazulla, C., Raugei, M., Fullarana-i-Palmer, P., 2010. Taking a life cycle look at crianza wine production in Spain: where are the bottlenecks? Int.J.LCA

Gerbens-Leenes, W., Hoekstra, A.Y., van der Meer, T.H. 2009. The water footprint of bioenergy. Proc Natl Acad Sci, USA 106:10219-10223

Global Carbon Project 2011. Carbon Budget 2009. An annual update of the global carbon budget and trends. http://www.globalcarbonproject.org/

Gnansounou, E., Panichelli, L., Dauriat, A., Villegas J.D. 2008. Accounting for indirect land-use changes in GHG balances of biofuels. Review of current approaches. Working paper Ref. 437.101. Lausanne, March 2008. http://lasen.epfl.ch/

Goedkoop et al. 2009a. ReCiPe Characterisation and Normalisation factors. Public Web site: http://sites.google.com/site/lciarecipe/characterisation-and-normalisation-factors. [Accessed on 31.1.2011]

Goedkoop et al., 2009b. ReCiPe 2008. A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level, http://www.lcia-recipe.net.

Guinée, J.B.; Gorrée, M.; Heijungs, R.; Huppes, G.; Kleijn, R.; Koning, A. de; Oers, L. van; Wegener Sleeswijk, A.; Suh, S.; Udo de Haes, H.A.; Bruijn, H. de; Duin, R. van; Huijbregts, M.A.J. Handbook on life cycle assessment. Operational guide to the ISO standards. I: LCA in perspective. IIa: Guide. IIb: Operational annex. III: Scientific background. Kluwer Academic Publishers, ISBN 1-4020-0228-9, Dordrecht, 2002, 692 pp.

Haberl, H., Schultz, N.B., Plutzar, C., Erb, K.H., Krausmann, F., Loibl, W., 2004. Human appropriation of net primary production and species diversity in agricultural landscapes. Agriculture, Ecosystems and Environment 102: 213-8.

Haberl, H., Erb, K.H., Krausmann, F., Gaube, V., Bondeau, A., Plutzar, C., 2007. Quantifying and mapping the human appropriation of net primary production in Earth's terrestrial ecosystems. PNAS 104: 12942-47.

Haberl H. 2009. Biomass, bio-energy and terrestrial ecosystems: a global perspective. IEA Bioenergy task 38 Workshop "Land use changes due to bioenergy", Helsinki 30.3.-1.4.2009. Available: http://www.ieabioenergy-task38.org/workshops/helsink09/Haberl.pdf

Hellmann F., Verburg, P.H., 2008. Spatially explicit modelling of biofuel crops in Europe, Working paper, Land Dynamics Group, Department of Environmental Science, Wageningen University, 48 pp.

Hertel, T.W., Tyner, W.E., Birur, D.K. 2010. Global impacts of biofuels. Energy Journal 31: 75–100.

Hoekstra, A., Chapagain, A. 2008.Globalization of Water. Sharing the Planet's Freshwater Resources, 208pp, 2008 Blackwell Publishing

ILCD 2010a. ILCD Handbook: International reference life cycle data system. General guide for life cycle assessment – detailed guidance. 1st ed. European Commission, Joint Research Centre, Institute for Environment and Sustainability. Available online: http://lct.jrc.ec.europa.eu/pdf-directory/ILCD-Handbook-General-guide-for-LCA-DETAIL-online-12March2010.pdf [Accessed on 31.1.2010]

IPCC. 2003a. Good Practice Guidance for Land Use, Land-Use Change and Forestry. Intergovernmental Panel on Climate Change. Available at: http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf.html

IPCC 2003. Good practice guidance for land use, land use change and forestry. Chapter 3.3. Cropland. IPCC National Greenhouse Gas Inventories Programme, Technical Support Unit, Hayama, Japan. p. 74-82. Available at: http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_files/Chp3/Chp3_3_Cropland.pdf

IPCC. 2006. IPCC Guidelines for National Greenhouse Gas Inventories; Volume 4; Agriculture, Forestry and Other Land Use. Intergovernmental Panel on Climate Change. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html.

IPCC. 2007a. IPCC Fourth Assessment Report: Climate Change 2007. Glossary. Available at: http://www.ipcc.ch/publications_and_data/ar4/syr/en/annexessglossary-j-p.html

IPCC. 2007b. Summary for Policymakers. In: Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)]. Cambridge University Press.

ISO 14040:2006. Environmental management. Life cycle assessment. Principles and framework.

JRC 2010. Impacts of the EU biofuel target on agricultural markets and land use: a comparative modelling assessment. JRC-IPTS, EUR 24449 EN -2010. http://ipts.jrc.ec.europa.eu

Kendall, A., Chang, B., Sharpe, B. 2009. Accounting for Time-Dependent Effects in Biofuel Life Cycle Greenhouse Gas Emissions. Environ. Sci. Technol. 43: 7142–7147.

Kim, H. Kim, S., Dale, B., 2009. Biofuels, Land Use Change, and Greenhouse Gas Emissions: Some Unexplored Variables. Environmental Science & Technology 43 (3): 961–967.

Kirkby, M.J., Irvine, B.J., Jones, R.J.A., Govers, G. 2008. The PESERA coarse scale erosion model for Europe. I. Model rationale and implementation. Eur. J. Soil Sci. 59 (6): 1293-1306.

Kløverpris, J., Wenzel, H., Banse, M., Milà i Canals, L., Reenberg, A. 2008a. Conference and Workshop on Modelling Global Land Use Implications in the Environmental Assessment of Biofuels. The International Journal of Life Cycle Assessment 13 (3) 178–183

Kløverpris, J., Wenzel, H., Nielsen, P.H. 2008b. Life Cycle Inventory Modelling of Land Induced by Crop Consumption. Part 1 : Conceptual Analysis and Methodological Proposal. Int J LCA 13 (1) 13-21.

Kløverpris, J., 2008c. Identification of biomes affected by marginal expansion of agricultural land use induced by increased crop consumption. Journal of Cleaner Production 17(4): 463-470.

Kløverpris, J., Baltzer, K., Nielsen, P., 2009. Life Cycle Inventory Modelling of Land Use Induced by Crop Consumption. Part II: Example of wheat consumption in Brazil, China, Denmark, and the USA. Int J LCA 15(1), 90-103.

Koellner, T., Scholz, R.W., 2007. Assessment of land use impacts on the natural environment. Part I: An analytical framework for pure land occupation and land use change. Int.J.LCA 12 (1) 16-23.

Kyläkorpi, I., Rydgren, B., Ellegård, A., Miliander, S., Grusell, E., 2005. The Biotope Method – A method to assess the impact of land use to biodiversity. Vattenfall.

Lambin, E.F., et al. 2001, “The causes of land-use and land-cover change: moving beyond the myths,” Global Environmental Change 11, 4: 261-269.

Lenzen, M., Lane, A., Widmer-Cooper, A., Williams, M., 2009. Effects of land use on threatened species. Conservation Biology 23 (2) 294-306.

Lindeijer, E. 2000. Review of land use impact methodologies. Journal of Cleaner Production 8, no. 4: 273-281.

Liska, A., Perrin, R., 2009. Indirect land use emissions in the life cycle of biofuels: regulations vs. science, Biofuels, Bioproducts and Biorefining 3(3), 318–328.

Mattila, T., Seppälä, J., Mäenpää, I. 2009. LCA for analysing environmental impacts of land use for various industrial branches and product groups. IEA Bioenergy task 38 Workshop “Land use changes due to bioenergy”, Helsinki 30.3.-1.4.2009. Available: http://www.ieabioenergy-task38.org/workshops/helsink09/Mattila.pdf

Mattila, T., Seppälä, J., Nissinen, A., Mäenpää, I., 2010. Land use impacts of industries and products in the Finnish economy: a comparison of three indicators. Biomass & Bioenergy (in press)

Mattila, T. & Antikainen, R. 2010. Muut elinkaarijohtamista tukevat menetelmät. In: Antikainen, R. (ed.). Elinkaarimetodiikkojen nykytila, hyvät käytännöt ja kehitystarpeet (Life cycle methods: current use, best practices and development needs). Reports of Finnish Environment Institute 7/2010, p. 62-72.

Monni, S., Korhonen, R., Savolainen, I., 2003. Radiative forcing due to anthropogenic greenhouse gas emissions from Finland: methods for estimating forcing of a country or an activity, Environmental Management 31(3), 401-411.

Mäkinen, T., Soimakallio, S., Paappanen, T., Pahkala, K., Mikkola, H., 2006. Liikenteen biopolttoaineiden ja peltoenergian kasvihuonekaasutaseet ja uudet liiketoimintakonseptit [Greenhouse gas balances and new business opportunities for biomass-based transportation fuels and agrobiomass in Finland]. Espoo 2006. VTT Tiedotteita - Research Notes 2357. 134 p. + app. 19 p. Available online: http://www.vtt.fi/inf/pdf/tiedotteet/2006/T2357.pdf

Milà i Canals, L., Bauer, C., Depestele, J., Dubreuil, A., Freiermuth Knuchel, R., Gaillard, G., Michelsen, O., Müller-Wenk, R., Rydgren, B., 2007a. Key elements in a framework for land use impact assessment within LCA. Int J LCA 12 (1): 5-15.

Milà i Canals, L., Muñoz, I., McLaren, S., Brandão, M., 2007b. LCA methodology and modelling considerations for vegetable production and consumption. CES Working Paper 02/07. ISSN: 1464-8083

Milà i Canals, L., Romanyà, J., Cowell, S.J. ,2007c. Method for assessing impacts on life support functions (LSF) related to the use of ‘fertile land’ in Life Cycle Assessment (LCA). Journal of Cleaner Production 15 (2007): 1426-1440.

Müller-Wenk, R., Brandão, M., 2010. Climatic impact of land use in LCA – carbon transfers between vegetation/soil and air. Int J LCA (2010) 15: 172-182.

Nerantziz, E.T., Tataridis, P. 2006. Integrated Enology - Utilization of winery by-products into high added value products. e-Journal of Science & Technology (e-JST) 3 (2006): 79-89.

Pfister, S., Koehler, A., Hellweg, S. 2009. Assessing the environmental impacts of freshwater consumption in LCA. Environ Science and Technology, 43 (11): 4098-4104.

Podmanicky, L., Balázs, K., Belényesi, M., Centeri, Cs., Kristóf, D., Kohlheb, N. 2011. Modelling soil quality changes in Europe. An impact assessment of land use change on soil quality in Europe. Ecological Indicators 11 (2011): 4-15.

Rassi, P., Alanen, A., Kanerva, T., Mannerkoski, I. 2001 Endangerment of Finnish Species in 2000. Helsinki: Finnish Ministry of Environment.

Renard, K.G., Foster, G.R., Weesies, G.A, McCool D.K., Yoder, D.C. 1997. Predicting soil erosion by water: a guide to conservation planning with the revised universal soil loss equation (RUSLE). USDA Agr. Handb. No 703, 1997.

Repo, A., Tuomi, M. and Liski J., 2010, 'Indirect carbon dioxide emissions from producing bioenergy from forest harvest residues', GCB Bioenergy, DOI: 10.1111/j.1757-1707.2010.01065.x

Ridoutt, B., Pfister, S. A revised approach to water footprinting to make transparent the impacts of consumption and production on global freshwater scarcity, Global Environmental Change (in press)

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin III, S.F., Lambin, E.F., Lenton, T.M., Scheffer, M., Folke, C., Schellnhuber, H.J., Nykvist, B., de Wit, C.A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P.K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R.W., Fabry, V.J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P., Foley, J.A., 2009. A safe operating space for humanity. Nature 461: 472-475. doi:10.1038/461472a

Scholes R. J., Biggs, R., 2005. A biodiversity intactness index. Nature 434, 7029: 45-49.

Searchinger, T., Heimlich, R., Houghton, R. A., Dong, F., Elobeid, A., Fabiosa, J., Tokgoz, S., Hayes, D., Yu, T-H., 2008. Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land Use Change. Science Vol. 319. no. 5867, pp. 1238 – 1240.

Stewart, M., and Weidema B. P. 2005. A Consistent Framework for Assessing the Impacts from Resource Use - A focus on resource functionality. The International Journal of Life Cycle Assessment 10, no. 4: 240-247.

Suomen Rehu. 2010. The official web pages of the company. Available: http://www.suomenrehu.fi/ [Accessed on 19.12.2010]

Tipper, R. et al.: A practical approach for policies to address GHG emissions from ILUC associated with biofuels, Arbeit für Ecometrica für Greenergy, Technical Paper - TP-080212-A; Jan 2009

Turner, B.T., Plevin, R.J., Hare, M., Farrell, A., 2007. Creating markets for green biofuels: Measuring and improving environmental performance. Research report UCB-ITS-TSRC-RR-2007-1. University of California Berkeley. Transportation Sustainability Research Center, April, 2007. Pp. 69.

Udo de Haes, H., 2006. How to approach land use in LCIA or, how to avoid the Cinderella effect?, International Journal of LCA 11: 219-221.

US EPA, 2010, Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis, EPA-420-R-10-006, February 2010, http://www.epa.gov/otaq/renewablefuels/420r10006.pdf

Wackernagel, M., Rees, W., 1996. Our ecological footprint: reducing human impact on the Earth. New Society Publishers, Philadelphia.

Wagendorp, T., Gulinck, H., Coppin, P., Muys, B., 2006. Land use impact evaluation in life cycle assessment based on ecosystem thermodynamics. Energy 31 (1) 112-125.

Wischmeier, W.H., Smith. D.D. 1978. Predicting Rainfall Erosion Losses: A Guide to Conservation Planning. U.S. Department of Agriculture, Handbook no. 537.

APPENDICES

Appendix I

Description of data collection tools and existing data sources on land cover and land use information

Data collection tools

There are several data collection tools available for primary data gathering available for land cover and land use information. According to EC 2001, these tools include:

- remote sensing,
- aerial photographs,
- sample surveys, area frame surveys and
- administrative data.

Remote sensing refers to acquiring information about the earth's surface without actually being in contact with it, normally utilizing satellites. The spectral and spatial resolution of different remote sensing systems varies. Spectral resolution refers to systems capacity to detect and distinguish different objects while the higher the spatial resolution is, the more complete and precise the shapes of the objects captured are, the more can be identified based on their shape and the more accurately their location, extent and area of objects can be determined. The spatial resolution of different systems varies from 1*1 meter to several hundred meters.

Aerial photographs are pictures taken by camera onboard an airplane, helicopter or balloon. Aerial photography has long traditions and therefore it offers significant amount of information on historic changes in the changes in landscape. In general, the large image scale enables exact identification, description and definition of even small objects. However, for the time being, large scale aerial photographs cover only small proportions of the earth's surface, and a lot of resources would be needed to cover the data gaps. Additionally, new high resolution remote sensing methods provide high quality data on land cover and land use reducing the need for traditional aerial photographs.

Sample surveys and area frame surveys refer to methods, in which the land cover and land use data is based on representative samples of the area instead of mapping the whole area. These surveys are designed for specific purposes and commonly used in agricultural statistics and also for ecological purposes.

Administrative data referring to administrative and statistic registers provides a possibility to link the physical entities of land to its socio-economic use. The data for the registers can be compiled in several ways e.g. by surveys or censuses.

Data on land use and land cover

Finland

Agricultural statistics

Agricultural statistics in Finland are available from the Matilda database updated by Tike, Information Centre of the Ministry of Agriculture and Forestry in Finland. Matilda includes information on agricultural structure, field crop, horticultural and livestock production, agricultural product prices and balance sheets for food commodities.

The field crop production statistics contain harvest data on Finland’s most important field crops, including cereals (wheat, rye, barley and oats), turnip rape, potato, sugar beet and herbage crops. The data is available annually from the 1920s onwards for the whole of Finland and also by the Employment and Economic Development Centre. The horticultural statistics contain data on the cultivation areas and harvest yields of horticultural plants grown outdoors and in greenhouses. The numbers and cultivation areas of farms with outdoor or greenhouse cultivation areas are presented by municipality, except for mushroom cultivation that is presented for the whole Finland. For research purposes it is possible to obtain information on a more detailed level than presented in the official statistics.

More information: http://www.agriculturalstatistics.fi/en/

Forest statistics

Forest and forestry related statistics in Finland are available from the Metinfo –services providing data on the forests, forest condition and forest resources, silviculture, forest management and forest use and also on other topics related to forests and forestry. The Metinfo is a service provided by the Finnish Forest Research Institute (Metla). Most of the data is currently only available in Finnish.

For more information: http://www.metla.fi/metinfo/

SLICES (Separated Land Use/Land Cover Information System)

SLICES is a project for producing an information system on land use, land cover, soil and areas with a special use or a restriction on use for the whole of Finland. The SLICES system is maintained and updated by the National Land Survey of Finland, and several Finnish research institutes participate in the project. SLICES data has been updated in years 2000 and 2005, and the 2010 update is forthcoming (Pekka Härmä, SYKE, pers. communication 9.3.2010)

The land use classification in SLICES is relatively detailed concerning the built environment, on the other hand, concerning agricultural and forest areas, the classification is relatively coarse. The SLICES data does not serve well data needs on land use change, because data on different years is not consistent. For example the land use classification and the methods have changed (Pekka Härmä, SYKE, pers. communication 9.3.2010)

More information: http://www.slices.nls.fi/

CORINE Land Cover

CORINE (Coordination of information on the environment) is a programme by the European Commission. One part of the programme is the land cover project, which is intended to provide consistent localized geographical information on the land cover in Europe.

In Finland, a satellite image mosaic, land cover map, land cover changes (during 2000-2006) and high-resolution land cover data for built and forest areas were produced in the European wide CORINE2006 and IMAGE2006 projects. The approach was the same that was applied in the CORINE2000 project, in which a satellite image map and a raster land cover database with a 25 m x 25 m resolution covering the whole of Finland was produced. Satellite image derived land cover data are combined with existing digital use and soil information (SLICES and Topographic Database of Finland). This database has been generalized so as to fit in with the European land cover map with a minimum mapping unit of 25 hectares. European datasets were finalized in autumn 2009 and the national version of land cover changes and land cover in 2006 will be completed during the spring of 2010.

The SLICES and CORINE systems are partly overlapping. However, SLICES is a Finnish system covering only Finland, while CORINE covers the whole Europe as well, and the data is available from the European Enviroment Agency (EEA). Moreover, CORINE has information on land cover changes (see classification of CORINE land cover (CLC) in Table A1.1), and it can be supplemented with more detailed data field specifically from e.g. the Agency for Rural Areas. Furthermore, CORINE data is more detailed than the SLICES data concerning especially forest areas.

Table A1.1: CORINE Land Cover (CLC) classes

(Available at: http://sia.eionet.europa.eu/CLC2000/classes [2 March 2011])

1.Artificial surfaces

- 1.1 Urban fabric
  - 1.1.1 Continuous urban fabric
  - 1.1.2 Discontinuous urban fabric
- 1.2 Industrial, commercial and transport units
  - 1.2.1 Industrial or commercial units
  - 1.2.2 Road and rail networks and associated land
  - 1.2.3 Port areas
  - 1.2.4 Airports
- 1.3 Mine, dump and construction sites
  - 1.3.1 Mineral extraction sites
  - 1.3.2 Dump sites
  - 1.3.3 Construction sites
- 1.4 Artificial, non-agricultural vegetated areas
  - 1.4.1 Green urban areas
  - 1.4.2 Sport and leisure facilities

2. Agricultural areas

- 2.1 Arable land
  - 2.1.1 Non-irrigated arable land
  - 2.1.2 Permanently irrigated land
  - 2.1.3 Rice fields
- 2.2 Permanent crops
  - 2.2.1 Vineyards
  - 2.2.2 Fruit trees and berry plantations
  - 2.2.3 Olive groves
- 2.3 Pastures
  - 2.3.1 Pastures
- 2.4 Heterogeneous agricultural areas
  - 2.4.1 Annual crops associated with permanent crops
  - 2.4.2 Complex cultivation patterns
  - 2.4.3 Land principally occupied by agriculture, with significant areas of natural vegetation
  - 2.4.4 Agro-forestry areas

3. Forest and seminatural areas

- 3.1 Forests
  - 3.1.1 Broad-leaved forest
  - 3.1.2 Coniferous forest
  - 3.1.3 Mixed forest

- 3.2 Scrub and/or herbaceous vegetation associations
  - 3.2.1 Natural grasslands
  - 3.2.2 Moors and heathland
  - 3.2.3 Sclerophyllous vegetation
  - 3.2.4 Transitional woodland-shrub
- 3.3 Open spaces with little or no vegetation
  - 3.3.1 Beaches, dunes, sands
  - 3.3.2 Bare rocks
  - 3.3.3 Sparsely vegetated areas
  - 3.3.4 Burnt areas
  - 3.3.5 Glaciers and perpetual snow

4. Wetlands
- 4.1 Inland wetlands
  - 4.1.1 Inland marshes
  - 4.1.2 Peat bogs
- 4.2 Maritime wetlands
  - 4.2.1 Salt marshes
  - 4.2.2 Salines
  - 4.2.3 Intertidal flats

5. Water bodies
- 5.1 Inland waters
  - 5.1.1 Water courses
  - 5.1.2 Water bodies
- 5.2 Marine waters
  - 5.2.1 Coastal lagoons
  - 5.2.2 Estuaries
  - 5.2.3 Sea and ocean

More information:
http://www.ymparisto.fi/default.asp?contentid=351128&lan=FI&clan=en
http://etc-lusi.eionet.europa.eu/CLC2006

Global data

On a global level, the European Space Agency (ESA) in partnership with JRC, EEA, FAO, UNEP, GOFC-GOLD[12] and IGBP provide the most recent product on global land cover, GlobCover. The GlobCover project has developed a service capable of delivering global composite and land cover maps using as input observations with a resolution of 300 metres. The GlobCover service has been demonstrated over a period of 19 months (December 2004 - June 2006), for which a set of MERIS (MEdium Resolution Imaging Spectrometer) Full Resolution (FR) composites (bi-monthly and annual for 2005) and a Global Land Cover map have been produced. The GlobCover Land Cover map is compatible with the UN Land Cover Classification System (LCCS). The results of the GlobCover project are accessible via the GlobCover Portal.

For more information: http://ionia1.esrin.esa.int/

---

[12] Global observation of forest and land cover dynamics. A panel of GTOS (Global Terrestrial Observing System) and its overall objective is to improve the quality and availability of observations of forests and land cover at regional and global scales and to produce useful, timely and validated information products from these data for a wide variety of users.

Data by the Food and Agriculture Organization of the United Nations (FAO)

The Food and Agriculture Organization of the United Nations (FAO) provides (at least) two data sets that are interesting concerning land use and land cover, namely Agro-MAPS and FAOSTAT. These are presented in the following.

Agro-MAPS: Global Spatial Database of Agricultural Land-use Statistics (version 2.5)

According to FAO (2010), Land-use information is critical for a wide variety of decision-making purposes, e.g. land degradation assessment and remediation, food security and early warning, climate change mitigation and adaptation, and policy formulation and planning. Despite the importance of land-use data, only a few regional and global level land-use data sets exist. Therefore, FAO in cooperation with IFPRI (International Food Policy Research Institute) and SAGE (Research Center of the Nelson Institute for Environmental Studies at the University of Wisconsin-Madison) set up in early 2002 the Agro-MAPS (*Mapping of Agricultural Production Systems*) Initiative to compile data on selected agricultural statistics aggregated by sub-national administrative districts. Agro-MAPS now permits, for the first time, a global overview of crop production statistics and their spatial variation at a sub national level (Table 3). The database will be periodically updated and more time-series data will be added.

Agro-MAPS contains data for primary food crops (according to the new FAOSTAT classification) on:
- area harvested (hectares),
- crop production (metric tonnes) and
- yield (metric tonnes/hectare).

The statistics for Agro-MAPS have been obtained mainly from published reports on national agricultural censuses, usually carried out every 5 to 10 years, or from annual estimates reported in published sources.

Table 3. Overview of the data contained in the Agro-MAPS. (FAO 2010).

Agro-MAPS data	**Number of crops**	**Range of years**	**Level of aggregation of Agro-MAPS data**	
			Admin^{1}*	Admin^{2}*
Africa	72	1981 to 2004	674 units	3916 2 units
Asia	20	1970 to 2001	1018 units	5371 units
Europe	18	1975 to 2001	441 units	705 units
Near-East in Asia	72	1984 to 2001	220 units	Not available
Latin America and Caribbean	45	1984 to 2001	504 units	8805 units
North America	26	1970 to 2002	63 units	3152 units
Oceania	30	1982 to 1997	Data available only for Australia	

*Admin^{1} and Admin^{2} refer to the classification of administrative units in the Agro-MAPS. For more information, see: FAO 2010.

FAOSTAT

FAO produces also FAOSTAT, in which the sub-category ResourceSTAT contains information on land use. The database is available on the internet[13]. The land use categories in the database are:

- country area,
- land area,
- agricultural area,
- agricultural area irrigated,
- arable land and permanent crops,
- arable land,
- temporary crops,
- temporary meadows and pastures,
- fallow land,
- permanent crops,
- permanent meadows and pastures,
- forest area,
- other land,
- inland water and
- total area equipped for irrigation.

The dataset covers years from 1961 to 2007, and the most resent update is from April 2009. The data is on country level and on more aggregated regional and continent levels. Data quality is estimated on qualitative level and classified as "official data", "semi-official and mirror data" and "estimated and calculated data". ResouceSTAT also contains data on fertilizers, pesticides, water, labour and machinery. The other sub-categories of FAOSTAT contain data on agricultural production (quantity produced, area harvested, yield per hectare), prices and trade, food supply and security, forestry and fisheries.

---

[13] www.faostat.fao.org

APPENDIX 2

The Water footprint methodology

Water footprint is one of the newest calculation tools to assess the sustainability of products and services. Water footprints can be calculated by using terms of blue water, green water and grey water (see Fig. A2.1). Blue water expresses the technical water used in the process, green water is the water from the nature, and grey water is the waste water to the recipient area.

Water footprint is a local indicator and it can be calculated for a product, for a process or production site or for an organization. There are different approaches to define the water footprint, depending on the purpose of the study and also ISO Standardization work is about to begin to define the guidelines for water footprint calculation. The water footprint calculation method has originally been developed by researchers at the University of Twente in the Netherlands (Hoekstra & Chapagain 2008). Led by environmental NGOs and academics, the interest in water footprint is growing fast, but a methodology for industrial processes and guidelines for data collection are still open.

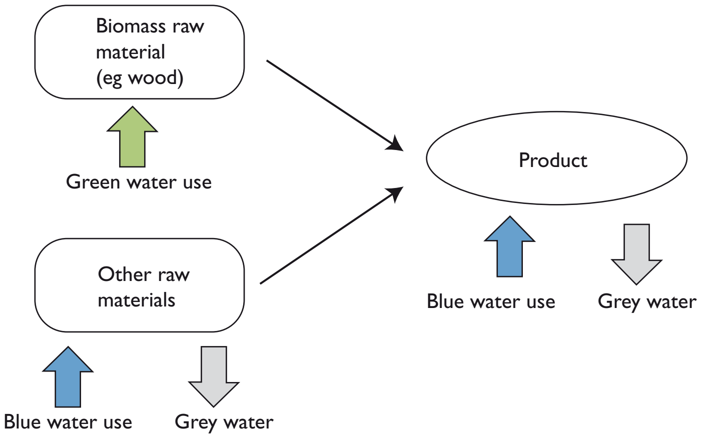

Figure A2.1. Structure of water footprint.

Fresh water consumption can be presented in life-cycle inventory results, and the environmental impacts are expressed e.g. as eutrophication, acidification, or toxicity. However, in the LCA methodology there is no cause-effect relationship between water use and environmental impacts or impacts on human health. Current inventory databases contain limited information about the water use and regional impact data is missing.

For further reading see e.g.: Water footprint network (WFN) (www.waterfootprint.org), Alliance for Water Stewardship, European water partners (EWP) (www.ewp.org), World Business Council for Sustainable Development (WBCSD) (www.wbcsd.org), UNEP/SETAC Life Cycle Initiative, CEO water mandate (http://www.unglobalcompact.org/Issues/Environment/CEO_Water_Mandate/index.html), Confederation of European Paper Industries (CEPI) guidelines for the pulp and paper industry and ISO/TC205/WG8 ISO standardization work that has started in November 2009.

APPENDIX 3

Data sources for the processes included in the beer or wine LCA case study.

Process	Data source	Data source description for primary data / Process name in Ecoinvent 2.2 database for the secondary data	EcoSpold Index number (Ecoinv.)
Barley cultivation Finland 2006	Primary	FAOSTAT 2010. Mäkinen et al. 2006	
Diesel refining	Ecoinvent	diesel, at refinery, RER	1541
Electricity production	Ecoinvent	supply mix, electricity, low voltage, at grid, FI	763
N Fertilizer production	Ecoinvent	ammonium nitrate, as N, at regional storehouse, RER	40
Chalk production	Ecoinvent	lime, from carbonation, at regional storehouse, CH	47
Pesticide production	Ecoinvent	glyphosate, at regional storehouse, RER	98
Transportation, road, 40 t	Ecoinvent	transport, lorry >32t, EURO4, RER [tkm]	7307
Barley transport to brewery	Primary	Distance estimated	
Malting and brewing	Primary	Carlsberg Breweries Environmental Report 2003 and 2004.	
Process heat production	Primary	Estimated to be light fuel oil	
Water supply	Ecoinvent	production, tap water, at user, RER	2288
Mash processing	Ecoinvent	feed, barley IP, at feed mill, CH	22
Soybean meal	Ecoinvent	soybean meal, at oil mill, BR	6666
Hops production	Ecoinvent	rape seed, extensive at farm[14]	220
Waste water treatment	Ecoinvent	treatment, sewage, to wastewater treatment, class 1, CH	2275
Glass bottle production	Ecoinvent	packaging glass, brown, at plant, RER	820
Transportation, road, lorry, 9 t	Ecoinvent	transport, lorry 7.5-16t, EURO4, RER	7301
Beer transportation from brewery to restaurant	Primary	Distance estimated	
Serving of beer and wine	Primary	Estimated storage time of beer and wine in restaurant was 20 days. Assumed that 1% of glasses would be broken during serving.	
Drinking glass production	Ecoinvent	packaging glass, white, at plant, RER	828
Washing of glasses	Secondary	A+ energy criteria for washing machines.	
Refrigerator	Secondary	A+ energy criteria for refrigerators.	
Wine production, Spain	Secondary	Gazulla et al. 2010; Int J LCA. DOI 10.1007/s11367-010-0173-6	
Wine transportation to restaurant	Primary	Distance estimated	
P Fertilizer production	Ecoinvent	ammonium nitrate phosphate, as P2O5, at regional storehouse, RER	39
Agricultural machinery	Ecoinvent	agricultural machinery, general, production, CH	32
Tractor production	Ecoinvent	tractor, production, CH	36
Combine harvester production	Ecoinvent	harvester, production, CH	34
Ethanol fermentation plant manufacture	Ecoinvent	ethanol fermentation plant, CH	6227

---

[14] Multiplied by a factor of two in order to correct for a more suitable level of yield for this case..

APPENDIX 4

Example of process land use data in the Ecoinvent v2.2 LCI-database

An example of the land occupation and transformation inventory data included in the Ecoinvent 2.2 LCI dataset (i.e. including upstream processes) for brown packaging glass, RER. Similar data is included in all the unit processes taken from Ecoinvent in the case study. Similar data is needed to be compiled for the primary data.

Packaging glass, brown, at plant, RER	**per 1 kg, glass**	**% of data class**
Occupation, arable (m2a)		
Occupation, arable, integrated (m2a)		
Occupation, arable, non-irrigated (m2a)	0.00039956	0.2 %
Occupation, arable, non-irrigated, diverse-intensive (m2a)		
Occupation, arable, non-irrigated, fallow (m2a)		
Occupation, arable, non-irrigated, monotone-intensive (m2a)		
Occupation, arable, organic (m2a)		
Occupation, construction site (m2a)	0.00044866	0.2 %
Occupation, dump site (m2a)	0.00040544	0.2 %
Occupation, dump site, benthos (m2a)	7.49E-05	0.0 %
Occupation, forest (m2a)		
Occupation, forest, extensive (m2a)		
Occupation, forest, intensive (m2a)	**0.1613**	**62.1 %**
Occupation, forest, intensive, clear-cutting (m2a)		
Occupation, forest, intensive, normal (m2a)	**0.08973**	**34.5 %**
Occupation, forest, intensive, short-cycle (m2a)	1.64E-05	0.0 %
Occupation, heterogeneous, agricultural (m2a)		
Occupation, industrial area (m2a)	0.00056338	0.2 %
Occupation, industrial area, benthos (m2a)	6.51E-07	0.0 %
Occupation, industrial area, built up (m2a)	0.001429	0.5 %
Occupation, industrial area, vegetation (m2a)	0.00024867	0.1 %
Occupation, mineral extraction site (m2a)	0.00038812	0.1 %
Occupation, pasture and meadow (m2a)		
Occupation, pasture and meadow, extensive (m2a)		
Occupation, pasture and meadow, intensive (m2a)		
Occupation, pasture and meadow, organic (m2a)		
Occupation, permanent crop (m2a)		
Occupation, permanent crop, fruit (m2a)		
Occupation, permanent crop, fruit, extensive (m2a)		
Occupation, permanent crop, fruit, intensive (m2a)	1.69E-05	0.0 %
Occupation, permanent crop, vine (m2a)		
Occupation, permanent crop, vine, extensive (m2a)		
Occupation, permanent crop, vine, intensive (m2a)		
Occupation, sea and ocean (m2a)		
Occupation, shrub land, sclerophyllous (m2a)	1.69E-05	0.0 %
Occupation, traffic area (m2a)		
Occupation, traffic area, rail embankment (m2a)	6.85E-05	0.0 %
Occupation, traffic area, rail network (m2a)	7.58E-05	0.0 %
Occupation, traffic area, road embankment (m2a)	0.0036022	1.4 %
Occupation, traffic area, road network (m2a)	0.00044933	0.2 %
Occupation, tropical rain forest (m2a)		
Occupation, unknown (m2a)		
Occupation, urban, continuously built (m2a)		
Occupation, urban, discontinuously built (m2a)	8.42E-07	0.0 %

Packaging glass, brown, at plant, RER	**per 1 kg, glass**	**% of data class**
Occupation, urban, green areas (m2a)		
Occupation, water bodies, artificial (m2a)	0.00040015	0.2 %
Occupation, water courses, artificial (m2a)	0.00020572	0.1 %
Occupation, total (m2a)	0.259841217	100.0 %
Transformation, from arable (m2)	3.07E-07	0.0 %
Transformation, from arable, non-irrigated (m2)	**0.00073409**	**25.1 %**
Transformation, from arable, non-irrigated, diverse-intensive (m2)		
Transformation, from arable, non-irrigated, fallow (m2)	5.60E-08	0.0 %
Transformation, from arable, non-irrigated, monotone-intensive (m2)		
Transformation, from dump site (m2)		
Transformation, from dump site, benthos (m2)		
Transformation, from dump site, inert material landfill (m2)	2.43E-06	0.1 %
Transformation, from dump site, residual material landfill (m2)	7.00E-07	0.0 %
Transformation, from dump site, sanitary landfill (m2)	2.17E-07	0.0 %
Transformation, from dump site, slag compartment (m2)	3.74E-08	0.0 %
Transformation, from forest (m2)	0.00018101	6.2 %
Transformation, from forest, extensive (m2)	**0.0018401**	**62.9 %**
Transformation, from forest, intensive (m2)		
Transformation, from forest, intensive, clear-cutting (m2)	5.86E-07	0.0 %
Transformation, from forest, intensive, normal (m2)		
Transformation, from forest, intensive, short-cycle (m2)		
Transformation, from heterogeneous, agricultural (m2)		
Transformation, from industrial area (m2)	9.95E-07	0.0 %
Transformation, from industrial area, benthos (m2)	4.39E-09	0.0 %
Transformation, from industrial area, built up (m2)	1.20E-07	0.0 %
Transformation, from industrial area, vegetation (m2)	2.05E-07	0.0 %
Transformation, from mineral extraction site (m2)	9.89E-06	0.3 %
Transformation, from pasture and meadow (m2)	8.74E-06	0.3 %
Transformation, from pasture and meadow, extensive (m2)		
Transformation, from pasture and meadow, intensive (m2)	5.99E-07	0.0 %
Transformation, from permanent crop (m2)		
Transformation, from permanent crop, fruit (m2)		
Transformation, from permanent crop, fruit, extensive (m2)		
Transformation, from permanent crop, fruit, intensive (m2)		
Transformation, from permanent crop, vine (m2)		
Transformation, from permanent crop, vine, extensive (m2)		
Transformation, from permanent crop, vine, intensive (m2)		
Transformation, from sea and ocean (m2)	7.50E-05	2.6 %
Transformation, from shrub land, sclerophyllous (m2)	4.35E-06	0.1 %
Transformation, from traffic area, rail embankment (m2)		
Transformation, from traffic area, rail network (m2)		
Transformation, from traffic area, road embankment (m2)		
Transformation, from traffic area, road network (m2)		
Transformation, from tropical rain forest (m2)	5.86E-07	0.0 %
Transformation, from unknown (m2)	6.61E-05	2.3 %
Transformation, from urban, continuously built (m2)		
Transformation, from urban, discontinuously built (m2)		

Packaging glass, brown, at plant, RER	per 1 kg, glass	% of data class
Transformation, from water bodies, artificial (m2)		
Transformation, from water courses, artificial (m2)		
Transformation, from, total (m2)	2.93E-03	100.0 %
Transformation, to arable (m2)	1.05E-05	0.4 %
Transformation, to arable, non-irrigated (m2)	**0.00073469**	**25.1 %**
Transformation, to arable, non-irrigated, diverse-intensive (m2)		
Transformation, to arable, non-irrigated, fallow (m2)	1.98E-07	0.0 %
Transformation, to arable, non-irrigated, monotone-intensive (m2)		
Transformation, to arable, organic (m2)		
Transformation, to dump site (m2)	2.90E-06	0.1 %
Transformation, to dump site, benthos (m2)	7.49E-05	2.6 %
Transformation, to dump site, inert material landfill (m2)	2.43E-06	0.1 %
Transformation, to dump site, residual material landfill (m2)	7.00E-07	0.0 %
Transformation, to dump site, sanitary landfill (m2)	2.17E-07	0.0 %
Transformation, to dump site, slag compartment (m2)	3.74E-08	0.0 %
Transformation, to forest (m2)	7.93E-06	0.3 %
Transformation, to forest, extensive (m2)		
Transformation, to forest, intensive (m2)	**0.001074**	**36.7 %**
Transformation, to forest, intensive, clear-cutting (m2)	5.86E-07	0.0 %
Transformation, to forest, intensive, normal (m2)	**0.00074077**	**25.3 %**
Transformation, to forest, intensive, short-cycle (m2)	5.86E-07	0.0 %
Transformation, to heterogeneous, agricultural (m2)	8.52E-06	0.3 %
Transformation, to industrial area (m2)	5.10E-06	0.2 %
Transformation, to industrial area, benthos (m2)	4.66E-08	0.0 %
Transformation, to industrial area, built up (m2)	2.91E-05	1.0 %
Transformation, to industrial area, vegetation (m2)	5.10E-06	0.2 %
Transformation, to mineral extraction site (m2)	0.00018419	6.3 %
Transformation, to pasture and meadow (m2)	1.91E-06	0.1 %
Transformation, to pasture and meadow, extensive (m2)		
Transformation, to pasture and meadow, intensive (m2)		
Transformation, to pasture and meadow, organic (m2)		
Transformation, to permanent crop (m2)		
Transformation, to permanent crop, fruit (m2)		
Transformation, to permanent crop, fruit, extensive (m2)		
Transformation, to permanent crop, fruit, intensive (m2)	2.38E-07	0.0 %
Transformation, to permanent crop, vine (m2)		
Transformation, to permanent crop, vine, extensive (m2)		
Transformation, to permanent crop, vine, intensive (m2)		
Transformation, to sea and ocean (m2)	4.39E-09	0.0 %
Transformation, to shrub land, sclerophyllous (m2)	3.39E-06	0.1 %
Transformation, to traffic area, rail embankment (m2)	1.59E-07	0.0 %
Transformation, to traffic area, rail network (m2)	1.75E-07	0.0 %
Transformation, to traffic area, road embankment (m2)	2.52E-05	0.9 %
Transformation, to traffic area, road network (m2)	3.91E-06	0.1 %
Transformation, to tropical rain forest (m2)		
Transformation, to unknown (m2)	1.81E-06	0.1 %
Transformation, to urban, continuously built (m2)		
Transformation, to urban, discontinuously built (m2)	1.68E-08	0.0 %
Transformation, to water bodies, artificial (m2)	5.22E-06	0.2 %
Transformation, to water courses, artificial (m2)	2.35E-06	0.1 %
Transformation, to, total (m2)	2.93E-03	100.0 %

APPENDIX 5

Description of characterization factors for land use used in the LCA case study

Characterisation factors used for the land use indicators in the Life cycle impact assessment (LCIA). Partly modified from the original source data listed below. The set of characterization factors is also available online at: www.ymparisto.fi/syke/finlca. Disclaimer: The authors of this report do not take any responsibility for the further use of the set of characterization factors presented below or its possible and unintended divergence from the original publications.

	Ecosystem damage (EDP)	**Ecological footprint (gm2a)**	**HANPP (kg C)**	**ReCiPe_Endpoint_Hierarchic (species yr)**	**Wagendorp2006_SED**	**Soil Organic Carbon MiC (SOC kgC yr m-2 yr-1)**	**Soil Organic Carbon Calculated by (Brandao 2010)**
Original sources (see reference list below):	**1)**	**2)**	**3)**	**4)**	**5)**	**6)**	**7)**
CO2 kg land C-change	0	0	0	0	0	0	0
CO2 kg fossil	0	0.27	0	0	0	0	0
CH4 kg	0	0	0	0	0	0	0
N2O kg	0	0	0	0	0	0	0
Occupation, arable (m2a)	0.61	2.51	0.2992	1.84E-08	0	9.7	5.7
Occupation, arable, integrated (m2a)	0	2.51	0.2992	1.84E-08	0.24	9.7	0
Occupation, arable, non-irrigated (m2a)	0.61	2.51	0.2992	1.84E-08	0.24	9.7	0
Occupation, arable, non-irrigated, diverse-intensive (m2a)	0.61	2.51	0.2992	1.92E-08	0.24	9.7	0
Occupation, arable, non-irrigated, fallow (m2a)	-0.11	2.51	0.2992	1.78E-08	0.24	9.7	0
Occupation, arable, non-irrigated, monotone-intensive (m2a)	0.74	2.51	0.2992	1.92E-08	0.24	9.7	0
Occupation, arable, organic (m2a)	0	2.51	0.2992	1.78E-08	0.24	9.7	0
Occupation, construction site (m2a)	0.7	2.51	0.38	1.93E-08	0.27	15	0
Occupation, dump site (m2a)	0.7	2.51	0.36	1.93E-08	0.28	15	0
Occupation, dump site, benthos (m2a)	0.7	2.51	0.36	1.93E-08	0.28	0	0
Occupation, forest (m2a)	0.49	1.26	0.14875	8.69E-09	0.05	0	0
Occupation, forest, extensive (m2a)	0.29	1.26	0.14875	8.69E-09	0.05	2	0
Occupation, forest, intensive (m2a)	0.63	1.26	0.14875	1.12E-08	0.05	2	0
Occupation, forest, intensive, clear-cutting (m2a)	0.73	1.26	0.14875	1.52E-08	0.25	2	0
Occupation, forest, intensive, normal (m2a)	0.73	1.26	0.14875	1.12E-08	0.05	2	0
Occupation, forest, intensive, short-cycle (m2a)	0.73	1.26	0.14875	1.52E-08	0.05	2	0
Occupation, heterogeneous, agricultural (m2a)	0.61	2.51	0.2992	1.78E-08	0.24	6.9	0
Occupation, industrial area (m2a)	0.8	2.51	0.38	1.93E-08	0.27	14.8	0
Occupation, industrial area, benthos (m2a)	0.8	2.51	0.38	1.93E-08	0.27	0	0
Occupation, industrial area, built up (m2a)	0.8	2.51	0.38	1.93E-08	0.27	15	0
Occupation, industrial area, vegetation (m2a)	0.39	2.51	0.26	1.93E-08	0.17	11	0
Occupation, mineral extraction site (m2a)	0.7	2.51	0.36	1.93E-08	0.28	15	0
Occupation, pasture and meadow (m2a)	0.52	0.46	0.0976	1.27E-08	0.17	5	0
Occupation, pasture and meadow, extensive (m2a)	0.52	0.46	0.0976	1.27E-08	0.17	5	0
Occupation, pasture and meadow, intensive (m2a)	0.52	0.46	0.0976	1.56E-08	0.17	5	0
Occupation, pasture and meadow, organic (m2a)	0	0.46	0.0976	9.52E-09	0.17	5	0
Occupation, permanent crop (m2a)	0.57	2.51	0.0976	1.52E-08	0.25	7	0

	Ecosystem damage (EDP)	Ecological footprint (gm2a)	HANPP (kg C)	ReCiPe_Endpoint_Hierarchic (species yr)	Wagendorp2006_SED	Soil Organic Carbon MiC (SOC kgC yr m-2 yr-1)	Soil Organic Carbon Calculated by (Brandao 2010)
Original sources (see reference list below):	**1)**	**2)**	**3)**	**4)**	**5)**	**6)**	**7)**
Occupation, permanent crop, fruit (m2a)	0.57	2.51	0.0976	1.52E-08	0.25	4	0
Occupation, permanent crop, fruit, extensive (m2a)	0.42	2.51	0.0976	1.12E-08	0.25	4	0
Occupation, permanent crop, fruit, intensive (m2a)	0.57	2.51	0.0976	1.52E-08	0.25	4	0
Occupation, permanent crop, vine (m2a)	0.57	2.51	0.0976	1.19E-08	0.25	4	0
Occupation, permanent crop, vine, extensive (m2a)	0.42	2.51	0.0976	1.19E-08	0.25	4	0
Occupation, permanent crop, vine, intensive (m2a)	0.57	2.51	0.0976	1.19E-08	0.25	4	0
Occupation, sea and ocean (m2a)	0	0.37	0	0	0.25	0	0
Occupation, shrub land, sclerophyllous (m2a)	-0.26	0.46	0	1.45E-08	0	0.83	0
Occupation, traffic area (m2a)	0	2.51	0.36	1.93E-08	0.27	15	0
Occupation, traffic area, rail embankment (m2a)	0.1	2.51	0.36	1.93E-08	0.27	12	0
Occupation, traffic area, rail network (m2a)	0.59	2.51	0.36	1.93E-08	0.27	15	0
Occupation, traffic area, road embankment (m2a)	0.59	2.51	0.36	1.93E-08	0.27	12	0
Occupation, traffic area, road network (m2a)	0.59	2.51	0.36	1.93E-08	0.27	15	0
Occupation, tropical rain forest (m2a)	-0.76	1.26	0	8.69E-09	0	0	0
Occupation, unknown (m2a)	0.63	2.51	0	3.04E-08	0.17	9.7	0
Occupation, urban, continuously built (m2a)	0.7	2.51	0.38	1.93E-08	0.27	14.6	0
Occupation, urban, discontinuously built (m2a)	0.3	2.51	0.34	1.93E-08	0.27	14.6	0
Occupation, urban, green areas (m2a)	0	2.51	0.26	1.93E-08	0.17	0	0
Occupation, water bodies, artificial (m2a)	0.61	1	0	0	0.25	0	0
Occupation, water courses, artificial (m2a)	0.61	1	0	0	0.25	0	0
Transformation, from arable (m2)	0.095	0	0	0	0	-485	0
Transformation, from arable, non-irrigated (m2)	0.095	0	0	0	0	-485	0
Transformation, from arable, non-irrigated, diverse-intensive (m2)	0.095	0	0	0	0	-485	0
Transformation, from arable, non-irrigated, fallow (m2)	0.455	0	0	0	0	-485	0
Transformation, from arable, non-irrigated, monotone-intensive (m2)	0.03	0	0	0	0	-485	0
Transformation, from dump site (m2)	0.025	0	0	0	0	-3750	0
Transformation, from dump site, benthos (m2)	0.025	0	0	0	0	0	0
Transformation, from dump site, inert material landfill (m2)	0.025	0	0	0	0	-3750	0
Transformation, from dump site, residual material landfill (m2)	0.025	0	0	0	0	-3750	0
Transformation, from dump site, sanitary landfill (m2)	0.025	0	0	0	0	-3750	0
Transformation, from dump site, slag compartment (m2)	0.025	0	0	0	0	-6000	0
Transformation, from forest (m2)	7.75	0	0	1.79E-06	0	-20	0
Transformation, from forest, extensive (m2)	12.75	0	0	1.79E-06	0	-20	0
Transformation, from forest, intensive (m2)	4.25	0	0	1.79E-06	0	-20	0
Transformation, from forest, intensive, clear-cutting (m2)	1.75	0	0	1.79E-06	0	-20	0
Transformation, from forest, intensive, normal (m2)	1.75	0	0	1.79E-06	0	-20	0
Transformation, from forest, intensive, short-cycle (m2)	1.75	0	0	1.79E-06	0	-20	0
Transformation, from heterogeneous, agricultural (m2)	0.095	0	0	0	0	-245	0
Transformation, from industrial area (m2)	0	0	0	0	0	-7400	0
Transformation, from industrial area, benthos (m2)	0	0	0	0	0	0	0
Transformation, from industrial area, built up (m2)	0	0	0	0	0	-7500	0

	Ecosystem damage (EDP)	**Ecological footprint (gm2a)**	**HANPP (kg C)**	**ReCiPe_Endpoint_Hierarchic (species yr)**	**Wagendorp2006_SED**	**Soil Organic Carbon MiC (SOC kgC yr m-2 yr-1)**	**Soil Organic Carbon Calculated by (Brandao 2010)**
Original sources (see reference list below):	**1)**	**2)**	**3)**	**4)**	**5)**	**6)**	**7)**
Transformation, from industrial area, vegetation (m2)	0.1025	0	0	0	0	-1100	0
Transformation, from mineral extraction site (m2)	0.025	0	0	0	0	-7500	0
Transformation, from pasture and meadow (m2)	0.14	0	0	0	0	-125	0
Transformation, from pasture and meadow, extensive (m2)	0.14	0	0	0	0	-125	0
Transformation, from pasture and meadow, intensive (m2)	0.14	0	0	0	0	-125	0
Transformation, from permanent crop (m2)	1.15	0	0	0	0	-350	0
Transformation, from permanent crop, fruit (m2)	1.15	0	0	0	0	-100	0
Transformation, from permanent crop, fruit, extensive (m2)	1.9	0	0	0	0	-100	0
Transformation, from permanent crop, fruit, intensive (m2)	1.15	0	0	0	0	-100	0
Transformation, from permanent crop, vine (m2)	1.15	0	0	0	0	0	0
Transformation, from permanent crop, vine, extensive (m2)	1.9	0	0	0	0	0	0
Transformation, from permanent crop, vine, intensive (m2)	1.15	0	0	0	0	0	0
Transformation, from sea and ocean (m2)	0.2	0	0	0	0	0	0
Transformation, from shrub land, sclerophyllous (m2)	5.3	0	0	0	0	-21	0
Transformation, from traffic area, rail embankment (m2)	0.175	0	0	0	0	-3750	0
Transformation, from traffic area, rail network (m2)	0.0525	0	0	0	0	-3750	0
Transformation, from traffic area, road embankment (m2)	0.0525	0	0	0	0	-3750	0
Transformation, from traffic area, road network (m2)	0.0525	0	0	0	0	-5250	0
Transformation, from tropical rain forest (m2)	780	0	0	5.92E-05	0	0	0
Transformation, from unknown (m2)	0.0425	0	0	7.04E-07	0	-1721	0
Transformation, from urban, continuously built (m2)	0.025	0	0	0	0	-7300	0
Transformation, from urban, discontinuously built (m2)	0.125	0	0	0	0	-7300	0
Transformation, from water bodies, artificial (m2)	0.0475	0	0	0	0	0	0
Transformation, from water courses, artificial (m2)	0.0475	0	0	0	0	0	0
Transformation, to arable (m2)	-0.095	0	0	0	0	485	0
Transformation, to arable, non-irrigated (m2)	-0.095	0	0	0	0	485	0
Transformation, to arable, non-irrigated, diverse-intensive (m2)	-0.095	0	0	0	0	485	0
Transformation, to arable, non-irrigated, fallow (m2)	-0.455	0	0	0	0	485	0
Transformation, to arable, non-irrigated, monotone-intensive (m2)	-0.03	0	0	0	0	485	0
Transformation, to arable, organic (m2)	0	0	0	0	0	485	0
Transformation, to dump site (m2)	-0.025	0	0	0	0	3750	0
Transformation, to dump site, benthos (m2)	-0.025	0	0	0	0	0	0
Transformation, to dump site, inert material landfill (m2)	-0.025	0	0	0	0	3750	0
Transformation, to dump site, residual material landfill (m2)	-0.025	0	0	0	0	3750	0
Transformation, to dump site, sanitary landfill (m2)	-0.025	0	0	0	0	3750	0
Transformation, to dump site, slag compartment (m2)	-0.025	0	0	0	0	6000	0
Transformation, to forest (m2)	-7.75	0	0	-1.8E-06	0	20	0
Transformation, to forest, extensive (m2)	-12.75	0	0	-1.8E-06	0	20	0
Transformation, to forest, intensive (m2)	-4.25	0	0	-1.8E-06	0	20	0
Transformation, to forest, intensive, clear-cutting (m2)	-1.75	0	0	-1.8E-06	0	20	0
Transformation, to forest, intensive, normal (m2)	-1.75	0	0	-1.8E-06	0	20	0

	Ecosystem damage (EDP)	Ecological footprint (gm2a)	HANPP (kg C)	ReCiPe_Endpoint_Hierarchic (species yr)	Wagendorp2006_SED	Soil Organic Carbon MiC (SOC kgC yr m-2 yr-1)	Soil Organic Carbon Calculated by (Brandao 2010)
Original sources (see reference list below):	**1)**	**2)**	**3)**	**4)**	**5)**	**6)**	**7)**
Transformation, to forest, intensive, short-cycle (m2)	-1.75	0	0	-1.8E-06	0	20	0
Transformation, to heterogeneous, agricultural (m2)	-0.095	0	0	0	0	245	0
Transformation, to industrial area (m2)	0	0	0	0	0	7400	0
Transformation, to industrial area, benthos (m2)	0	0	0	0	0	0	0
Transformation, to industrial area, built up (m2)	0	0	0	0	0	7500	0
Transformation, to industrial area, vegetation (m2)	-0.1025	0	0	0	0	1100	0
Transformation, to mineral extraction site (m2)	-0.025	0	0	0	0	7500	0
Transformation, to pasture and meadow (m2)	-0.14	0	0	0	0	125	0
Transformation, to pasture and meadow, extensive (m2)	-0.14	0	0	0	0	125	0
Transformation, to pasture and meadow, intensive (m2)	-0.14	0	0	0	0	125	0
Transformation, to pasture and meadow, organic (m2)	0	0	0	0	0	125	0
Transformation, to permanent crop (m2)	-1.15	0	0	0	0	350	0
Transformation, to permanent crop, fruit (m2)	-1.15	0	0	0	0	100	0
Transformation, to permanent crop, fruit, extensive (m2)	-1.9	0	0	0	0	100	0
Transformation, to permanent crop, fruit, intensive (m2)	-1.15	0	0	0	0	100	0
Transformation, to permanent crop, vine (m2)	-1.15	0	0	0	0	0	0
Transformation, to permanent crop, vine, extensive (m2)	-1.9	0	0	0	0	0	0
Transformation, to permanent crop, vine, intensive (m2)	-1.15	0	0	0	0	0	0
Transformation, to sea and ocean (m2)	-0.2	0	0	0	0	0	0
Transformation, to shrub land, sclerophyllous (m2)	-5.3	0	0	0	0	21	0
Transformation, to traffic area, rail embankment (m2)	-0.175	0	0	0	0	3750	0
Transformation, to traffic area, rail network (m2)	-0.0525	0	0	0	0	3750	0
Transformation, to traffic area, road embankment (m2)	-0.0525	0	0	0	0	3750	0
Transformation, to traffic area, road network (m2)	-0.0525	0	0	0	0	5250	0
Transformation, to tropical rain forest (m2)	-780	0	0	-5.9E-05	0	0	0
Transformation, to unknown (m2)	-0.0425	0	0	-7.0E-07	0	1953	0
Transformation, to urban, continuously built (m2)	-0.025	0	0	0	0	7300	0
Transformation, to urban, discontinuously built (m2)	-0.125	0	0	0	0	7300	0
Transformation, to water bodies, artificial (m2)	-0.0475	0	0	0	0	0	0
Transformation, to water courses, artificial (m2)	-0.0475	0	0	0	0	0	0

List of source data references for the land use characterization factors above:

1) Koellner, T., Scholz, R.W., 2007. Assessment of land use impacts on the natural environment. Part I: An analytical framework for pure land occupation and land use change. Int.J.LCA 12 (1) 16-23.

2) Ewing, B., Reed, A., Galli, J., Kitzes, J., Wackernagel, M., 2010. Calculation methodology for the National Footprint Accounts, 2010 Edition. Oakland: Global Footprint Network.

3) Haberl, H., Erb, K.H., Krausmann, F., Gaube, V., Bondeau, A., Plutzar, C., 2007. Quantifying and mapping the human appropriation of net primary production in Earth's terrestrial ecosystems. PNAS 104: 12942-47.

4) Goedkoop et al. 2009. ReCiPe Characterisation and Normalisation factors. Public Web site: http://sites.google.com/site/lciarecipe/characterisation-and-normalisation-factors. [Accessed on 31.1.2011]

5) Wagendorp, T., Gulinck, H., Coppin, P., Muys, B., 2006. Land use impact evaluation in life cycle assessment based on ecosystem thermodynamics. Energy 31 (1) 112-125.

6) Milà i Canals L, Muñoz I, McLaren S, Brandão M. 2007b. LCA methodology and modelling considerations for vegetable production and consumption. CES Working Paper 02/07. ISSN: 1464-8083

7) Brandao M, Milà i Canals L, Clift R. 2010. Soil organic carbon changes in the cultivation of energy crops: Implications for GHG balances and soil quality for use in LCA. Biomass and Bioenergy (2010), doi:10.1016/j.biombioe.2009.10.019

DOCUMENTATION PAGE

Publisher	Finnish Environment Institute (SYKE)			*Date* September 2011
Author(s)	Tuomas Mattila, Tuomas Helin, Riina Antikainen, Sampo Soimakallio, Kim Pingoud and Helena Wessman			
Title of publication	**Land use in life cycle assessment**			
Publication series and number	The Finnish Environment 24/2011			
Theme of publication	Environmental Protection			
Parts of publication/ other project publications	The publication is avalable only on the internet: www.ymparisto.fi/publications			
Abstract	As human population is continuously increasing, productive land is becoming even more limited resource for biomass production. Land use and land use change cause various environmental impacts. At the moment the focus is on land use related greenhouse gas emissions, but changes in carbon cycles and storages, soil quality and soil net productivity, and loss of biodiversity are growing in importance. Additionally, changes in land use and land cover also affect water quality and availability. Currently, land use related terminology is diverse, and the methodologies to assess the impacts of land use and land use change are still partly under development. The aim of this study was to discuss how land use induced environmental impacts can be taken into consideration in the life cycle assessment (LCA). This report summarises the results of the FINLCA project's (Life Cycle Assessment Framework and Tools for Finnish Companies) two tasks (WP 2.1 land use and WP 5.2 biomaterials). The study was conducted in co-operation with the Finnish Environment Institute (SYKE) and VTT Technical Research Centre of Finland. As a result, we show that it is possible to make land use impact assessment with LCA. Indicators are available for climate impacts and for all the other identified land use impact categories (resource depletion, soil quality, and biodiversity). However, limited land use related data reduces the reliability of the results. Most widely used life cycle impact assessment (LCIA) methods (e.g. ReCiPe, CML or EI99) cover only one aspect of land use induced environmental impacts. Additionally, some of the land use indicator results are difficult to understand and communicate. From the company perspective, we considered that accounting of land occupation (m^2a) and transformation (m^2 from and to) is a good starting point together with the relatively simple ecological footprint indicator for productive land occupation (resource depletion). A more comprehensive and challenging approach to land use impact assessment in LCA is to include all three impact categories and add the SOC/SOM indicator for soil quality impacts and EDP or PDF indicator for biodiversity. In case no quantitative assessment can be done, we propose that companies would map their raw materials' origins. Even a qualitative assessment related to products' life cycles would help to identify if there are any potential land use or direct and indirect land use change risks.			
Keywords	Land use, life cycle analysis, indicators, environmental impact assessment, environmental impacts, climate impacts, biodiversity, companies			
Financier/ commissioner				
	ISBN (pbk.)	ISBN 978-952-11-3926-0 (PDF)	ISSN (print)	ISSN 1796-1637 (online)
	No. of pages 86	*Language* English	*Restrictions* Public	*Price (incl. tax 8 %)*
For sale at/ distributor				
Financier of publication	Finnish Environmental Institute (SYKE) P.O.Box 140, FI-00251 Helsinki, Finland			
Printing place and year				

KUVAILULEHTI

Julkaisija	Suomen ympäristökeskus (SYKE)			*Julkaisuaika* Syyskuu 2011
Tekijä(t)	Tuomas Mattila, Tuomas Helin, Riina Antikainen, Sampo Soimakallio, Kim Pingoud ja Helena Wessman			
Julkaisun nimi	**Land use in life cycle assessment** (Maankäyttö elinkaariarvioinnissa)			
Julkaisusarjan nimi ja numero	The Finnish Environment 24/2011 (Suomen ympäristö 24/2011)			
Julkaisun teema	Ympäristön suojelu			
Julkaisun osat/ muut saman projektin tuottamat julkaisut	Julkaisu on saatavana vain internetistä: www.ymparisto.fi/publications (englanniksi)			
Tiivistelmä	Kasvavan väestömäärän ja kulutuksen vuoksi biomassan tuotantoon soveltuva maa on muuttumassa yhä niukemmaksi resurssiksi. Lisäksi maankäyttö ja maankäytön muutos aiheuttavat erilaisia ympäristövaikutuksia. Tällä hetkellä maankäytön vaikutusten arvioinnin pääpaino on kasvihuonekaasuissa, mutta hiilen kierrossa ja varastoissa, maan laadussa ja tuottavuudessa sekä biodiversiteetissä tapahtuvien muutosten merkitys kasvaa jatkuvasti. Maankäyttö ja sen muutokset vaikuttavat myös veden laatuun ja saatavuuteen. Maankäyttöön liittyvä käsitteistö on epäyhtenäistä, ja maankäytön ja sen muutosten ja niiden vaikutusten arviointiin käytettävät menetelmät ovat jatkuvan kehitystyön kohteena. Tässä tutkimuksessa tarkasteltiin sitä, miten maankäyttöön liittyvät ympäristövaikutukset voidaan ottaa huomioon elinkaariarvioinnissa (LCA). Raportti on yhteenveto FINLCA (Elinkaarimetodiikkojen foorumi yritysten päätöksenteon tueksi) -hankkeen työpakettien WP 2.1 maankäyttö ja WP 5.2 biomateriaalit tuloksista. Tutkimus tehtiin Suomen ympäristökeskuksen (SYKE) ja VTT:n yhteistyönä. Tuloksena todetaan, että maankäytön vaikutusarviointi on mahdollista LCA:ssa. Indikaattoreita on saatavilla sekä ilmastovaikutuksille että muille tunnistetuille maankäytön vaikutusluokille (resurssien ehtyminen, maan laatu ja biodiversiteetti). Kuitenkin saatavilla olevan lähtötiedon laatu heikentää indikaattoritulosten luotettavuutta. Tärkeimmät ja useimmin käytetyt LCA:n vaikutusarviointimenetelmät (LCIA), esim. ReCiPe, CML ja EI99, kattavat vain yhden osa-alueen maankäytön ympäristövaikutuksista. Lisäksi osa indikaattoreista on vaikeasti ymmärrettäviä, mikä vaikeuttaa niistä viestimistä. Yritysnäkökulmasta tuotteiden elinkaarisen maankäytön varauksen ja maankäytön muutoksen arviointi on hyvä lähtökohta resurssien ehtymisen näkökulmasta, varsinkin jos sitä täydennetään ekologisen jalanjäljen indikaattorilla. Kattavampi, mutta myös haasteellisempi lähestymistapa sisältää kaikki kolme maankäytön vaikutusluokkaa. Tällöin tarkasteltaviin indikaattoreihin tulisi lisätä SOC/SOM kuvaamaan maan laadun muutoksia sekä EDP tai PDF biodiversiteettiä. Jos kvantitatiivista arviointia maankäytöstä ja sen muutoksista ei voida tehdä, suosituksena on, että yritykset kartoittaisivat raaka-aineidensa alkuperän ja tämän perusteella kvalitatiivisesti arvioisivat tuotteidensa elinkaariset riskit suoraan ja epäsuoraan maankäytön muutokseen liittyen.			
Asiasanat	Maankäyttö, elinkaarianalyysi, indikaattorit, ympäristövaikutusten arviointi, ympäristövaikutukset, ilmastovaikutukset, biodiversiteetti, yritykset			
Rahoittaja/ toimeksiantaja				
	ISBN (nid.)	ISBN 978-952-11-3926-0 (PDF)	ISSN (pain.)	ISSN 1796-1637 (verkkoj.)
	Sivuja 86	*Kieli* Englanti	*Luottamuksellisuus* Julkinen	*Hinta (sis. alv 8 %)*
Julkaisun myynti/ jakaja				
Julkaisun kustantaja	Suomen ympäristökeskus (SYKE) PL 140, 00251 Helsinki			
Painopaikka ja -aika				

PRESENTATIONSBLAD

Utgivare	Finlands miljöcentral (SYKE)			*Datum* September 2011
Författare	Tuomas Mattila, Tuomas Helin, Riina Antikainen, Sampo Soimakallio, Kim Pingoud och Helena Wessman			
Publikationens titel	**Land use in life cycle assessment** (Markanvändning i livscykelanalysen)			
Publikationsserie och nummer	Miljön i Finland 24/2011			
Publikationens tema	Miljövård			
Publikationens delar/ andra publikationer inom samma projekt	Publikationen finns tillgänglig bara på internet: www.ymparisto.fi/publications (på engelska)			
Sammandrag	Ökningen av folkmängden och konsumtionen innebär att marken som kan användas för produktion av biomassa i allt högre grad blir en bristresurs. Dessutom har såväl markanvändningen som förändringarna i markanvändningen olika slags miljökonsekvenser. I de nuvarande bedömningarna av markanvändningens konsekvenser ligger huvudvikten på växthusgaser men förändringarna i kolets kretslopp och förråd, i markens kvalitet och produktivitet samt i biodiversiteten ökar hela tiden i betydelse. Markanvändningen och dess förändringar påverkar också kvaliteten och tillgängligheten av vatten. Markanvändningens nomenklatur är oenhetlig, och metoderna för bedömning av markanvändningen och dess förändringar med de därtill hörande konsekvenserna är föremål för ständigt utvecklingsarbete. I denna studie utreddes hur miljökonsekvenserna i samband med markanvändning kan beaktas i livscykelanalysen (LCA). Rapporten är ett sammandrag av resultaten från FINLCA-projektets (Forum för livscykelmetodiker till stöd för beslutsfattare inom företag) arbetspaket WP 2.1. markanvändning och WP 5.2. biomaterial. Forskningen skedde som samarbete mellan Finlands miljöcentral (SYKE) och VTT. Som slutsats kan konstateras att bedömningen av markanvändningens konsekvenser kan ske inom livscykelanalysen. Det finns tillgängliga indikatorer för såväl klimatkonsekvenser som de övriga identifierade kategorierna för markanvändningens konsekvenser (sinande av resurserna, markens kvalitet och biodiversitet). Man måste dock konstatera att kvaliteten på utgångsinformation försvagar pålitligheten av indikatorresultaten. De viktigaste och oftast anlitade LCA-metoderna för konsekvensbedömning (LCIA), t.ex. ReCiPe, CML och EI99, täcker bara ett delområde av markanvändningens miljökonsekvenser. Dessutom är några av indikatorerna svårbegripliga vilket gör det svårare att informera om dem. Ur företagens perspektiv är bedömningen av markanvändningsreservationen och förändringarna av markanvändningen under produkternas livscykel en god utgångspunkt, särskilt om den kompletteras med en indikator för det ekologiska fotavtrycket. En mera omfattande bedömning, som dock innebär en större utmaning, omfattar alla tre konsekvensklasserna för markanvändning. Då bör man bland indikatorerna också ha SOC/SOM för beskrivning av förändringar i markens kvalitet samt EDP eller PDF som indikator för biodiversitetskonsekvenser. Förutom huvudslutsatsen i rapporten ges också en rekommendation att om företaget inte har möjlighet att göra en kvantitativ bedömning av markanvändningen och dess förändringar, kan man göra en kvalitativ bedömning av riskerna i samband med råvarornas ursprung.			
Nyckelord	Markanvändning, livscykelanalys, indikatorer, miljökonsekvensbedömning, miljökonsekvenser, klimatpåverkan, biodiversitet, företag			
Finansiär/ uppdragsgivare				
	ISBN (hft.)	ISBN 978-952-11-3926-0 (PDF)	ISSN (print)	ISSN 1796-1637 (online)
	Sidantal 86	*Språk* Engelska	*Offentlighet* Offentlig	*Pris (inneh. moms 8 %)*
Beställningar/ distribution				
Förläggare	Finland miljöcentral (SYKE) PB 140, 00251 Helsingfors			
Tryckeri/tryckningsort -år				

Land use and land use change and the environmental impacts they cause are under lively discussion. However, currently, land use related terminology is diverse, and the methodologies to assess the impacts of land use and land use change are still partly under development. The aim of this study was to discuss how land use induced environmental impacts can be taken into consideration in the life cycle assessment (LCA). The report summarizes a wide literature review and results of a case study on land use impact assessment with life cycle assessment (LCA).

LAND USE IN LIFE CYCLE ASSESSMENT

S Y K E

ISBN 978-952-11-3926-0 (PDF)
ISSN 1796-1637 (online)

THE FINNISH ENVIRONMENT 24 | 2011