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Assessing the sustainability of liquid biofuels from evolving technologies

A Finnish approach

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Abstract

The use of biofuels in transportation is increasing and promoted in many areas with the aims of reducing greenhouse gas emissions in the transport sector, securing the energy supply, and improving the self-sufficiency and employment. However, a number of recent studies have concluded that large-scale production of biofuels may cause significant environmental and social problems. Firstly, greenhouse benefits from substituting fossil fuels with biofuels may be questionable due to auxiliary material and energy inputs required, direct land-use impacts and, in particular, due to indirect system impacts e.g. land-use changes leading to deforestation. Secondly, other environmental impacts, such as nutrient losses, toxic emissions, and biodiversity losses, may also be significant and are not well known, in particular those related to technologies still under development. Thirdly, production of biofuels from raw materials that also are, suitable for food production, have been found to increase food prices, thus causing social problems. Consequently, research on and development of biofuels is more and more focusing on raw materials not directly competing with food production. In addition, a number of initiatives on sustainability criteria for biofuels have been announced by various institutions, with the aim of ensuring that the production of biofuels does not cause serious harm to the environment and society.

A sustainability assessment is an extremely complicated and challenging task due to the lack of a unique, objective, and commonly agreed methodology, even though life cycle assessment (LCA) provides a generally accepted methodological background. The definitions of system boundary and reference scenario and other assumptions will have a significant impact on the results. In addition, the

sustainability criteria included in different approaches and studies vary, which makes the comparison of the results difficult.

This report presents perspectives on varying challenges and problems that are encountered when assessing the sustainability of biofuels in general. The report aims to identify the most critical factors of different environmental implications that are caused by increased production and use of biofuels. The main uncertainties and sensitivities associated with the assessment task are discussed and suggestions for further research needs are provided. The technological focus is on evolving technologies of highest interest from the Finnish point of view, that are the production of FT diesel from forest residues, production of NExBTL diesel from palm oil and tallow, and bioethanol production based on domestic lignocellulosic raw materials. Critical sustainability aspects of imported Brazilian bioethanol made from sugar cane are also addressed.

The report also provides a brief summary and assessment of sustainability criteria relevant for biofuels that have been proposed by various organisations, institutions, and countries. Finally, the implications of three different biofuel scenarios on the Finnish economy are briefly assessed.

The most critical factors with regard to environmental impacts of production and use of biofuels were noted to be site-specific features, direct soil implications through cultivation or harvesting of raw materials, identification, quantification and allocation of indirect impacts through market mechanisms, substitution credits from the use of co-products and biofuels, and lack of data concerning technologies still under development. In addition, indicators used to measure greenhouse or other environmental impacts may have a significant impact on the results and thus need to be carefully considered in order to avoid the drawing of misleading conclusions.

According to macro-economic scenario analysis, the increased use of biofuels has the effect of raising both consumer prices and costs of production. Consequently, it tends to drive down consumption and production in most sectors of the economy, and also makes investment less attractive. While the effects of increased domestic biofuel production are slightly negative at the level of the whole economy, the increased demand for crops and wood obviously increase activity in agriculture and in particular, in forestry.

Further research work is certainly required in various areas and dimensions related to the sustainability of biofuels. Topics that should be further elaborated include e.g. the assessment procedure of sustainability, case studies of current and new technologies and raw materials, uncertainties related to these, site-specificity and perceived harmful effects. More data and knowledge is also required for socio-economic dimension of sustainability and economic implications of biofuels towards a specific reference scenario. The need for case-specific and more comprehensive analysis with different perspectives and indicators is obvious. Both micro-level bottom-up and macro-level top-down analyses are required to ensure that biomass use is as sustainable as possible with regard to its various dimensions.

Preface

In 2007, the Ministry of Employment and the Economy (TEM; formerly the Ministry of Trade and Industry) and Tekes the Finnish Funding Agency for Technology and Innovation started a *development programme for 2nd generation biofuels for transport*. The programme is coordinated under the *BioRefine – New biomass products programme* of Tekes that also started in 2007.

This project – Environmental and economic implications of second generation biofuels for transport (BIOVAIKU) – was a part of the *above mentioned programmes*. The project was carried out between 1 October 2007 and 31 October 2008 by VTT Technical Research Centre of Finland, Finnish Environment Institute (SYKE), MTT Agrifood Research Finland, Finnish Forest Research Institute (Metla) and The Government Institute for Economic Research (VATT). The project was financially supported by TEM, Tekes, VTT, SYKE, MTT, Metla, and VATT. The work of VTT was also supported by Bioenergy Network of Excellence of the EU.

The aim of the project was to assess greenhouse gas, other environmental and economic impacts of producing and using certain second generation or evolving biofuels suitable for current vehicle stock in Finland. The availability and competition of raw materials were aimed to be studied in 3–4 technology and target scenarios. In addition, the objective was also to summarise and assess the sustainability criteria, which have been recently proposed and announced by various other organisations. Identification of the most critical issues and the main need for additional information related to assessment of sustainability of biofuels was set as one of the main expected outcomes.

The following persons formed the steering group of the project: Timo Heikka (Stora Enso Oyj), chairman; Sampo Soimakallio (VTT), secretary; Christine Hagström-Näsi (Metsäklusteri Oy), Riitta Lempiäinen (Neste Oil), Reijo Kuivalainen (Foster Wheeler Energia Oy), Pekka Piiroinen (Danisco), Markku

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Various researchers from all of the research organisations involved in the project formed the project group:

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- VATT: Juha Honkatukia.

This is the final report of the project. On behalf of the whole project group, the editors would like to acknowledge their gratefulness to the funders and to the steering group for providing useful guidance and comments during the project. The report only reflects the views of its authors and hence does not constitute a formal viewpoint of the Finnish Ministry of Employment and the Economy.

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Appendix A: Summary and analysis of the proposed sustainability criteria
Appendix B: Properties of raw materials
Appendix C: Availability of woody biomass

List of symbols

B	Boracium
BAU	Business as usual
BOD	Biological Oxygen Demand
BSE	Bovine Spongiform Encephalopathy, commonly known as Mad-Cow Disease (MCD)
BSI	Better Sugarcane Initiative
BTL	Biomass to Liquid
Cd	Cadmium
CEN	European Standardisation Organisation
CFC	Chlorinated FluoroCarbons
CHP	Combined Heat and Power
CH_4	Methane
CML 92	A one characterisation method for acidification
Co	Cobalt
COD	Chemical Oxygen Demand
CO_2	Carbon Dioxide
CO_2-eq.	Carbon Dioxide Equivalent
Cr, CRIV	Chrome, Chrome IV

CSIRO	Australia's Commonwealth Scientific and Industrial Research Organisation
Cu	Copper
DALYs	Disability Adjusted Life Years
DF	Dioxins and Furans
DG-AGRI	European Commission's Directorate-General for Agriculture
DM	Dry Matter
EBB	European Biodiesel Board
EC	European Commission
ECFIN	European Commission Directorate – General for Economic and Financial Affairs
EEC	European Economic Commission
EFB	Empty Fruit Bunches
EFPRA	European Food Processing and Rendering Association
ENVIMAT	Environmental impacts of material flows caused by the Finnish economy – research project
EPFL	Ecole Polytechnique Federale de Lausanne
ETS	Emission Trading Scheme
EU	European Union
EURO4	European standards limiting certain non-CO_2-emissions (CO, HC, NO_x, PM) in exhaust gases in vehicles.
EURO5	European standards limiting certain non-CO_2 -emissions (CO, HC, NO_x, PM) in exhaust gases in vehicles.
Eurostat	Statistical Office of the European Communities
Evira	The Finnish Food Safety Authority
FAME	Fatty Acid Methyl Esters
FAO	Food and Agriculture Organisation of the United Nations
FAOSTAT	FAO Statistical Database

FFB	Fresh fruit bunches
FFV	Flexible-fuel vehicle
FSC	Forest Stewardship Council
FT	Fischer-Tropsch
GBEP	Global Bioenergy Partnership
GDP	Gross Domestic Production
GHG	Greenhouse Gas
GM	Genetically modified
GRI	Global Reporting Initiative
GTL	Gas to Liquid
GWP	Global Warming Potential
HCV	High Conservation Value
HFCs	HydroFluoroCarbons
Hg	Mercury
HGF	Helmholtz Gemeinschaft Deutscher Forschungszentren
HI	Harvest Index
H_3PO_4	Phosphoric acid
IEA	International Energy Agency
IISD	International Institute for Sustainable Development
IPCC	Intergovernmental Panel on Climate Change
IPPC WGI	Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change
ISO	International Standard Organisation
IUCN	The International Union for Conservation of Nature
JRC	Joint Research Centre of the European Union
K	Potassium
K_2O	Potassium Oxide

LCA	Life Cycle Analysis
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LCC	Life Cycle Costing
LCSA	Life Cycle Social Accounting
LOH	Lowest hurdle
LIPASTO	a calculation system for traffic exhaust emissions and energy consumption in Finland
Metla	Finnish Forest Research Institute
MMM	Finnish Ministry of Agriculture and Forestry
Mn	Manganese
MONASH	A Dynamic General Equilibrium Model of the Australian Economy
MPOB	Malaysian Palm Oil Board
MSMA	Monosodium methanearsonate
MTT	MTT Agrifood Research Finland
N	Nitrogen
NEA/OECD	Nuclear Energy Agency of the OECD
NExBTL	Next Generation Biomass to Liquid, renewable synthetic diesel developed by Neste Oil
NGOs	Non-Governmental Organisations
NH_3	Ammonia
Ni	Nickle
NMVOC	Non-methane volatile organic compounds
N_2O	Nitrous Oxide
NO_x	Nitrogen Oxides
O_3	Ozone
OECD	Organisation for Economic Co-operation and Development

P	Phosphorus
PAHs	Polyaromatic compunds
Pb	Lead
PEFC	Programme for the Endorsement of Forest Certification schemes
PFCs	PerFluoroCarbons
PM	Particulate Matter
PME	Palm methyl ester
P_2O_5	Phosphorus Pentoxide
POCP	Photochemical ozone creation potentials
POME	Palm Oil Mill Effluent
RAINS	Regional Air Pollution Information and Simulation model
RCG	Reed Canary Grass
RES	Proposal for a Directive of the European Parliament and of the European Council on the Promotion of the Use of Energy from Renewable Sources, EC 2008b
RSB	Roundtable of Sustainable Biofuels
RSPO	Roundtable on Sustainable Palm Oil
RTRS	the Roundtable on Responsible Soy
S	Sulphur
Sb	Antimony
SF_6	Sulphur Hexafluoride
SiO_2	Silica
Sn	Tin
SS	Self-sufficiency
SS	Suspended Solids
SYKE	Finnish Environment Institute
TEM	Finnish Ministry of Employment and the Economy

TS	Total Solids
TSE	Transmissible Spongiform Encephalopathy
UK	United Kingdom
UNECE	United Nations Economic Commission for Europe
UNEP/SETAC	The United Nations Environment Programme (UNEP) and the Society for Environmental Toxicology and Chemistry (SETAC)
UNCSD	United Nations' Commission for Sustainable Development
UNFCCC	United Nations' Framework Convention on Climate Change (committed in 1992)
V	Vanadium
VATT	the Government Institute for Economic Research
VATTAGE	Economic equilibrium model
VOCs	Volatile Organic Compounds
VTT	VTT Technical Research Centre of Finland
WCED	World Commission on Environment and Development
WTO	World Trade Organization
WWF	World Wildlife Foundation
Zn	Zink

1. Introduction

The so called RES Directive Proposal (Proposal for a Directive of the European Parliament and of the Council on the Promotion of the Use of Energy from Renewable Sources, EC 2008), aiming to promote the use of renewable energy sources in the EU, was announced as a part of the integrated proposal for a Climate Action. It aims to establish an overall binding target of a 20% share of renewable energy sources in energy consumption and a 10% binding minimum target for biofuels in transport to be achieved by each Member State, as well as binding national targets by 2020 in line with the overall EU target of 20%. It states that the binding character of the biofuel target is an appropriate subject to production being sustainable, second-generation biofuels becoming commercially available, and the Directive 98/70/EC of the European Parliament and of the Council of 13 October 1998 relating to the quality of petrol and diesel fuels and the Council Directive 93/12/EEC9 being amended to allow for adequate levels of blending. (EC 2008)

In Finland, Biofuels Directive 2003/30/EC is implemented by obligation for biofuels with national targets of at least 2% in 2008, 4% in 2009 and 5.75% in 2010. On 17 December 2008, European Parliament adopted EU's climate and energy package, which lay down mandatory targets for renewable energy. At least 10% of transport fuels must be renewable by 2020. Renewable fuels in transport sector include e.g. biofuels, hydrogen, and green electricity.

Besides greenhouse gases causing climate change, the emissions from the life-cycles of biomass-based fuel chains include other compounds regarded as hazardous to human health and the environment. These emissions may be released to the air, soil, or water, thus causing various impacts, including acidification, trophospheric ozone formulation, eutrophication, ecotoxicity and human toxicity. The emissions and different processes during the life-cycle of the biomass-based products may also lower the quality of the air, soil and water.

Significant impacts on the local and global water economy may also occur. Additionally, the cultivation and harvesting of biomass have an impact on biodiversity. Furthermore, social and economic implications in such areas as workers rights, child labour, women's equity, employment, and local economy are associated with the use of biomass. These impacts can vary significantly due to various raw materials, production conditions, end-use products, and regions. Many of these impacts, other than climate change, are more relevant on the local than on the global level.

Global biomass and land area for biomass production are limited resources, in particular concerning the technically and economically attractive ones. Consequently, the boosting production of biofuels may increase the competition for raw materials and land between various end-use purposes of biomass, such as for food and feed, materials, chemicals, fuel use, and electricity and/or heat production. Examples of these kinds of indirect impacts of increasing biofuel production are rain forest and permanent grassland clearings for palm oil and soy cultivation that have occurred in Southeast Asia and South America. The implications of such impacts may be very negative, examples being remarkable losses in carbon pools and biodiversity in very diverse and sensitive regions like tropical rain forests. Famine and poverty, due to increased food prices may furthermore be the indirect results of increased production and use of biomass for energy purposes.

Sustainability, that is environmental, economic, and social implications of biomass-based products, such as biofuels, varies significantly between the products depending on many factors. Sustainability assessment is an extremely complicated and a challenging task due to the lack of a unique, objective, and commonly agreed methodology. Consequently, the definitions of system boundary, reference scenario, and other assumptions will have a significant impact on the results and are subject to significant uncertainties and sensitivities. For example, inclusion or exclusion of system impacts caused by market mechanisms due to the biofuel production on land-use or the energy system may have more impact on the greenhouse gas balances than the other life-cycle phases together. In addition, other environmental impacts than climate change, as well as social and economic impacts are typically very case and site specific and are caused in life-cycle phases that may not be of significant importance, when assessing only greenhouse gas emissions. Consequently, the selection of the approach suitable for the comprehensive assessment of sustainability is a very challenging task.

In order to ensure sustainable production of biomass-based products and biofuels, several initiatives and certification systems on sustainability criteria for biomass and/or biofuels have been proposed or are being prepared by various organisations, institutions, and countries. Work on sustainability criteria of biomass has also been started by the European standardisation organisation CEN. These initiatives vary from each other e.g. depending on the scope of the application, the validity, the extent, issues considered for environmental, social, and economic aspects, and on conditions set for fulfilling the sustainability criteria.

This report presents perspectives on varying challenges and problems that are encountered when assessing the sustainability of biofuels in general. The report tries to identify the most critical factors of different environmental implications that are caused by increased production and use of biofuels. The main uncertainties and sensitivities associated with the assessment task are discussed and suggestions for further research needs are provided. Sustainability criteria relevant for biofuels and that have been proposed by various organisations, institutions, and countries are briefly summarised and assessed.

The technologies considered include NExBTL renewable diesel derived from palm oil, other vegetable oils, and animal-derived tallow; FT biodiesel[1] and bioethanol derived from wood, forest residues, and agricultural lignocellulosic raw materials (e.g. Reed Canary Grass and straw). In addition, imported bioethanol from Brazilian sugar cane is considered. The availability of raw materials and the suitability of the particular technologies for Finland are assessed and pros and cons with respect to their feasibility and sustainability are provided. In addition, the implications of three different biofuel scenarios on the Finnish economy are also briefly assessed. The scenarios are based on the assumption of fulfilling the mandatory 10% minimum target for biofuels in transportation proposed by the EC in 23 January 2008.

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[1] In this report, biodiesel without any specifications refers to fuel corresponding to diesel oil derived from any renewable raw material. Thus, it includes FAME biodiesel, hydrotreated biodiesel (e.g. NExBTL), and synthetic FT diesel derived from gasification.

2. Assessing the sustainability of energy systems and biofuel chains

2.1 The sustainability concept

Although there is no generally agreed definition of sustainability, the concept of sustainable development that was launched in 1987 by WCED in the so-called Brundtland Report "*Our common future*" seems to be the most frequently cited one and has since become the dominant role model of future societal development. The textual connotation of the concept is, however, still controversially debated not only by politicians, but also by the scientific community. An overview of the variety of definitions launched can be found in several publications (e.g. Huetinga & Reijnders 2004; Spangenberg 2004).

Nowadays sustainable development is often depicted schematically using three circles or pillars for the target dimensions of environment, economy, and society, to which are added the time (inter-generational equity) and north-south dimensions (intra-generational equity). The equal treatment of the three dimensions is not without controversy, and Levett for example proposes the "Russian Doll" model as an alternative (Levett 1999). From this perspective, sustainability means that human society has to develop within the boundaries set by the environment, and that the economy has to satisfy societal needs – not the reverse (Burgherr 2005).

In 1995 the UN Commission on Sustainable Development (UNCSD) added the institutional dimension to the three previously considered dimensions of sustainability. However, institutional questions are largely considered to be responses and are not easily quantified as indicators (IAEA et al. 2005).

Based on these four dimensions, several comprehensive frameworks for integrated assessments have been developed, e.g. the "Ecological Footprint" (Wackernaagel & Giljum 2001) and the "Sustainability Barometer" launched by the German Federal Environment Agency (UBA 2000). Another approach is the "Prism of Sustainability" launched by Spangenberg (2002).

The "Capital Stock Model" developed at the World Bank is based on the premises that there are three different types of capital stock, environmental, economic, and social. Sustainability capital then corresponds to the sum of these three capitals and sustainable development can only be reached if the capital is preserved for future generations: i.e. when it is possible to live off the interest rather than on the capital. Depending on how far environmental, economic, and social capital can be substituted for each other, various types of sustainability can be distinguished (SDC & ARE 2004).

- ✓ *Strong sustainability* requires that each type of capital is preserved independently, which implies that the different types of capital can complement but not substitute each other.
- ✓ *Weak sustainability* means that the total capital is preserved, but there is substitutability between the three different types of capital.
- ✓ *Sensible sustainability* means also that the total capital is preserved, but there are critical limits for each type of capital, below which the stock must not fall. Such thresholds can for example be environmental standards or guaranteed human rights.

A decade after the Brundtland Commission expressed its call for sustainable development the International Institute for Sustainable Development (IISD) started a debate on how to measure, monitor and assess progress towards sustainable development. In 1996 the so-called "*Bellagio Principles*" were launched with the aim of starting up and improving assessment activities of various stakeholders, such as international institutions, national governments, and non-governmental organizations (Hardi & Zdan 1997). These principles can be assigned to the following four basic aspects: (Burgherr 2005)

I. Establishment of a vision of sustainable development (Principle 1);

II. Description of the content of the assessment (Principles 2 to 5);

III. Description of key issues of the process of assessment (Principles 6 to 8);

IV. Necessity for establishing a continuing capacity for assessment (Principles 9 and 10).

Recently another integrative approach of sustainability assessment has been launched by HGF in Germany (Grünwald 2002; Hartmuth et al. 2005). This concept aims to contribute to upgrading the operationalisation of the vision of sustainability, by complementing the normative "top-down" approach with an inductive, problem-oriented "bottom-up" approach. In this approach sustainability is operationalised in the ecological, economic, social, and institutional dimensions. Thereby, not the limited perspectives on each individual dimension are considered, but instead, three overall goals of sustainability, which are projected onto the dimensions allowing for an integrative perspective (Burgherr 2005). The following three essential elements can be distinguished:

- ✓ *Constitutive elements* of sustainability, including inter- and intra-generational equity, global perspective, and an anthropocentric approach.
- ✓ *Substantial rules (What?)* that define the minimum requirements of sustainable development. Specifically, the aim of safeguarding human existence, maintaining the societal productivity potential, and conservation of alternatives for development and action.
- ✓ *Instrumental rules (How?)* characterize the ways of achieving these requirements. This includes rules such as internalization of external social and ecological costs or a fair general framework for global economy.

2.2 Criteria and indicators for sustainability assessment

The use of indicators is a common way of describing and monitoring complex systems and of providing information to decision makers and the public. Generally indicators have three important functions in sustainability assessment (McCool & Stankey 2004):

a) For description of the existing conditions and performance of a system;

b) As a measure of the effectiveness of actions and policies to move a system towards a more sustainable state;

c) For detecting changes in economic, environmental, social, and cultural systems.

Indicators need to be selected and defined with great care to fulfill these requirements. In the case of poorly chosen and used indicators a variety of severe problems can occur, including e.g. over-aggregation, measuring of unimportant parameters, dependence on a false model, deliberate falsification, diverting attention from direct experience, overconfidence and incompleteness (Meadows 1998).

The development and selection of indicators often result in long lists of indicators selected on the basis of subjective perception. Such indicator lists tend to treat some topics in depth, while others are ignored. Having too many indicators can also result in confused priorities and overwhelming details for both developers and users. Many of these problems can, however, be avoided by using a stringent selection of criteria.

Criteria need to be formulated in such a way that they can be transformed into quantifiable indicators for which the necessary data are available. The definition of criteria and associated indicators is depending on the objectives and the specific aims, which represent the boundary conditions of the sustainability assessment under study (Hirschberg et al. 2004).

Criteria and indicators related to the social dimension of sustainability are, however, often not expressible in a fully quantitative manner. In general, social indicators reflect topics such as population and demography, labour, markets, income, housing, local infrastructure, health and social security. Therefore, social indicators reflect more the aims of traditional social policy than attempts to measure social effects of technologies. One crucial problem with the measurement of social effects of technologies is that social indicators cannot be derived from an overarching functional societal theory, because a consensual widely accepted theory about basic societal functions does not exist. (Burgherr 2005)

In general indicators should be: (Burgherr 2005)

- ✓ *Scientific* (measurable and quantifiable, meaningful, clear in value and content, appropriate in scale, no redundancy or double counting, robust and reproducible, sensitive and specific, verifiable and hierarchical);
- ✓ *Functional* (relevant, compelling, leading, possible to influence, comparable and comprehensive);
- ✓ *Pragmatic* (manageable, understandable, feasible, timely, covering the different aspects of sustainability, and allowing international comparison to the extent necessary).

2.3 Energy in the context of sustainable development

Energy is undoubtedly one of the main driving forces of modern civilization and takes up a central role in sustainable development, both on a global and national level, as it is closely linked to the three dimensions of sustainable development; that is to economic, ecological and social aspects. On the one hand, the availability of energy is a key requirement for economic activities and development. On the other hand, supply and use of energy are responsible for a substantial part of the environmental pollution. Thirdly social affluence is closely linked to the availability and supply of energy for i.e. housing, heating, lighting, transport and other service functions.

From a social perspective different population groups should have equal access to energy resources and services, and additionally intra- and intergenerational aspects need to be resolved. It is thus the challenge of current and future policy strategies to define the boundary conditions of the energy systems in such a way that a sustainable development becomes possible. Examples of guidelines for the operationalisation of sustainable development in the energy sector are the following (MED-CSP 2005):

- ✓ Equity of access
- ✓ Conservation of resources
- ✓ Compatibility with environment, climate, and health
- ✓ Social compatibility
- ✓ Low risk and high error tolerance
- ✓ Comprehensive economic efficiency
- ✓ Meeting the need of supply at any time
- ✓ International co-operation.

Similarly NEA/OECD (2000) has compiled a list of subjects relevant to the energy sector that should be addressed by indicators:

- ✓ Resource availability and geographical distribution
- ✓ Intensity of energy use and material flows
- ✓ Critical environmental load limits
- ✓ Land use and impact on natural habitat
- ✓ Potential for causing major and irreversible environmental impacts.

In addition to these approaches several initiatives towards the development of suitable indicators and criteria for sustainability assessment of biomass and biofuels have been taken by other organisations. These are dealt with below.

2.4 A summary of various initiatives on sustainability criteria for biomass and biofuels

In order to ensure the sustainable production of biomass-based products and biofuels, several organisations have presented and proposed initiatives and certification systems on sustainability criteria for biomass and biofuels. In Table 1 a summary of the most critical points on the basis of the following initiatives and certification systems are presented: the EU Directive Proposal; national level criteria from the Netherlands, United Kingdom (UK) and Germany; criteria prepared by certain NGOs (Roundtable of Sustainable Biofuels (RSB) and Swan labelling) and certification systems for biomass energy crops (RSPO; palm oil, BSI; sugar cane, and RTRS; soy) and forests (FSC and PEFC).

In general, the comparison of the criteria is a challenging task, as each of the initiatives or certification systems has a slightly different scope and goal. Some criteria focus only on biofuels (EU, UK, RSB and Swan label) and some on biomass (Germany, RSPO, BSI, RTRS, FSC and PEFC), while the initiative of the Netherlands consider both aspects. Furthermore, some criteria cover the whole life cycle of the product and some only the cultivation phase.

The environmental and socio-economic aspects included in the initiatives vary considerably. Biodiversity is considered in all of the initiatives analysed (see Table 1). Water quality, soil quality and ecotoxicity, as well as social and economic impacts are also included in most of the initiatives. Climate change aspects are included in all general biofuel/biomass initiatives, but not in those initiatives concentrating on a specific raw material (RSPO, BSI, RTRS, FSC and PEFC). Some of the initiatives, e.g. the EU RES directive proposal provide a methodology for calculating greenhouse gas balances of biofuels and emission reduction, when compared to reference fuels.

Generally speaking, life cycle thinking has only been applied for greenhouse gases, while the approach towards other environmental and socio-economical aspects is different. For example, regarding the criteria of air pollution it can be stated that the biofuel production should not directly or indirectly lead to air pollution. Still there are no actual e.g. quantitative guidelines on how to avoid air pollution besides a requirement to obey national and local laws and regulations.

The reason why greenhouse gas issues are considered on a very detailed level in many of the initiatives assessed is probably due to the fact that one of the main aims of biofuels is generally considered to be a reduction of GHGs when compared to fossil counterparts. As a consequence there exists a number of studies dealing with greenhouse gas balances of biofuels, but only a few of the studies assess other dimensions of sustainability. In addition, not all dimensions of sustainability, e.g. social aspects, can be measured objectively in quantitative terms.

Greenhouse gas balances of biofuels are in many contexts perceived as a well or adequately known issue. However, there is also number of studies pointing out that there are significant uncertainties and lack of knowledge involved in greenhouse gas balances of biofuels, including the definition of system boundaries and the functional unit, the use of allocation methods, and the inclusion of other greenhouse gases than CO2, CH4, and N2O. Additionally, the timing of emissions and sinks of greenhouse gases (the dynamics) or the uncertainty range for default parameters are not considered in any of the reviewed initiatives. These aspects of greenhouse impacts are discussed more profoundly in Chapter 4. A more detailed summary of various sustainability initiatives is presented in Appendix A.

Of the reviewed sustainability initiatives greenhouse gas impacts are not considered in the BSI, RTRS, FSC and PEFC, but are taken into account at least to some extent in all the other ones. Some of the initiatives, e.g. the EU RES Directive Proposal provides a methodology for calculating greenhouse gas balances of biofuels and emission reduction when compared to reference fuels.

The definition of the system boundary is one of the most critical issues when assessing greenhouse gas balances of any kind of a system, as various approaches and assumptions may lead to significant differences in the results. In order to enable a quantitative assessment of the greenhouse impact, the system boundary should be clearly defined. However, by doing so, the analysis will be more or less subjective, as the possible impacts outside the system boundary are not considered. For example, the EU RES directive proposal provides relatively clear guidelines and methodology on how greenhouse gas impacts should be calculated. Competition of raw materials for land use is, however, not considered in that particular methodology. Such indirect impacts may lead to changes in land use outside the considered system boundary and thus cause significant emissions of carbon dioxide, e.g. due to deforestation.

Table 1. Environmental and socio-economic aspects of the sustainability criteria for biomass and biofuels in different initiatives launched.

	EU	**NED**	**UK**	**GER**	**RSB**	**Swan label**	**RSPO**	**BSI**	**RTRS**	**FSC**	**PEFC**
Applicability	BF	BF/ BM/ BE	BF	BM	BF	BF	BM	BM	BM	BM	BM
Environmental aspects											
Climate change	+	+	+	+	+	+	+	-(+)	-	-	-
Energy balance	-	-	-	(+)	(+)	+	-	-	-	-	-
Air quality	-	+	+	+	+	-	+	+	-	-	-
Water quality	(+)	+	+	+	+	-	+	+	+	+	+
Use of water	-	+	+	+	+	-	+	+	+	(+)	(+)
Soil quality	(+)	+	+	+	+	-	+	+	+	+	+
Ecotoxicity	(+)	+	+	+	(+)	-	+	+	+	+	+
Human toxicity	-	-	-	-	-	+	-	+	-	-	-
Biodiversity	+	+	+	+	+	+	+	+	+	+	+
Sustainable land use and competition with other resources	+	+	-	+	+	-	+	-	(+)	+	+
GMOs	-	-	-	-	+	-	+	-	-	+	- (+)*
Waste management and recycling	-	+	(+)	-	-	-	+	-	-	+	-
Social impacts	-	+	+	-	+	+	+	+	+	+	+
Economic impacts	-	+	-	-	+	-	+	+	+	+	+

General overview of the criteria.

\+ and a shaded area indicate that the category is covered by the initiative. Note that the level of detail in methodology, indicators etc. may still vary per certification system.

(+) and a shaded area indicate that the category is mentioned in the initiative, but only on a general level or the initiative covers the issue only partly.

\- indicates that the category is not covered by the initiative.

If a sustainability initiative provides rules for calculating greenhouse impacts, it should also provide guidelines for allocating emissions from co-products. The use of one particular allocation method leads inevitably to subjective results.

Many of the reviewed initiatives include CO_2, CH_4, and N_2O as greenhouse gases to be considered. It can be seen as reasonable, as these gases are typically the most relevant ones with regard to biofuel production. However, if some other direct or indirect greenhouse gas plays a significant role in some biofuel chain, it should be taken into account. In some of the initiatives greenhouse gases to be considered have not been defined.

When analysing the greenhouse impact of any kind of a system, the emissions and sinks of greenhouse gases should be considered over the whole life-cycle of the particular system. Consequently, in addition to spatial system boundary, the timing of inputs and outputs of the system should be taken into account. The consideration of dynamics is the more important the longer the rotation period of the biomass is and the shorter the time to mitigate climate change is. Dynamics are not considered in any of the reviewed initiatives.

Direct land use change, e.g. due to cultivation or harvesting of biomass, may significantly cause emissions of carbon that is otherwise stored or accumulated in biomass or the soil. These kinds of emissions should be considered, but are not discussed in all of the initiatives reviewed. The pay back time of carbon storage losses is set as 20 and 10 years by the EU RES directive proposal and the UK initiative, respectively. In addition, the use of certain carbon rich areas for biofuel production is restricted e.g. by the EU RES directive proposal. A relatively short pay back time for carbon losses is reasonable as the pay back time should be the shorter the more rapid the emissions and the atmospheric concentrations of greenhouse gases need to be reduced. However, as the reference development of carbon storage is not known, the short pay back time may overestimate the negative influence caused by the biofuel chain considered.

Some of the initiatives including the EU RES directive proposal provide default values that can be used when calculating greenhouse gas impacts of biofuel chains. The default values are presented for certain individual parameters and for a relative emission reduction of certain biofuels. However, many of the parameters required in assessing greenhouse gas impacts of biofuels are subject to significant uncertainties and sensitivities, which may have considerable impact on the results (Soimakallio et al. 2009). Such parameters include e.g. nitrous oxide emissions from soils, soil carbon balances, and emissions from the production of the electricity consumed in the biofuel processes. None of the reviewed initiatives provide any uncertainty range for default parameters. In addition, the parameter set provided is not adequately separated and detailed to consider e.g. the impact of regional differences.

Finally, one of the most critical issues is the way in which greenhouse impacts of biofuels are measured. It is very typical to compare the emissions from a biofuel system to a selected reference system by using the GWP method. The selection of a functional unit towards the greenhouse impacts calculated is crucial. For example, in the EU RES directive proposal the minimum acceptable emission reduction of a biofuel system is defined as 35% compared to the fossil reference system. As the emissions are calculated in relation to the energy content of fuels, the possible change in the end-use efficiency is not considered. A more problematic issue related to the particular indicator is the fact that it does not measure the effectiveness of biomass in climate change mitigation. In other words, it is possible to get significant relative emission reductions by wasting a lot of low greenhouse gas emitting biomass. As global biomass resources are limited and the challenge to reduce emissions to mitigate climate change is huge, the biomass should be used as effectively as possible from climate change mitigating point of view. Consequently, significantly more appropriate indicators would be the measurements that take into account the greenhouse gas emission reduction achieved per biomass and/or land area consumed (see e.g. Schlamadinger et al. 2005, Pingoud et al. 2006; Soimakallio et al. 2009). These kinds of indicators are sort of hybrids of relative energy and greenhouse gas balance indicators.

In general it can be concluded that measuring the sustainability of biofuels and biomass is difficult. There are three sustainability aspects – environmental, economic, and social – of which each consist of numerous sub-categories. Often the implications of the aspects are contradictory. This makes the setting up of strict sustainability criteria for biomass or biofuels a very challenging task. This is reflected in the number and scope of existing initiatives and certification systems. Many criteria (such as the GHG-balance and land use change) cannot be covered within the existing initiatives and certification systems (see also van Dam et al. 2008). Therefore, further development of the criteria to ensure sustainable production of biomass and biofuels is needed urgently.

Most of the initiatives analysed here consider sustainability on a very general level. Sustainability and its closely related concept eco-efficiency includes also the idea of continuous improvement, which is not seen in most of the initiatives, although for example, in some initiatives, in the sub-category of soil quality the importance of continuous improvement is pointed out.

One of the main problems of the criteria is that indirect effects of biomass production, like competition with food or other use of raw materials, or undesirable effects on biodiversity cannot be monitored or even identified. Furthermore, most of the criteria are not compatible with WTO rules and therefore their use at least as a mandatory obligation is difficult, as the trade of biomass is covered by the WTO rules. Standards for the production of biomass potentially run the risk of arbitrary discrimination and hidden protectionism, and therefore the standards must be in line with the principles of the WTO.

Different initiatives analysed here have different starting points, purposes, and terminology. Partly because of this, the final result is also very ambivalent, and it is difficult or even impossible to compare the initiatives and estimate their contribution towards sustainability. Therefore a better international coordination between initiatives is required to improve the coherence and efficiency in further development of biomass certification systems (van Dam et al. 2008). Currently, the Dutch and the UK's initiatives are the most comprehensive ones.

From the consumers' point of view, it is almost impossible to know different initiatives and their real impact on sustainability. This is a problem with all certificates and eco-labels. The consumer has to rely on experts creating the certification systems, which again always are kind of compromises between environmental, social, and different economic aspects.

Currently, the sustainability of biomass and biofuels is an open question. A coherent and unanimous international system to measure the sustainability of biomass and biofuels is evidently needed. New approaches towards more sustainable biofuel and biomass production are being taken for example in the standardisation work by the European standardisation organisation (CEN). It work will mainly be based on the existing sustainability criteria. How effective the final criteria will be in reality in promoting the sustainability remains to be seen. The functioning is highly dependent on the succes of the enforcement of these schemes. However, the capability of countries to enforce the requirements is highly questionable (GBEP 2008). Even advanced countries may have difficulties. A recent survey commissioned by the UK government found that 4 out of 5 litres of biofuel supplied at British pumps failed to meet basic industry standards for sustainability. Biofuel manufacturers could not prove that their biofuel feedstock had not been grown by trashing rainforests or by harming the livelihoods of poor farmers. Additionally, the origin of half of the biofuels in UK fuel tanks was unknown (Anon. 2008).

3. Life cycle framework for assessing environmental sustainability of biofuels

3.1 LCA as a tool for sustainability assessment

The sustainability of a fuel product depends on its environmental, economic, and social impacts throughout the product's entire life cycle. The complete life cycle of the fuel product includes everything from raw material production and extraction, processing, transportation, manufacturing, storage, distribution and use. A fuel chain and its life cycle stages cause various harmful impacts on the environment. In addition, the life cycle stages can have harmful effects or benefits of different economic and social dimensions. For this reason, the total management of complete fuel chains (cradle-to-grave) from different perspectives is of crucial importance in order to achieve sustainable fuel products and systems in our society. For this purpose life cycle assessment (LCA) appears to be a valuable tool and its use for the assessment of the sustainability of not only fuel products, but also of other commodities has increased dramatically in recent years.

In the application of LCA on a biofuel product system, the functional unit offers a reference unit, for which the inventory and impact assessment results will be presented, making it possible to compare the results with the results of reference products. This reference product is typically a fossil fuel or an alternative biofuel product. In the context of biofuels, the system boundary can be determined as "well to tank", "tank to wheel" or "well to wheel".

Inventory data and environmental interventions representing a "well to wheel" perspective, are the core elements of a LCA. However, the inventory data are usually not sufficient for making a decision regarding which fuel alternative is the best from the viewpoint of environmental aspects. For example, it is difficult to give an answer to the question, whether emissions of sulphur dioxide (SO_2)

should be regarded as more severe than emissions of nitrogen oxides (NO_x). In comparative studies, such as biofuel comparisons typically are, it may be found that biofuel A is better than biofuel B with regard to some emissions, but poorer with regard to others. In such cases, the impact assessment phase should be included. Life cycle impact assessment (LCIA) helps to interpret the results of the inventory from the environmental impact point of view. However, a life cycle study does not always need to use impact assessment. In some cases conclusions can be drawn and judgements and valuations are possible just on the basis of the results of the inventory phase.

The economic and social dimensions of sustainability have so far not been included in LCA. However, these dimensions throughout an entire life cycle of a product can be assessed with the help of tools called life cycle costing (LCC) and life cycle social assessment (LCSA). In addition, environmental extended input-output modelling offers possibilities to combine all three dimensions of product systems being assessed (e.g. Hertwich 2005).

When assessing environmental impacts of any kind of a system the most critical issue to be responded to is: *“What is compared with what?”* The particular question culminates in the requirement to define the reference system (e.g. product and land use) and system boundary for the assessment procedure. Consequently, significant methodological problems are encountered. This chapter discusses the main issues, problems, and factors that are involved in carrying out the phases of goal and scope definition and inventory analysis in order to generate data on environmental interventions (emissions, land use, and resource extractions) and for the assessment of environmental impacts from production and use of biofuels.

3.2 Reference system and system boundary

The first problem encountered, is how to define the functional unit of a biofuel product and its reference systems. Reference systems describe here the alternative fuel chains for the biofuel products. The difference between the impacts of the fuel chains will give the answer to the question: *“What would be the impacts of implementing a certain biofuel chain instead of not implementing it?”* The particular biofuel chain may already exist or may just be forecasted to be implemented in the future. The latter option is more interesting, when the impacts of the increasing use of biofuels are of concern.

The selection of the reference system depends on the perspective of the study. On one hand it may be interesting to study the direct absolute impacts that the implementation of a certain biofuel chain has on the environment. On the other hand, it is more practical to study the relative impacts compared to a reference system (e.g. fossil fuel). For this reason, LCA is a tool for quantifying potential impacts. Fundamentally, both potential and absolute impacts caused by a change in the system, e.g. increasing and decreasing amounts of biofuels and fossil fuels, respectively, are of main interests in this study.

When defining the reference system, relevant issues to be considered are in particular the reference use of raw materials, land, required auxiliary inputs (i.e. energy carriers and chemicals), and products. These issues are not illustrated in Figure 1.

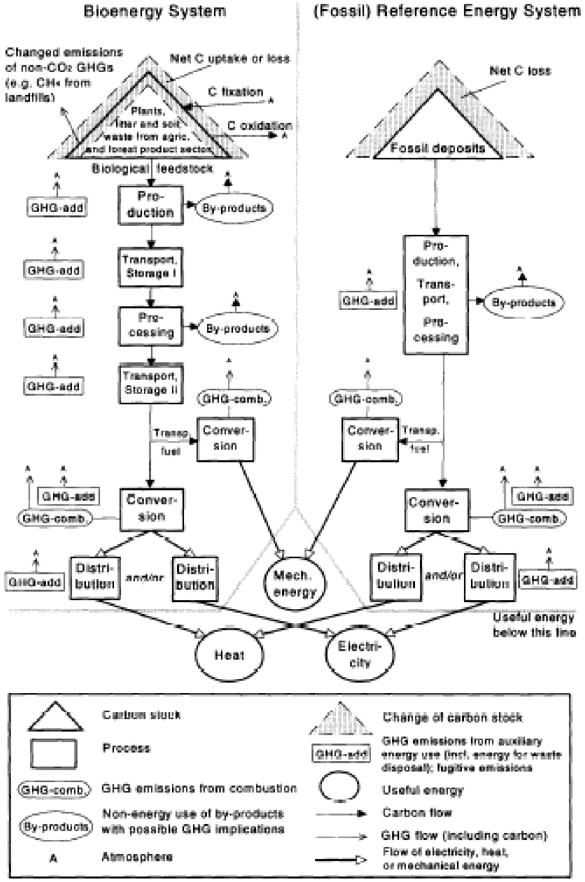

Figure 1. Principle flow-charts of a bioenergy system and a (fossil) reference system for assessing and comparing greenhouse gas impacts of both systems (Schlamadinger et al. 1997). The system boundary presented for both systems is only for illustrative purposes.

The raw materials and the associated land area may be used just for the particular biofuel purpose under consideration, but they may also be used initially for some other purposes e.g. for food, animal feed, materials, or energy production. In the latter case, it is likely that the initial purpose will be satisfied by producing the particular product somewhere else or by some other method (Figure 2). Consequently, such indirect impacts due to competition of raw materials or land area are important to consider in the assessment, but may be very difficult to quantify in a traditional LCA approach. The challenge is to include these indirect impacts in the LCA calculations based on the use of a functional unit.

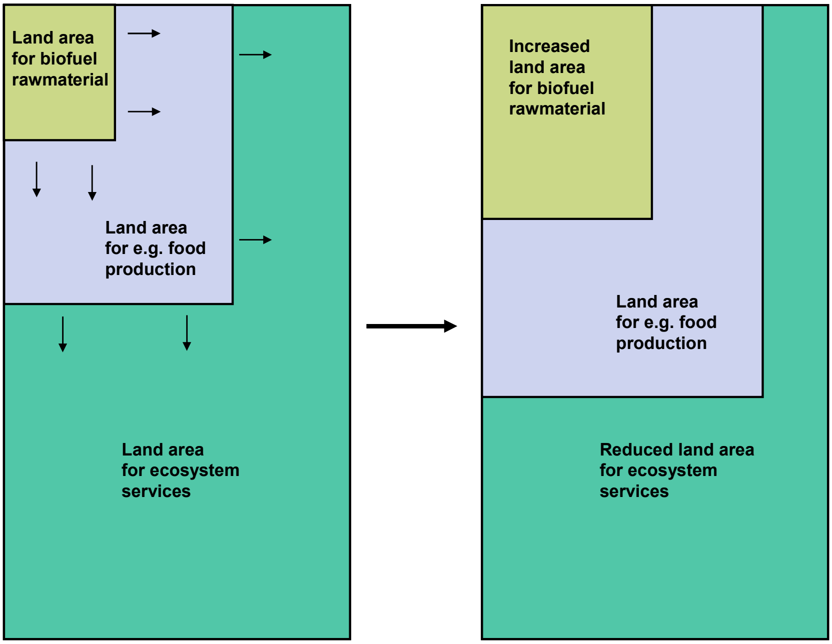

Figure 2. As a consequence of increasing biofuel raw material production, the land area for producing biomass for other purposes may shift to another location, thus reducing the land area available for e.g. ecosystem services.

The implementation of a certain biofuel chain increases the use and thus also the production of auxiliary inputs that are required. At the same time, the increased use of biofuels decreases the relative need for conventional fuels. Both mechanisms have implications on the production and prices of such commodities, whose environmental impacts may vary significantly depending e.g. on the prevailing market mechanisms and on many associated and complicated factors.

Environmental impacts of implementing a certain biofuel chain instead of not implementing it may be very extensive and impossible to identify in practice. In order to quantify the emissions, land use, and resource extractions, the system boundary should be defined somehow and this is the fundamental dilemma. The lack of data and knowledge is encountered, when setting a too extended system boundary, but relevant information may be left out by setting a more limited one. Consequently, preliminary identification of the key factors causing environmental impacts is crucial before carrying out the inventory analysis, in which the most relevant inputs (emissions, land use, and resource extractions) will be assessed.

Environmental impacts of different actions may emerge immediately or during a longer period of time. For example, cultivation or harvesting of biomass may degrade the soil resulting in lowering of yield rates in the future. In addition, it may take decades (long rotation forests) or even hundred years (peat) for the carbon released during biomass combustion to be absorbed back into the growing biomass. Furthermore, the lifetime of greenhouse gases, particles, other emission compounds, and the timing and duration of related environmental impacts vary significantly. Consequently, the definition of a dynamic system boundary that takes into account the timing of inputs, outputs, and related impacts is necessary.

3.3 Allocation

When the functional unit, reference system, and system boundaries have been defined the problem of allocating inputs and outputs between the products over the system boundary is encountered. Extension of the system boundary to avoid allocation, whenever possible, is suggested in the ISO 14044 Standard. However, due to lack of information, as discussed earlier, it is impossible to completely avoid allocation in practice. When allocation cannot be avoided, allocation based on physical relationship (e.g. mass, energy content etc.) is suggested in ISO 14044. Furthermore, where physical relationship alone cannot be established or used as the basis for allocation, other relationships (e.g. price) between them are suggested.

The selection of the allocation procedure may significantly influence the environmental impact results as illustrated in Figure 3. The use of any kind of an allocation method is more or less subjective and leads to problems when interpreting the results. Typically used allocation methods are based e.g. on the mass, the energy content, or the price of the products, or on the substitution credits of co-products. All above-mentioned methods have their own pros and cons, and these are also discussed later in this report.

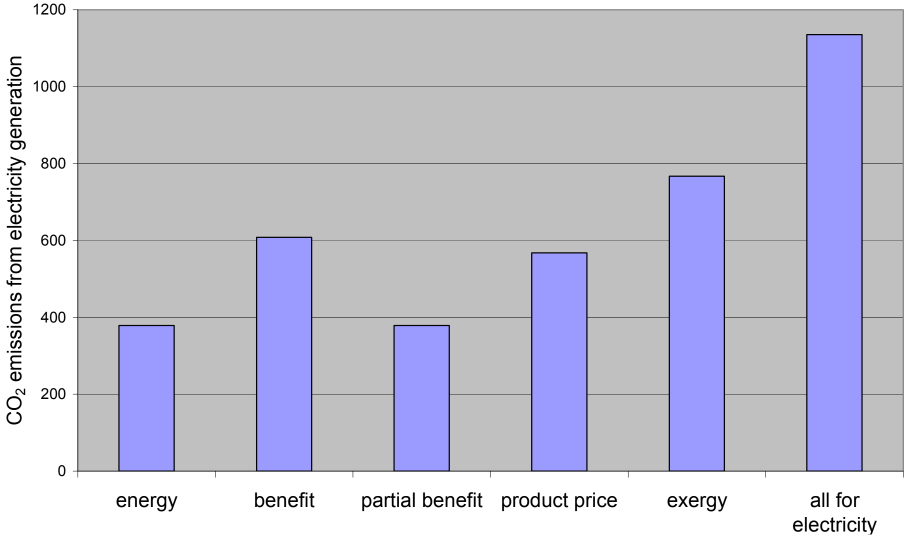

Figure 3. The influence of various allocation methods on CO_2 emissions from electricity production for a typical coal-fired CHP-plant (power to heat ratio equals 0.5). The assumptions used are the same as those used by VTT (VTT 2007), when assessing the influence of the same allocation methods on the efficiency of electricity production. The absolute numbers are for illustrative purposes only. Energy content in enthalpic terms and exergy content of the products are used in the corresponding methods. The electricity is assumed to be two times as expensive as heat. In the benefit method the emissions are allocated to power and heat in the ratio corresponding to assumed alternative production forms (condensing power and heating boiler).In the partial benefit method emissions are allocated to heat on the basis of the fuel consumption of alternative heat production (90% efficiency assumed), and the remaining share is allocated to power.

Physical units (e.g. mass and energy content) are relatively easy to measure and are stable over time, which makes them attractive to use as a basis of allocation. However, they do not necessarily reflect the purpose of the products at all. For example, mass-based allocation for energy carriers is not reasonable, as the energy content is not considered. Furthermore, the allocation based on the energy content is not reasonable if one or more of the co-products are intended for non-energy-related use purposes. An allocation method based on physical units may also allocate inputs and outputs to the by-product streams that have no utility value (waste streams). As suggested by ISO 14044, this problem can be avoided by defining the ratio between co-products and waste, and by allocating inputs and outputs only to co-products. However, this ratio may change and make the allocation procedure unstable over time, as does the allocation based on the price of products.

The substitution method is not actually an allocation method but a method of avoiding allocation by extending the system boundary, so that the use of the associated products is considered. The main problem with the method is to define the scenario and to account for avoided environmental impacts of reference products that will be substituted by co-products of the system considered.

3.4 Substitution effects

When considering any product chain in practice, co-products are always involved at least in some part of the chain. Furthermore, when aiming to assess environmental impacts comprehensively, the environmental impacts of the use of co-products should be taken into account. Otherwise, the requirement for allocation with its methodological problems, as discussed previously, is again encountered.

If the system boundary is extended to include the use of co-products involved, the effects of replacing reference products should be considered. The main problem, however, is to define what products are to be replaced and what are the environmental impacts of doing so. In principle, substitution of certain products reduces the requirement for such products providing environmental credits. However, the issue is not that straightforward at all.

Firstly, there may be several products with a similar end-use purpose but a very different emission profile. It may thus be very difficult to define exactly, which products will be replaced by which co-products. Secondly, even if the product can be defined, it is very difficult to ensure that the particular product is really replaced. It is possible that the theoretical replacement lead in practice to more ineffective production or use of particular products with no or even negative emission credits. Market powers have a significant impact on producers and other actors involved. Even if the market powers are relatively well known, it is very difficult to quantify their indirect environmental impacts, as the influences may be very far-reaching with complicated cause and effect relationships. These problems are encountered not only with substitution effects of co-products, but also with biofuels. For example, it is not obvious that in reality one litre of biofuel produced replaces the corresponding amount of fossil fuel, if more products are available and the overall end-use efficiency thus decreases.

The complexity of the substitution issue and the interactions between co-products and substitutes are illustrated in Figure 4 where soybean meal production is assumed to increase by 1000 g (Dalgaard et al. 2008). Soybean oil is assumed to replace palm oil and rapeseed oil in case a, and b, respectively. The avoided production of palm kernel meal and rapeseed cake is assumed to be replaced by additional meal production based on soybean meal and spring barley in order to keep the protein and energy content of the meal constant. The system forms a loop which is iterated by Dalgaard et al. 2008 (Figure 4). In practice, vegetable oils form one and co-produced animal meals another kind of interconnected pool where the products are more or less used as replacements of each other depending on availability, prices etc.

3.5 Emission sources and impacts

Emissions to air and water over the life-cycle of products are caused in various phases of the product chain and can for biofuels be roughly linked to raw material production, harvesting, storage and transportation, and to biofuel processing, storage, transportation, distribution, and use. The emissions result from the requirement of auxiliary energy carriers and other goods, such as chemicals and fertilisers over the lifecycle of the particular inputs. In addition, emissions are caused as process emissions from biological, chemical, and physical reactions in soil and biomass, due to cultivation and harvesting of raw materials and processing of biofuels.

Environmental impacts of biofuels can be roughly separated into direct and indirect impacts, although the boundary between them is more or less unclear. Direct impacts can be assumed to be caused within the "*defined system boundary*", from the use of auxiliary energy and inputs of other non-energy related goods, production of infrastructure, process emissions from cultivation and harvesting of raw materials and processing of biofuels, and from biofuel combustion. All other impacts can be seen as indirect impacts as they are significantly influenced by market mechanisms. The use of auxiliary inputs (e.g. electricity, fossil fuels, chemicals, machinery etc.) and land area for production of biofuels likely increase competition between them, causing complicated transition effects. In addition, the substitution effects from replacing products by coproducts of biofuels or fossil fuels by biofuels can be seen as indirect impacts of producing biofuels.

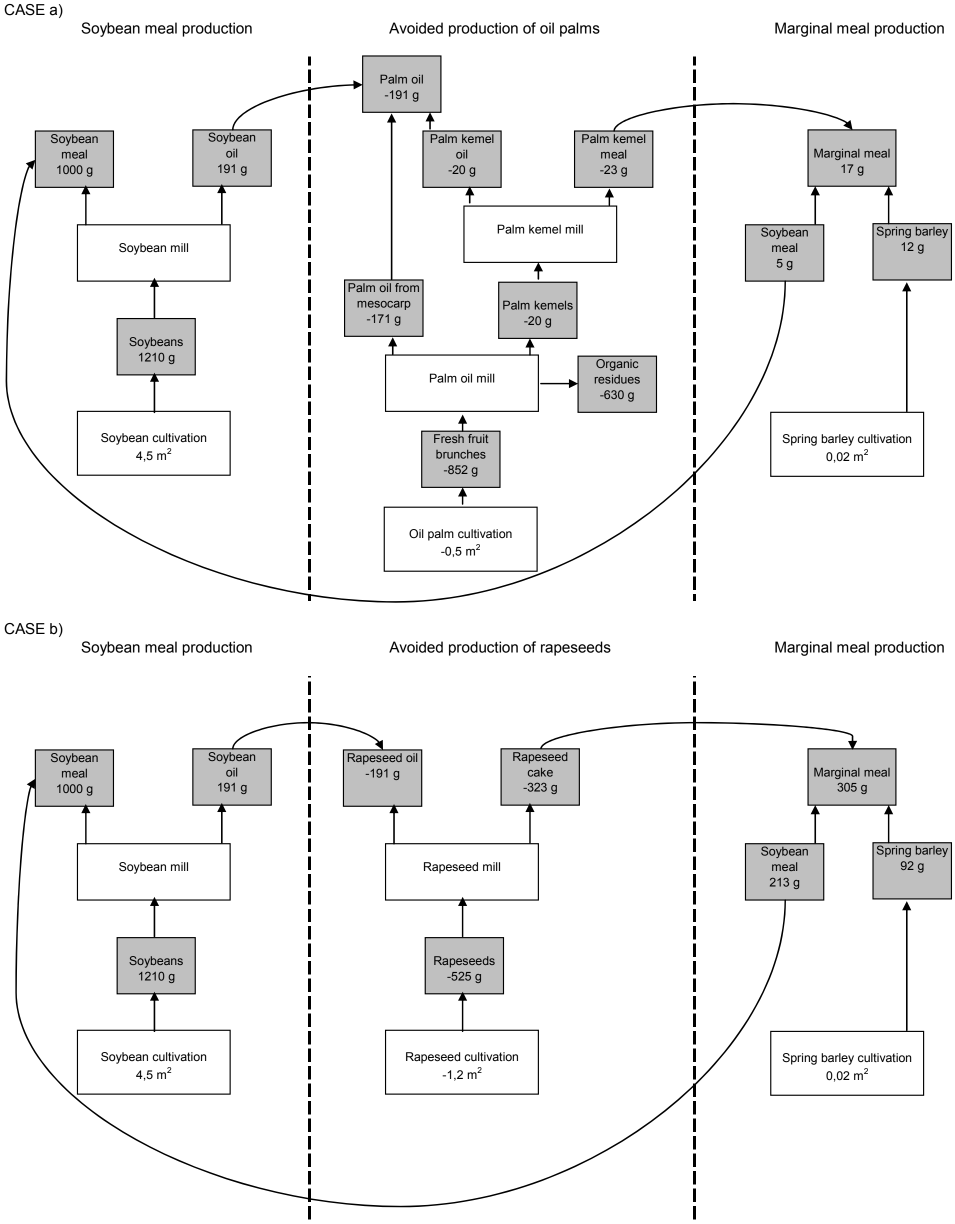

Figure 4. Soybean/palm loop (CASE a) and soybean/rapeseed loop (CASE b) for LCA of soybean meal based on Dalgaard et al. (2008). An increased demand for 1000 g of soybean meal produced results in avoided production of 852 g of fresh fruit bunches in oil palm cultivation or -525 g avoided production of rapeseeds and increased production of soybean meal and spring barley equalling to 5 g and 12 g in the case of palm oil replacement and 213 g and 92 g in the case of rapeseed oil replacement, respectively.

Both direct and indirect impacts may be difficult to quantify, due to lack of knowledge and data. As regards direct impacts the main uncertainties and lack of knowledge are involved in impacts of biomass harvesting on soil carbon and nutrient balances, feedback mechanism from soil to biomass productivity, nitrous oxide emissions from fertilization and cultivation, process emissions from technologies under development, and emissions of certain substances, in particular heavy metals. In addition, many case specific characteristics, e.g. regional cultivation circumstances, available energy sources or transportation distances, may cause significant sensitivity in the results between various cases.

Indirect impacts may be very difficult or impossible to recognize as a whole in an objective manner. However, their significance may be remarkable. If biofuel production increases the competition between raw materials or the land area, it means that more resources are likely used to satisfy the needs of all competing purposes. This may lead to very harmful impacts such as deforestation and destruction of tropical peat swamps. Such impacts may compensate or even worsen the overall environmental benefit that would have been achieved by replacing fossil fuels by biofuels. In addition to land use changes, also other indirect impacts occur due to the use of auxiliary inputs, e.g. electricity, chemicals etc., and the replacement of products by coproducts and biofuels. All indirect impacts are subject to significant uncertainties, which may be very difficult to quantify in practice. In addition, there is typically a lack of knowledge, of where the indirect impacts take place, thus making site-specific or regional environmental impact assessment, in particular, very difficult.

3.6 Identification of key environmental impacts

Various environmental impacts are caused by a number of different compounds emitted to the air or water. For example, greenhouse impact results from direct and indirect greenhouse gas emissions. Direct greenhouse gases include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6), which are regulated under the Kyoto protocol, but also ozone depleting compounds CFCs, HCFCs, and halons regulated under the Montreal Protocol, and non-regulated water vapour, ozone (O_3), and certain synthetic compounds (fluorinated ethers, perfluoropolyethers, hydrocarbons). The atmospheric lifetime and radiative efficiency of the compounds vary significantly depending on the gas. In addition to direct greenhouse gases, certain compounds including carbon monoxide, volatile organic compounds, nitrous oxides, halocarbons, and hydrogen have an indirect impact on the global warming through various atmospheric reactions (IPCC 2007a). Furthermore, some of the compounds have both a warming and a cooling or just a cooling impact on the global mean temperature. All the above-mentioned compounds are not highly relevant for biofuel production, e.g. fluorinated greenhouse gases, but many are at least to some extent.

It is very typical that greenhouse impacts of a certain product chain are studied by only considering the relevant compounds regulated under the Kyoto Protocol. As regards biofuels, CO_2, CH_4, and N_2O are likely the most relevant greenhouse gases to be considered.

In addition to climate change, other environmental issues that are relevant for biofuels should also be assessed. Acidification is mainly caused by sulphur dioxide (SO_2), nitrogen oxides (NO_X), and ammonia (NH_3). Most of the tropospheric ozone formation is caused by nitrogen oxides (NO_x) and hydrocarbons (HC, including methane CH_4 and volatile organic compounds VOC). Eutrophication means enhanced primary production of natural biomass in terrestrial or aquatic ecosystems, due to increased nutrient (nitrogen (N) and phosphorus (P)) inputs. Nutrients can be directly discharged to soil or water, or they (mainly NO_x and NH_3) can be emitted to air from where they are deposited to water and soil.

Ecotoxicity and human toxicity are impacts caused by different substances, which are harmful in various concentrations in the environment. Human action causes emissions of thousands of substances to the air, soil and water. It is, however, problematic to measure all harmful substances released to the environment. For this reason, often only restricted data on emissions causing toxic impacts is available from different process units along the biofuel chain. Typically metals and some organic compounds released from point sources are assessed in international emission inventories. Such emissions are: Arsenic (As), cadmium (Cd), cobalt (Co), chrome, chrome IV (Cr, CrIV), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb), tin (Sn), antimony (Sn), vanadin (V), zink (Zn), PAH-coumpounds (PAH), dioxins and furans (DF).

In some cases (e.g. in the use of peat), life cycle toxic impacts of biofuel products can also be of significant importance. In addition, toxic emissions to the soil from the use of e.g. pesticides and indirect emissions from land use are worth taking into account in the inventory analysis. Unfortunately, they are, however, often missing in LCA applications, due to the lack of relevant data.

Besides the emissions of different substances to the environment, the biofuel chains also cause other environmental interventions. These interventions and their impacts are not yet well-established in life cycle impact methods, and therefore, in this project, they are only analysed qualitatively. Firstly, impacts of land use are caused by different types of land occupation and transformation. The latter describes the change in the area of a land use type per year. Secondly, especially in arid and semi-arid regions, the use of irrigation water in biofuel raw material production may be significant. Furthermore, the refining processes also require water. Thirdly, biofuel raw material production has certain impacts on soil health and soil production capacity, including such aspects as the content of soil organic matter, erosion and compaction, soil acidification and nutrient level, and salinity. The fourth, very important, aspect is biodiversity. Negative biodiversity impacts may appear as losses of ecosystems, habitats, species, or genetic variety.

3.7 Environmental impact assessment

In life cycle impact assessment (LCIA) the values of environmental interventions assessed in the inventory analysis are interpreted on the basis of their potential contribution to the environmental impact. The term “potential contribution” indicates that the result of LCIA is not an absolute value, and that LCIA is a relative approach to environmental assessments. The idea is that comparative studies do not need such detailed data on temporal and spatial aspects, as do the more absolute methods such as the environmental risk assessment. The strength of LCA is its focus on an overall impact.

In LCIA appropriate impact categories (e.g., climate change and acidification) are selected first on the basis of the existing inventory data and the general knowledge about cause-effect relationships. After that the inventory data is assigned according to impact categories (classification). In the characterisation, the chosen characterisation factors enable an aggregation of the emissions within each impact category. The emission values are converted into impact category indicator results, by multiplying the emission values by the corresponding characterisation factors. In order to produce scientifically based characterisation results, the determination of characterisation factors within a certain impact category is a key issue.

Before characterisation, indicators for the categories (e.g. radiative forcing in climate change, H^+ release in acidification) and models to quantify the contributions of different environmental interventions to the impact categories are selected. Characterisation factors are derived from the calculations of the model.

From a decision maker's perspective, impact category indicator results are more manageable forms than data on environmental interventions, but due to indicators' proxy characteristics they are difficult to interpret. In order to obtain a more comprehensive view of impact category indicator results, normalisation and weighting can be conducted. In normalisation the impact category indicator results of the studied product is divided by the reference value of the same impact category. A reference value is the impact indicator result calculated on the basis of an inventory of a chosen reference system (e.g. all society's activities in a given area and over a specified period of time) (Consoli et al. 1993; Wenzel et al. 1997; Finnveden et al. 2002).

Normalisation can further help the interpretation of impact category results, but in practice comparative evaluations require data about trade-offs between different category indicator results in order to choose the best alternative. The trade-offs are determined as weighting factors (weights) in the weighting phase. In practice, the determination of weights is based on value choices.

Although there is an approximate consensus on the procedural framework of LCIA, the methods may vary in LCA applications. Different methods can easily produce different results. The results depend among other things on the coverage of impact categories, the chosen impact category indicators, and the models chosen for characterisation factors. Furthermore, a reference system used in normalisation can affect the interpretation. When the aim of a study is to combine different impact category indicator results into a single value, the results are highly sensitive to changes in the impact category weights (e.g. Seppälä 1999). Because there is no clear consensus among the LCA community on the determination of weights (see e.g. Finnveden et al. 2002), the LCA community has been reluctant to use single value scores in LCA case studies (Barnthouse et al. 1997). According to the International Organisation for Standardization (ISO 14040 2006), weighting shall not be used for comparative assertions disclosed to the public, due to its subjective character.

3.8 Socio-economic impacts

Along with environmental aspects, also socio-economic issues are an essential part of the biofuel sustainability. Key aspects of *social sustainability* include job creation, ownership, access to food, land and water, labor conditions, and general rural development, while the *economic sustainability* implies that the total costs to society, including financial costs, environmental, and social costs, should be outweighed by the benefits (GBEP 2008). Sometimes the scope of the economic sustainability refers to issues such as the development of local prosperity (employment, infrastructure, training, services) and the efficiency of production (see also Chapter 6).

Social sustainability is often seen as a target, which can be measured with different assessment methods (Raitio & Rannikko 2006). However, even though the social sustainability has often been an issue both in social and scientific discussions, the concrete content is still unclear and variable. The main reason for this is that social sustainability is strongly related to the context under review. In different regions and sectors the concrete definition of social sustainability may differ. In the same society there may be winners and losers in a social and economic sence. Therefore it is important to ask the questions such as: *"Who is the beneficiary?* or *"From who's viewpoint are we looking at sustainability?"* Furthermore, social sustainability is strongly linked with the other fields of sustainability. Negative environmental sustainability trends, such as climate change, can have serious negative impacts on social sustainability (Rossi & Lambrou 2008). Economic development has its implications on society, for example on the employment. Furthermore, competition of land and raw materials between different purposes has several environmental, social, and economic linkages.

The concept of social sustainability aims at a society, which can adapt and create positive responses in changing situations (Antikainen et al. 2007). On the other hand, social sustainability is an anthropocentric concept, in which an individual's own control over his/her life is stressed (Raitio & Rannikko 2006). Therefore, issues such as gender equity and abandonment of forced and child labour are seen as essential parts of social sustainability.

Several sets of indicators for socio-economic sustainability of biomass and biofuels have been introduced (see Section 2.4 and Appendix A). Additionally, more general indicators including socio-economic aspects have been developed by for example the Global Reporting Initiative (GRI), EU/Eurostat, and the

United Nations' Commission for Sustainable Development. A set of Finnish national indicators has also been developed. In LCA, socio-economic aspects are often excluded or only discussed on a general level, because currently, there is no methodology to include socio-economic aspects into the LCA. However, the UNEP/SETAC Life Cycle Initiative has established a task force on the "Integration of socio-economic aspects into LCA". It aims at developing a sound methodology for a Social LCA (LCSA).

4. Greenhouse gas impacts

4.1 Timing issues in mitigation of climate change

Various compounds have different impacts on global warming due to various atmospheric lifetimes and specific radiative forcing properties of the compounds. There is a large scientific consensus on that increasing atmospheric concentrations of greenhouse gases have an increasing impact on the global mean temperature (IPCC 2007a). The increase in the global temperature may have serious and irreversible impacts on the ecosystems. These implications are not well known, but are very likely the more serious the more the global mean temperature increases, as illustrated in Figure 5.

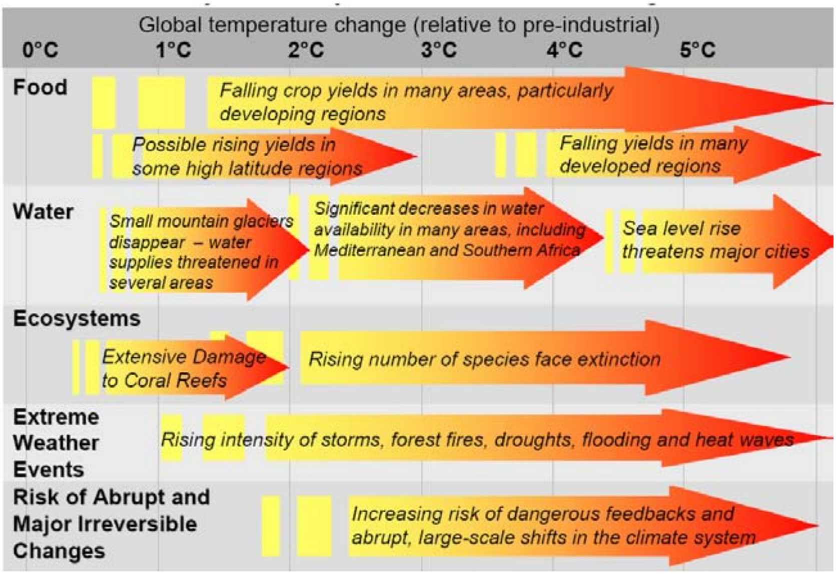

Figure 5. Impacts of global temperature rise (Stern 2006).

The current atmospheric concentration of carbon dioxide equals approximately some 380 ppm CO_2 (IPCC 2007a). In addition, other greenhouse gases (mainly methane and nitrous oxide) regulated under the Kyoto Protocol and CFC gases regulated under the Montreal Protocol correspond to some 50 and 25 ppm CO_2-eq. respectively (IPCC 2007a). However, inertia of many natural processes linked to climate change is huge (Figure 6). The temperature increase is delayed due to particle emissions, which decrease radiative forcing and the large heat capacity of the oceans. By taking these factors into account the common calculatory concentration of greenhouse gases and other factors equals some 375 ppm CO2-eq (IPCC 2007b). The current growth of greenhouse gas concentrations in the atmosphere is approximately 2 ppm CO_2-eq.

When assessing the effectiveness of various actions on mitigating the climate change the fundamental issue to be considered is the target. The ultimate objective of the United Nations' Framework Convention on Climate Change (UNFCCC 1992) is the stabilisation of atmospheric concentrations of greenhouse gases at a level that prevents dangerous anthropogenic interference with the climate system. However, the UNFCCC has not provided any concrete limits for global temperature increase, atmospheric concentrations of greenhouse gases or emission reductions required. The lower the global temperature increase is desired to be limited to, the lower is the stabilisation level of greenhouse gas concentrations in the atmosphere and the more rapidly the greenhouse gas emissions are needed to be reduced (Figure 6).

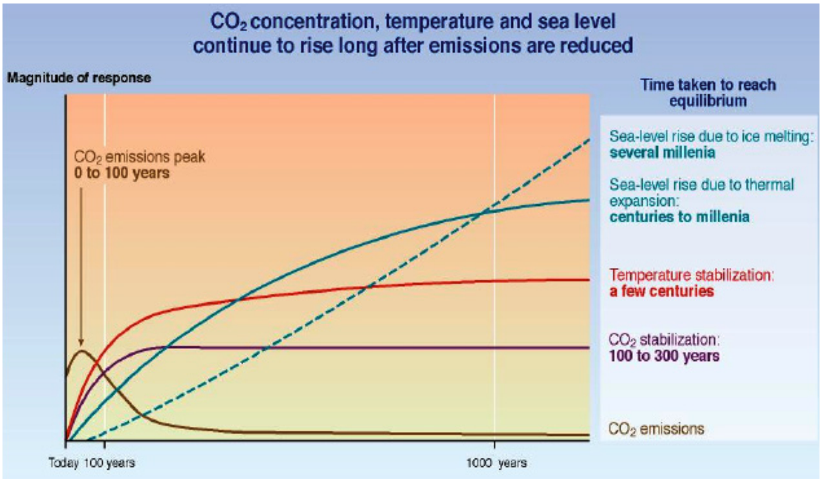

Figure 6. Time frames and inertial factors associated with climate change in principle. Time frames should be considered for illustrative purposes only (IPCC 2001).

The European Union has proposed that the global warming should be limited in maximum to 2 degree Celsius above the pre-industrial period (EC 1996, 2007). The target for stabilising atmospheric greenhouse gas emissions sets the frames for a time horizon that is relevant to consider, when assessing the effectiveness of various actions to mitigate climate change. As regards the 2 degree target proposed by the EU, the time frame for any single emission reduction action should correspond to overall emission reductions required to achieve the target. According to IPCC (2007c), global emissions should be reduced by at least 50% by year 2050 compared to year 2000 in order to maintain a reasonable likelihood of achieving the 2 degree target.

4.2 The generic alternatives of treating biomass stocks in climate change

The capability of plants to sequester carbon and emit to the atmosphere vary between species. Short rotation biomass such as agrobiomass decays rapidly after growing. Instead, long rotation biomass such as pine or spruce in boreal forests may exceed the rotation period of 100 years and consequently act relatively long as storage of organic carbon. The rotation period of carbon is a very important factor to be considered, when assessing the effectiveness of various methods to use biomass in the mitigation of climate change. A large pool of terrestrial carbon is the soil, which is also influenced by the utilisation of biomass. The turnover rate of this pool is usually slow, but human-induced land-use changes can convert soil into a strong source of emissions.

Basically, biomass can be used in three different ways in mitigation of climate change: in carbon substitution, sequestration or conservation. The effectiveness of various methods depends on the time-frame relevant for the target to mitigate climate change, the carbon sequestration rate and the substitution credits available. The dynamics of carbon sequestration and substitution is illustrated in Figure 7.

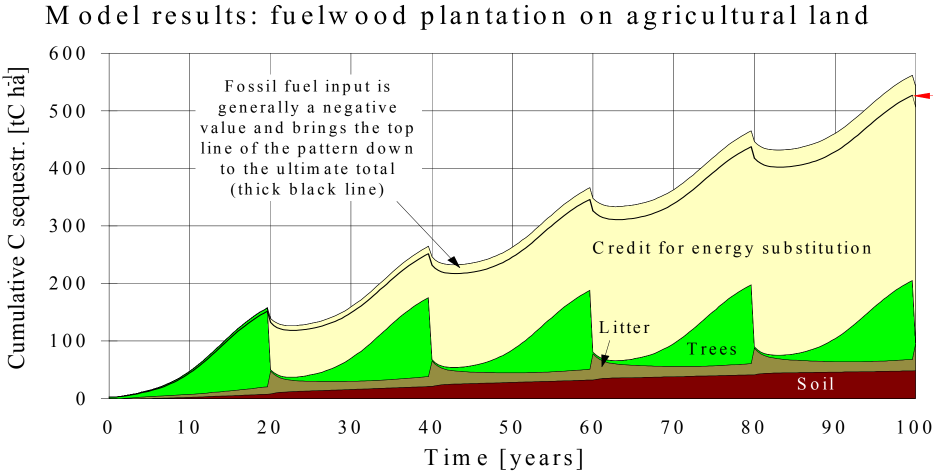

Figure 7. Illustration of net carbon uptake in soil and litter, net carbon increase in trees and saved carbon emissions from the replacement of fossil fuels with bioenergy when one hectare of agricultural land is afforested to produce a biofuel with a 20 year rotation (Joanneum Research 2008).

In **substitution management** biomass is used to displace fossil fuel based emissions. Substitution credits may take place directly through fossil energy replacement or indirectly through energy intensive material replacement in the case of biomass based products. The most significant substitution credits likely take place when cascading the biomass use: first as products and at the end of their life cycle as energy.

In **sequestration management** atmospheric carbon is accounted into terrestrial ecosystems. The possible methods include e.g. reforestation, increasing of biomass stocks in existing forests and long-living products, and changing of agricultural practices to increase soil carbon balances. In the case of land-use changes e.g. forestation or plantation, however, the climatic impacts are not only caused by the changes in atmospheric greenhouse gases balances but also by the changes in surface albedo. For example, Betts (2000) found that the change in surface albedo by the planting of coniferous forests in areas with snow can contribute significantly to the radiative forcing. Brovkin et al. (1999) found that cooling due to the albedo change from deforestation was of the same order of magnitude as the increased radiative forcing from CO_2 and solar irradiation. Bala et al. (2007) found that a global-scale deforestation event could have a net cooling influence on the Earth's climate. On the other hand, Matthews et al.

(2004) suggest that carbon emissions from land cover changes (deforestation) tend to exceed the cooling that results from change in the surface albedo. However, significant uncertainties are involved in the impacts of the changes in the surface albedo due to land-use changes, but due to the potential significance of the issue, more research work is certainly required.

In **conservation management** significant carbon stocks are protected. These may include e.g. native forests and peatlands including high carbon stocks per land area. For example, tropical peat swamp forests are areas with high terrestrial carbon stocks per land area. They are at the moment hot spot areas of carbon dioxide emissions globally, due to land-use changes. Conservation management of this kind of terrestrial carbon stocks would be an efficient means of reducing greenhouse gas emissions.

From climate change mitigating perspective the main advantage of substitution management over sequestration and conservation management is that substitution management creates cumulative credits due to displaced fossil carbon emissions compared to the reference scenario. The biomass stock harvested and used for substitution is compensated by re-growth of new biomass, which can be rapid or take a long time, or in case of unsustainable forest management is not compensated for at all. A major factor to be considered is the time frame that is relevant with the fundamental target to mitigate climate change (e.g. the 2 degree target). There is also a risk that the biomass carbon stock is lost, due to natural disturbances (e.g. forest fires) without any substitution credits. This could make sequestration and conservation managements more uncertain in some cases. However, the more rapidly atmospheric concentrations of greenhouse gases are needed to be reduced the more an important role such options play.

4.3 Principal indicators for choosing the most efficient mitigation alternatives

Biomass is a limited resource. In addition, the challenge to mitigate climate change will require significant emission reductions in the upcoming few decades. The required reductions in greenhouse gas emissions are not possible to be achieved exclusively by biomass despite the management options selected. Consequently from climate change mitigating point of view, the biomass should be used as effectively as possible to provide optimal reductions in greenhouse gas emissions within a given time frame that is relevant with the fundamental target to mitigate climate change (e.g. 2 degree target).

When substitution management is applied and biomass is harvested, the effectiveness of various end use applications to mitigate climate change should be measured by using appropriate indicators. Such indicators should measure objectively the achieved benefits on radiative forcing, compared to a reference scenario and per biomass harvested within the relevant time frame. The use of the radiative forcing method taking into account dynamics of greenhouse gas emissions and sinks is therefore suggested. Such a method does consider the release of carbon dioxide into the atmosphere during biomass decay or combustion, accumulation of carbon into growing biomass, and the timing differences between them. The simplified static consideration of emissions only weighted with GWP factors may also be appropriate, if the possible exceeding of the biomass rotation period compared to the relevant time under consideration is somehow taken into account. Otherwise, the suitability of the GWP method for assessing greenhouse impacts over the life cycle of any action is questionable.

The practical problems encountered in defining appropriate indicators to measure the effectiveness of actions in mitigating climate change are associated with the lack of knowledge of the exact time frame and uncertainties of carbon sequestration and storage permanence. In addition, the problems with definition of system boundary, reference scenario, and other methodological issues make any indicator more or less subjective.

In addition to biomass, also suitable land area to produce biomass or money that can be used for climate change mitigation may be limiting factors. Schlamadinger et al. (2005) propose principal indicators appropriate to measure the optimal use of biomass in climate change mitigation as achieved emission reduction per biomass, land area or money depending on the limiting resource. In practice, also other factors, such as different environmental or social impacts may also be limiting factors for biomass use. Thus, the optimal use of biomass is always a trade-off between various dimensions of sustainability and depends on the weighting of various impacts.

4.4 Importance of various factors on greenhouse gas impacts of biofuels

Greenhouse gas impacts of biofuel production and use depend significantly on the defined spatial and dynamic system boundary, as discussed in the earlier Chapters. In addition, the uncertainties and sensitivities involved in the assumptions and the indicators selected to measure the greenhouse gas impact may significantly influence the results. Therefore, no quantitative assessment of greenhouse gas impacts of producing and using biofuels were given in this report for any of the studied biofuels. The importance of various factors on greenhouse gas impacts of biofuel production and use is illustrated in Chapter 8 based on the published studies and expert assessment.

5. Other environmental impacts than climate change

In LCAs the number of impact categories assessed varies depending, for example, on the chosen assessment methodology, objectives, product systems, and the cost recourses of projects. However, a starting point should be that all relevant impact categories related to the product systems should be taken into account. In this work, the selection of impact categories were done on the basis of the results obtained from published LCA studies of biofuels. In addition, the classification of impact categories recommended by the LCA community (Udo de Haes et al. 2002, Guinée et al. 2002) has been used. In addition to climate change the following other impact categories were assessed:

- Acidification
- Tropospheric ozone formation
- Particular matter
- Eutrophication
- Ecotoxicity and human toxicity
- Land use
    - Soil health and production capacity
    - Impacts on biodiversity
- Use of water.

Here, main points of each environmental aspect are briefly summarized. Based on literature and published studies, a more detailed screening of what is generally known about the other impact categories in connection to biofuels and especially the following fuel chains: NexBTL, FT-diesel, ligno-cellulosic ethanol and sugarcane ethanol is presented in Chapter 8. These biofuels are seen as potential for Finland even though some of them are still in their development phase. In that context, we also summarize the state of art for assessing other environmental impacts in LCA.

5.1 Acidification

Acidification refers to the reduced capacity of the ecosystem to neutralise or buffer acidifying atmospheric deposition. Most important acidifying compounds are sulphur dioxide (SO_2), nitrogen oxides (NO_X) and ammonia (NH_3). As different ecosystems have different buffering capacities, it is important to know where the emissions take place in order to obtain reliable results. However, in practice, the characterisation of acidification in the LCAs of biofuels has been based on site-generic[2] characterisation factors. In the future, there is a need to use site-specific or country-dependent approaches for assessing acidification. Acidifying emissions are formed in the agricultural phase (use of fertilizers, use of machinery, potential land clearing or harvesting by biomass burning), in transportation, production and use of auxiliary energy and chemicals, and when using the biofuel in vehicles.

5.2 Tropospheric ozone formation

Most of the tropospheric ozone is formed photo-chemically and chemically when nitrogen oxides (NO_x), carbon monoxide (CO), and volatile organic compounds (VOC, including methane CH_4) react in the atmosphere. The ozone formation process is rather complex as it depends on the presence of precursors and meteorological factors, and due to the short lifetime of ozone under specific conditions. Therefore, when determining the characterization factors in LCA, it is important to know the emission gradient and the population density. Emissions causing ozone originate in different combustion and burning processes.

5.3 Particulate matter

Formation of particulate matter (PM) is a problem especially to human health. Main sources of PM include different types of combustion processes, forest fires, and road dust. In biofuel chains, the emissions originate mainly from the production stage, the use of auxiliary energy, transportation, and machinery used for mechanical handling.

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[2] Site-generic means that the characterization factor does not depend on the location where emission takes place. Site-specific or country-dependent factors take the emission location into account.

5.4 Eutrophication

Eutrophication, enhanced primary production of natural ecosystems, is caused directly by N and P emissions from human activities, i.e. agriculture, forestry, industrial and residential waste waters, and indirectly via N deposition due to emissions of NH_3 and NO_x from agriculture, traffic, and energy production. The response in the environment (eutrophication) of a certain nutrient release depends on the local environmental circumstances. The Finnish waters for example are very sensitive to eutrophying emissions. Agriculture is the main source of eutrophying emissions in many areas, also in Finland. Increased biofuel production, if added on the currently existing production area, increases the potential for nutrient leaching.

5.5 Ecotoxicity and human toxicity

Different substances released to the air, water and soil, during the life cycle of the biofuel, have toxicological effects on animals, plants, and humans. Some of the substances are also carcinogenic. To be sustainable, the risk of cancer or other toxicological effects must not increase when fossil fuels are replaced with biofuels. In this study the following substances were considered, due to their significance and for data availability reasons (see ENVIMAT 2008): arsenic (As), cadmium (Cd), cobalt (Co), chrome, chrome IV (Cr, CrIV), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb), tin (Sn), antimony (Sb), vanadium (V), zinc (Zn), PAH-compounds (PAH), and dioxins and furans (DF). There are also many volatile hydrocarbons like 1,3-butadiene, benzene, formaldehyde, acetaldehyde, 1-3-butadiene in exhaust gases of both gasoline and biofuel powered vehicles. These compounds are known to have carcinogenic or mutagenic activity.

5.6 Impact aspects related to land use

Land is a limited resource. Increasing biofuel production requires additional land area. Significant expansion of the bioenergy production area seems not to be possible without conflicts between fuel, food and feed production, production of other biomass raw materials, and other ecosystem services, such as maintenance of carbon storages and biodiversity. Bioenergy production occupies and transforms land directly and also indirectly by causing displaced functions to move to other areas (see Figure 2). In the LCA methodology, impacts related to land use is still under development. Direct and indirect land use change can lead to several negative environmental impacts, such as to losses of carbon stocks and of habitats and species in high value biodiversity areas.

5.6.1 Soil health and production capacity

Unsustainable use of land leads to reduction in soil fertility and production capacity, which furthermore, can lead to yield losses. Soil health and production capacity is closely related to soil biodiversity. In biofuel chains, soil health and production capacity relates mainly to the raw material production phase in agriculture and forestry. Similarly to many other environmental impacts, the methods for assessing soil health and production capacity in the LCA are still insufficient.

5.6.2 Impact on biodiversity

Biodiversity losses are probably one of the most important implications of expanding biofuel production. One of the main concerns is that the biofuel production causes directly or indirectly destruction of high biodiversity value areas such as to tropical rainforests, thus causing permanent and significant losses of habitats and species. In Finland, the main threat is related to the use of logging residues and stumps, which can have severe implications on the forest saproxylic (deadwood dependent species).

5.7 Use of water

Water shortage is a significant problem in many areas, and expanding production of biofuels in areas depending on irrigation may considerably increase the water problem. Despite water consumption being a severe problem in many regions so far, consumption as well as water depletion, water quality, and water pollution indicators have been neglected in many LCA studies on biofuels. One important reason is that a uniform methodology on water resources is lacking from the LCA. In general it can be said that biofuel crops that do not threaten the water resources (e.g. not needing irrigation) should be preferred, but the actual sufficiency of water depends on many factors, such as the climate (rain, evapotranspiration), the crop species, agricultural management practices, and other water uses in the region. In addition, in the future climate change can significantly change the global water economy.

6. Socio-economic aspects

The biofuels have raised the question about the socio-economic sustainability of biofuels and especially in developing countries expanding production has been identified to pose a considerable risk to aspects such as land use rights, food availability, workers rights, equity, etc. Assessment of socio-economic sustainability is – if possible – even more difficult than the assessment of environmental sustainability. Several sets of criteria and certification systems including socio-economic aspects have been and are being developed (see Section 2.4). However, there are serious doubts if these kinds of systems can secure sustainability especially in regions where the starting point for social sustainability is unsatisfactory and corruption levels are high (see e.g. Doornbosch & Steenblik 2007; Biofuelwatch et al. 2007). Furthermore, there is relatively little knowledge available on how biofuel production in reality impact on socio-economic aspects. Anyhow, some of the aspects are discussed in the following. However, a complete picture cannot be given in this context.

Rossi and Lambrou (2008) explored the potential gender-differentiated socio-economic risks associated with the large-scale production of 1st generation3 liquid biofuels in developing countries. They concluded that the production of liquid biofuels may even exacerbate particularly such pre-existing gender-based socio-economic inequalities as terms of access to and control of land and productive assets in general, as well as historic discriminatory practices. The employment opportunities and conditions on plantations may also differ for men and women, and therefore they may be exposed to different work-related health risks. The resilience of rural communities and individuals, in particular women and female-headed households, to exogenous shocks (e.g. climate change) may

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[3] According to UN 2007, 1st generation refers to biofuels made from sugar, starch, vegetable oil or animal fats using conventional technology.

also be lowered along with the environmental and socio-economic risks associated with biofuels. These consequences can occur if the production threatens their socio-economic activities, their natural resource base and the associated knowledge.

Socio-economic sustainability has often been an issue when the total sustainability of Brazilian sugarcane ethanol has been discussed. Claims that especially workers´ rights are trampled have been presented by e.g. media. However, it seems that the competition with food production associated with the indirect and induced impacts of the increasing sugarcane production is the major bottleneck in socio-economically sustainable sugarcane ethanol production (Smeets et al. 2008). On the other hand, Goldemberg et al. (2008) argue that "sugarcane growth does not seem to have an impact on food areas, since the area used for food crops has not decreased. The expansion is mainly taking place over pasture lands." They also argue that an increase in the sugarcane production without a wide spatial expansion is possible by growth of overall agricultural and industrial productivity, development of new species, and genetic improvements. In addition to the competition with food production Smeets et al. (2008) concluded that working conditions and worker rights, child labour, and social responsibility and benefits are medium bottlenecks in socio-economical areas of concern, and even though improvements have already been made in these areas, more work need to be done. Goldemberg et al. (2008) also see needs for improvements in these areas, especially in working conditions and child labor. Even though the Brazilian government has signed international recommendations and given laws on these issues, the inspections are not sufficient and violations in these areas exist. On the other hand they point out that the employment and wages are, for example, better in sugarcane business than in many other comparable areas. Many sugarcane mills also provide schools, daycare, health care, and meals for the workers and their children.

The 2nd generation[4] biofuels, using raw materials not competing with food, are often seen as salvage for socio-economic problems. However, even though, the 2nd generation biofuels are not expected to have similar socio-economic implications as the 1st generation biofuels, they may bring additional pressure on forests and wood resources. Women in least developed countries may spend even more than one third of their productive time in collecting and transporting

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[4] According to UN 2007, 2nd generation fuels are made from lignocellulosic biomass feedstock using advanced technical processes.

wood for heating and cooking. Because the help of the children is needed they might be prevented from attending school (GBEP 2008). Therefore it is necessary to ensure that the 2nd generation biofuels do not even further endanger these scarce resources. The recommendation of Rossi & Lambrou (2008) is that when developing 2nd generation biofuels, the gender-differentiated risks and opportunities need special attention. In developed countries, socio-economic sustainability concerns are somewhat different, and they relate more to job creation and to the protection and recreational values of the environment. In future, the latter aspects may be emphasized even more. For example Raitio & Rannikko (2006) studied social sustainability of the use of forests in Eastern Finland, and discovered that the importance of wood use and forestry for locals as a source of livelihood was not very important anymore. On the other hand, dependence on forests still exist, but more through tourism and recreation.

7. Sustainability aspects of evolving biofuel technologies from a Finnish point of view

7.1 Trends in the production and use of liquid biofuels

Worldwide use of transport biofuels equalled 24.4 Mtoe in 2006, whereas the use was only 10.3 Mtoe and 6 Mtoe in 2000 and 1990, respectively. Biofuels accounted for 1.5% of the overall road transport fuel demand in 2006. According to forecasts by the International Energy Agency (IEA 2006), the use of gasoline and diesel for road transport will double in the next 25 years and greenhouse gases will increase commensurably unless preventative actions are taken and/or new car and engine technologies are introduced. Road traffic causes already some 84% of all emissions from the transport sector in the EU. The share of traffic of total energy consumption in the European Community is over 30% and is constantly growing, as are the GHG emissions. This is why the European Commission's White Paper claims that traffic dependency on fossil oil (currently 98%) should be reduced by using alternative fuels such as biofuels. (EC 2007)

The main transport biofuels on the market today are bioethanol, different fatty acid methyl (or ethyl) esters (FAME biodiesel) and to a lesser extent also methane (biogas). Bioethanol has, by far, the largest market share, although the biodiesel market is currently growing at a faster rate. The production of ethanol was about 18 Mtoe in 2005. The main producers were Brazil and the USA. Biodiesel derived from palm oil, exported from Indonesia and Malaysia to the European Union, accounts for the majority of biodiesel trade (IEA 2008). The FAME biodiesel production was about 2.4 Mtoe in 2005, Germany being the main producer.

IEA (2006) predicts that the use of biofuels in transport would rise from 20 Mtoe in 2005 to 92 or 147 Mtoe in 2030 corresponding to 4% or 7% of the world transport fuel demand in the Reference scenario or the Alternative Policy scenario, respectively. Second generation biofuels are expected to become commercially viable but still to make only a small contribution to the total supply of biofuels by 2030. Most of the growth is expected to come from the United States, Europe, China and Brazil. Within the recent few years several countries, including the United States, China and the European Union, have announced aggressive policies for encouraging the production and use of biofuels. Some countries, in particular the EU, have started to reconsider their ambitious biofuel policies due to the concern of sustainability issues. (IEA 2008)

The European Commission and Parliament has set a 10 per cent binding minimum target for biofuels or renewable energy in transport to be achieved by each Member State by 2020. A 10% replacement of EU's diesel demand by conventional FAME biodiesel would account for about 19% of world vegetable oil production in 2020. A 10% replacement of EU gasoline by bioethanol would use about 2.5% of the world's cereals production. OECD expects the average world agricultural yield improvement to remain at about 1% per annum, which is less than half of their forecast of the world demand increase (2.3% per annum). So if the EU target would be covered by increased use of crop-based biofuels, more land will be planted with crops and increased demand of biofuels will cause land-use changes.

If the biofuel target for Finland in 2020 is covered solely by agro-based, first generation biofuels produced from domestic agricultural resources, rapeseed for biodiesel should be grown on at least 250 000 hectares of arable land and barley for bioethanol on at least 160 000 hectares of arable land (MMM 2005). Presently rapeseed and barley for non-fuel purposes are grown on 90 000 ha and 530 000 ha, respectively, and the size of set-aside fields in Finland is in total approximately 500 000 ha.

Alternative options are the production of so-called 2nd generation biofuels from lignocellulosic resources (like wood, straw, and reed canary grass) and/or the import of biofuels. Optional routes include the use of animal based waste grease or tallow and used cooking oils for biodiesel production and organic wastes from the food sector for bioethanol production. These routes are applicable in case sufficient amounts of raw materials of acceptable quality can be collected and delivered to processing plants at reasonable cost. Hydrogenation of oils and fats is a new process that has entered the market. A good example is the NExBTL process of the Finnish oil refiner Neste Oil. The first plant of the annual production capacity of 170 000 tonnes of renewable diesel has been in operation since 2007 and the second plant of the same capacity is under construction in Neste Oil's Porvoo refinery, Southern Finland. So far imported palm oil has been the main raw material, but all kinds of vegetable oil (soybean oil, rapeseed oil etc.), used cooking oils, and tallow, either domestic or imported, can be utilised as raw material.

The economics of current biofuel technologies are heavily dependent on feedstock costs. As a result there is considerable pressure on the cheapest feedstocks. Therefore there are a number of technologies being developed to allow the production of biofuels from lingocellulosic and other low-cost raw materials. The impetus behind this development is twofold: new technologies allow the use of wastes, residues, and feedstocks that currently have little value or use and they enable more sustainable or more efficient land use. These new technologies have typically high investment costs and cost-effectiveness is sought by large-scale plants and integrating the biofuels production to existing chemical or forest plants in addition to utilising low-cost feedstocks. There are already demonstration plants in operation and more demonstration plants are being planned and/or under construction. For example, the forest company UPM Kymmene has activities in developing ethanol production from waste streams and FT diesel production from woody biomass (Sohlström 2007). The forest company Stora Enso, and Neste Oil have founded a joint venture NSE Biofuels and they are developing their own FT diesel process (Jääskeläinen 2008).

Currently, biofuels account for only some 2–3% of the total use of transport fuels in Finland. In 2007, the use of gasoline and diesel in the transport sector of Finland was 186 000 tons of gasoline and 220 000 tons of diesel (Finnish Oil and Gas Federation 2007). According to a baseline scenario given in the national energy and climate strategy (TEM 2008), combined consumption of fossil diesel and gasoline in transport sector is predicted to remain approximately at current level by 2020, but the share of biofuels increases to 10%. In addition, share of diesel fuel is projected to increase in Europe, and Finland can be assumed to follow that trend.

7.2 Studied biofuel scenarios for Finland

In this study three alternative biofuels scenarios for Finland for the period 2008–2020 were assessed. The aim of the scenario definitions was to find completely different, but yet possible development paths for liquid biofuels production in Finland. The generated scenarios are representing different political and economical circumstances, which will highlight the implications of national policies and means to react on set production targets. All scenarios were built on the target of the RES Directive Proposal, that is, that the share of biofuels in the transport sector should be at least 10% by 2020. The raw materials and technologies considered are dealt in more detail in Chapters 7.3, 7.4, and 1.1.1.

The generated scenarios are

- *Business as usual (BAU)*
- *Lowest hurdle (LOH)*
- *Self-sufficiency (SS).*

The BAU Scenario refers to the continuation of the present political environment and economical baseline, considering the support for increasing production of renewable energies and global trends of increasing the price of the energy. The production levels of liquid biofuels are forecasted to increase globally on all continents and it is assumed that the most severe ecological risks linked to the production have been adequately solved.

Furthermore, in the BAU scenario, it is assumed that the government is supporting the investments needed for production and utilisation of biofuels. The companies are importing substantial amounts of wood from Russia as raw material and palm oil from South-East Asia for the production of biodiesel. National and EU subsidies support the production of energy crops on agricultural land. Trade of biofuels and raw materials is free and limited mainly by transportation costs. Finland is also exporting biofuels, due to the better price on central European markets.

The product range in the *BAU* scenario combines the import of available biofuels (mainly bioethanol), the import of raw materials (mainly palm oil), and the utilisation of domestic resources (mainly forest and agricultural residues) for biorefineries. The main technology of domestic biofuel production is FT diesel production, which however, does not start until the end of the inspection period. Other new technologies include biodiesel production with the NExBTL-process and bioethanol production from wastes. In this scenario the total amounts of transport fuels used in Finland in 2010 or 2020 are not expected to increase compared to the present situation, since the increase of traffic is expected to be compensated by increasing the energy-efficiency of vehicles. The share of biofuels is expected to grow from 5.75% to 10%, that is, the total use of biofuels will increase from 230 000 ton to 400 000 ton.

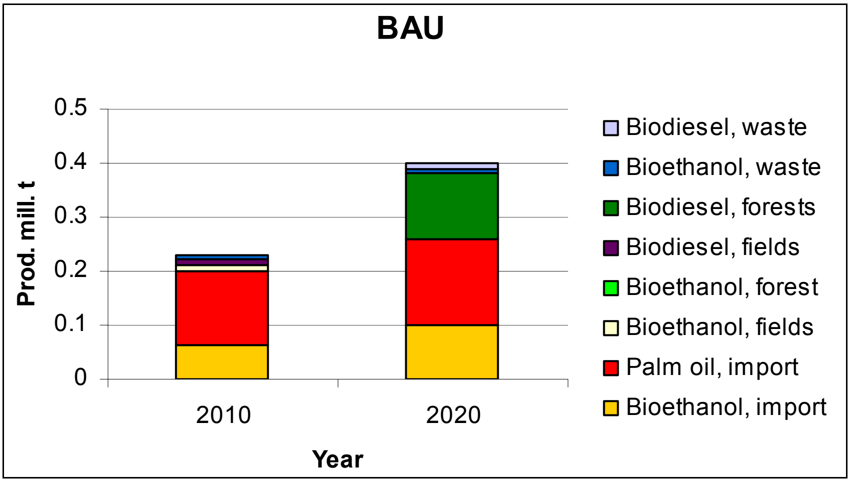

Figure 8. Product ranges in the BAU scenario.

Assuming that 1.2 ton of vegetable oil and/or tallow is needed for the production of 1 ton of NExBTL and that 2.5 ton (dry mass) of forest residues is needed for the production of 1 ton of FT-diesel. The total amounts of domestic raw materials and of imported biofuels that are needed in 2020 are presented in Table 2. The shares of different biofuels of the total biofuel use are shown in Figure 8. This BAU scenario means that roughly 300 000 tons of forest residues (dry mass) and 14 000 tons of domestic tallow or waste oils, in addition to the import of 160 000 tons of palm oil and 100 000 tons of bioethanol, are needed in 2020. The production of a small amount (about 8 000 tons) of bioethanol from domestic waste resources is also foreseen.

Table 2. The use of main biofuels and the need of raw materials for domestic production in 2020 according to the BAU scenario.

Biofuel	**Use in 2020**	**Conversion rate material**	**Need of domestic raw**		
			forests	**fields**	**waste**
	Mill.tons	*t d.m./ t biofuel*		*Mill. tons d.m.*	
Bioethanol, import	0.1		-	-	-
Palm oil, import	0.16		-	-	-
Biodiesel, forests	0.12	2.5	0.30	-	-
Bioethanol, waste	0.008	*not defined*	-	-	*not defined*
Biodiesel, tallow	0.012	1.2	-	-	0.014

The ***LOH Scenario*** refers to a situation where the price of fossil fuels and regulations for renewable energy production are threatening the competitiveness of Finnish industry. The obligations for renewable energy production will be reached as cost-effectively as possible. The long-term implications on the economy and the environment are seen as secondary aspects, and fulfilling the targets will be done with minimum costs, without harming the industry or the Finnish economy.

Governmental subsidies for raw material procurement and biorefining are minimised and products are not an important part of the regional development or employment policies. The refining processes and product transports are utilising the present infrastructure with no extra investment costs.

The product range in the LOH scenario is based on the cost effectiveness of different production technologies. Imports of raw materials and biofuels are playing an important role and the main share of the target quota is covered by importing palm oil for biodiesel. As the domestic raw material from the forests (logging residues and stumps) is cost competitive, FT diesel production starts before year 2020. The rest of the own production is covered by bioethanol production from straw and reed canary grass and from the side products of forest industry. (See Figure 9) The total forecasted amounts of biodiesel and bioethanol needed in Finland in 2020 are the same as in the BAU scenario.

This LOH scenario means that roughly 400 000 tons of forest residues (dry mass) and 10 000 tons of domestic rapeseed oil or tallow, in addition to the import of 200 000 tons of palm oil and 40 000 tons of bioethanol, are needed in 2020. For the domestic production of bioethanol (20 000 tons) roughly 110 000 tons of straw and RCG from the fields are needed. (See Table 3)

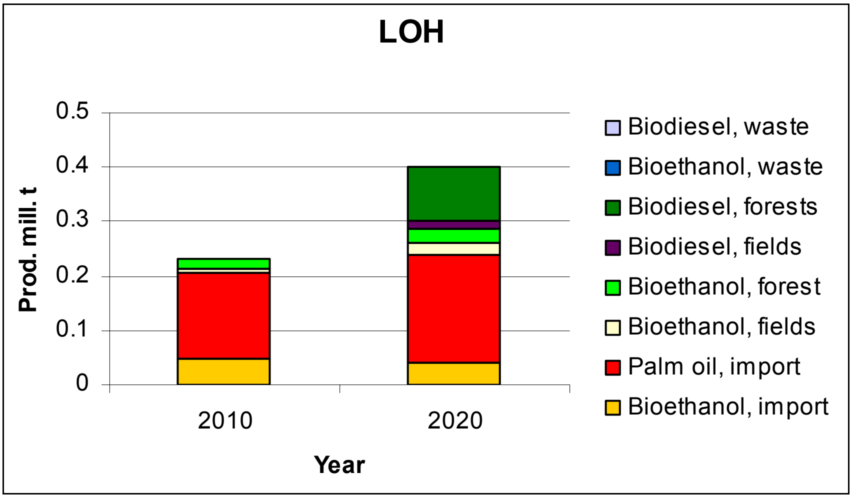

Figure 9. Product ranges in the LOH scenario.

Table 3. The use of main biofuels and the need of raw materials for domestic production in 2020 according to the LOH scenario.

Biofuel	**Use in 2020**	**Conversion rate material**	**Need of domestic raw**		
			forests	**fields**	**waste**
	Mill. tons	*t d.m./ t biofuel*	*Mill. tons d.m.*		
Bioethanol, import	0.04		-	-	-
Palm oil, import	0.20		-	-	-
Bioethanol, fields	0.02	5.3	-	0.11	-
Bioethanol, forest	0.03	5.3	0.15	-	-
Biodiesel, fields	0.01	1.2		0.01	-
Biodiesel, forests	0.10	2.5	0.25	-	-

The ***SS Scenario*** refers to the maximisation of domestic biomass production, biorefining and biofuel utilisation. The prices of fossil fuels are forecasted to increase due to the global demand and high prices of emissions from industries. Market failures are creating uncertainties on the fuel supply security. The availability of biomass-based raw materials is decreasing due to competition and ecological reasons, but the EU is keeping the targets for renewable energies constant. Maintenance and supply security is an important part of national energy policy.

Finland is producing all the necessary raw materials in forests and on fields. Wood imports are minimal as Russia is also investing strongly in biorefineries and is heading for global biofuel markets too. The import of palm oil is decreasing due to increased global demand, higher prices and ecological reasons. The same holds true for import of bioethanol. Utilisation of woody biomass from domestic sources is increasing and in the end of the inspection period, Finland is reaching the technical potential of woody biomass production.

Finland is trying to prevent exports of raw materials and biofuels by setting aggressive feed-in tariffs. The government is strongly supporting research and development, subsidising raw material production and procurement, and supporting biorefinery investments. The employment and regional policy is an important part of renewable energy production, but also ecological sustainability is seen as an important criterion, when selecting the proper production technologies.

The product range in the SS scenario is diverse due to limited raw material resources (see Figure 10). The price development of fossil fuels makes the production of more expensive biofuels profitable. Main technology is the FT diesel production from woody biomass, but since the raw material costs are increasing by intensive forest utilisation, also other technologies and raw material resources, such as energy crops and agricultural wastes are used both for biodiesel and bioethanol production. The total forecasted amounts of biodiesel and bioethanol needed in Finland in 2020 are the same as in the BAU scenario.

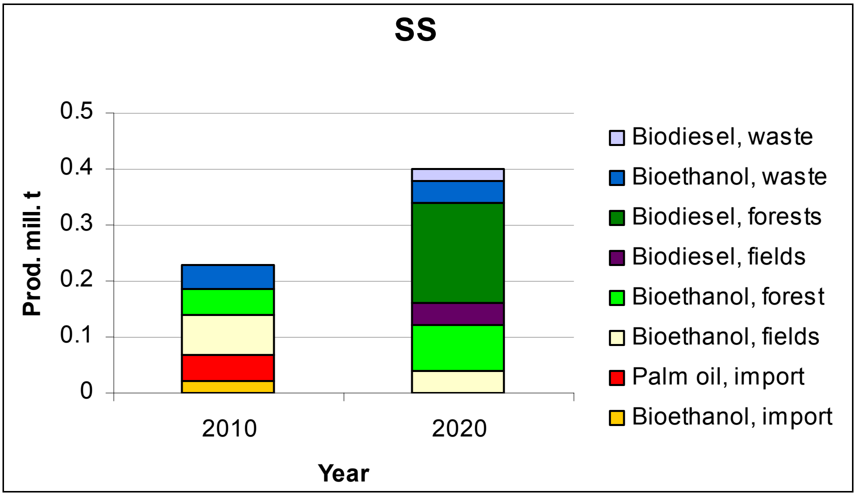

Figure 10. Product ranges in the SS scenario.

This SS scenario means that roughly 870 000 tons of forest residues (dry mass), 690 000 tons (dry mass) of RCG and straw, and 24 000 tons of domestic rapeseed oil or tallow are needed. For the domestic production of bioethanol (40 000 tons) further, roughly some 110 000 tons of organic wastes are needed. No import of palm oil or bioethanol is foreseen. (See Table 4)

Table 4. The use of main biofuels and the need of raw materials for domestic production in 2020 according to the SS scenario.

Biofuel	**Production**	**Conversion rate**	**Need of domestic raw**		
			forests	**fields**	**waste**
	Mill. tons	*t d.m./ t biofuel*	*Mill. tons d.m.*		
Bioethanol, fields	0.04	5.3	-	0.21	-
Bioethanol, forest	0.08	5.3	0.42	-	-
Biodiesel, fields	0.04	1.2	-	0.48	-
Biodiesel, forests	0.18	2.5	0.45	-	-
Bioethanol, waste	0.04	*not defined*	-	-	*not defined*
Biodiesel, tallow	0.02	1.2	-	-	0.024

The need of raw materials in each scenario is greatly depending on the selected biofuels production processes and therefore the accurate calculations of required quantities of raw materials need a careful definition of the production environment (integrated or stand-alone production), of process technology specifications, of raw material conditions (minimizing biomass or electricity consumption, raw material quality), and also of other process related variables. In raw material calculations, the following assumptions for production and processes were made:

- FT diesel from forests; integrated production, need for raw material 2.5 t d.m./ t FT diesel
- bioethanol from fields, need for raw material 5.3 t d.m./ t bioethanol
- biodiesel from import and waste; need for raw material 1.2 t d.m./ t biodiesel
- bioethanol from import; need for raw material 15 t/ t EtOH
- bioethanol from waste; process conditions are not defined in this study.

The purpose of this chapter was to estimate the levels of biofuel production in Finland in different future scenarios. It also presents the requirements for domestic raw material production. The availability and properties of different raw materials is discussed in the next chapter.

7.3 Availability and sustainability aspects of raw materials for biofuels production in Finland

In the following chapters domestic raw materials suitable for production of liquid biofuels in Finland are presented. A screening of environmental aspects, other than climate change, of different biofuel chains is furthermore presented in Chapter 8.

7.3.1 Forest raw materials

Forests are the largest source of renewable biomass in Finland and in whole Europe. Currently, forest-based raw materials are mainly used for forest industries' own needs, but the biomass use for energy production and also for other purposes is increasing. Conventional forest-based biomass for energy uses contains logging residues and stumps from clear-cut areas and small trees from thinnings. Including the above-mentioned fractions the technically harvestable energy wood potential in Europe is estimated to be 187 million m^3, which equals approximately 150 million tons of fresh wood (Asikainen et al. 2008). This amount corresponds to about 411 TWh or 36 Mtoe of energy. The current annual use of roundwood resources in Europe is approximately 450 million m^3, which equals 65% of the total annual growth of forests (UNECE Timber Committee 2005).

As forest residues are generated as by-products of final fellings or thinnings, the development of loggings have a significant impact on the availability of forest residues for harvesting. Boreal forests are relatively long-rotation biomass with a typical circulation period of roughly 100 years. Consequently, conservation and sequestration management of forests as discussed in Chapter 4.2 are also viable options to mitigate climate change. The optimal ratio between substitution, conservation and sequestration management of forests in order to maximize the greenhouse gas benefits should be carefully studied. The available forest residue potentials presented in this Chapter are based on the current annual loggings.

The theoretical biomass potential for energy usage in Finland is estimated at 63 million m^3 (excluding bark) (Asikainen et al. 2008). This amount includes forest based logging residues and stumps from current fellings and 25% of net annual increment, which is the margin between annual increment and fellings. However, the annual technical potential of energy wood available for harvesting in Finland is estimated to be 15.9 million m^3, consisting 6.5 million m^3 of logging residues and 2.5 million m^3 of stumps from final felling sites and 6.9 million m^3 of small-diameter trees from early thinnings (Kuusinen & Ilvesniemi 2008).

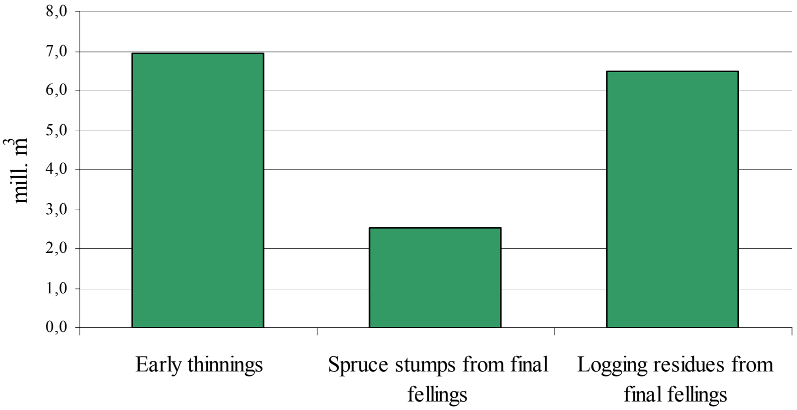

Figure 11. Technical potentials of energy wood in Finland (Kuusinen & Ilvesniemi 2008).

Selected properties of woody biomass

The energy content of woody biomass depends on its chemical composition and the amount of energy stored in organic molecules (Richardson et al. 2002). During combustion, energy is released by the cleavage of high-energy bonds between carbon and hydrogen. The higher the carbon and hydrogen contents are the higher is the heating value of the material. In addition, wood contains also oxygen, nitrogen, and inorganic elements, but these do not contribute to the heating value. The carbon and hydrogen contents of different tree components are presented in Table B3 in Appendix B.

Trees require different mineral elements for growth and life processes. The mineral content of tree components varies depending on the soil, site fertility, tree size and age, and season (Richardson et al. 2002). Young trees contain usually higher concentration of mineral elements than mature trees. One of the most essential elements for forest growth on mineral soils is nitrogen. Stemwood has low nitrogen content, 0.1–0.5%, but foliage has higher concentration, up to 1–2% respectively. During the combustion process, nitrogen is oxidized, producing NO_x emissions. Other harmful minerals in the combustion process are sulphur (emissions), chlorine (corrosion problems), and heavy metals (emissions and ash recycling). Mineral concentration in the dry mass of small-sized trees from first commercial thinnings in Finland is presented in Table B4 in Appendix B.

The chemical composition of a tree component is defining its heating value. Different tree species have differences in the composition of lignin, resins, terpenes, and waxes as well as in the composition of cellulose and hemicelluloses. The mineral elements do not contribute to the heating value. Softwood species have typically higher heating values than hardwoods (Table B5 in Appendix B).

The common practise is to measure woody biomass by volume and the transport and storage facilities are also dimensioned for volume rather than for mass. Therefore it is important to estimate also the energy density, that is, the effective heating value per volume unit. Since the basic density of hardwood species, especially birch trees is considerably higher than that of softwood species, the energy density of birch trees is higher than that of softwood species (Table B6 in Appendix B).

Logging residues from final fellings

Logging residues, i.e. branches and stem tops, are produced during the final felling, when trees are under the bucking and debranching operation. Traditionally logging residues have not been collected from the logging site and they have been left on the site, but recently it has been a common practise to collect the residues and to produce forest chips for different energy related purposes like small-scale heating plants. Thus the use of logging residues for biofuel production will compete with the use of the residues for heat and power generation.

The logging residue potential is highest on nutrient rich Norway spruce (Picea abies) stands. For spruce the amount of residues per hectare is considerably larger than for Scots pine (Pinus sylvestris), because of the larger share of the crown mass; the share of needles in the total crown biomass is about 30%. The total production of woody biomass at fertile spruce stands can reach 750–800 m^3/ha during a 100 years rotation period in southern Finland and 500–650 m^3/ha in northern Finland respectively. The removal of stem wood in final felling is approximately 250–400 m^3/ha and the total quantity of logging residues is approximately 100–150 m^3/ha. However, only 2/3 of the total quantity of residues is recovered due to technical and environmental reasons. A map showing the availability and regional distribution of logging residues in Finland is included in Appendix C.

With extraction of residues, a substantial amount of nutrients is removed from the forest stand, especially if the extraction is carried out immediately after the felling operation. Thus, the common recommendation is to leave residues on the stand to dry and drop nutrient rich needles on the ground. According to Finnish forest management recommendations (Koistinen & Äijälä 2006) 30% of the logging residue nutrient content should be left on the logging site. It has been estimated that with Norway spruce even 20% of the total dry weight of logging residues may be left on the site merely because of needle drop (Nurmi 1999). Residue drying on the logging site together with unrecovered residues cuts down the highest peak of nutrients outtake and prevents the negative effects on forest stand productivity. However, more research is needed about the long-term effects of extraction on soil properties.

Stumps from final fellings

Stump lifting from final felling sites is one of the latest operations considering the utilization of woody biomass for bioenergy production, but traditionally tree stumps and roots have been used for centuries for instance in tar production. Currently stump-lifting operations are still rare and they are done on a small scale only in Finland and in Sweden. However, stumps are a noticeable large potential resource of woody biomass having good storage properties and energy potential. A map showing the availability of stumps in different parts of Finland is included in Appendix C.

The stump lifting requires that the logging residues are collected from the logging site and therefore the best stands for stump lifting are those of spruce. Scots pine stumps are more difficult to lift due the deeper root system compared to the spruce stumps. The main problem from utilization perspective is the large amount of impurities like soil and stones attached to the root system. The lifting is usually done by excavator-based machinery with special stump lifting accessories attached to the crane. The accumulation of stump material is ca. 20–30% of stem wood volumes, which equals close to 100 m^3/ha on the best stump lifting sites.

Stump harvesting decreases the amount of nutrients and organic soil from the logging site and may lead to increased mineralisation and leaching. Because of these reasons stump lifting is not recommended on nutrient poor sites or on sites that have a thin layer of humus (Koistinen & Äijälä 2006). Finnish recommendations suggest also that approximately 20 stumps/ha (diameter > 15 cm) should be left evenly distributed in the stand and an intact zone on the shore of waterways and ditches should be reserved. It is important that an area as small as possible of the mineral soil is exposed, to prevent the nutrients', heavy metals', and aluminium of leaching to the groundwater. At least 70–85% of the total logging area should be covered with a humus layer.

The silvicultural effects of stump harvesting are not only negative. The prevention of the spread of root rot (*Heterobasidium annosum*) is seen as one of the most positive effects of stump lifting, but also the soil preparation and planting costs may be reduced.

Small-diameter trees from early thinnings

Silvicultural operations like cleanings and pre-commercial thinnings are important actions during the forest rotation in order to produce better quality timber wood. Suitable sources of energy wood chips from thinnings are usually small diameter trees and non-marketable species from young forests and seedling stands. However, young forest silvicultural operations are expensive and often economically unsustainable due to low productivity and subsidies are needed to cover the costs. The economically profitable operation requires large average stem size, large stem number, and favourable stand conditions. At the moment, only a fraction of all thinning sites are profitable without subsidies. However, most of the economically sustainable felling sites are already under utilization and the need to find raw material also from thinnings is becoming more important. To make the operations on thinning sites more profitable, new harvesting technologies have been developed during the last years. The reserve of woody biomass from thinnings is equally available in different parts of Finland. A map showing the availability in different parts of Finland is included in Appendix C.

Thinning operation releases space and light for the remaining trees on the stand. After the thinning the trees are under highest annual growth and the need of nutrients is the highest. The extraction of branches and stem tops will remove nutrients such as nitrogen from the forest, especially if they are collected immediately as fresh after thinning. This removal can decrease the forest stand productivity with some percentages. Therefore it's important to find the balance between biomass outtake and stand conditions. It has been estimated (Harstela 2004) that even with a lower production level, the advantages of thinning operations are overcoming the negative effects of unmanaged forest stands. According to guidelines (Koistinen & Äijälä 2006), whole tree harvesting is not recommended in logging sites with poor nutritional condition or thin humus layer and it should not be done more than once per forest rotation.

More recently the use of pulp wood sized timber for biorefineries in particular and for direct energy production in general has been discussed. This discussion has been initiated from the closures of production capacity of pulp and paper industry units in Finland. Especially in the situation where wood imports from Russia continue, there is excess pulpwood from the early thinnings that is not being used. Their raw material quality is far more constant and quantities of contamination or any undesired components are smaller than e.g. stumpwood or logging residues. Thus normal roundwood seems to be a potential, large source of raw material for biorefineries. Exact volumes of roundwood available for biorefineries or energy production have not been counted yet. Nevertheless, it can be estimated that over 5 million m^3 pulp wood sized timber could be harvested in Finland for biorefineries without endangering the raw material supply of existing forest industries. The use of roundwood as raw material also has only minor impacts on nutrient balances and other negative effects of harvesting. However, it must be kept in mind that a large share of this raw material base is on the soft soils where harvesting technology and methods have to be carefully selected.

Forest fertilization in connection to biomass extraction

There are complex relationships between organic matter and nitrogen mineralization in soil. This makes it difficult to predict how much nitrogen should be compensated for with fertilization, or should only the nutrient rich needles be left on the logging site after whole tree harvesting. In addition, fertilization is not recommended after clear cutting, because it may lead to nutrient leaching.

Studies on the effects of whole tree harvesting on the growth of a new tree generation have usually revealed some minor decline. There is still some uncertainty on whether the declining growth is due to smaller amounts of nitrogen in the soil or due to organic matter extraction and its negative effects on the mineralization rate (Smolander et al. 2008). However, the situation in these studies have usually been such that all branches have been removed from the logging site, even though in practice a part of residues and nutrient rich needles are usually left on the site after logging.

The compensation of nutrient removal with fertilizers has been criticized because of fossil fuel consumption in fertilizer production. One ton of firewood contains approximately 5 MWh of energy. The equal amount comprises 1–4 kg of nitrogen. To produce and transport one kilogram of nitrogen in the fertilizer we need only about 12 kWh of energy. Thus, one kilogram of N (12 kWh) produces 1–5 MWh of energy (Ågren & Hyvönen-Olsson 2006). However, production and use of N fertilizers may generate N_2O emissions, the amount of which is very difficult to predict, but may be significant.

Energy efficiency of forest biomass production

The productivity of the forest machinery and thus the fuel consumption per produced quantity of raw material is greatly depending on the quality of the forest site (average tree species and size, terrain conditions, forest density), size of the machine, and of course, on the skills of an operator. Table 5 illustrates the typical minimum and maximum values for forest operations.

Table 5. Typical minimum and maximum productivities of forest operations and machine fuel consumptions.

Operation	**Machine**	**Productivity, m^3/h**		**Consumption, l/m^3**		**Consumption, l/kg d.m.**	
		min	*max*	*min*	*max*	*min*	*max*
final felling	harvester	15	35	0.31	0.73	0.0008	0.0018
	forwarder	15	22	0.41	0.60	0.0010	0.0015
thinning	harvester	5	15	0.73	2.20	0.0018	0.0055
	forwarder	10	14	0.64	0.90	0.0016	0.0023
forwarding of logging residues	forwarder	8	12	0.75	1.13	0.0019	0.0028
bundling of logging residues	bundler	8	17	0.65	1.38	0.0016	0.0034
stump lifting	excavator	8	12	1.56	2.34	0.0039	0.0059
chipping	chipper	30	90	0.90	1.20	0.0023	0.0030

7.3.2 Peat

In Finland the share of peat of annual energy production has been about 5–7% in years 2000–2007 (Statistics Finland 2008a). The peat resources in Finland are estimated at 12 800 TWh, which corresponds approximately to 1 100 million toe (Virtanen et al. 2003). In year 2000 the carbon content of Finnish peatlands was estimated at 5960 Mt, of which 5304 Mt as peat. Nearly 55% of Finnish peatlands have been drained for forestry (5.7 million ha), 38.4% (4,0 million ha) are pristine peat bogs, and 0.8% are in agriculture use (85 000 ha). The rest is under water reservoirs, in peat harvesting or under roads (Turunen 2008). In 2006 the area of peat extraction in Finland was approximately 75 000 ha (Statistics Finland 2008b).

The production and use of peat have a warming impact on the climate. Especially the CO2 emissions from combustion of peat have the largest impact on climate of the total peat utilisation life cycle. Table 6 gives the greenhouse gas fluxes in Finland for 2006 during different phases of the peat utilisation life cycle. Greenhouse gases of CO2, CH4 and N2O have been combined by using 100 year GWP-factors (methane 21 times, nitrous oxide 310) (IPCC 1996). Peat combustion has the largest greenhouse gas emissions.

Table 6. The total greenhouse gas fluxes related to the Finnish peatlands and their utilisation in 2006. Values that are given are the combined number of CO_2, CH_4, and N_20 emissions and sinks per Mt CO2-eq/a.

Different GHG fluxes related to peatlands and their utilisation		**Mt CO_2eq/a**	**Source**
Pristine peatland	Ombrotrofic	1.7	Saarnio et al. 2007
	Minerotrofic	6.2	“
Forestry-drained peatland	Peat decay and root respiration	7.3	Statistics Finland 2008c
	Accumulation of dead organic matter	-0.8	“
	Carbon accumulation in forest growth	18.7	“
Agricultural peatland		5.75	“
Energy use of peat	Combustion	9.93	“
	Peat production area	0.72	“

If pristine peat bogs are taken into peat production, there are remarkable impacts on the landscape. Ditching and drainage changes the ecosystem completely. Peat production along with draining are the main reasons threatening mire species in Finland, and these are also future threats for these species (Aapala 2001). The threatened mire species are mainly invertebrates, vascular plants and cryptogams (Rassi et al. 2001). Peat production has been one of the main factors contributing to the loss of mire area (and therefore mire habitats) in Finland, and remains such also in the future (Kaakinen et al. 2008). Also the water system of the area is changed and even flooding may occur. If the peatlands taken into peat production have already been drained for forestry or agriculture, the changes on the surrounding environment are smaller. The Association of Finnish Peat Industries (2006) has stated in their environmental principals, that they will primarily take already drained areas into peat production.

After-treatment of the bottom of a peatland by afforestation creates a carbon stock over a long-time horizon, which is approximately 5.5 kg of carbon/m^2. If the after-treatment choice is paludification, it is assumed, that the emissions and sinks are of the same magnitude as those of normal pristine peatlands (in this case fen).

The use and production of peat has also other environmental impacts e.g. dust and noise impacts. The dust emissions from milled peat production have been estimated at about $0.67 * 10^3$ g/MJ_{peat} (The Association of Finnish Peat Industries 2008). Mineral and nitrogen content in dry matter (DM) of peat is presented in Appendix B.

7.3.3 Reed canary grass

Reed canary grass (*Phalaris arundinacea* L.) (RCG) is a native, rhizomatous perennial grass grown mostly for forage in the northern hemisphere. Its potential as a fibre and energy source has been evaluated both in Sweden and Finland (Landström et al. 1996, Saijonkari-Pahkala 2001) and also in a EU research project (Olsson et al. 2004). Chopped, dry RCG is used mixed with other solid biofuels like peat, wood chips, bark or saw dust in CHP plants. The highest momentary shares of grass in the fuel have been about 15% of the total energy value of the fuel (Leinonen et al. 2007).

In Finland, more than 20 power plants with a rated thermal input of more than 20 MW_{th} have experiences of the utilization of RCG (Leinonen et al. 2007), and there are more than 100 plants that are able to use grass and straw biomass in fluidized bed combustion (The Finnish Bioenergy Association 2007). The current growing covers more than 20 000 ha (Statistics Finland 2008d). The long-term goal of the Ministry of Agriculture and Forestry is to increase the RCG area to 100 000 ha (Ministry of Agriculture and Forestry 2008) including also other use than direct combustion at CHP plants.

Annual phosphorus (P) and potassium (K) fertilisers given to RCG are 5–16 kg/ha and 20–41 kg/ha respectively (Pahkala et al. 2005). Nutrient rates are dependent on soil type and the age of the plantation (Pahkala et al. 2005). Control of annual weeds can be needed in the sowing year by using herbicides allowed for RCG. (Peltokasvien kasvinsuojelu 2008). After the last harvesting, when the height of the plants is at least 70 cm, the plantation is destroyed by spraying the area with glyphosate.

The first yield is harvested in early spring, two years after sowing. The harvesting period is about 10–15 days, when the moisture content of the dead grass is between 10 and 20%. Harvesting can be done by mowing, followed by baling or chopping. Yield levels between 3–6 t/ha have been frequently recorded for young stands in the first spring harvests. The delayed harvests yield approximately 7–8 t/ha on clay soil and more than 10 t/ha on mull soil after the second harvesting. Dry matter yields depend also on the growth during the previous year, the age of the plantation, cultivars, and harvest losses that are critical for the yield. The mineral and nitrogen content of RCG in comparison to those of different cereal crops and straw is given in Appendix B.

Based on field tests done in Finland the average content of cellulose in RCG is 46–49% (DM), that of hemi-cellulose 25–32% and that of lignin 4–10%. The content of ash in RCG is on average 5–9%. (Pahkala & Kontturi 2008a)

RCG can maintain its productivity year after year even under relatively low levels of fertilizer application. The experimental areas harvested in springtime have been productive for 15 to 16 years, but the age of the ley can be shorter in practice. The average annual fieldwork requirement is about five hours per hectare, including establishment, annual fertilization and harvesting, and finally the destruction of the crop stand (Pahkala et al. 2005).

7.3.4 Straw

Straw is a by-product of commercial field crops such as cereal grains, oilseed crops (turnip rape, oilseed rape, linseed), and pulse crops (peas, faba beans). Seed yields of these crops are harvested by threshing when the straw material is left on the field surface in swaths. Presently only a minor part of the cereal straw yield is utilised: 20% for animal bedding in pig and cow houses, and about 6 million kg (2400 ha) for energy purposes (MMM 2004), and the rest is chopped and mulched into the soil. There is no information about the use of residues from oilseeds, linseed, or other combine harvested crops.

The potential straw yield can be estimated by using the information about seed yield, seed dry matter content (DM), harvest index (HI), and harvest losses. The total biomass is composed of seed and straw yield. Data for harvested seed yield is given for the most important species in public statistics (Statistics Finland, Eurostat and FAOSTAT). Harvest index (proportion of seed yield of total biomass in dry matter), has been studied separately for each species. For example, HI for spring cereals is from 0.40 (wheat) to 0.55 (6-row barley) (Peltonen-Sainio et al. 2007). For oilseed rape HI values are between 0.22–0.38 (Hay 1995), and for turnip rape 0.27–0.46 (Pahkala 2004).

Most harvest losses originate from the stubble remained standing on the field. Usually the threshing height is about 15 to 20 cm resulting in a straw loss of about 21–29% at 15 cm and 28–38% at 20 cm (Figure 12). The proportion of straw losses from the stubble is depending on the straw height. In a study by MTT the straw length was highest for winter rye, turnip rape, and broad bean and lowest for linseed and triticale. Losses originating from the harvesting operation and baling can be comparable to those of hay. The number of days suitable for harvesting dry straw varies annually, averaging between 10 and 12. Every tenth year there is only 5–7 days for successful harvesting. If the crop is harvested in September, there are fewer possibilities to get dry straw (Pahkala and Keskitalo 2006).

The risks and lack of knowledge with regard to the technically potential yields of straw for i.e. biofuel production are the following: Quantities of current use of straw, potential forms of use, harvest losses in baling, carbon losses with removed straw, quality changes in storage, and “grey” straw.

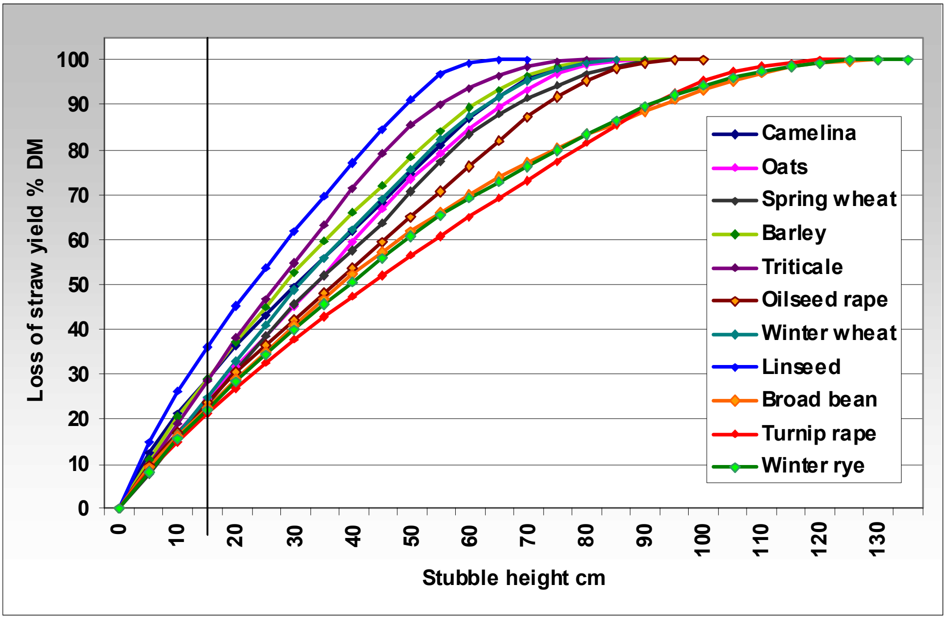

Figure 12.The effect of stubble height on the loss of straw yield (% of DM) at harvesting Finnish field crops. The line is set at 18 cm. (Source of the data: Pahkala, K. 2008a.)

In the future, there will most probably be more straw available for energy use. However, agricultural residues play an important role in controlling erosion and maintaining soil carbon, nutrients, and soil physical properties. Quantities of removable residues depend on crop rotation, field-management practices within rotation (direct drill or ploughing) and climate. In the USA no-till or reduced tilling systems allow the removal of more residues (wheat, corn residues) than ploughing (Nelson et al. 2004). As Finland is situated in the North and in a humid area the negative influence of straw removal may not be as obvious as in dry and warmer countries. Autumns are usually rainy and the straw harvesting is not possible every autumn. If straw is harvested every second year, there is a possibility to get more than 1000 million kg of cereal straw and more than 60 million kg of oilseed straw annually. The dry matter yield is estimated for year 2007 using seed yields (moisture content 13% for cereals and 9% for oilseeds), specific harvest index numbers, and excluding a stubble of 18 cm. The regional distribution of the straw potential in Finland is presented in Table 7.

Table 7. The straw yields (DM) counted by using seed yields (moisture content 13% for cereals and 9% for oilseeds), specific harvest index numbers, excluding stubble biomass of 18 cm. (Source: Areas, grain and seed yields: Statistics Finland 2008e; straw yields: Pahkala, K. 2008b.)

TE keskus 2007	Cereals 1000 ha	Grain yield mill kg	Straw mill kg DM	Oilseeds 1000 ha	Seed yield mill kg	Straw mill kg DM
Uudenmaa	114	452	323	13	20	25
Varsinais-Suomi	119	770	499	22	29	37
Satakunta	88	331	213	5	6	8
Häme	113	433	275	10	12	16
Pirkanmaa	89	299	194	8	10	12
Kaakkois-Suomi	75	261	178	7	9	11
Etelä-Savo	22	65	40	0	0	0
Pohjois-Savo	45	139	82	1	0	2
Pohjois-Karjala	26	72	45	1	0	0
Keski-Suomi	36	113	72	2	2	2
Etelä-Pohjanmaa	129	487	305	12	13	16
Pohjanmaa	98	379	227	8	9	11
Pohjois-Pohjanmaa	93	303	178	2	0	2
Kainuu	5	14	8	0	0	0
Lappi	2	5	3	0	0	0
Ahvenanmaa	4	16	10	0	0	0
	1057	4137	2650	89	110	145

7.3.5 Rapeseed oil

Cultivation of spring turnip rape and spring rape is possible on most soil types found in Finland. The most favourable ones are various sandy soils especially those rich in humus. Also clay soils are suitable for oilseed crops if the soil structure is in good condition. Yields on humus and peat soils can be high, but the ripening especially with rape may delay too much on peat soils. The only soil types that are not suitable for *Brassica* oilseed crops are silt and silty clays, as they can easily build crust on sowings if it rains heavily. Suitable pH-value for *Brassica* oilseeds is 6–6.5 and in humus soils 5.5–6. (Pahkala 2008b)

Oilseed rape is an annual crop, whose seeds contain approximately 44% oil and 23% protein. Typical yields in Central Europe are between 2.4 and 3.5 tonnes per hectare. There are several reasons for varying yields in the different countries such as climate, soil type and agricultural practices. In Finland the normal yield is only 1.3–1.6 tons/ha. This is a problem in terms of the environment, as the environmental impacts per tonne increase if the yield is continuously lower than expected. Rapeseed yields are better than turnip rape yields, but a problem is, that many parts of Finland are kind of extreme limit areas for rape cultivation, due to our climate, and therefore there is a higher risk to fail. In 2007 the total production area of rapeseed oil in Finland was 89 000 hectares and the total annual production 110 000 tons.

The present cultivation of turnip rape in Finland is spread over 13 regions (out of 15), but cultivation has been continuous and significant only in eight western and southern regions of Finland (Pohjanmaa, Etelä-Pohjanmaa, Satakunta, Pirkanmaa, Varsinais-Suomi, Häme, Uusimaa and Kaakkois-Suomi) (Statistics Finland 2008e). However, in the last four years cultivation has been practised also in regions close to the big lakes or the Gulf of Bothnia (Pohjois-Savo, Pohjois-Pohjanmaa and Pohjois-Karjala), where the microclimate is favourable. It is possible that cultivation can increase in these regions if the agricultural policy and other conditions are favourable. The yields of spring turnip rape and spring rape have slightly declined in the main growing regions (Peltonen-Sainio et al. 2007), but in the northern areas the short growing season is also seen as a risk.

There are several environmental impacts in the rapeseed oil production chain, especially in the cultivation phase. Production of fertilizers consumes energy and especially nitrogen fertilizers are energy intensive. In rapeseed cultivation, for its part, pretty high nitrogen fertilization is needed. Production of lime consumes energy too, but in terms of climate change, carbon dioxide releasing from the lime on the field, is more significant.

On the fields, some machine work is needed and that causes also some air emissions, as well as rapeseed drying does. N_2O is released from the field because of processes of the soil, and fertilizers increase the amount of this emission substantially. However, the eutrophication impact of agriculture is significant and is generally considered as one of the most important environmental impacts of cultivation.

Rapeseed oil processing can be divided into two different process steps: pressing and extraction. Processing 3 tons of rapeseeds produces approximately 1.3 tons of rapeseed oil and 1.7 tons of rape meal. The process generates approximately 57 litres of wastewater per tonne rapeseed oil produced. (Vihma et al. 2006)

Oil from traditional rapeseed (*B. napus*) or its related cultivars (*B. rapa* and *B. juncea*), has a typical composition of 5% palmitic (C16:0), 1% stearic (C18:0), 15% oleic (C18:1), 14% linoleic (C18:2), 9% linolenic (C18:3) and 45% erucic fatty acid (C22:1).

7.3.6 Animal-derived tallow

Tallow is an animal fat obtained by rendering animal carcasses and waste from slaughterhouses and food industry. The vegetable oil that is closest to tallow is palm oil. It is assumed that approximately the same amount of biodiesel can be produced from 1 ton of palm oil as from 1 ton of tallow (AEA 2008). Tallow is solid at room temperature and it can be stored for extended periods without any need for refrigeration to prevent decomposition, provided it is kept in an airtight container to prevent oxidation.

Industrially, tallow is not strictly defined as fat of some specific animal. In this context, tallow is animal fat that conforms to certain technical criteria, including its melting point, which is also known as titre. It is common for commercial tallow to contain fat derived from other animals than cattle, such as pigs. In this study, both the terms tallow and animal fats are used when referring to rendered animal fats.

The composition of the fatty acids in tallow is typically 46% saturated and 54% mono-unsaturated and poly-unsaturated fatty acids. The percentages vary a little depending on raw materials.

The production of tallow in the EU totals approximately 2.5 Mt per annum and there is an estimated 14 Mt/a of tallow available globally. The amount of tallow available in Finland is roughly only some 20 000 tons per year. In 2005, 725 000 tons of tallow was combusted in the EU, 94 per cent of it being Category 1 and Category 2[5] tallow. Also, 647 000 tons of animal fats was used in oleochemical and soap industry, mainly consisting of Category 3 fats. 191 000 tons of animal fats (79%), gelatine and blood products (21%) were used in food production. (EFPRA 2008)

The Finnish rendering plants consume electricity about 0.07 kWh/kg animal waste, heat from about 0.8 to 0.9 kWh/kg, and about 0.17 kWh/kg for heat recovery. Most of the heat is consumed for the drying and sterilization of the animal waste. On the other hand, the rendering plants use various amounts of animal fat as a fuel for internal heating, and by doing so they replace the use of fossil fuels.

The water consumption per 1 kg of slaughtered animals is 9.9–17.5 litres and in addition to this amount the rendering plants consume water about 0.44–0.5 l/kg animal waste.

Chemicals used in slaughterhouses and rendering plants include detergents (mainly alkaline), refrigerants, fuels (heavy and light oil, natural gas), carbon dioxide, as well as preserving agents (formic acid, lactic acid, sulphuric acid, sodium benzoate). Rough LCA-based estimates of total impacts of tallow production and use for biofuel purposes have been done by i.e. AEA in the UK (AEA 2008), CSIRO in Australia (Beer et al. 2007) and MTT in Finland (Kaustell et al. 2008).

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[5] According to the EU Regulation the animal derived by-products are divided into three categories:

- ✓ Category 1 (high-risk) material, which consists of material that could be or is polluted with TSE (Transmissible Spongiform Encephalopathy) diseases, forbidden substances, e.g. hormones or environmental toxins and is suspected of presenting serious health risks, e.g. BSE.
- ✓ Category 2, which includes material with risk of other animal diseases than TSE or the risk of animal medicines. Dung and intents of digestive tracts of mammals also belong to category 2.
- ✓ Category 3 (low-risk) material consists of animal by-products from animals accepted for human consumption, including e.g. lungs, ventricles and blood. Organic waste from food industry, restaurants, institutional kitchens and households is also considered as Category 3 material.

7.4 Availability and sustainability aspects of imported biofuels

As it is most unlikely that Finland can reach the set targets for the share of biofuels in the transport sector solely based on domestic raw materials already by 2010 or even by 2020, the availability and sustainability aspects of imported biofuels (biodiesel and sugarcane ethanol) and of imported vegetable oils suitable for the NExBTL-process are also dealt with in the following sections. Presently soybean oil is not used as a raw material in the NExBTL process, but as the reason for this is more a question of price and availability than of its suitability the production of soybean oil is also discussed in the following chapters. Larger demand of palm oil for biodiesel production may lead to increased production of soybean oil for food purposes and thus the sustainability aspects of soybean oil should also be assessed. A screening of environmental aspects of different biofuel chains is furthermore presented in Chapter 8.

7.4.1 Production and use of biodiesel

The global market for biodiesel is expected to grow explosively in the next ten years. Although Europe currently represents 90% of global biodiesel consumption and production, the U.S. is now ramping up production at a faster rate than Europe, and Brazil is expected to surpass U.S. and European biodiesel production by the year 2015 (Biodiesel 2020 2008). The global biodiesel market is estimated to reach 37 billion gallons by 2016, growing at an average annual rate of 42 percent (Jatropha world 2008). According to Biodiesel 2020, it is possible that biodiesel could represent as much as 20% of all on-road diesel used in Brazil, Europe, China, and India by 2020. If governments continue to aggressively pursue set targets; enact investor-friendly tax incentives for production and blending; and help to promote research and development in new biodiesel feedstocks such as jatropha and algae, the prospects for biodiesel will be realized even faster than anticipated.

Biodiesel has been produced on an industrial scale in the European Union since 1992. The production has grown significantly over the past ten years. There has been an average increase of 36% per annum between 1992 and 2007 (see Figure 13) (Biofuels platform 2008). Today, there are approximately 120 plants in the EU producing more than 6 million tons of biodiesel annually. These plants are mainly located in Germany, Italy, Austria, France and Sweden. More than half of the biodiesel in the EU is today produced in Germany.

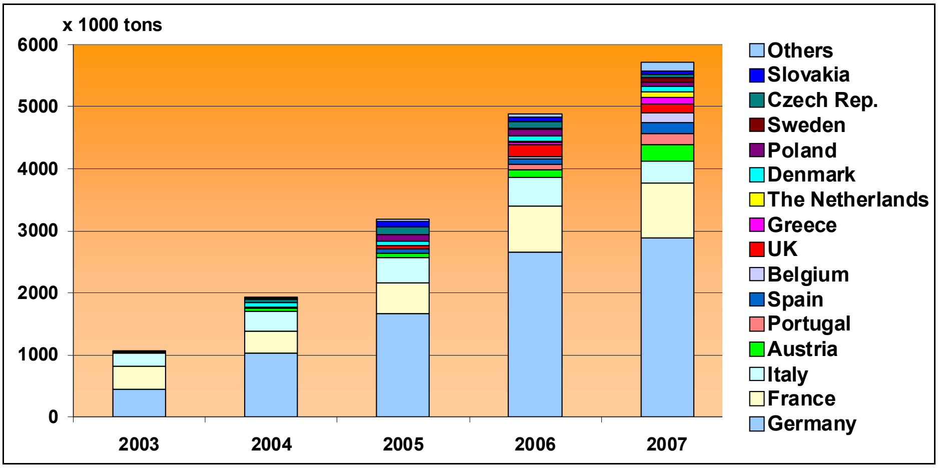

Figure 13. Biodiesel production in the EU between 2003 and 2007 (Source: European Biodiesel Board, 2003–2008).

Biodiesel feedstock markets world-wide are in a transition from increasingly expensive first generation feedstocks, such as soy, rapeseed, and palm oil to alternative, lower cost, non-food feedstocks. As a result, a surge in demand for alternative feedstocks is driving new growth opportunities in the sector. Biodiesel production from non-food feedstocks is gaining attraction around the world. For example, China recently set aside an area the size of England to produce jatropha and other non-food plants for biodiesel. India has up to 60 million hectares of non-arable land available to produce jatropha and intends to replace 20% of diesel fuels with jatropha-based biodiesel. Also in South America and Africa, there are significant programs underway dedicated to producing non-food crops such as jatropha and castor oil for biodiesel. (Biodiesel 2020 2008)

The suitability of fats and plant oils for diesel use is due to their molecular structure and high energy content. However, fats or plant oils as such are not suitable for high-speed diesel engines (light- and heavy-duty vehicles), and further processing is required. The traditional transesterification process with methanol, using sodium or potassium hydroxide as a catalyst, results in traditional biodiesel, Fatty Acid Methyl Esters (FAME) and glycerol as a co-product. Another option is to use a hydrotreatment process (e.g. the NExBTL-process) for the production of high-quality paraffinic biodiesel.

Benefits of FAME esters are good cetane numbers, low sulfur content, no aromatics, and good lubricity. However, the FAME biodiesel has also drawbacks: e.g. high viscosity, poor cold properties, problematic distillation characteristics (dilution of engine oil), difficult impurities (triglycerides, glycerol and alcohols), problems with materials, and poor storage stability (Graboski & McCormick 1998, WWFC 2006). Due to these problems the current European EN 590 (2004) specification for diesel fuel limits the maximum concentration of FAME in diesel to 5% (7 volume-% anticipated in the future). The European standard EN 14214:2003 sets requirements for the quality of FAME used for automotive fuels.

The seed oils of plants are structurally similar to long chain hydrocarbons derived from petroleum, and thus represent excellent renewable resources for oleochemical production. Oils produced in oil seed plants include a wide range of fatty acids with five dominating ones: palmitic, stearic, oleic, linoleic and linolenic acids, which are present in most food oils. In addition to these common fatty acids, there are a great number of other fatty acids occurring in high amounts in seed oils from various wild plant species. These unusual fatty acids include functional side groups, such as epoxy and hydroxy groups, conjugated or acetylenic bonds, unusual mono-unsaturated fatty acids, and medium and very long chain fatty acids. Other unusual plant oils are the ones made up of wax esters instead of trialcylglycerols. (Carlsson et al. 2007)

Various vegetable oils, even animal fats or tall oil, can be esterified. (Ma et al. 1999, Graboski & McCormick 1998). There is, however, a difference in the contents of saturated and unsaturated fatty acids in animal fats and vegetable oils. While rapeseed and soybean oil consist mainly of unsaturated oleic and linoleic acid, animal fats like tallow have a major content of saturated fatty acids like palmitic and stearic acid. Generally, the ignition properties of FAME esters are good (cetane numbers over 50). Compounds that include long-chained, saturated, and branched carbon-chains have higher cetane numbers than the unsaturated fatty acid compounds. This may affect the emission performance of FAME. Generally, FAME biodiesel reduces CO, HC, PM, and PAH emissions, but increases NO_x emissions (McCormick et al. 2001; Sharp et al. 2000, Chang & Gerpen 1997). As mentioned, cold properties of FAME esters are generally poor and further decreases with a rising content of saturated fatty acids. Tallow

FAME has a relatively high cloud point because of the high levels of saturated fatty acids.

Differences in life-cycle emissions of different types of biodiesel arise at the stage of oil production and processing. In the case of oil-seed crops, there is a need to account for energy and raw materials inputs into fertiliser production, land cultivation, materials transportation, harvesting, and oil extraction. Similarly, when animal-derived tallow is used as feedstock, energy used in farming activities, needs to be accounted for. In both cases appropriate allocation procedures for multiple product streams need to be observed. In the processing stage of crude bio-oil auxiliary energy and material inputs, as well as byproducts, wastes, and emissions must be considered. Environmental impacts and sustainability aspects of vegetable oil production and alternative biofuel chains are dealt with in the following chapters.

7.4.2 The NExBTL process

The Finnish company Neste Oil Ltd has been one of the frontrunners in promoting the production of 2nd generation biodiesel and has developed their own NExBTL-process. The first production facility, with a production capacity of 170 000 tons per year is located in Porvoo, Finland. A second unit of the same capacity will be in operation in 2009, also at the Porvoo site. Neste Oil also plans to build massive biodiesel production plants at least in Singapore (capacity 800 000 tons/year) and in Rotterdam (capacity 800 000 tons/year). (Neste Oil 2007)

Neste Oil's NExBTL production plant in Porvoo, Finland needs about 200 000 tons of raw materials per year to make 170 000 tons of biodiesel. Presently Neste Oil imports palm oil from Malaysia and has agreed to use some domestically produced rapeseed oil and 20 000 tons of animal fats or tallow, and is also willing to acquire additional tallow from outside of Finland if available at a reasonable cost. (Neste Oil 2006 & 2008) Flow diagram of the NExBTL process for renewable biodiesel production and the connections of various land, raw material and co-product use options are illustrated in Figure 14.

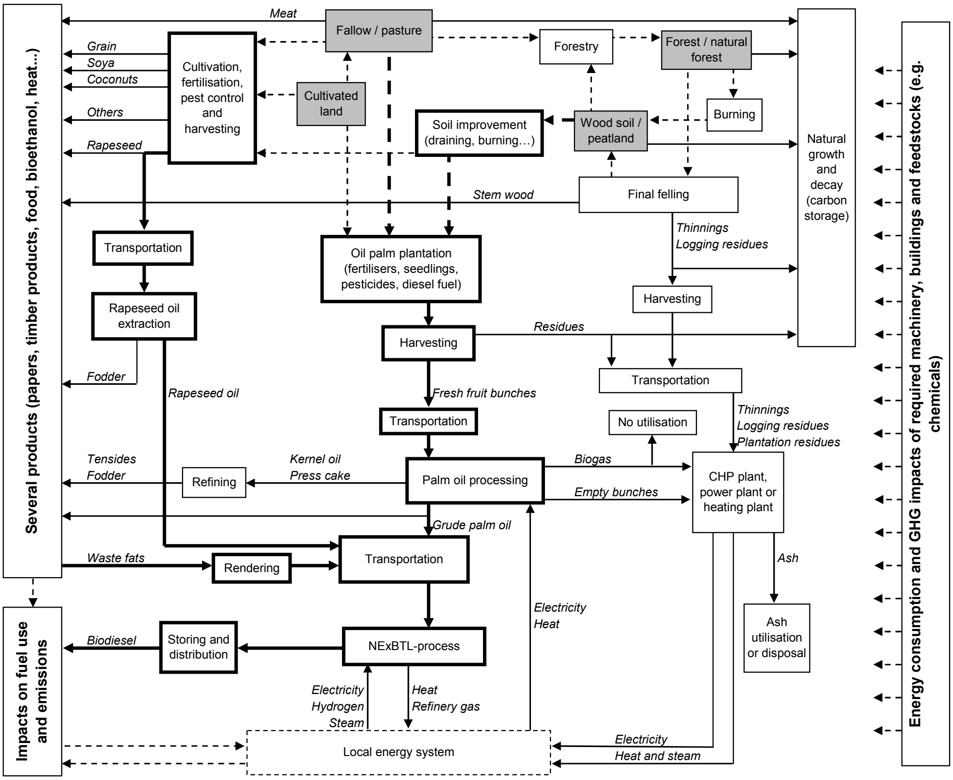

Figure 14. A flow diagram of the NExBTL process for renewable biodiesel production and the connections of various land, raw material and co-product use options.

In the NExBTL-process raw materials are pumped from the storage tanks to the pre-treatment unit, where they are purified. Chemicals needed in the pre-treatment process are H_3PO_4 (75%) and NaOH (50%). Together with water these chemicals formulate palm oil, tallow, soybean oil and/or rapeseed oil into fatty acids.

Fatty acids from the pre-treatment stage are transformed into n-paraffines at a temperature of 330–450°C and further on into branched paraffines in the isomerization stage, which also takes place at a high temperature. The latter process is done to make the cold tolerance properties of the biomass-based diesel better. Both processes need hydrogen and produce acidic wastewater and the latter process also releases fluegases.

Hydrogen needed at the conversion process is taken from the refinery's own hydrogen production line. The processing of hydrogen produces also steam, which is pumped to the steam network of the refinery. Natural gas and fuel gas are used for hydrogen production in the steam reformer.

The following treatment stage is stabilization. Before final storage the NExBTL components are separated from gases and gasoline components that emerge in the process. Altogether 20 tons of NExBTL components are produced per hour in the Porvoo production plant.

Inputs of the conversion process are pre-treated vegetable oils and/or animal fats as a raw material (1 191 kg), electricity, hydrogen (42 kg), steam (29 MJ) and cooling water (25 kg). Steam is produced at the Kilpilahti site (Table 8). 70% of the electricity is produced at the Kilpilahti site and 30% is taken from the grid.

Annually roughly 172 000 tons of NExBTL biodiesel, 12 000 tons of propane (72 kg/ton of biodiesel) and 1 400 tons of biogasoline (25 kg/ton of biodiesel) are formed during the conversion process (Table 9). Propane is exploited in the hydrogen production process and biogasoline elsewhere in the refinery.

Table 8. Inputs per 1 ton of NExBTL (Nikander 2008).

Raw material	1 191 kg
Cooling water	25 kg
Electricity	50 MJ
Hydrogen	42 kg
Process chemicals	3 kg
Process water	25 kg
Steam	29 MJ

Wastewater formed in the pre-treatment stage is treated in the wastewater treatment unit of the refinery. The wastewater comes from washing and drying of the raw material. Solid waste formed in the pre-treatment stage is dried and used as an energy resource outside the Kilpilahti site.

The waste from the pre-treatment process consists of dried solid waste, which includes oil/fat, water, phosphorus, nitrogen and metals (Fe, Ca, and Mg). The pre-treated fat mixture is transferred into an intermediate storage.

Table 9. Byproducts per 1 ton of NExBTL (Nikander 2008).

Dried solid waste	13 kg
Waste water	111 kg
Propane	72 kg
Gasoline	25 kg
CO_2 from production of electricity	0.003 ton
CO_2 from production of steam	0.04 ton

Neste Oil strives to exploit raw materials that do not compete with food production and that are produced locally and in a sustainable manner. The company has also set a clear target, according to which no raw materials utilised in NExBTL production should compete with food production by the year 2020. (Neste Oil 2008) Included in their future plans is the use of crude wax made from forest residues via gasification and Fischer-Tropsch synthesis.

Conventional diesel fuel contains a number of hydrocarbons, aromatics, naphthenes and paraffins, whereas NExBTL is a paraffinic fuel resembling Gas-to-Liquids, GTL, synthetic fuel. The cetane number of NExBTL biodiesel is high, due to the hydrogenation, and this means that the fuel ignites fast and burns efficiently. NExBTL has low sulphur, nitrogen and aromatics content, and no oxygen. NExBTL biodiesel performs well in cold temperatures as the cloud point of the product can be adjusted to between -30°C and -5°C in the isomerisation process. The density of NExBTL biodiesel is lower than that of the conventional diesel. Using NExBTL as a high-concentration blend, or even as such requires no investments in the fuel distribution infrastructure or in the existing vehicle fleet.

Fuel properties of paraffinic fuels result in significant emission reductions and good engine performance when compared to conventional diesel fuel (Alleman & McCormick 2003). Generally, substantial reductions in e.g. CO, HC, NO_x and PM emissions are observed (Kuronen 2007).

According to Neste Oil, the preservability of NExBTL is good, which is why the long-term storage of the product is not a problem (Stade & Siitonen 2006). Due to its quality, it is possible to blend tens of percents of NExBTL into diesel. The higher the NExBTL content is the smaller are the direct emissions. NExBTL can even be used as 100% fuel, which is presently done on a trial basis in the City of Helsinki.

A detailed LCA-study of the NExBTL biodiesel chain's energy consumption and GHG balance has recently been published (Nikander 2008).

7.4.3 Palm oil production and use

The global demand for palm oil has grown rapidly during the last decade. According to Soyatech 2009, Palm oil is currently mainly used for food and about 20% of palm oil is used in non-food applications, mainly as feedstocks for soap making and oleochemicals. The use of palm oil has increased rapidly in recent years, also due to the increased use as a raw material for biofuel production. This has raised environmental and social concerns including those related to forest and habitat conservation, biodiversity losses, the destroying of pristine peat bogs, the use of fire to clear land for cultivation purposes, the need to protect waterways, and the rights of indigenous communities (Cargill 2008).

Production of palm oil has both direct and indirect impacts on land-use and emissions from terrestrial ecosystems in South East Asia. Oil palm plantations established on drained peatlands, cause direct emissions from oxidation of the peat layer within and outside the plantations.

There are, however, attempts to create rules for sustainable palm oil production by the RSPO as described in Chapter 2. The greenhouse gas criteria for palm oil production within RSPO are still under development (RSPO 2007). A proper certification could in principle guarantee that palm oil is not produced on deforested peatlands with high emissions from oxidating soil. However, unfortunately a certification would not be a guarantee of preventing the huge peatland emissions. Firstly, it is very difficult to guarantee the origin of palm oil, as there appears to be no reliable means to separate sustainably produced oil from unsustainably produced oil by just examining the final product. Secondly, even if the origin of the palm oil could be assured, nothing would actually prevent unsustainable palm oil production to move to deforested peatlands, this being a macro-phenomenon of growing biofuel demand, with a similar marginal impact as plantations established directly on peat soils.

Hooijer et al. (2006) estimate that some 25% of current palm oil plantations are on peatlands and that as much as over 50% of new plantations will be developed on peatlands.

Natural peatlands with high watertable do not release any carbon dioxide. The watertable in tropical peat swamp forests is close to the soil surface even in the dry season. In addition, even methane emissions appear to be very low from natural tropical peatlands. (Jauhiainen et al. 2005). Drainage of peatlands leads, however, to aeration of the peat material and hence to oxidation (also called aerobic decomposition). This oxidation of peat material (which consists of some 10% plant remains and 90% water) results in CO_2 gas emissions.

An approximate relation between the CO_2 emission and the watertable depth in peatlands in different climate conditions is shown in the bottom of Figure 15 (as presented in Hooijer et al. 2006). In tropical conditions the oxidation due to drainage and lowering water table is very rapid, whereas in boreal conditions it is negligible compared to tropics. Moreover, peatlands in SE Asia are generally drained to much greater depths than is common in temperate and boreal peatlands.

According to the relationship in Figure 15a conservative estimate for annual carbon dioxide emissions is between 70 and 100 tonnes for each hectare. Much lower water-table depths as 1 m are common in the plantations so that the emissions due to peat oxidation could be even higher. Production of 1 tonne of palm oil on peat soil causes CO_2 emissions between 10 and 30 tonnes through peat oxidation (assuming annual production of 3 to 6 tonnes of palm oil per hectare, under fully drained conditions, and excluding fire emissions).

These emissions neither include the instant emissions from deforestation, preceding cultivation of oil palm on tropical peatlands. Fargione et al. (2008) use an allocation period of 25 years for this emission leading to an estimate of 34 t CO_2/ha/yr. The estimated instant loss due to deforestation of rainforest is 860 t CO_2, which is partly compensated by the growing C stock in oil palm plantation estimated at 14 t CO_2/ha/yr. By using the same allocation period as above Rieley presents an annual emission estimate of as much as 170 t CO_2/ha/yr (see Carbopeat 2007; JRC 2008) for the combined emissions from deforestation and drainage of peat swamp forests. The driver for illegal logging and deforestation of peat swamp forests is not merely palm oil production. However, the huge emissions from peat oxidation could be brought down by elevating the water table and restoring tropical peatlands.

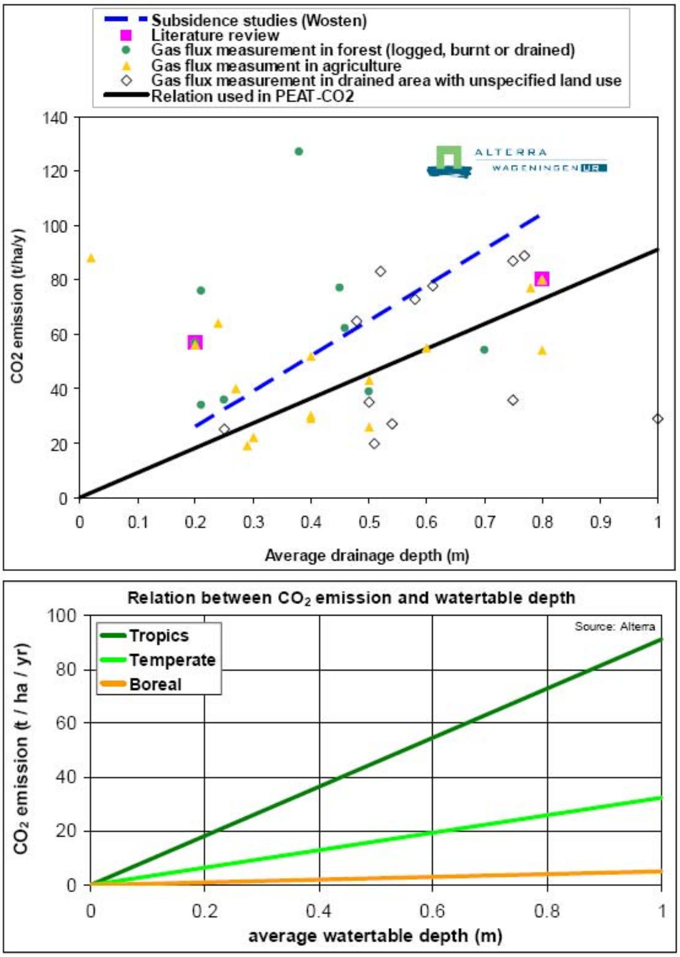

Figure 15. Relation between drainage depth and CO_2 emission from decomposition (fires excluded) in tropical peatlands according to Hooijer et al. 2006. The average water table depth in a natural peatland is near the soil surface (by definition, as vegetation matter only accumulates to form peat under waterlogged conditions). Top: The relation for tropical areas, including SE Asia, based both on long-term subsidence studies and shorter-term gas flux emission studies applying the 'closed chamber method'. Results of different methods were combined to derive a linear relation. This relation needs to be further developed, as it should be non-linear: in reality CO_2 emissions are known to be limited with drainage depths up to 0.2–0.3 m. Also, CO_2 emissions for a given drainage depth will change over time. However, use of a constant and linear relation is deemed acceptable for long-term assessments and for drainage depths between 0.25 m and 1.1 m according to Hooijer et al. 2006. Bottom: Tropical drained peatlands have far higher CO_2 emissions than temperate and boreal drained peatlands at the same drainage depth, because of higher decomposition rates in permanently hot and humid climates. Moreover, peatlands in SE Asia are generally drained to much greater depths than is common in temperate and boreal peatlands.

Forested tropical peatlands in SE Asia store at least 42 000 Megatonnes of soil carbon according to Hooijer et al. (2006). This carbon is increasingly released to the atmosphere due to drainage and fires associated with plantation development and logging. Peatlands make up 12% of the SE Asian land area, but account for 25% of current deforestation. Out of 27 million hectares of South-East Asian peatlands, 12 million hectares (45%) are currently deforested and mostly drained. The current likely CO_2 emissions of drained peatlands caused by decomposition only, amounts to 632 Mt/a (between 355 and 874 Mt/a). This emission will increase in coming decades, unless land management practices and peatland development plans are changed, and will continue well beyond the 21st century. The current total peatland CO_2 emission of 2000 Mt/a equals almost 8% of global emissions from fossil fuel burning. These emissions have been rapidly increasing since 1985 and will further increase unless preventive actions are taken. Over 90% of this emission originates from Indonesia, which puts the country in 3rd place (after China and the USA) in the global CO_2 emission ranking.

Peat subsidence due to drainage in palm-oil plantations, around five centimetres a year, along coastal areas will lead to serious problems of salination. This will eventually result in a total loss of agricultural productivity, including palm oil plantations themselves.

Biodiversity is also drastically reduced in monoculture palm oil plantations. Studies have shown that palm oil plantations can support no more than 20 percent of the original rainforest diversity, and often less.

An oil palm plantation is economically productive for 20–25 years. At this time harvesting becomes uneconomic due to reduced production and increased tree height and decreased soil fertility if expensive fertilisers are not employed (Härdter et al. 1997). Many calculations assume that the oil palm plantations are renewed at the end of their 25-year lifespan. In practice, the plantations are, however, often abandoned because of soil exhaustion, and new areas are prepared instead. (JRC 2008a)

In fact, there is plenty of scope for expanding palm oil production onto degraded forest land and rubber tree plantations, without provoking loss of soil carbon, but this is regarded less productive and economic than cutting the primary forest. Local land use regulations need to be adjusted accordingly. There is a similar problem in Brazil, where soybean expansion is mostly onto ranches, and ranchers then further cut the rainforest, because ranching is still cheaper than feeding their cattle on soybean-meal, which can be exported.

Many companies find it more profitable to abandon the existing oil palm plantation (Webster 2004) and make additional money by logging a new section of forest instead. Some companies do not even establish the plantation (Okamoto 1999, Curran et al. 2004). In East Kalimantan for example, 2 million hectares of land had been reserved for oil palm development by 2002 and 3.1 million hectares of forest had been cleared ostensibly for plantation development, but only 300 000 hectares had actually been planted (Potter 2005).

The oil palm can grow on various soils such as latosoils developed over various parent rocks, young volcanic soils, alluvial clays, and peat soils and is tolerant of relatively high soil acidity (pH 4.2–5.5) (Ataga & van der Vossen 2007), but the optimum pH is from 5.5 to 7 (El Bassam 1998). Major criteria for suitability are soil depth (>1.5 m), soil water availability at field capacity (1–1.5 mm per cm of soil depth), organic carbon (>1.5% in the topsoil), and cation exchange capacity (>100 mmol/kg). Soils should be well drained with no signs of permanent waterlogging, but the oil palm is fairly tolerant of short periods of flooding (Ataga & van der Vossen 2007).

Fertilisers are used every year, but the rates of application are different depending on the age of the plants (Pleanjai et al. 2004). The need of fertilisation is lower during the first 2–3 years than in the mature plantations. Recommendations for NPK, given by MPOB, FAO and other, at the mature stage are roughly: 150 kg/ha N, 40 kg/ha P, and 280 kg/ha K (Pahkala & Kontturi 2008b).

One oil palm produces about 150 kg of fruit bunches annually (Yusoff 2006). Harvesting of the fruit bunches starts after 2.5 years in South-East Asia (Ataga & van der Vossen 2007). Fruit bunches ripen and are harvested through the year by hand at 2–3 times per month. One man can harvest 100–150 bunches per day (Pahkala & Kontturi 2008b). The bunch weight increases from 5 kg (3 year after planting) to about 50 kg (15 year old trees) (The oil palm – Fact file 1999). The dry weight of the pruned fronds is 10.4 t/ha (Yusoff 2006).

Fruit bunches are transported from the tree area to the roads with small trucks (grabbers) or tractors, and then to the local oil mill with bigger trucks or using tractors and small trucks (Teoh 2002). The crude palm oil is finally transported from the local oil mills to the refining mill by trucks.

Crude palm oil mills require about one ton of water to process one ton of FFB, therefore they tend to be located close to a watercourse (Rock 2001). In areas where the palm is grown and processed, palm oil mill effluents (POME) contribute significantly to surface water pollution. Besides that, POME contains acid and has a high organic load. When discharged into watercourses the dissolved oxygen in the water will be depleted, affecting aquatic life and making the water unsuitable for consumption.

Palm oil mills are generally self-sufficient in terms of energy due to the availability of adequate quantities of fibre and shell materials, which are used as solid fuel in the steam boiler. The problems associated with the burning of these solid fuels are the emissions of dark smoke and carbon dioxide. To avoid problems with nearby communities and local authorities, mills employ a cyclone as air pollution control equipment for particulate removal. However, most mills are unable to treat their particulate matter to meet the emission standards.

In the factory, fruit bunches are first treated in an autoclave to destroy lipases and to facilitate the threshing. Separated fruits are next treated in a digester in which they are stirred to a pulp at a temperature of 95–100°C for 20–75 min depending on the method of oil separation. The oil is extracted from the fibres with a screw press and clarified to remove any dirt, fibres, or gum. The quantity and quality of the produced oil has been found to depend on the variety of oil palm, soil type, age of trees, and handling of fruits. Pre-extraction conditions like particle size, heating temperature, heating time, and moisture content are also known to affect the yield and quality of oil during extraction. The production of palm oil involves temperatures, pressures and times, which can affect the yield of the produced oil.

Results have demonstrated that processing parameters affect the yield of palm oil. It has been established that (Baryeh 2001):

- ✓ Increase in extraction pressure increases the oil yield. Pressures above 25 MN/m^2 should however not be used as these pressures do not increase yield significantly.

- ✓ Increase in the heating temperature increases the yield up to 100°C heating temperature. Heating temperatures above or below 100°C do not increase the yield appreciably.

- ✓ The yield increases as the heating time increases. However, heating times of more than 20–30 min are not advisable since these do not increase the yield significantly and in certain cases they even decrease the yield. An increase in the extraction time increases the yield up to a time of 6–12 min depending on other processing parameters.

Electricity is the dominant source of energy for the production process. The total energy consumption of all electric machines used in the production process is about 17–18 kWh/ ton FFB. Diesel oil is used for the diesel generator to start up the boiler and the generator. External fuel used in the production process is about 0.024 l diesel oil/ton FFB. (Chavalparit 2006)

A crude palm oil mill uses a lot of water in the production process. Channel water is usually the water source. This water is treated by coagulation and filtration. Alum and polymer are used as coagulants and flocculants in the clarifier. The average water consumption is equal to 1.20 m3/ton FFB or 720 m3/day. The quantity of water consumption per ton FFB does not differ much from that of crude palm oil factories, due to the fact that most of the water is used as boiler feed and turbine cooling water. The cooling water of the turbine is recycled in the production process for cleaning of the machines and for domestic purposes. (Chavalparit 2006)

Environmental impacts of the processing stage of palm oil are mainly related to the treatment of the palm oil mill effluent (POME), the residue that remains when palms are crushed (on average ~13.3 ton/4 ton of crude palm oil), the required steam consumption in the mill, and the utilisation or waste treatment of empty fruit bunches (EFB). POME is a colloidal suspension of 95–96% water, 0.6–0.7% oil and 4–5% total solids including 2–4% suspended solids originating from the mixture of a sterilizer condensate, separator sludge and hydrocyclone wastewater. The raw or partially treated POME has an extremely high content of degradable organic matter, which is partly due to the presence of unrecovered palm oil.

The ratio of BOD and COD is about 0.76, which means that the organic compounds in wastewater are easily biodegradable. It has been found that the BOD of the wastewater after anaerobic digestion (anaerobic pond 3) is reduced to 460 mg/L (99% BOD removal efficiency). The total solids (TS) and suspended solids (SS) in the wastewater are also very high: 57.7 and 30.9 g/l respectively. The SS in the wastewater originate from the fine particles of the fibers that contaminate the oil-water slurry while pressing the fiber. Wastewater from this industry also contains high amounts of nitrogen and phosphorus containing compounds. The oil content in the wastewater is 7 250 mg/l. Raw wastewater also contains high color concentration (10,000 pt. Colour unit). (Chavalparit 2006)

Leaching agrochemicals and sediments are also causing severe water pollution, leading to fish and coral kills. A recent study by WWF found that effluents from palm oil mills and chemical and fertiliser run-offs enter rivers on which local communities depend and there is a high concentration of heavy metals, particularly lead, in the fish (Johnston 2008). Paraquat dichloride, a toxic herbicide banned in several countries, is quite commonly used on palm oil plantations.

7.4.4 Soybean oil production

Soybean is the most important oilseed and protein crop in the world. Soybean oils are sold as "vegetable oil," or end up in a wide variety of processed foods. Another and increasing purpose of use is the biofuels. The remaining soybean husks are used mainly as animal feed. Soybeans can also be directly used as human food. The seeds are also applicable for many non-food products. The lecithin in the seeds can be used as an emulsifier for pharmaceuticals, printing inks, pesticides, etc. The protein (soybean meal) can be used for the production of synthetic fibres, plastics, glues, etc. The oil is utilized in making candles, celluloid, core oil, electric insulation, glycerin, paints, soaps, etc.

The soybean is a part of a complex system including other plants with high oil and protein production such as oil palm and rapeseed that can replace each other to various extents. Even though the fatty acid composition of rapeseed, soy, and palm oil is not the same and they are not completely substitutable, the oils can substitute each others within most important applications, such as frying oil/fat, margarine, shorthening and salad oils, and also for biodiesel production. Similarly, the co-product of the soy oil, soy protein can be substituted with e.g. palm kernel meal or rapeseed meal (see more about the calculation of substitution effects in LCA in Section 3.4 and Dalgaard et al. 2008). On the global market, the substitutable plants and products form a kind of a pool, in which the increase or decrease of one component affect one and another. This affects also the effects caused by the production and consumption of the respective plants. Currently, the main implication is perhaps, how and where the increase or decrease of one component changes the land use and what are the ecological and the social consequences.

Main producers of soybeans are U.S.A., Brazil, Argentine and China *(*FAO 2007*)*. Main world soybean meal exporters in 2007 were Argentine (51%), Brazil (22%), and the United States (14%). Mainly due to the increases in world demand for chicken and pork feed (Elbersen et al. 2008) the global production of soybean has recently grown rapidly, more than by 30% between the years 2000 and 2007 (FAO 2009). The main growth areas are Argentina and Brazil (Van

Berkum & Bindraban 2008). According to FAO statistics, between the years 2000 and 2007 the area harvested in Argentina grew almost by 90% to 16 million hectares and in Brazil by 50% to 21 million hectares. The total yield in Argentina more than doubled to 45.5 Mt/a and in Brazil it grew by almost 80% to 58 Mt during the same period of time (FAO 2009). U.S.A. was, however, still the largest soybean producer with 31 million hectares area harvested and annual yield of 10.7 Mt in 2007. In the 2002–2003 growing season, 30.6 million tons of soybean oil were produced worldwide, constituting about half of the edible vegetable oil production worldwide, and 30% of all fats and oils produced, including animal fats and oils derived from tropical plants. (USDA 2004)

Since 1970, the growth of soybean cultivation in Brazil has been even more dramatic, expanding from 3 million ha in 1970 to 18.5 million ha in 2003, with demand expected to increase further due to its use as a biofuel feedstock (Bickel and Dros 2003). As Latin American countries increase their investment in soy cultivation, the associated ecological and social implications can be expected to intensify. Soybean cultivation is one reason for expansion of agricultural area to and corresponding devastation especially in the Cerrado and Amazon regions, causing losses of irreplaceable ecosystems and carbon stocks.

In addition to the ecological problems, the wave of large-scale soy farms has had sosial sustainability impacts, e.g. impact on land access. Large-scale farms displace inhabitants and land users, who tend to rely on extensive cattle rearing and small-scale agriculture for their livelihoods. In general they do not have official proof of ownership of the land. Customary rights to land holdings, known as *posse*, are partially recognised by law, but often only entitle the owner to a meagre level of compensation in the event that the land is taken over for soy cultivation. There have been reports of intimidation and the use of violence to force the original inhabitants to vacate the land (van Gelder & Dros 2002).

In Brazil, soybean cultivation displaces eleven traditional agricultural workers for every new worker it employs. Soybean cultivation is low intensity in terms of employment, as on average, one permanent worker can manage 167–200 ha of soy (Bickel & Dros 2003). Therefore, once land is cleared for soy cultivation, opportunities for employment are very low and this often leads to depopulation, with displaced farmers moving to peri-urban slums or to forest areas to clear new farmland. The phenomenon occurred already in the 1970s, when 2.8 million people were displaced by soybean production. Many of these now landless people moved to the Amazon where they cleared pristine forests. This can be expected in turn to impact the access of forest communities to land. In Santarém in the state of Pará (Brazil), 600 families sold their land to plantation owners between 2000 and 2003, and 70% of the population in some communities were displaced (van Gelder & Dros 2002). On the other hand, in the Cerrado region, where transgenic soybean production is expanding, displacement has been relatively modest as the area is not densely populated (Altieri & Pengue 2006).

Due to the large interest in soybeans, it has been one of the first plants that have also been a large interest of the biotech industry. Criticists have pointed out that this also can lead to ecologically and socially unsustainable situations. For example, in Argentina, recently 60 000 farms were closed down while the area planted with Roundup Ready soy[6] nearly tripled. In 1998, there were 422 000 farms in Argentina, while in 2002 there were only 318 000, a reduction by a quarter. In one decade, the soybean area increased by 126 percent at the expense of dairy, maize, wheat, and fruit production. In the 2003/2004 growing season, 13.7 million hectares of soybean were planted, but there was a reduction of 2.9 million hectares in maize and 2.15 million hectares in sunflowers. For the biotech industry, huge increases in the soybean area cultivated and a doubling of yields per unit area are an economic and agronomic success. For the country, this means more imports of basic foods, therefore loss of food sovereignty, increased food prices, and hunger (Pengue 2005). Additionally, it has been presented that the use of Roundup Ready plants increases the use of the herbicide causing increased ecological risks.

Intensive soybean cultivation has also led to massive soil nutrient depletion. It is estimated that continuous soybean production in Argentina has resulted in the loss of one million metric tons of nitrogen and 227 000 metric tons of phosphorous from soils nationwide. The cost of replenishing this nutrient loss with fertilizers is estimated at US$ 910 million. Increases in nitrogen and phosphorus in several river basins of Latin America is certainly linked to the increase in soy production (Pengue 2005).

Particularly high rates of erosion also accompany soy production, especially in areas where long cycles of crop rotation are not implemented. Soil cover loss averages 16 tons per hectare of soy in the US Midwest. It is estimated that in Brazil and Argentina soil loss averages between 19–30 tons per hectare, depending on management practices, the climate, and the terrain incline. Herbicide tolerant

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[6] Roundup Ready soybean is genetically modified being resistant to herbicide Roundup.

soy varieties have increased the feasibility of soy production for farmers, many of which have begun cultivation on fragile lands prone to erosion (Jason 2004).

Mono-cultural production of soy in the Amazon Basin has rendered much of the soil infertile. Poor soils necessitate increased application of industrial fertilizers for competitive levels of productivity. In Bolivia, soybean production is expanding eastward, and areas in the east already suffer from compacted and degraded soils. One hundred thousand hectares of depleted former soy-growing lands have been abandoned to cattle grazing, which leads to further degradation (Fearnside 2001).

Soybeans are mainly cultivated in the sub-tropical areas (El Bassam 1998; Martin et al. 2006). It is a short-day plant and needs 4–5 months of frost-free growth season from planting to harvest. The optimum temperature for soybean is 24–25°C and the need of rainfall is 500–750 mm during the growth period. About 70-90 kg of soybean seed is sown per hectare and the annual yield in the United States, Brazil, and Argentina varies between 2.2–2.9 tons per hectare (FAO 2009).

Soil fertility is essential for soybeans to reach full yield potential, as adequate soil fertility – corrected if necessary with lime and fertilizers – helps to reduce risks from weather stresses, diseases, and nematodes (Mullen et al. 1998). Soybean is a nitrogen fixing crop, and therefore no or only little N-fertilizing is needed. Soybean is a heavy user of potassium, but needs phosphorus fertilization only on soils low in available phosphorus. Each ton of soybeans contains approximately 50 kg of potassium and 15 kg of phosphorus. According to Jungbluth et al. (2007a), the annual average fertilizer need in soybean cultivation in USA is 5 kg N, 16 kg P_2O_5 and 25 kg K_2O and in Brazil, 30 kg P_2O_5 and 30 kg K_2O, with no need for additional nitrogen.

Weed control mechanically or with herbicides, such as glyphosate, is often needed during the first few weeks after sowing. The broad-spectrum weed control is a primary reason for the popularity of glyphosate and Roundup Ready crops (Hartzler & Boerboom 2006). The importance of insect pests in soybeans is extremely variable from year to year, in large part due to environmental conditions. Production practices also have an impact on the occurrence of pest insects in soybeans.

Soybeans combined at 14% moisture content or higher should be dried, if they are being placed in storage. With adequate drying methods, soybeans could be harvested at moisture content as high as 20%. However, a good practical compromise for maximum harvest moisture content is about 18%.

To produce soybean oil, the soybeans are cracked, adjusted for moisture content, rolled into flakes, and solvent-extracted with a commercial hexane. The oil is then refined, blended for different applications, and sometimes hydrogenated.

7.4.5 Sugarcane based bioethanol

Sugarcane is widely cultivated all over the world. Top producers of sugarcane are Brazil and India, followed by China, Pakistan, Mexico, and Thailand. The abundance of sugarcane for ethanol production in Brazil is mainly a result of the Brazilian Alcohol Program (Proalcool), which was established in 1975 for the purpose of reducing oil imports by producing ethanol from sugarcane. Sugarcane cultivation causes many environmental and social problems, and also problems to human health. Therefore a Better Sugarcane Initiative (BSI) has been created to give guidelines for more sustainable sugarcane production and processing. Draft principles and criteria for sustainable sugar production and processing practices have been drawn, but these are still not open for public in general. The website of the organization provides lot of sugarcane information (www.bettersugarcane.org). The initiative is assessed in more detail in Section 2.3 and Appendix A.

Brazil's sugar cane production evolved from 80 Mt/a in 1970 to 425 Mt/a in 2006 (Macedo 2007). In 2005/06, around 50 percent of the sugarcane was used in ethanol production, and the other half in sugar production. These figures refer to the weight of crop residue ready for industrial processing, excluding the vegetable matter on sugar cane tips and leaves. According to one Brazilian sugar cane association, the average productivity is about 78–80 t of cane per hectare, while in São Paolo it ranges from 80 to 85 t/ha, both considering a complete life cycle with five cuts (Macedo et al. 2008). According to the Jungbluth et al. (2007a) database land use in Brazil for sugar cane cultivation was 55700 km^2 in 2004, of which 60% is located in the state Sao Paolo. In the last 25 years the area for sugar cane cultivation has increased at an average of 0.97% per year. The increase up to 2010 is expected to be around 9% per year, and new areas for sugarcane cultivation are explored in Brazil.

In cultivation, fertilization (inorganic fertilizers, stillage, ash) and liming are used. Sugarcane is also capable of biological N-fixation. The stillage is applied to the soil as an additional fertilizer to ameliorate the soil properties like the availability of nutrients, the capacity of cation exchange, the soil structure and the microbiological activity. By the application of the stillage on the fields mineral fertilizers can be substituted: nitrogen around 7.5%, P_2O_5 around 2.2%, and K_2O around 29.4% (Jungbluth et al. 2007a). The stillage is either transferred by pipelines or is directly transported by trucks to the fields and is applied there.

In Brazil, the sugar cane fields are not normally irrigated. However, elsewhere in the world, irrigation can be remarkable.

The use of pesticides in Brasil is regulated by legislation. The control or management of weeds encompasses specific methods or combinations of mechanical, cultural, chemical, and biological methods. Pesticide consumption in sugar cane crops is lower than in citric, corn, coffee, and soybean crops. The use of insecticides is low and that of fungicides is virtually nil. However, more herbicides are still used on sugar cane crops than on coffee and corn crops, but less herbicide are used than on citric crops, and the same amounts as on soybean crops. It seems impossible to use this to totally eliminate herbicides, as expected, especially because of the rise of unusual of pests. (Arrigoni & Almeida 2007; Ricci 2007).

Mechanical harvesting is gradually phasing out the traditional manual harvesting. According to Macedo et al. (2008), in 2002 some 35% of the cane area was mechanically harvested. By 2005/2006, the figure was already 50% and in a scenario for 2020, mechanical harvesting has completely phased out the manual one. This follows the legislation according to which in the State Sao Paolo all sugarcane burning must end by 2021 in areas where the terrain allows for mechanized harvesting, and by 2031 in all other areas (UNICA 2008). If the harvesting is done by hand, the field is sometimes burned to destroy dead leaves and to kill venomous snakes. This causes emissions of methane and carbon monoxide to the air, and there are several negative effects on the flora, the fauna, and human health. The increase in mechanical harvesting, however, leads to increasing use of diesel in the harvesting phase and to the loss of jobs.

Raw materials and auxiliaries needed in the fermentation process include water, sulphuric acid, NaOH, lime, lubricants, antifoam and cyclohexane (Jungbluth et al. 2007a; Macedo et al. 2008). Small quantities of antibiotics are also needed (Jungbluth et al. 2007a).

The wastewater from the washing and other processes and the stillage from the distillation unit are used as fertilizer in the sugar cane cultivation. About 10–13 l of stillage per l ethanol has been reported. It contains organic matter, phosphorus, nitrogen, and potassium. The COD is estimated at around 15 to 35 g/l.

The 95% ethanol is either stored as a final product or dehydrated to anhydrous ethanol (99.7%). Dehydration requires energy and produces anhydrous ethanol and wastewater, which is applied to the sugarcane fields together with stillage (Jungbluth et al. 2007a).

The process yield depends on cane quality (sucrose content), and the efficiency of sucrose utilization. The industrial sugar recovery efficiency is at present around 90%, and large improvements in today's technologies are not expected. Therefore, in the future, the possibilities to enhance ethanol yields are mainly related to the improvements in the quality of the cane (Macedo et al. 2008).

In the ethanol conversion process, the distilleries are self-sufficient in terms of the production and consumption of energy. The energy is supplied by the burning of bagasse (de Olivieira et al. 2005).

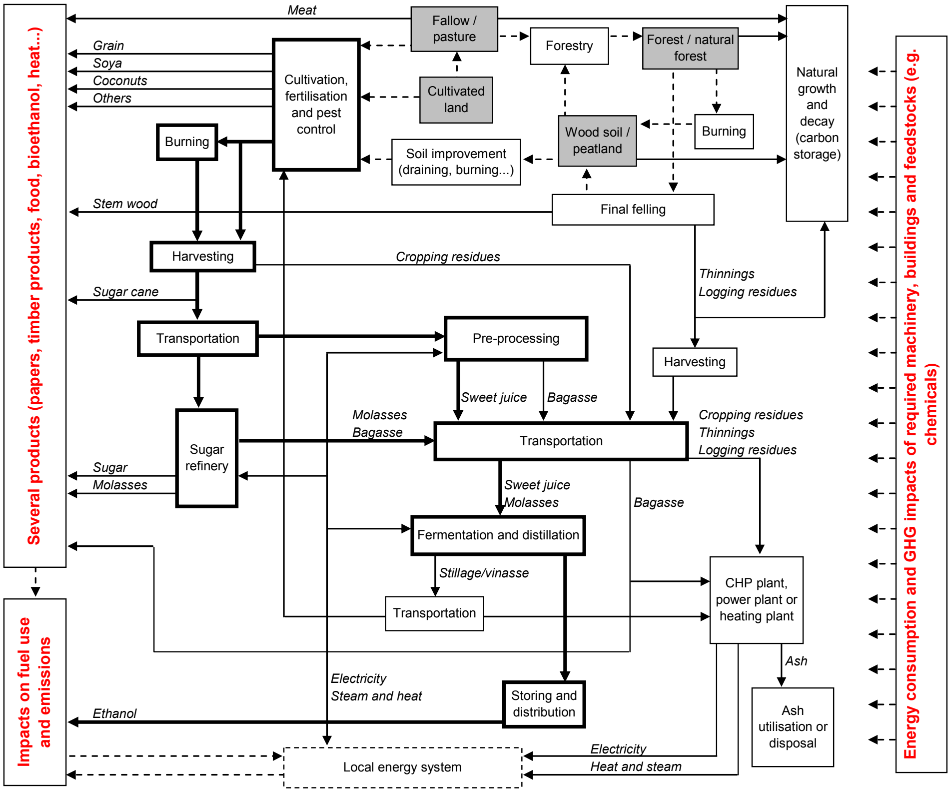


Figure 16. Flow diagram of the sugar cane ethanol process and the connections of various land, raw material and co-product use options.

Several LCA- or sustainability studies on bioethanol production from sugarcane have been done (De Oliveira et al. 2005; Zah et al. 2007; Goldemberg et al. 2008; Macedo et al. 2008; Smeets et al. 2008). A screening of the main environmental sustainability aspects are presented in Chapter 8. The flow diagram of sugar cane ethanol production from cradle to grave is illustrated in Figure 16.

7.5 Production of evolving biofuels

Most of the so-called 2^{nd} generation biofuel processes being developed are still at a pilot or demo scale and not yet implemented in a full industrial scale. They are considered complex and rather expensive, but the benefit is that they can use cheaper feedstock. They are also generally considered to emit less greenhouse gases than typical 1^{st} generation biofuels based on field crops, as the growing of the feedstock has low inputs, and the processes are typically planned to use biomass and/or waste streams for process heat generation.

With respect to 2^{nd} generation biofuels, only a few studies present a comprehensive assessment including a wider set of environmental impact indicators. The fundamental problem in assessing environmental impacts of technologies under development is the lack of reliable data of the commercial scale production. In addition, many technical details are carefully protected by companies and organisations developing the technologies. Consequently, the knowledge of the environmental impacts of such technologies still rely more on speculations than empirical data.

7.5.1 Fischer-Tropsch diesel (FT)

FT technologies have been used on a commercial scale to produce gasoline and diesel for example in South Africa (Sasol) from coal since 1950’s and in Malaysia (Shell) from natural gas. In the FT synthesis the so-called synthesis gas (or syngas) consisting mainly CO and H2 is converted into long-chain hydrocarbons. Biomass is an option for raw material of synthesis gas, but biomass-based FT plants are not yet commercially installed. However, a similar kind of process was in operation in Finland in 1980’s, when ammonia was produced from peat-based synthesis gas in Kemira plants in Oulu. On-going research, development and demonstrations of the technologies are presently being carried out in several countries. The first commercial-scale plant is expected to be in operation in 2012–2015.

A German company Choren has opened a 2nd generation biomass-to-liquid (BTL) plant in Freiberg, Saxony in Eastern Germany. Its full annual capacity is 18 million litres (approximately 15 300 tons). The production of FT diesel is scheduled to be started in 2009 using forest residues, wood and waste timber as raw materials. At full capacity it will use 65 000 metric tons of wood dry matter as a feedstock. Shell, Daimler and Volkswagen are Choren's partners.

In Finland, Neste Oil and the forest industry company Stora Enso are building a demo plant that will be jointly owned by both companies at Stora Enso's Varkaus factory. In the demo plant gasification of biomass and gas cleaning for the purity needed by the Fischer-Tropsch synthesis will be demonstrated, starting early in 2009.

Another forest industry company, UPM-Kymmene Oyj, has announced that it will focus strongly on advanced biofuels. UPM co-operates with Andritz and its associated company Carbona on the development of technologies for biomass gasification and synthetic gas purification.

In biomass-based Fischer-Tropsch (FT) diesel production the raw material is first gasified, the product gas is then cleaned and processed to form synthesis gas. The synthesis gas is then converted into long-chain hydrocarbons with the FT synthesis. Also transportation fuels like methanol, dimethyl ether, methane or hydrogen can be produced from biomass in similar-type of processes. The process consists of the following basic steps: pre-treatment, gasification, gas cleaning and conditioning, FT synthesis, upgrading, and recycling. The process steps are depicted in Figure 17.

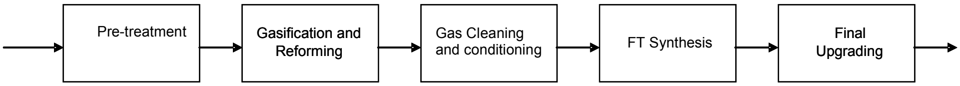


Figure 17. Basic steps of the Fischer-Tropsch process.

Pre-treatment includes drying and size reduction of the biomass. After pre-treatment the biomass is gasified using oxygen or steam. Direct gasification with air has been ruled out because the nitrogen dilution strongly increases downstream equipment size and costs. Different reactors can be used for gasification. The produced gas consists mainly of CO and H_2, CO_2, steam, methane and higher carbon compounds, and inorganic impurities (like sulphur and nitrogen coumpounds). Typically, the levels of S and N in wood are such that the concentrations of H_2S and NH_3 in the gas from the gasifier would be around 100 ppm and 2 000 ppm, respectively.

The impurities in the gas have to be cleaned out, as the FT synthesis is fairly vulnerable to them. Impurities like heavy metals, alkalines and chlorine are separated from the product gas by filters and the particular waste stream containing various impurities should likely be handled as hazardous wastes. Tars contain a lot of potential CO and H2, which should preferably be taken into use. There are currently three applicable ways of gasification and tar removal for the FT diesel process (IEA Bioenergy 2008a):

- fluidised-bed gasification + catalytic reforming,
- fluidised-bed gasification + solvent-based tar removal,
- and entrained-flow gasification at high temperatures.

In Finland, the research and development work is focused on fluidised-bed gasification and catalytic reforming of tars (Figure 18).

CO_2 and sulphur compounds are removed using commercial solvent-using scrubbing processes, like Rectisol. The main share of CO_2 is removed from the synthesis gas before the FT synthesis due to technical reasons, as CO_2 as an inert gas inhibits desired reactions in the FT synthesis.

In the FT synthesis carbon monoxide (CO) and hydrogen (H_2) react on a catalyst surface producing water and long-chained hydrocarbons. Mainly iron-based catalysts like Cobalt (Co) and Iron (Fe) are used. Contaminants in the syngas would inhibit the catalysts reducing its efficiency and increase the need for replacement of catalysts (Hamelinck et al. 2004; Huber et al. 2006; Spath & Dayton 2003). The basic approach for the biomass-based FT plant is that synthesis gas purified to the quality required by the FT synthesis will be produced. Also catalysts that are more tolerant of impurities than the current ones are under development. Additionally, catalyst regeneration and recycling methods are developed.

A range of products are a result of the FT synthesis. The selection of products is defined by the used catalyst and reaction parameters. The final step is the upgrading of the FT liquids to FT fuels, one of them being FT diesel. Technology for the final upgrading of FT liquids is commercially available from suppliers of oil-refinery processes.

FT diesel, regardless of the raw material, has similar properties as conventional diesel and thus it is easy to take it into use without engine modifications or construction of a new fuel distribution system. FT diesel can also be mixed in any proportion with conventional diesel.

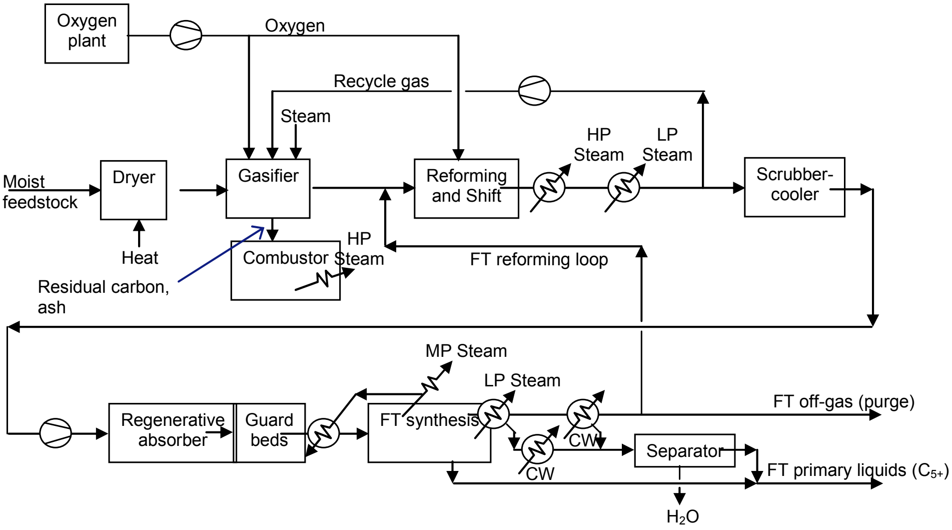


Figure 18. The fundamentals of a Finnish model for the Fischer-Tropsch diesel process (McKeough & Kurkela 2007; Saviharju & Mckeough 2007).

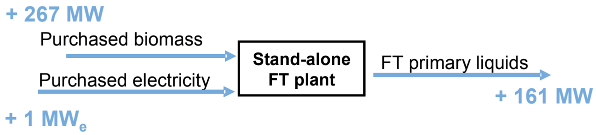
In the overall synthesis-gas route to transportation biofuels, both the gasification and the synthesis steps yield significant amounts of by-product energy in the form of steam or fuel gas. Application of the conversion process at a mill site will be highly favourable if the by-product energy of the conversion process can fully be utilised in the mill.

All the basic steps in the FT process are based on known technology. The challenges relate to the cleaning of the gas as gasification of biomass has so far focused on applications, which are less sensible to impurities in the gas than FT synthesis. Also keeping the capital costs reasonable is one of the challenges regarding the FT process. In order to improve the cost-efficiency the scale of FT diesel processing should likely be large. This may cause significant impacts related to raw material availability and transportation for the particular and also other purposes. In Finland, the aim is to reduce costs by integrating biofuel production to e.g. a pulp and paper mill (McKeough & Kurkela 2007a). The forest-products industry offers attractive platforms for the production of biofuels because significant synergy is derivable from the integration of biofuel production with existing industrial processes (in comparison with stand-alone production in dedicated plants), reasonably-priced residues and wastes are available on site, the existing wood procurement infrastructure of the forest-products industries can be used to full advantage and the annual operating times of the mills are long, e.g. 8 000 h/a.

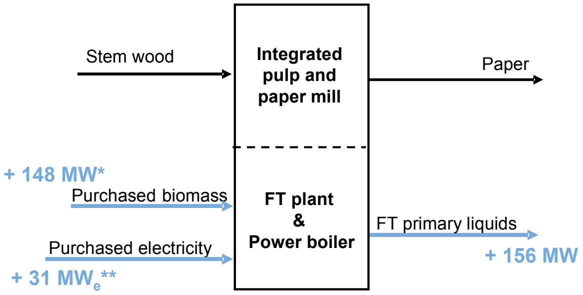
The integration of the production of FT diesel into forest industry enables efficient utilisation of by-product energy of FT diesel production, and thus the total efficiency of the production can be increased. In the integrated system the heat produced in the FT process reduces the requirement for heat production in an integrated CHP plant. Consequently, the electricity production is also lowered resulting in a need for separately produced extra electricity. This can be purchased from the grid or produced within the integrate. Examples of energy flows of stand-alone and integrated units are presented in Figure 19. In addition, upgrading based on mild hydrocracking and hydrotreatment is required to convert these liquids into marketable and/or blendable automotive fuels (McKeough & Kurkela 2007b). It is presumable that the auxiliary energy and material inputs required in the upgrading process of FT primary liquids are close to those of upgrading palm oil into NExBTl (see Chapter 7.4.2).

Soimakallio et al. (2009) assessed greenhouse gas balances of FT diesel in three different concepts: integrated to a pulp and paper mill by minimising either a) external electricity or b) biomass feedstock and c) a stand-alone concept. The reductions in greenhouse gas emissions compared to the bio-carbon consumed, when replacing fossil diesel are presented in Figure 20. According to Soimakallio et al. (2009), the particular emission reduction significantly depends on emissions from electricity production and losses in soil carbon balances. However, Soimakallio et al. (2009) did not consider the possible impacts of changes in raw material availability, e.g. due to timing of final fellings or raw material competition, on the greenhouse gas balances of FT diesel. The process flows of FT diesel and the connections of various raw material, land and co-product use are illustrated in Figure 20.

CASE A) STAND ALONE FT PLANT (267 MW_{feed})
Energy flows (LHV basis)



CASE B) NET CHANGES WITH INTRODUCTION OF FT PLANT (260 MW_{feed})
Incremental energy flows (LHV basis)



CASE C) NET CHANGES WITH INTRODUCTION OF FT PLANT (260 MW_{feed})
Incremental energy flows (LHV basis)

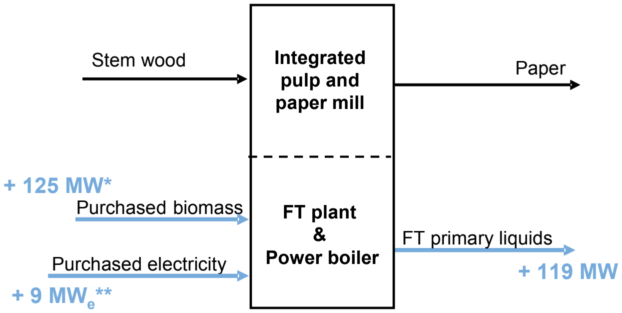


Figure 19. Energy flows of a stand alone FT plant (CASE A) and incremental energy flows upon introduction of a FT plant and a new (smaller) power boiler in two examples of FT plant integration with a pulp and paper mill by minimising the biomass feedstock input (CASE B) and the electricity input (CASE C). The figures are based on McKeough & Kurkela (2007b).

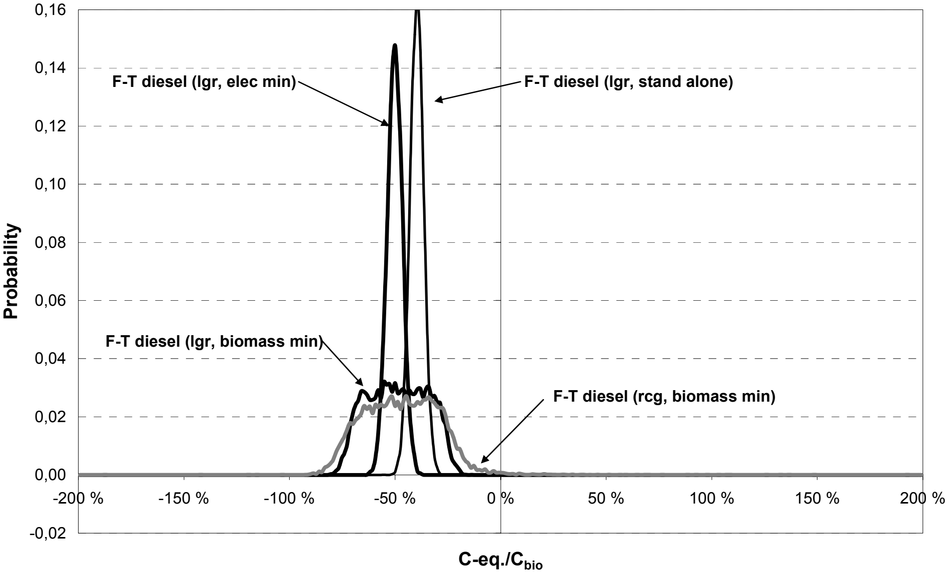


Figure 20. Probability distributions for reduced carbon equivalent emission per consumed biocarbon when replacing reference fuels. In the figure 'Elec' refers to electricity production, 'lgr' refers to 'logging residues' and 'rcg' refers to reed canary grass. In addition, 'Elec min' and 'biomass min' refer to integrated FT diesel processing cases with minimum external electricity and biomass, respectively (Soimakallio et al. 2009).

According to Kirkinen et al. (2009), in a time period of 100 years the greenhouse impact of peat-based FT diesel is likely to be greater than the impact of fossil diesel. The impact can be lowered to some extent by producing peat from the cultivated peatland (strong greenhouse gas emissions from the decaying peat layer are avoided) with new peat production techniques, and utilising the produced biomass (logging residues or RCG) in the after-treatment as for diesel well. However, within the given time frame relevant for ambitious climate change mitigation (see Chapter 4), peat-based FT diesel cannot respond to the challenge.

In a LCA study of FT diesel Baitz et al. (xxx), show very encouraging results ranging from 5 to 42% improvement for acidification, 3 to 29% for eutrophication, and 89 to 94% in the case of summer smog, depending on the scenario considered. Reinhardt et al. (2006) have assessed different FT diesel routes. All investigated pathways give favourable results in terms of summer smog, but are mixed for acidification and eco-toxicity, and unfavourable in terms of eutrophication. Environmental impacts related to FT diesel are discussed in more details in Chapter 8.

7.5.2 Lignocellulosic-based ethanol production

A wide range of technologies are under development to produce ethanol from lignocellulosic biomass, but none of them have reached the commercial production. The raw materials most potential to be used at first in large-scale 2nd generation bioethanol production are side-streams of processing sugarcane, cereal grains, corn and rice, and fibre-containing waste streams. The first commercial-scale plant is expected to be in operation in 2012–2015, but demonstration plants have already been built and technologies tested. An example of pilot facilities is Etek Etanolteknik in Sweden and examples of demonstration plants are the Abengoa plants in Spain and the USA and the Iogen plant in Canada (IEA Bioenergy 2008b).

In Finland, UPM and Lassila & Tikanoja (L&T) are testing a new ethanol and energy production concept that utilises commercial and industrial waste. The St1 oil company has started a production of fuel ethanol in Finland. Their concept is based on a number of small-scale plants (capacity of several thousand tonnes) utilising the Etanolix process, which use food-industry waste as raw material and a centralized distillation plant for the production of absolute ethanol. The first plant has been in operation since 2007. St1 is also developing an ethanol concept based on lignocellulosic raw material.

There are several processes for converting lignocellulosic material into ethanol. Fermentation processes usually consist of the following main steps. First lignocellulosic material is cut or grinded into small pieces (eg. chips, pieces, or powder). The next process phase is hydrolysing of the cellulose and hemicelluloce into sugars. For the hydrolysis both enzymatic and so-called acid hydrolysis methods are under development. Formed sugars are then fermented to ethanol. Depending on the process concept, hydrolysis and fermentation steps can occur separately or simultaneously. Finally ethanol is separated from the solids and distilled (Figure 21). Estimated ethanol yields from the lignocellulosic feestocks range between 110 and 300 l/t dry matter (IEA Bioenergy 2008b).

Main questions that still need to be solved are e.g. how to convert the lingocellulosic material from its natural form into an aqueous mixture suitable for hydrolysis of the polysaccharide polymers into sugars and the development of more efficient microbes that will ferment efficiently all sugars available.

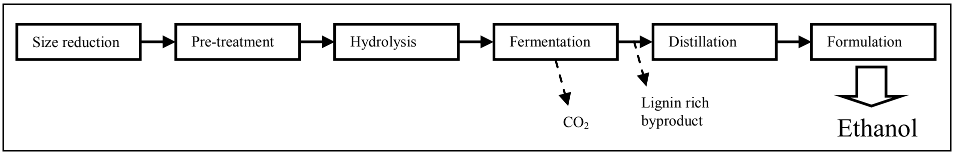


Figure 21. The main steps in a lignocellulose-to-ethanol production concept.

One of the most critical steps in converting lignocellulosic material into bioethanol is the technology needed to open up the structure of the plant material for the enzymes to start hydrolysing the polysaccharide polymers into sugars. The majority of the current proposed commercial-scale ethanol processes plan to use enzymes in the hydrolysis rather than acids. The effective hydrolysis of the interconnected matrix of cellulose, hemicellulose and lignin requires a number of cellulases to overcome a number of barriers: unreactive crystalline cellulose, presence of lignin blocking reactive sites, low substrate surface area, low hydrolysis rates, substrate inhibition, and product inhibition. The main focus of current R&D efforts is on optimising pretreatment techniques to address these barriers. Steam explosion at mildly acidic conditions is the current state-of-the-art technology. (IEA Bionergy 2008b)

In addition development of enzymatic hydrolysis involves the following challenges (IEA Bionergy 2008b):

- minimising the impact of inhibitors that reduce the effectiveness of enzyme activity
- reducing the cost of enzymes, including their recycling
- identifying wether separate or simultaneous hydrolysis and fermentation processes represent the least cost route.

A key goal for the commercialisation of lignocellulosic ethanol is that all sugars released are fermented into ethanol. Hexoses can easily be fermented to ethanol using yeasts and bacteria provided there is an absence of inhibitors such as furfural, hydroxyl methyl furfural, or natural wood-derived inhibitors such as resin acids. Research activities focus on developing improved micro-organisms for the fermentation of pentose sugars. For cost effective processing, micro-organisms able to co-ferment both hexose and pentose sugars are essential. Currently there are no such commercially viable micro-organisms that are able to convert both hexose and pentose sugars at high yields. Also their sensitivity to inhibitors and the formation of unwanted by-products needs to be overcome. (IEA Bionergy 2008b)

According to Weymarn (2007), the steam and electricity consumption per MJ ethanol produced is 1.4 MJ_{steam} and 0.05 $MJ_{electricity}$, respectively, in the process concept designed for straw and reed canary grass in the Finnish conditions. Water consumption per ton ethanol equals roughly 20 tons including the steam not returned back to the power plant. Water consumption may reduce significantly by further integration of steam and water streams (von Weymarn 2007).

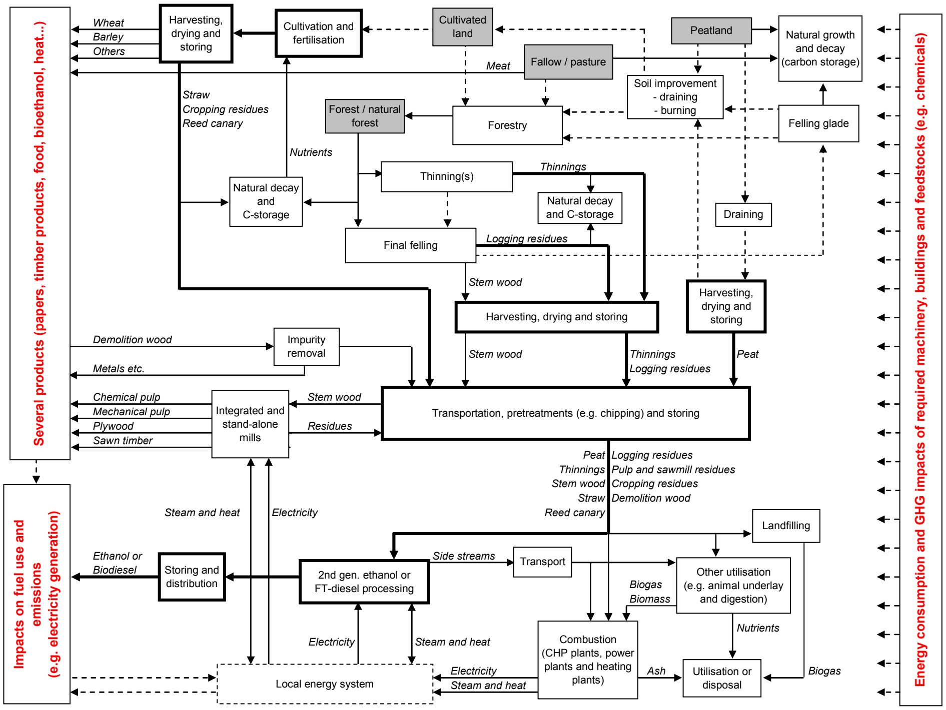


Figure 22. Flow diagram of the FT diesel and lignocellulosic ethanol production, and the connections of various land, raw material and co-product use options.

In addition to bioethanol, also substantial amounts of CO_2, waste-water, and a “solid” residue consisting of lignin, leftover carbohydrates, protein and cells is formed in the process. Most of the by-products are formed in two process phases; namely in the separation of solids after fermentation and in distillation.

In fact, expressed as dry matter some 20% and 80% of feedstock input ends up as ethanol and “solid” residue stream, respectively (von Weymarn 2007). The “solid” residue has high energy content and by combusting it considerable amounts of heat and electricity can be produced. Another option may be anaerobic digestion.

The ethanol production and the connections of various raw material, land, and co-product use are illustrated in Figure 22. Environmental impacts related to lignocellulosic ethanol are discussed in more details in Chapter 8.

7.6 Economic implications of alternative biofuels scenarios for Finland

7.6.1 Scenario variables and economic impact indicators

The estimation of economic implications of alternative biofuels scenarios for Finland has been carried out with the aid of the VATTAGE model (Honkatukia 2009). The BAU scenario is following the economic baseline development and therefore the results of economic implications are estimated and presented for the Lowest hurdle (LOH) and Self-sufficiency (SS) scenarios in relation to the economic baseline development.

The main background variables behind the generated scenarios are

- global energy prices
- EU targets for traffic liquid biofuels
- changes of forest industry and its products on global markets
- national reaction to changes and production targets.

Scenarios have been evaluated in relation to several different indicators. The following results have been calculated:

- need of domestic and imported raw materials for production
- domestic production vs. import of liquid biofuels
- needs for investments in procurement of raw materials, production and infrastructure
- influence on employment and economy of different sectors.

Environmental aspects are not evaluated at the scenario level as these have been assessed at production chain and technology level in the previous chapters.

The macroeconomic assumptions on the baseline for the Kyoto period follow the EU Stability Pact assumptions for Finland. Thereafter, the economy is assumed to converge to a long-run scenario that is consistent with the EU Ageing Working Group assumptions (ECFIN 2006). These assumptions give more details than the national energy and climate strategy assumptions for the demand for services, whereas the sector-level growth of the economy is covered in much more detail in the climate strategy. Overall, the economy grows by slightly more than two per cent a year on average until 2025. Growth is fastest during the last years of the current decade and begins to slow down, driven first and foremost by the ageing of the population after 2010. Ageing is also reflected in faster-than-average growth of pension and age-related service expenditures, both public and private. General government expenditures, on the other hand, grow slower than the average.

The growth of energy consumption follows the forecast in the National energy and climate strategy as used in the evaluation of its economic impacts (Honkatukia & Forsström 2008). There, industrial production is assumed to grow at an average annual rate of 3.5 per cent until 2010. Emissions of greenhouse gases are expected to grow accordingly, unless additional measures are taken, although at a slower pace than the economy. By 2010, CO_2 emissions are expected to be close to 67 M tons. To reach the Finnish emission target (1990 levels), CO_2 emissions from fossil fuels will have to be cut by 14 per cent (while the other green house gases can be cut slightly more). In the longer run, by 2025, the CO_2 emissions are expected to rise well above 70 Mt. The structure of energy use is also changing, with electricity consumption growing from 85.2 TWh to 95 TWh by 2010, and to 108 TWh by 2025.

7.6.2 Methodology for prediction of economic implications

The economic effects of increasing the production of biofuels in Finland have been studied with the aid of a dynamic general equilibrium model of the Finnish economy. The VATTAGE-model (Honkatukia 2009) is based on the MONASH model (Dixon & Rimmer 2002), which forms the basis of many single-country models. The distinguishing features of the model concern its dynamics. Three inter-temporal links connect consecutive periods in the model: (1) accumulation of fixed capital, (2) accumulation of financial claims, and (3) lagged adjustment mechanisms, notably in the labour markets and in the balancing of the public sector budgets. Together, these mechanisms result in gradual adjustment to any policy shocks to the economy.

Biofuel production is imposed on the economy with blending standards regardless of the cost of biofuels, and the increased use of domestic sources for biofuels is likewise imposed on the refining industry. This has both negative and positive effects on the economy. Agriculture and forestry face increased demand from the refining industry, which increases their output. At the same time, however, production costs rise in the refining industry, and fuel costs in the economy rise overall. This rise in costs has several effects. For the consumers, the immediate effect of rising prices is lower purchasing power, thus reducing consumption and demand. In the industries, the rental price of capital is affected by rising costs, tending to decrease investments. Finally, in the labour markets, decreased profitability initially leads to a fall in demand for labour. In the longer run, real wages are assumed to adjust, leading to employment recovering.

7.6.3 Effects on Finnish macro-economy

The main macroeconomic results are shown in Figure 23, Figure 24, Figure 25, and Figure 26. These figures give the effects on GDP, private consumption, investment, and employment. Because the increased use of biofuels has the effect of raising both consumer prices and costs of production, it tends to drive down consumption and production in most sectors of the economy, and also makes investment less attractive. Thus, in the short run, the cost of biofuels has mostly negative effects at the aggregate level. These effects are not large by any means, but the accumulated decrease in GDP by 2020 is around 0.15 per cent compared to the baseline, nevertheless. In terms of GDP growth, only about 0.015 per cent of growth is taken up by the measures necessary for increasing the use of biofuels.

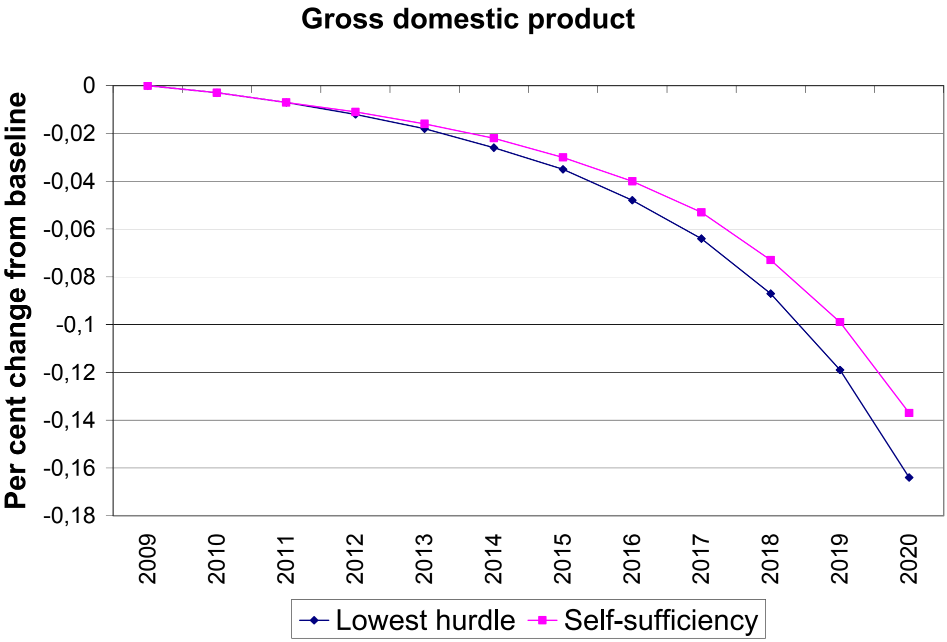


Figure 23. Effects on Finnish gross national product in Lowest hurdle and Self-sufficiency scenarios.

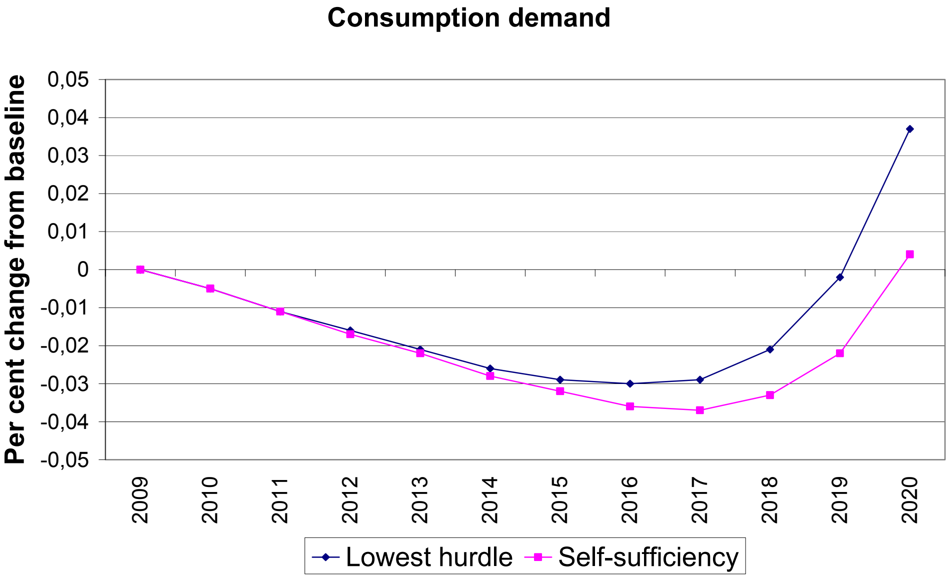


Figure 24. Effects on consumption demand in Finland in Lowest hurdle and Self-sufficiency scenarios.

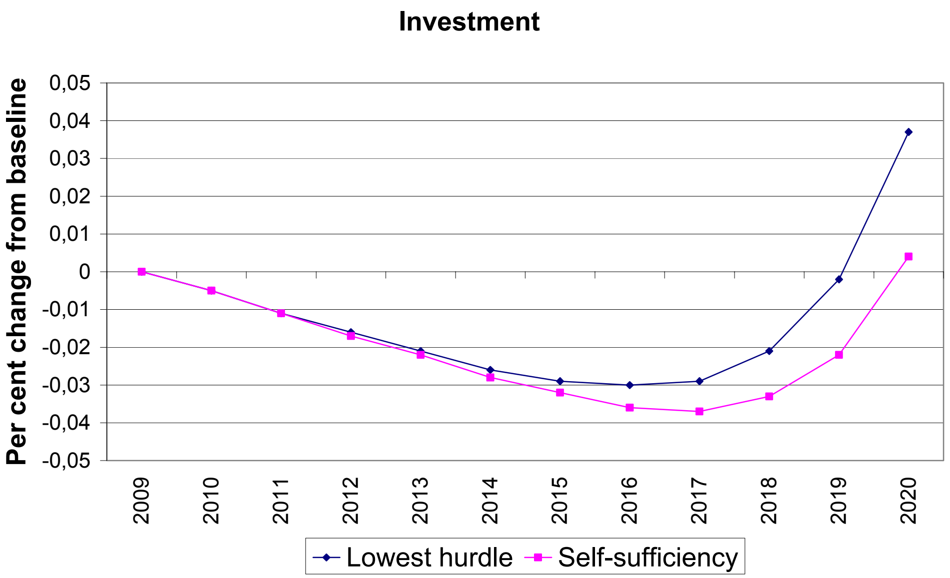


Figure 25. Effects on Investments in Finland in Lowest hurdle and Self-sufficiency scenarios.

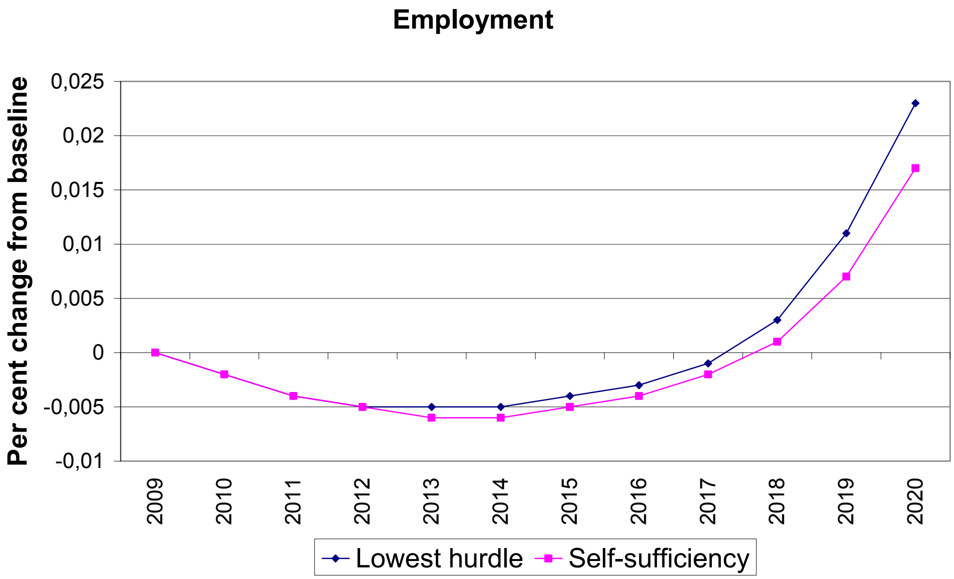


Figure 26. Effects on employment in Finland in Lowest hurdle and Self-sufficiency scenarios.

It is also apparent from Figure 24 that consumption demand starts to recover towards the end of the 2010s as employment is picking up again, as shown in Figure 26. The reason for the continued negative GDP effect stems from the effect of higher costs on competitiveness. This effect is illustrated in Figure 27.

Figure 27 shows the contribution of expenditure aggregates to GDP in the year 2020. It is easy to see that in both scenarios the largest effects stem from exports and imports rather than the domestic components of GDP (private consumption and investment). Exports fall by just under 0.3 per cent compared to the baseline in the Lowest hurdle scenario and by a little more than 0.3 per cent in the Self-sufficiency scenario, whereas imports actually increase by 0.1 to 0.2 per cent, which has the effect of decreasing GDP. Thus their combined contribution to GDP is negative.

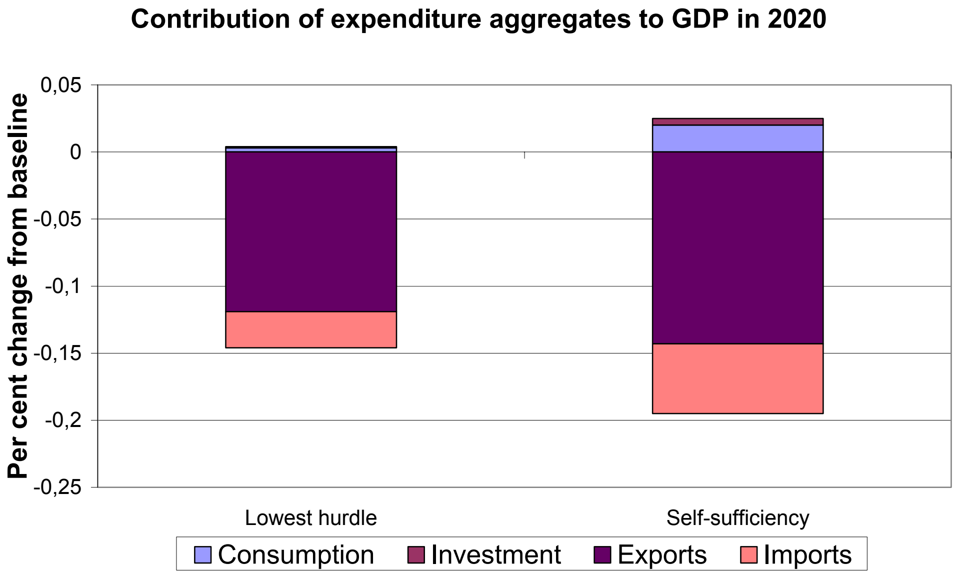


Figure 27. Contribution of expenditure aggregates to GDP in 2020 in Lowest hurdle and Self-sufficiency scenarios.

Figure 28 shows the contributions of income side aggregates on GDP. By far the largest effect stems from technological change. The switch to biofuels necessitates the use of costlier technologies, which shows up as a decrease in technological change compared to the baseline. A smaller contribution stems from decreased investments and lower employment, which are reported as the change in the use of primary factors.

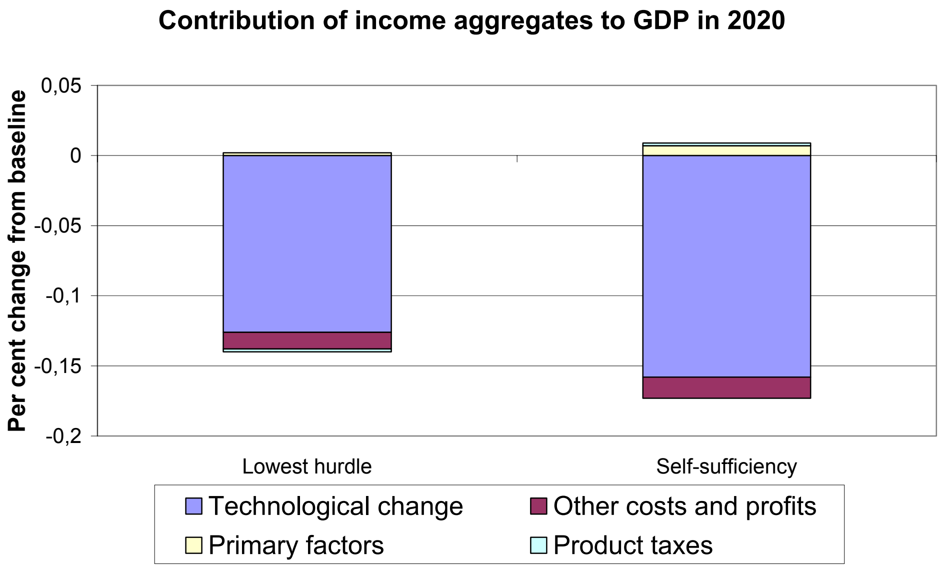


Figure 28. Contribution of income aggregates to GDP in 2020 in Lowest hurdle and Self-sufficiency scenarios.

7.6.4 Effects on Finnish agriculture and forestry

While the effects of increased domestic biofuel production are negative at the level of the whole economy, the increased demand for crops and wood obviously increase activity in agriculture and forestry. Figure 29 and Figure 30 capture this effect both for production and employment, both of which grow compared to the baseline. From the figures it is clear that the effects are larger in the forestry sector than in the agriculture, since the potential for increased use of wood is much larger than in crop-based biofuel production. We do not explicitly consider long-run limitations to production imposed by the availability of agricultural land or by the sustainability of forestry, but it appears that the increases in production predicted by the economic model would be within existing production possibilities. In terms of the number of workers employed, the results indicate an increase by 4000–5000 workers.

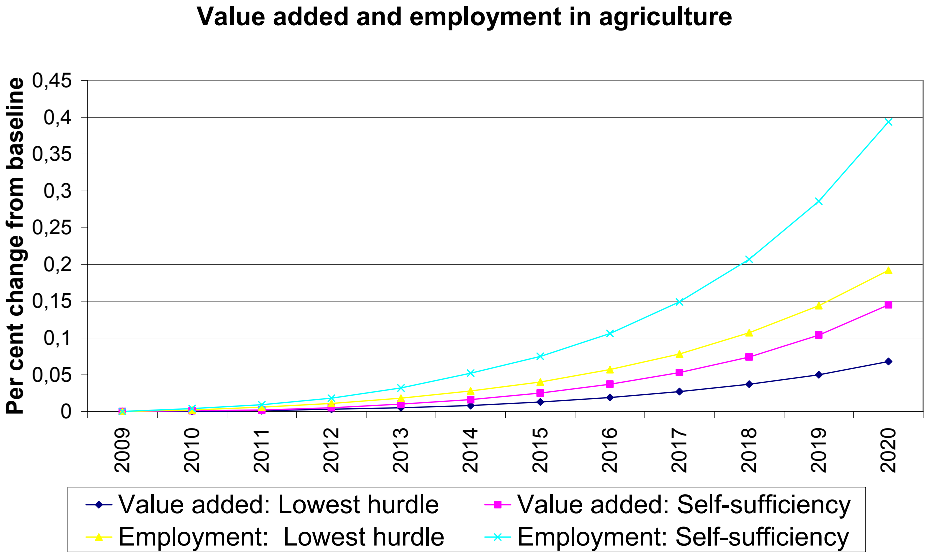


Figure 29. Value added and employment in agriculture in Finland in Lowest hurdle and Self-sufficiency scenarios.

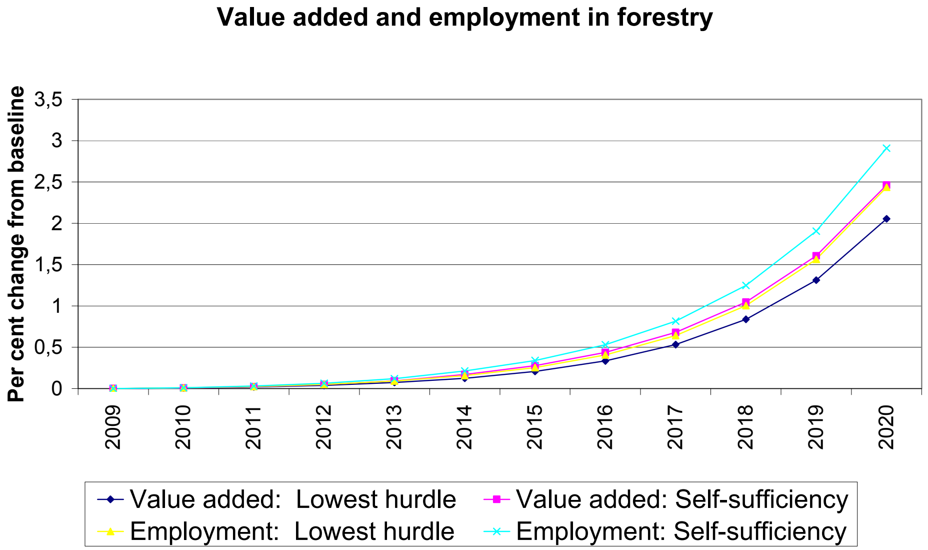


Figure 30. Value added and employment in forestry in Finland in Lowest hurdle and Self-sufficiency scenarios.

8. Environmental impacts of studied biofuels

A fuel chain and its life cycle stages, including everything from raw material production and extraction, processing, transportation, manufacturing, storage, distribution and use, cause various harmful impacts on the environment. Life cycle assessment (LCA) is a tool to analyse the complete life cycle of a product, and its use for the assessment of the sustainability of not only fuel products, but also other commodities has increased dramatically in recent years.

In LCAs a number of impact categories assessed varies depending, for example, on the chosen assessment methodology, objectives, product systems and the cost recourses of projects. However, a starting point should be that all relevant impact categories related to the product systems should be taken into account. In the assessments of biofuels, often only climate change and energy balances are analysed, but, currently, increasing attention is being paid to the "other environmental impacts" of biofuels meaning impacts other than climate change.

First, the significance of various factors on greenhouse gas impact of production and use of biofuels are illustrated. Secondly, literature and published studies to screen what is generally known about the other impact categories in connection to biofuels and especially the following fuel chains: NexBTL, FT-diesel, ligno-cellulosic ethanol and sugarcane ethanol, are used. These biofuels are seen potential for Finland, even though some of them are still in their development phase. We also summarize the state of art for assessing other environmental impacts in LCA. The selection of impact categories discussed is done on the basis of the results obtained from the published LCA studies of biofuels. In addition, the classification of impact categories recommended by the LCA community (Udo de Haes et al. 2002; Guinée et al. 2002) has been used. The following other impact categories, than climate change, were assessed to be relevant:

- acidification
- tropospheric ozone formation

- particular matter
- eutrophication
- ecotoxicity and human toxicity
- land use
    - soil health and production capacity
    - impacts on biodiversity
- use of water.

8.1 Climate change

Objective assessment of greenhouse gas impact of biofuel production and use is a very challenging and difficult task as the results significantly depend on the assumptions made and the indicators used for the assessment. As discussed in Chapter 3, the definition of both spatial and dynamic system boundary and the selection of allocation methods for energy and material flows over the system boundary are the most critical issues to be considered. Furthermore, the handling of uncertainties and sensitivities related to the data for parameter sets used may have significant impact on the results. Finally, the selection of indicator(s) used to measure the greenhouse gas impact may remarkably influence on the interpretation of the results and thus also on conclusions drawn (see Chapter 4.3). Consequently, very different conclusions have been drawn in various studies related to greenhouse gas impacts of biofuels.

Greenhouse gas impacts of biofuels can be roughly separated into direct and indirect impacts, although the boundary between them is more or less unclear. Direct impacts can be assumed to be those that can be managed or influenced within the first-hand links to the biofuel chain from the use of auxiliary energy, other non-energy related goods inputs, production of infrastructure, process emissions from cultivation of raw materials, process emissions from harvesting of raw materials, processing of biofuels and from biofuel combustion. Second-hand impacts can be considered to be those influenced by complex market mechanisms. The use of auxiliary inputs (e.g. electricity, fossil fuels, chemicals, machinery etc.) and land area for production of biofuels likely increase competition between them, causing complicated transition effects. In addition, the substitution effects from replacing products by coproducts of biofuels or fossil fuels by biofuels can be seen as indirect impacts of producing biofuels.

Both direct and indirect impacts may be difficult to quantify due to lack of knowledge and data. As regards direct impacts the main uncertainties and lack of knowledge are related to the impacts of biomass harvesting on soil carbon and nutrient balances, the feedback mechanism from soil to biomass productivity, nitrous oxide emissions from fertilization and cultivation, process emissions from technologies under development, and emissions of certain substances, in particular heavy metals. In addition, many case specific characteristics, e.g. regional cultivation circumstances, available energy sources, or transportation distances, may cause significant sensitivity in the results between various cases.

The capability of plants to sequester carbon and emit to the atmosphere vary between species. Short rotation biomass such as agrobiomass decays rapidly after growing. Instead, long rotation biomass such as pine or spruce in boreal forests may exceed the rotation period of 100 years and consequently act relatively long as storage of organic carbon. The rotation period of carbon is a very important factor to be considered, when assessing the effectiveness of various methods to use biomass in the mitigation of climate change. A large pool of terrestrial carbon is the soil, (e.g. peat swamps), which is also influenced by the utilisation of biomass. The turnover rate of this pool is usually slow, but human-induced land-use changes can convert soil into a strong source of emissions.

In this work, the illustration of the significance of various factors on greenhouse gas impact of studied biofuel production and use chains by using indicative *minus* and *plus* signs is carried out. The results are presented in Table 10, Table 11, Table 12, and Table 13 and are based on the discussions of various chapters of the report. A *minus* sign (-) refer to a factor increasing greenhouse gas emissions in the particular fuel chain. A *plus* sign (+) has the opposite implication. One, two and three signs refer to likely low, moderate and high significance, respectively. In addition, factors with high uncertainty are marked with a red font. It should be noted that the results should be considered with special care and be used for indicative purposes only. The number of minus or plus signs of certain factors should not be compared between various chains, as they do not illustrate the absolute greenhouse gas emissions. For example, two signs for a certain factor and production chain do not necessarily mean that the particular factor cause more greenhouse gas emissions in absolute terms than one sign given for the same factor for some other chain.

The greenhouse gas impacts given in Table 10, Table 11, Table 12, and Table 13 are separated to direct and indirect impacts. Greenhouse gas emissions caused in cultivation, harvesting, storage, transportation and pretreatment of raw materials, processing, storage and distribution of biofuel, as well as in combustion of biofuel are considered as direct impacts. Instead, changes due to competition of raw materials or land use, system impacts of auxiliary energy, chemical, machinery, plant and infrastructure production, and substitution credits from co-product and biofuel use are considered as indirect impacts.

As discussed in Chapter 4, global greenhouse gas emissions should be reduced remarkably within the few upcoming decades in order to mitigate the worst risks of climate change. Thus, the circulation period of biomass is a crucial factor, when assessing the effectiveness of biomass use options in climate change mitigation. Combustion is more favourable for biomass whose rotation period is short, that is shorter than the time frame for climate change mitigation. Instead, combustion of long-rotation biomass e.g. wood from boreal forests and in particular peat cannot be considered as carbon neutral, as the rotation period exceeds the particular time frame. This was considered for greenhouse gas impacts of FT diesel based on logging residues by Soimakallio et al. (2009) and on peat by Kirkinen et al. (2009)[7]. Thus, the greenhouse gas emissions from combustion of such raw materials have been marked as high relevance in Table 11 and Table 12. The particular emissions are to some extent compensated by avoided emissions from raw material natural decay in the reference case, which is, however significantly lower in the case of peat (Kirkinen et al. 2009).

Cultivation of raw materials plays a significant role in greenhouse gas emissions, particularly if nitrogen fertilizers are significantly used in relation to yield rate[8]. Also soil carbon losses may be relatively significant[9]. Instead, auxiliary energy consumption in machinery for cultivation, harvesting and transportation of raw materials is not typically a very significant factor for greenhouse gas emissions due to relatively high energy intensity of the raw

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[7] See Chapter 7.5.1.

[8] According to Mäkinen et al. 2006, relatively low yield rates for turnip rape cultivation in Finland (typical appr. 1.6 t/ha) compared to N-fertilizer requirement (appr. 100 kg/ha) takes place. Similarly, corresponding figures for typical EU-15 rape cultivation are 3 t/ha and 180 kg/ha for yield rate and N-fertilizer, respectively (JEC 2007). Due to significant uncertainties in soil-based N_2O emissions (e.g. the factor may be significant also for biomass requiring less nitrogen fertilization compared to yield rate, e.g. for reed canary grass (Soimakallio et al. 2009).

[9] Soil carbon losses may be significant for agricultural biomass cultivation based on ploughing (e.g. IPCC 2006). In addition, soil organic carbon is an important determinant of soil fertility and within limits crop productivity is positively related to the soil organic matter content (several sources referred by Reijnders 2008). Similarly, harvesting of logging residues and stumps may change the forest carbon and nutrient cycles due to export of organic matter and nutrients with the raw material (e.g. Kuusinen & Ilvesniemi 2008, Palosuo et al. 2008).

material yield and transportations or relatively short transportation distances[10]. For imported biofuels, decentralised or low yielding raw materials this impact may be more significant.

Direct greenhouse gas emissions from biofuel processing are assessed to be of low significance due to the fact that the process emissions are mainly based on auxiliary energy use, which is typically produced from raw material feedstock or purchased from the power plants in the form of electricity (Mäkinen et al. 2006, Soimakallio et al. 2009). If, however, greenhouse gas intensive fuels are used to produce the process heat/steam, the direct emissions may be more significant, as in the case of peat-based FT diesel (Kirkinen et al. 2009).

As illustrated in Table 10, Table 11, Table 12, and Table 13 and noted e.g. by JRC 2008b, indirect impacts play possibly the most significant role in greenhouse gas emissions of biofuel production and use. Such impacts are difficult to quantify and manage within the individual biofuel system considered, as they are significantly influenced by market mechanisms. The competition of raw materials and land use may cause pressure to clear more land for biomass production (as noted in the case of palm oil for example[11]) or to replace the biomass by other types of biomass or raw materials. For example, increasing use of forest residues, due to biofuel production, may increase the use of peat in power and heat production. Similar system impacts are relevant to be considered for any other use of goods (e.g. chemicals, machinery) or energy carriers (e.g. electricity). In addition, the substitution credits from replacement of other products by co-products[12] and fossil

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[10] Auxiliary energy requirement of logging residues and stump harvesting, transportation, and crushing compared to energy content of the particular raw materials is typically only a few percentages and not a critical factor. The primary energy input of RCG cultivation and truck transportation (70 km) compared to the energy content of RCG equals together some 7–8%. (Mäkinen et al. 2006). The auxiliary energy requirement compared to the energy content of harvested peat is low, corresponding typically to only some 1% (e.g. Mälkki & Frilander 1997).

[11] Growing consumption of palm oil and expanding oil palm plantations threaten local forests and peatlands, their carbon stock, biodiversity and other ecosystem services. Tropical peatlands contain huge amount of stored carbon, which is released by decomposition when land is drained for cultivation. The press and NGOs have highlighted the huge emissions of soil carbon, which derive from planting oil palms on tropical peat-forest or from cutting the Amazonian rainforest. According to the recent analysis (Carbopeat 2007; JRC 2008b), the CO_2 losses from oil palm plantations on drained peat-forest could be about 170 t/ha/y, if both deforestation and oxidation due to peatland drainage is taken into account, and 100 t/ha/y, if only drainage is considered. In this worst case scenario for palm oil the CO_2 emissions could be of the order 10 times higher than with fossil diesel fuel.

[12] Processing of FT-diesel requires a significant amount of auxiliary energy in relation to the energy content of the produced biofuel. Significant amount of heat/steam is co-generated and should be utilised effectively to improve the overall efficiency of the process (Soimakallio et al. 2009).

fuel by biofuels significantly influences on the results. More research work to quantify the magnitude of different types of indirect impacts is clearly required.

Table 10. Significance of various factors on greenhouse gas impacts of NExBTL diesel production and use (for illustrative purposes only).

Explanations	Emissions	Emissions		
RED = impact not well known, BLACK = impact relatively we	increase	decrease		
Low significance	-	+		
Moderate significance	--	++		
High significance	---	+++		
NExBTL	palm oil	turnip rape	rape	waste cooking oils and animal tallow
Direct impacts				
Carbon circulation period of the raw material (years)	1	1	1	1-10
Raw material cultivation				
- auxiliary energy consumption	-	-	-	
- fertilisation	--	---	---	
- liming	-	-	-	
- ploughing	--	--	--	
- pesticide, herbicide use	-	-	-	
Raw material harvesting				
- auxiliary energy consumption	-	-	-	
- soil implications	-	-	-	
Raw material storage and processing				
- auxiliary energy consumption	-	-	-	-
- decay and material losses	-	-	-	-
Raw material transportation				
- auxiliary energy consumption	--	-	-	--
NexBTL - hydrotreatment process				
- auxiliary energy consumption	-	-	-	-
- auxiliary chemical consumption (process emissions)	-	-	-	-
NexBTL - hydrogen production				
- auxiliary energy consumption	-	-	-	-
- auxiliary chemical consumption (process emissions)	-	-	-	-
NexBTL storage				
- auxiliary energy consumption	-	-	-	-
- material losses due to vaporisation	-	-	-	-
NexBTL distribution				
- auxiliary energy consumption	-	-	-	-
- material losses due to vaporisation	-	-	-	-
NexBTL combustion	-	-	-	-
Indirect impacts				
Transfers and changes in biomass and land use				
- competition of land use	---	---	---	
- competition of raw material	---	---	---	---
Production of goods, infrastructure				
- auxiliary electricity	--	--	--	--
- auxiliary energy carriers	-	-	-	-
- auxiliary chemicals	--	--	--	-
- machinery, plants and infrastructure	--	--	--	--
Substitution credits				
- from co-products	++	++	++	++
- fossil fuel replacement by NexBTL	+++	+++	+++	+++

Table 11. Significance of various factors on greenhouse gas impacts of FT diesel production and use (for illustrative purposes only).

Explanations	Emissions increase	Emissions decrease
RED = impact not well known, BLACK = impact relative		
Low significance	-	+
Moderate significance	--	++
High significance	---	+++

F-T diesel	logging residues	stumps	thinnings	reed canary grass	straw	peat
Direct impacts						
Carbon circulation period of the raw material (years)	~100	~100	~100	1	1	~1000
Raw material cultivation						
- *auxiliary energy consumption*				-		
- *fertilisation*				---		
- *liming*				-		
- *ploughing*				-		
- *pesticide, herbicide use*				-		
Harvesting						
- *auxiliary energy consumption*	-	-	-	-	-	-
- *compensation fertilisation*	--	--	-		--	
- *soil implications*	--	---	-	--/++	--/++	---
Raw material storage and processing						
- *auxiliary energy consumption*	-	-	-	-	-	-
- *decay and material losses*	--	--	--	-	-	-
Raw material transportation						
- *auxiliary energy consumption*	-	-	-	-	-	-
F-T diesel - biowax processing						
- *auxiliary energy consumption*	-	-	-	-	-	---
- *auxiliary chemical consumption (process emissions)*	-	-	-	-	-	-
- *ash handling / recirculation*	-	-	-	-	-	-
F-T diesel - biowax transportation						
- *auxiliary energy consumption*	-	-	-	-	-	-
F-T diesel - processing						
- *auxiliary energy consumption*	--	--	--	-	-	--
- *auxiliary chemical consumption (process emissions)*	-	-	-	-	-	-
F-T diesel storage						
- *auxiliary energy consumption*	-	-	-	-	-	-
- *material losses due to vaporisation*	-	-	-	-	-	-
F-T diesel distribution						
- *auxiliary energy consumption*	-	-	-	-	-	-
- *material losses due to vaporisation*	-	-	-	-	-	-
F-T diesel combustion	---	---	---	-	-	---
Indirect impacts						
Transfers and changes in biomass and land use						
- *competition of land use*	-	-	-	---	-	
- *competition of raw material*	---	---	---	-	-	
Production of goods, infrastructure						
- *auxiliary electricity*	---	---	---	---	---	---
- *other auxiliary energy carriers*	-	-	-	-	-	-
- *auxiliary chemicals*	-	-	-	---	-	-
- *machinery, plants and infrastructure*	--	--	--	--	--	--
Substitution credits						
- *avoided decay of raw materials*	+++	+++	+++		++/--	+
- *heat from biowax processing*	+++	+++	+++	+++	+++	+++
- *fossil fuel replacement by F-T diesel*	+++	+++	+++	+++	+++	+++

Table 12. Significance of various factors on greenhouse gas impacts of lignocellulosic ethanol production and use (for illustrative purposes only).

Explanations	Emissions increase	Emissions decrease
RED = impact not well known, BLACK = impact relatively well known		
Low significance	-	+
Moderate significance	--	++
High significance	---	+++
Lignocellulosic ethanol	reed canary grass	straw
Direct impacts		
Carbon circulation period of the raw material (years)	1	1
Raw material cultivation		
- auxiliary energy consumption	-	
- fertilisation	---	
- liming	-	
- ploughing	-	
- pesticide, herbicide use	-	
Harvesting		
- auxiliary energy consumption	-	-
- compensation fertilisation		--
- soil implications	--/++	--/++
Raw material storage and processing		
- auxiliary energy consumption	-	-
- decay and material losses	-	-
Raw material transportation		
- auxiliary energy consumption	-	-
Ethanol processing		
- auxiliary energy consumption	-	-
- auxiliary chemical consumption (process emissions)	-	-
- ash handling / recirculation	-	-
Ethanol storage		
- auxiliary energy consumption	-	-
- material losses due to vaporisation	-	-
Ethanol distribution		
- auxiliary energy consumption	-	-
- material losses due to vaporisation	-	-
Ethanol combustion	-	-
Indirect impacts		
Transfers and changes in biomass and land use		
- competition of land use	---	-
- competition of raw material	-	-
Production of goods, infrastructure		
- auxiliary electricity	-	-
- other auxiliary energy carriers	-	-
- auxiliary chemicals	---	-
- machinery, plants and infrastructure	--	--
Substitution credits		
- avoided decay of raw materials		++/--
- heat and electricity from ethanol processing	+++	+++
- fossil fuel replacement by ethanol	+++	+++

Table 13. Significance of various factors on greenhouse gas impacts of sugarcane ethanol production and use (for illustrative purposes only).

Explanations	Emissions increase	Emissions decrease
RED = impact not well known, BLACK = impact relatively well known		
Low significance	-	+
Moderate significance	--	++
High significance	---	+++
Impact not well known		
Impact relatively well known		
Sugar cane ethanol	sugar cane	
Direct impacts		
Carbon circulation period of the raw material (years)	1	
Raw material cultivation		
- *auxiliary energy consumption*	-	
- *fertilisation*	-	
- *liming*	-	
- *ploughing*	--	
- *pesticide, herbicide use*	-	
Harvesting		
- *auxiliary energy consumption*	-	
- *compensation fertilisation*		
- *soil implications*	-	
Raw material storage and processing		
- *auxiliary energy consumption*	-	
- *decay and material losses*	-	
Raw material transportation		
- *auxiliary energy consumption*	-	
Ethanol processing		
- *auxiliary energy consumption*	-	
- *auxiliary chemical consumption (process emissions)*	-	
- *ash handling / recirculation*	-	
Ethanol storage		
- *auxiliary energy consumption*	-	
- *material losses due to vaporisation*	-	
Ethanol distribution		
- *auxiliary energy consumption*	--	
- *material losses due to vaporisation*	-	
Ethanol combustion	-	
Indirect impacts		
Transfers and changes in biomass and land use		
- *competition of land use*	---	
- *competition of raw material*	-	
Production of goods, infrastructure		
- *auxiliary electricity*	-	
- *other auxiliary energy carriers*	-	
- *auxiliary chemicals*	-	
- *machinery, plants and infrastructure*	--	
Substitution credits		
- *avoided decay of raw materials*		
- *cropping residues, sugar, molasses, bagasse, stillage, vinasse*	+++	
- *fossil fuel replacement by ethanol*	+++	

8.2 Acidification

Acidification refers to the reduced capacity of the ecosystem to neutralise or buffer acidifying atmospheric deposition. Acidifying compounds may fall to the soil or water with rain or snow as wet deposition, or in the form of particles or gases as dry deposition. Acidification is harmful to plants and especially to aquatic species. For example, mass deaths of fish can occur in acidified lakes. In acid conditions, many hazardous substances, especially heavy metals become more easily soluble and can be absorbed by living organisms. Acid deposition is corrosive and therefore damages construction and other materials.

Most important acidifying compounds are sulphur dioxide (SO_2), nitrogen oxides (NO_X) and ammonia (NH_3).

In Finland, sulphur dioxide emissions mainly originate from energy production using fossil fuels (especially heavy oil and coal). Oil refining is one significant single source of SO_2 emissions. The sulphur content of biofuels is small, and in the biofuel chains, the significance of SO_2 emissions is relatively low. SO_2 emissions can take place if auxiliary chemicals or energy is produced using fossil energy. Machinery and transportation are other sources in regions where sulphur-containing gasoline and diesel are still permitted. Additionally, ocean ships are also a significant source of SO_2 emissions.

Nitrogen oxides are formed in all combustion processes from fuel nitrogen and from the nitrogen in the combustion air. In 2006, about 95% of the Finnish NO_x emissions came from energy production, traffic and machinery (Finnish Environment Institute 2008). In biofuel chains, NO_x-emissions are built up in all phases: in the use of machinery, transportations, processing (use of energy), in the use of auxiliary chemicals and materials (use of energy) and in the final use of biofuel. Use of fertilizers and denitrification in soil also causes NO_x emissions, which, however, are relatively small, compared to the emissions from combustion.

The main source of ammonia emissions is agriculture, which causes 92% of the Finnish NH_3 emissions (Finnish Environment Institute 2008), animal production (manure) being the main cause. Therefore NH_3 can be a significant factor in those bioenergy forms using manure as raw material (e.g. biogas). Ammonia can also be released from soil and fertilizers (both organic and inorganic) by microbiological and other activities. In vehicles a small amount of ammonia is produced by the aftertreatment devices (see Aakko-Saksa 2009). The share of transportation of Finnish NH_3 emissions is 7.5% (Finnish Environment Institute 2008).

Acidifying emissions (SO_2, NO_x) are also formed if burning is used as a method in land clearing or harvesting. Although forest clearing is prohibited in Malaysia and Indonesia, illegal burning still occurs. Additionally, drainage of tropical peat swamp forests increases the risk of uncontrolled peat fires and emissions of acidifying emissions. Preharvest biomass burning is currently common in Brazil's sugarcane fields, even though it is being gradually phased out.

In coming years, tightening emission regulations will significantly reduce acidifying emissions from vehicles and machinery by 2020 (Karvosenoja 2008). The new regulations apply similarly to biofuels and conventional fuels. Conventions of the International Marine Organisation (IMO) will reduce SO_2- and NO_x-emissions from ocean ships.

Actual impacts of the acid deposition on the environment depend largely on the receiving environment. Some areas have naturally a better buffering capacity against acid deposition than others. Nutrient poor areas in Northern Finland are typically sensitive to acidification, whereas in more fertile regions, soils and the bedrock often contain higher concentrations of calcium, which helps to neutralize acidification.

8.2.1 State of art for assessing acidification in LCIA

Acidification is one of the most common impact categories used in LCIA. In the beginning of the 1990s, there existed only one characterisation method for acidification, the so-called CML 92 method (Heijungs et al. 1992). This approach is simply based on the use of acidification potentials. These potentials take their basis in the number of hydrogen ions, which can theoretically be released from a specific substance. The potentials are usually expressed as the equivalent emissions of sulphur dioxide selected as the reference substance. The method is still currently common practice in LCIA, due to its simplicity.

Since the end of the 1990s, several authors have produced country-dependent[13] characterisation factors (see Section 2.4.2) for acidification, by using the results of atmospheric dispersion models and critical loads for Europe (Potting et al. 1998; Huijbregts & Seppälä 2001; Krewitt et al. 2001; Potting &

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[13] Country-dependent, site-dependent or site-specific characterisation factors take into account the location of an emission source, as the same amount of emissions can cause different responses in surrounding ecosystems, depending e.g. on local atmospheric conditions and the sensitivity of ecosystems subject to deposition from that source.

Hauschild 2004; Hettelingh et al. 2005; Seppälä et al. 2006; Posch et al. 2008). In these methods, the sensitivity of the ecosystem is quantified by the so-called critical load of acidifying emissions. The recent studies (Seppälä et al. 2006; Posch et al. 2008) based on the newest data, atmospheric dispersion models, and the use of accumulated exceedance indicator are determined as a best practice for assessing acidification in the work of European platform on LCA (Huijbregts 2008).

In the United States, nation-wide critical loads for acidification are not available. Therefore, Norris (2003) has used depositions obtained with the atmospheric dispersion model TRACI for the determination of state-dependent characterisation factors for acidifying emissions.

In the LCA community there is a need to develop a global LCIA methodology for regional environmental problems such as acidification. The key question concerns the appropriate methodology for characterisation. The European methods seem to be more scientifically based, but they require more input data, which are mostly missing from other continents. At present, (politically) accepted critical loads for acidification on a continental scale are only available in Europe, although there have been efforts made on a global scale (Bouwman et al. 2002), in South-East Asia (Hettelingh et al. 1995), and in eastern Canada (Ouimet et al. 2006). Dispersion models capable of modelling the fate of acidifying emissions are available in Europe, North America, and Asia.

8.2.2 Recent results on acidification in biofuel LCAs

Even thought the climate change is the most often studied impact category in biofuel LCAs, there are some studies considering also acidification. However, due to several differences in the assessment methods, system boundaries and functional units, among others, and sometimes also unclear system descriptions, the results are very difficult or even impossible to be compared with each other. Generally speaking, all the studies considering acidification follow more or less the traditional LCA methodology, and system impacts are not considered. These are common features for most LCAs and impact categories. A general picture of acidification can anyway be given on the basis of previous studies. In the following, we give some examples of the results relating to NExBTL, FT-diesels, 2nd generation (cellulosic) bioethanol and sugarcane bioethanol.

In a review by Menichetti and Otto (2008), it was concluded that most studies indicate that biofuels underperform conventional fuels in terms of acidification potential. Von Blottnitz and Curran (2007) had a similar result in their review concerning published articles on life cycle environmental impacts of bioethanols. First of all, only six articles out of 47 reviewed considered acidification. In three studies, the acidification impact of biofuel (sugar beet, wheat, potato, corn stover, and agricultural cellulosic waste) was larger than the one of conventional fuel. For waste bagasse, the impact was found to be lower. In two studies, which both considered sugar beet, wheat and potato, no significant change was observed.

No study considering acidification potential for the whole *NExBTL* chain was found. The recent study on NExBTL by Nikander (2008) only considers GHG balance and energy consumption. Crude *palm oil* production in Malaysia was studied by Yusoff and Hansen (2007), including plantation, transportation and milling phases. Construction of buildings and machinery and, more importantly land clearing and plantation start-up were excluded from their study. The researchers present the results only in weighted values assessed with the Eco-indicator 99 method, in which acidification and eutrophication are combined into one impact category. Therefore it is impossible to compare the results with other studies. However, the impact category was found to be relatively significant, ranking 4th among 14 impact categories studied after respiratory inorganics, fossil fuels, and climate change. The plantation phase caused more than 50% of the impact.

In the extensive study of Schmidt (2007), LCI of *palm oil* and *rapeseed oil* was performed. A large share of the data for the study was based on general databases such as the Swiss Ecoinvent and the Danish LCAfood. The acidification potential of rapeseed oil was estimated to be twice as large as the one of palm oil. In an Australian LCA study, the NO_x-emissions of *conventional palm oil* were about 20% higher than for conventional ultra-low-sulphur diesel, about half of the emissions originating from the upstream and other half from the tailpipe (Beer et al. 2007). The biomass burning was not taken into account, even though the authors state that it can be a very significant NO_x source. Zah et al. (2007) also found a higher acidification potential for *palm oil biodiesel* than for conventional biodiesel.

In the use phase (fuel combustion in vehicles), it has been estimated that there are no significant benefits for NExBTL in SO_2 emissions, if compared to gasoline and diesel with very low S-content and no impact on relatively small NH_3 emissions from transportation. In NO_x emissions, a reduction of 5%–19% can be achieved (see Table 14 and Aakko-Saksa 2009).

Jungbluth et al. (2007b) studied *FT-diesel* production (well to tank) from several biomass sources (miscanthus, straw, and wood) and using different conversion technologies. They found that the acidifying impact between different technology chains may be as large as 3-fold. BTL-FT from straw using centralized entrained flow gasification was found to have the least acidifying impact, while the allothermal circulating fluidized bed gasification using short rotation wood had the largest impact on acidification. The biomass production was the most significant phase, and therefore the type of biomass and the conversion rate were concluded to play a major role in further performance improvements. When compared with conventional fossil counterparts using the Eco-indicator 99 method, the BTL fuels showed a higher acidification and eutrophication potential (combined in the same impact category) than the fossil fuels (Jungbluth et al. 2008). However, the significance of the impact category in the total environmental impact was very small.

Fu et al. (2003) studied *bioethanol derived from cellulose* from agricultural and wood waste. The emissions were studied for E10 (10% blend of bioethanol with gasoline), and the system boundaries were limited to include only emissions directly linked to the studied chains. E10 using cultivated biomass as raw material and fossil electricity from the grid as the process energy source, about 50% of the acidifying emissions originated from fuel combustion, 30% from gasoline manufacturing and 10% from enzyme manufacturing. The share of transportation, feedstock cultivation and steam production accounted for about 10% of the acidifying emissions. In all four scenarios studied, acidification impact was assessed to be more severe for biofuels than for pure gasoline. Kemppainen and Shonnard (2005) also studied the production of bioethanol from lignocellulosic feedstocks (virgin timber and recycled newspaper, excluding the use phase). They found that the acidification impact was slightly lower (ca. 10%) for newspaper-to-ethanol than for timber-to-ethanol. The refining phase produced most (ca. 90%) of the acidifying emissions.

Acidification potential for the Brazilian sugarcane ethanol was found to be higher than for conventional fossil gasoline, and about the same level than for Swiss wood and sugar beet ethanols, for example (Zah et al. 2007). For bioethanol made from raw materials, such as Swiss potato, European rye and US maize, the acidification potential was considerably higher than for the sugarcane ethanol. In a comparative assessment of sugar production similar results were achieved, Australian sugarcane was found to have lower acidifying potential than the US corn and about the same as the UK sugar beet (Renouf et al. 2008).

The significance of sugarcane pre-harvest burning on acidifying emissions can be high. According to Renouf et al. (2008) this phase can cause up to 3.9 kg SO_2 and 31.1 kg NO_x emissions per hectare, the average being 1.3 kg SO_2 and 10.6 kg NO_x per hectare. Compared to, for example, the emissions from an average gasoline-fuelled passenger car with a catalytic converter (EURO 3 -level), these figures are relatively large. As calculated, using figures from the LIPASTO emission database (2002), this kind of a car could drive almost 200 000 km to reach similar SO_2 emissions and about 100 000 km to reach similar NO_x emissions.

8.2.3 Concluding remarks on acidification

Compared to the fossil counterparts, biofuels in general seem to cause higher acidification potential, even though significant differences between raw materials and technologies exist. The significance of acidification in the total environmental impact of biofuels does, however, not score very high.

Table 14. Potential sources of acidifying emissions in reference biofuel chains.

Raw material	Emission parameter	Production	Refining			Final use*
			NexBTL	FT-diesel	Bioethanol	
Palm oil	SO_2	Emissions can originate from fuels used in machinery and transportation (especially tankers), and if SO_2 containing fuels are used as energy source in production of auxiliary chemicals and energy. Potentially land clearing with illegal and uncontrolled burning.	Refining is probably a minor source of SO_2 and NO_x emissions during the NExBTL life chain. Refining is not a significant source of NH_3.	-	-	SO_2: No significant benefit if compared to gasoline and diesel containing very low of S. In general, SO_2 emissions from final use very low. Reduction in NO_x emissions ~5–19%. The significance of the final use in life chain NO_x emissions is relatively high. No impact on relatively small NH_3 emissions from transportation.
	NO_x	Emissions from machinery, transport, use of energy and fertilizing. Potential sources include uncontrolled biomass burning during land clearing and fires in tropical peat swamp forests. Schmidt (2007) calculated NO_x emissions of 3.2 kg/ha of oil palm plantations (not including burning as part of land clearing or peat fires).				
	NH_3	Emissions from fertilizer application, soil and crops. Schmidt (2007) calculated NH_3 emissions of 18.3 kg/ha of oil palm plantations.				
Rapeseed oil	SO_2	The significance of agricultural production is relatively high in SO_2 emissions from turnip rape NExBTL chain.				
	NO_x	Emissions from machinery, transport, use of energy and fertilizing are relatively high. Schmidt (2007) estimated NO_x emissions of 2.9 kg/ha of a rapeseed field in Denmark				

	NH_3	Emissions from fertilizer application, soil and crops are relatively high compared to other phases. Schmidt (2007) estimated NH_3 emissions of 9.5 kg NH_3/ha of a rapeseed field in Denmark.				
Waste oils	SO_2	Use of waste oils as raw material reduces emissions when replacing raw materials that create emissions				
	NO_x					
	NH_3					
Reed canary grass	SO_2	See rapeseed oil	-	Refining is probably a minor source of SO_2 and NO_x emissions during the life chain of FT-diesel. Refining is not a significant source of NH_3.	Refining can cause some emissions of SO_2. Refining is probably a minor source of NO_x and NH_3.emissions.	**FT-diesel:** SO_2: No significant benefit if compared to very low-S gasoline and diesel. NO_x: In many cases, emission trend comparable to NexBTL No impact on relatively small NH_3 emissions from transportation. **Ethanol:** SO_2: No significant benefit if compared to gasoline and diesel containing very low-S. NO_x: Flexifuel cars (E85) ~20% reduction when compared to gasoline. Buses nearly 30% reduction when
	NO_x	Emissions originate from machinery, transportation, and fuel use of production of auxiliary chemicals and energy.				
	NH_3	Emissions from fertilizer application, soil and crops.				
Round wood	SO_2	Relatively low importance.				
	NO_x	Emissions sources use of machinery and transport, relatively low importance.				
	NH_3	N-fertilization of forests very limited, therefore relatively low importance.				
Logging residues	SO_2	Emissions allocated to round wood. If logging residues are considered as another main product, a part of the emissions of round wood production is allocated here.				
	NO_x					
	NH_3					
Peat	SO_2	Relatively low importance.			-	

	NO_x	Relatively low importance.				compared to diesel buses (with no aftertreatment). No impact on relatively small NH_3 emissions from transportation.
	NH_3	Not relevant				
Straw	SO_2	Emissions allocated to grains. If straw is considered as another main product, the emissions similar to reed canary grass.			See above	
	NO_x					
	NH_3					
Sugarcane (BR)	SO_2	Emissions can originate from fuels used in machinery and transportation (especially tankers), and if fossil fuels are used as energy source in production of auxiliary chemicals and energy. Biomass burning during land clearing and before harvesting. Relatively low importance.		-	Refining is a relatively significant source of SO_2 and NO_x in the life chain of the sugarcane ethanol. However, total acidifying emissions are low. Refining is not significant a source of NH_3	
	NO_x	Emissions originate from machinery, transportation, and fuel use of production of auxiliary chemicals and energy. Biomass burning during land clearing and before harvesting. Relatively low importance.				
	NH_3	Emissions from fertilizer application, soil and crops, relatively low importance.				

- = the raw material is not used in this refining process.

* = for more details, see Aakko-Saksa 2009

FI = Finland

BR = Brazil

8.3 Tropospheric ozone formulation

Most of the tropospheric ozone is formed photo-chemically and chemically when ***nitrogen oxides (NO_x)***, ***carbon monoxide (CO)*** and ***volatile organic compounds (VOC, including methane CH_4)*** react in the atmosphere forming a phenomena called smog. High tropospheric ozone levels are hazardous to human health mainly causing respiratory effects. Excessive concentrations of ozone also reduce the growth of trees and crops. The impact category is sometimes called as photo-oxidant formation or summer smog.

Main sources of NO_x, CO, and VOC are traffic and machinery. Another important source of carbon monoxide and hydrocarbons is small-scale combustion of wood. Additionally, uncontrolled burning, which can take place for example in pre-harvest burning, land clearing, and after drainage of tropical peat swamp forests, can cause a significant amount of these emissions. In Australia, Renouf et al. (2008) estimated the emissions of non-methane volatile organic compounds (NMVOC) from sugarcane pre-harvest burning to be up to 19.1 kg/ha, the average being 6.5 kg/ha, which accounts roughly for the annual NMVOC emissions of an average working machine in Finland (LIPASTO emission database 2002).

In coming years, tightening emission regulations in EU will significantly reduce emissions forming tropospheric ozone from vehicles and machinery by 2020. The new regulations apply similarly to biofuels and conventional fuels.

8.3.1 State of art for assessing tropospheric ozone formation in LCIA

Tropospheric ozone formation is one of the frequently used impact categories in LCA applications. The simplest site-generic characterisation factors for ozone formation have been based on the model calculations in which the contribution of individual VOCs to the formation of ozone in the "worst" meteorological conditions of certain regions of USA and Europe (e.g. Derwent et al. 1996, 1998) were assessed. This kind of photochemical ozone creation potentials (POCP) expressed as ethene-equivalents do not include factors for nitrogen oxides, although NOX is the most important compound to cause tropospeheric ozone formation in Northern Europe.

The chemistry and (non-)linearity of ozone formation is rather complex, as it depends on the presence of precursors and meteorological factors, and due to the short lifetime of ozone under specific conditions. For example, in order to determine the characterisation factors for human health damage caused by ozone, it is important to know the emission gradient and population density. For this reason, the atmospheric dispersion models covering continental areas have been used to assess more reliable characterisation factors. Hauschild et al. (2006) have produced country-dependent characterisation factors of Europe for both vegetation and human health effects using European RAINS model with AOT indicators (= the accumulated amount of ozone over the threshold values of human health and vegetation).

van Zelm et al. (2008) have produced the most advanced European characterisation factors of human health for NO_X and the group of VOCs using the small grid size of 25 x 25 km^2 in the atmospheric dispersion model of Europe with the indicator of Disability Adjusted Life Years (DALYs).

At present, accepted site-specific characterisation factors for tropospheric ozone formation on a continental scale are only available in Europe, although there have been efforts to model ozone formation on a global scale. Dispersion models capable of modelling the fate of ozone forming emissions are available in Europe, North America and Asia.

8.3.2 Recent results on tropospheric ozone formation in biofuel LCAs

Similar to the acidification potential, the tropospheric ozone formation potential is not a very often studied impact category in the biofuel LCAs. In the review by Menichetti & Otto (2008), 7 studies out of 30 were found to consider summer smog formulation. In another review by von Blottnitz and Curran (2007) only 3 studies out of 47 reviewed considered photochemical smog. The results were contradictory, two of the studies showed decreased impact for bioethanol when compared to conventional fuel (bioethanol from sugar beet, wheat and potato and bioethanol from agricultural cellulosic waste), while bioethanol from corn stover showed increased impact compared to conventional fuel.

No study considering tropospheric ozone formation within the whole *NExBTL* chain was found. The *palm methyl ester* (PME) has been found to have about 4 times higher summer smog potential than the conventional diesel (Zah et al. 2007), but only limited conclusions from this can be drawn as PME and NExBTL are not comparable products. The explanation for the large difference relates probably to the land clearing. Beer et al. (2007) concluded that *palm oil* *biodiesel* had, during its life chain, CO emissions about 20% and NMVOC emissions about 40% lower than those of an ultra-low-sulphur diesel (land clearing by burning not included).

NExBTL can be produced from various raw materials, and the raw material choice can have significant differences in their performance also in this impact category. For example, the potential impact of *rapeseed oil* to photochemical smog was estimated to be about 1.5–2.6 times higher than the impact of *palm oil* (Schmidt 2007). Land transformation was taken into account by assuming that 50% of oil palm expansions take place by transformation of grassland and the other 50% take place by transformation of degraded/secondary forest. It can be assumed that the impact of waste oils on tropospheric ozone is lower than virgin vegetable oils, but no data were available on the subject.

Uncontrolled biomass burning, occurring also in palm oil production, in order to clear land for plantations, caused several serious smog episodes in South-East Asia in 1990s. Consequently, the burning practises were banned in both Indonesia and Malaysia in 1997. Unfortunately, illegal burning is still common in land clearing. A main part of the burning has taken place in oil palm plantations (Wakker 2005). Additionally, the drainage of tropical peat swamp forests increase the risk of fires. Besides emissions forming tropospheric ozone uncontrolled biomass burning causes acidifying and particulate emissions to the air.

Use of NExBTL has found to considerably reduce CH_4, NMVOC, and CO emissions when compared to conventional diesel fuel. In light-duty vehicles, the VOC reductions are about 45% and CO reductions about 40%. In heavy-duty (EURO3) vehicles the VOC reductions are about 9% and CO reductions about 16%, respectively (Aakko-Saksa 2009).

Jungbluth et al. (2008) estimated that the full life cycle respiratory effects of different *BTL-FT-diesels* are about twice as large as those of a low-sulphur diesel. However, the Ecoindicator 99 -method applied in that study does not directly consider only tropospheric ozone, but also other emissions, e.g. particles among others. The emissions reductions in *the use phase of FT-diesel* are assumed to be comparable to NExBTL. Both of these fuels result in significantly lower exhaust emissions than conventional diesel fuel (Aakko-Saksa 2009).

2nd generation (lignocellulosic) *ethanol* made either from cultivated or waste biomass was found to cause less severe impacts on summer smog than conventional gasoline (Fu et al. 2003). Kemppainen & Shonnard (2005) concluded that newsprint-to-ethanol had a slightly smaller impact on summer smog than timber-to-ethanol (well to tank). No comparison to gasoline was made in the study.

Summer smog potential of Brazilian *sugarcane ethanol* was highest of all the 13 ethanols studied by Zah et al. (2007). The reasons for high impact were not clearly indicated, but the pre-harvest biomass burning is most likely the main reason, as the processing phase of ethanol seems to have a negligible photochemical oxidation potential (Quintero et al. 2008).

In the use phase, ethanol appears to have negative impacts on tropospheric ozone formulation compared to that of gasoline because it increases aldehyde emissions (Jacobson 2007), even though it may reduce NO_x, CO and VOC emissions (see Table 15, Szwarc 2007).

8.3.3 Concluding remarks on tropospheric ozone formation

The biofuels life chain impact appears to be negative in terms of ozone forming emissions in most cases, and especially if uncontrolled biomass burning is occurring during the life chain (land clearing, biomass burning).

Table 15. Potential sources of tropospheric ozone forming emissions in reference biofuel chains. For information on CH4, see greenhouse gas impacts (Section 4 in the main report) and for NOx, see acidification (Section 2 in this appendix).

Raw material	**Emission parameter**	**Production**	**Refining**			**Final use***
			NexBTL	**FT-diesel**	**2G bioethanol (sugarcane 1G bioethanol)**	
Palm oil	NMVOC	Machinery, transportation, relatively low significance. Potentially land clearing with illegal and uncontrolled burning, relatively high significance.	Relatively low significance on ozone forming emissions compared to raw material production and final use -phases	-	-	High significance on ozone forming emissions compared to raw material production and refining -phases Use of NExBTL reduces CH_4, NMVOC and CO emissions when compared to conventional diesel fuel. → Light-duty: HC -45%, CO -40% → Heavy-duty, Euro 3: HC -9%, CO -16%.
	CO					
Rapeseed oil	NMVOC	Main sources machinery and transportation, relatively high significance due to low yield /ha.				
	CO					
Waste oils	NMVOC	Use of waste oils as raw material reduces emissions when replacing raw materials that create emissions				
	CO					
Reed canary grass	NMVOC	Main sources machinery and transportation, relatively high significance when compared to refining and final use -phases.	-	Relatively low significance on ozone forming emissions compared to raw material production and final use -phases	Relatively low significance on ozone forming emissions compared to raw material production and final use -phases	High significance on ozone forming emissions compared to raw material production and refining -phases
	CO					
Round wood	NMVOC	Main sources machinery and transportation, relatively low significance.				
	CO					

Logging residues	NMVOC	Emissions allocated to round wood. If logging residues are considered as another main product, a part of the emissions of round wood production is allocated here.				**FT-diesel:** CH_4, NMVOC, CO: In many cases, emission trend comparable to NexBTL. **Ethanol:** CH_4, NMVOC, CO: In flexifuel vehicles using E85 no change or slight reduction in HC and CO emissions at normal temperature when compared to gasoline, increase at low ambient temperature. In VOC emissions, ~30% reduction when E85 is compared to gasoline. Contradictory information for buses using ethanol, possibly negligible effect. Ethanol increases aldehyde emissions.
	CO					
Peat	NMVOC	Main source machinery (~87% of NMVOC and ~93% of CO emissions in the production phase), but also transportation (Leijting 1999).			-	
	CO					
Straw	NMVOC	Emissions allocated to grains. If straw is considered as another main product, the emissions similar to reed canary grass.			See above	
	CO					
Sugarcane (BR)	NMVOC	Machinery, transportation. Pre-harvest burning and land clearing with uncontrolled burning may be significant sources.		-	Relatively low significance on ozone forming emissions compared to raw material production and final use -phases	
	CO					

- = the raw material is not used in this refining process.
* = for more details, see Aakko-Saksa 2009
FI = Finland
BR = Brazil

8.4 Particulate matter

Particulate matter (PM) originates directly (primary particles) from various sources, including such as combustion processes (industrial, households and traffic and machinery), forest fires and road dust. Particulate matter can also be formed in the atmosphere from different gaseous compounds, such as VOC-compounds, nitrogen and sulphur oxides and ammonia (secondary particles). In this section, we concentrate on the primary particles, and the emissions of the substance forming secondary particles are discussed in Sections 2 and 3.

Particulate matter is classified according to the particle size. Generally attention is paid on the particles that are 10 micrometers in diameter or smaller because those are the particles that generally pass through the throat and nose and enter the lungs. Once inhaled, these particles can affect the heart and the lungs and cause serious health effects. The smaller the particle is, the more hazardous it normally is. Particles are often divided into two categories: inhalable coarse particles, between 2.5–10 μm and fine particles, 2.5 μm and smaller. Sometimes ultrafine particles (< 1 µm) are classified separately. In addition to health effects, particulate matter reduces visibility and can, for example lower the photosynthesis capacity of plants.

In biofuel chains, the main potential PM sources include transportation and machinery and auxiliary energy production. However, uncontrolled biomass burning is still a significant source both in Malaysia and Brazil. Additionally, in tropical peat swamp forests, the risk of uncontrolled peat fires increases dramatically due to drainage. Particulate emissions from the fires are a major health problem in the area. Several conventions and regulations already validated will reduce PM emissions similarly to the other atmospheric air emissions.

8.4.1 State of the art for assessing particulate matter (PM) in LCA

The assessment of particulate matter as an own impact category in LCAs has not long tradition. For example, it is missing in the Nordic Guidelines on Life-Cycle Assessment (Lindfors et al. 1995) and SETAC's best practice guideline (Udo de Haes et al. 2002). Particulate matter aspects have sometimes been included in the human ecotoxicity category. However, the scientific basis of the inclusion has somehow been unclear.

In the current advanced methods, the particular matter related human health impact is estimated as a function of exposure and potency. In LCIA, exposure in terms of inhaled particle mass or yearly average ambient concentration multiplied by the exposed population is considered as the midpoint, while health outcomes are considered endpoints. The potency of particulate matter is summarized in terms of exposure-response functions, which are derived from epidemiological studies. Furthermore, atmospheric dispersion models covering continental areas have been used in the determination of characterisation factors for both primary and secondary particulates.

Characterisation factors based on the use of dispersion models and both intake fractions and accumulated exposure/exposure-response functions are currently available in USA/Canada (e.g. Pope et al. 2002) and Europe (e.g. Krewitt et al. 2001; van Zelm et al. 2008). In principle, the approaches allow to calculate country- or grid-dependent characterisation factors. However, they are not yet publicly available.

8.4.2 Recent results on particulate matter in biofuel LCAs

In the analysis of Beer et al. (2007), *palm oil biodiesel* had about 40% lower PM emissions than the ultra-low-sulphur biodiesel (well-to-wheel; land clearing with burning not taken into account). About 35% of the biodiesel emissions originated from the use phase. If biomass burning is taken into account, it makes both Malaysian *palm oil biodiesel* and Brazilian *sugarcane ethanol* chains considerably worse than their conventional counterparts in terms of particulate matter formation (Zah et al. 2007).

No relevant studies handling particulate emissions during the whole life cycle of FT-diesel or 2nd generation bioethanol were found. Main source of however, PM emissions in FT-diesel chain is likely to be the final use phase. The final use of fuels is important also because most of particulates from vehicles are small in size. PM2.5 presents about 95% of PM10 (Aakko et al. 2000). The majority of studies have found sharp reductions in particulate emissions in the final use phase from both ethanol and FAME biodiesels compared to conventional fuels (EC 2006; Lapuerta et al. 2008). Paraffinic fuels, such as NExBTL and FT fuels show significant reductions in PM emissions when compared to conventional diesel fuel. The reduction is about 25% for light duty vehicles (Rantanen et al. 2005; ASFE 2007). For heavy duty vehicles even a greater reduction (30–45%)

is reported (Kuronen et al. 2007). In future, particulate filter will be increasingly used and this will reduce the effect of fuel in absolute terms as PM emission level will be very low, and on advanced engine technologies (EURO4 and EURO5)[14] fuel effects on PM emissions are small (Carbone et al. 2005).

Potential sources of PM in biofuel chains are considered in Table 16.

8.4.3 Concluding remarks on particulate matter

In those biofuel chains in which biomass burning is part of land clearing or harvesting, PM emissions are significantly high compared to fossil counterparts. In other chains, the PM emissions are not considerably higher than those of conventional fuels. In the final use of biofuels, PM emissions are typically lower for biofuels than for conventional fuel with older engine technologies. However, with advanced technologies (EURO4 and EURO5) fuel effects on PM emissions appear to be small. Even in this case, the benefit of using biofuels may be seen e.g. as lower emissions of particle-associated polyaromatic hydrocarbons.

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[14] EURO4 and EURO5: European standards limiting certain non-CO2 emissions (CO, HC, NOx, PM) in exhaust gases in vehicles.

Table 16. Potential particulate matter sources in the studied biofuel chain. For information on SOx, NOx and NH3 see acidification (Section 2 in this appendix) and for VOCs, see tropospheric ozone formulation (Section 3 in this appendix).

Raw material	Production	Refining			Final use*
		NexBTL	**FT-diesel**	**2G bioethanol (sugarcane 1G bioethanol)**	
Palm oil	Machinery and transportation, production of auxiliary energy. Uncontrolled and illegal biomass burning in land clearing, very high significance if occurring.	Production of auxiliary energy, low significance if compared to production and final use -phases.	-	-	Relative significance of use phase is relatively high in case of no uncontrolled biomass burning occurring in raw material production. **NExBTL, FT-diesel** Paraffinic fuels, such as NExBTL and FT fuels show significant reductions in PM emissions when compared to conventional diesel fuel. The reduction is about 25% for light duty vehicles (Rantanen et al. 2005, ASFE 2007). For heavy duty vehicles even a greater reduction (30–45%) is reported (Kuronen et al. 2007). In future, particulate filter will be increasingly
Rapeseed oil	Machinery and transportation, production of auxiliary energy, relatively high significance due to low yield /ha.				
Waste oils	Use of waste oils as raw material reduces emissions when replacing raw materials that create emissions				
Reed canary grass	Machinery and transportation, production of auxiliary energy, relatively high significance.	-	Production of auxiliary energy, low significance if compared to	Production of auxiliary energy, low significance if compared to	

Round wood	Machinery and transportation, production of auxiliary energy, low significance.		production and final use -phases.	production and final use -phases.	used and this will reduce the effect of fuel in absolute terms as PM emission level will be very low. **Ethanol** Lower PM emissions than gasoline
Logging residues	Emissions allocated to round wood. If logging residues are considered as another main product, a part of the emissions of round wood production is allocated here.				
Peat	Machinery and transportation, low significance.			-	
Straw	Emissions allocated to grains. If straw is considered as another main product, the emissions similar to reed canary grass.			see above	
Sugarcane (BR)	Machinery and transportation, production of auxiliary energy, low significance. Pre-harvest biomass burning, very high significance.		-	Production of auxiliary energy, relatively low significance.	

- = the raw material is not used in this refining process.
* = for more details, see Aakko-Saksa 2009
FI = Finland
BR = Brazil

8.5 Eutrophication

Eutrophication means enhanced primary production of natural ecosystems due to increased nutrient input. In this section only aquatic eutrophication is considered because terrestrial eutrophication can be assessed according to the same principles as acidification (see Seppälä et al. 2006; Posch et al. 2008) and the same nitrogen emissions (NO_X and NH_3) to the air are causing terrestrial eutrophication. In addition, terrestrial eutrophication is not considered as a significant problem as aquatic eutrophication in Finland.

In the coastal and inland waters, aquatic eutrophication may cause harmful algal blooms, oxygen depletion, and overall fisheries habitat decline. For aquatic ecosystems, the main sources of nutrients are direct N and P emissions from human activities, i.e. industrial and residential waste waters and agriculture. Also N deposition due to emissions of NH_3 and NO_x from agriculture, traffic, and energy production increase nutrient load to ecosystems.

In the biofuel chains, the main source of nutrient emissions is generally biomass production, especially agriculture. Increasing biofuel production from agricultural raw materials can therefore significantly increase eutrophication of waters. In the United States, it has been estimated that the increase in corn cultivation required to meet the official goals for renewable fuels by the year 2022 would increase the annual flux of dissolved inorganic nitrogen in Mississippi and Atchafalaya rivers by 10–34% causing serious extra threat to the water quality of the Gulf of Mexico (Donner & Kucharik 2008). In Finland, similar estimates have not been done, but obviously, if the production of agricultural biofuel raw materials increases without simultaneous decrease in the feed and food production area, the total eutrophying impact increases.

The response in the environment (eutrophication) of a certain nutrient release depends on the local environmental circumstances. The impacts taking place in Finnish coastal and inland waters, due to nutrient releases, are fairly well known. Due to the characteristics of the Finnish waters they are very sensitive to eutrophying emissions. In certain areas aquatic eutrophication is not conceived as an environmental problem because no harmful impacts appear. In those areas other environmental problems related to excessive nutrient use may rise, such as problems on ground waters.

In Table 17 the main attention is focused on the potential eutrophying impact of the biofuel chains studied, due to direct N and P releases to the water. Potential impacts – on both aquatic and terrestrial eutrophication – caused by deposited N can be assessed, based on the emission estimates presented in Section 2 (Acidification).

As non-point pollution, nutrient discharges from forestry and field cultivation are difficult to estimate. Emission levels are strongly affected by crop and soil type, fertilization levels, soil nutrient content, precipitation, and other climatic conditions and cultivation methods.

Besides direct nutrient emissions from raw material production also indirect emissions may take place, due to land use changes caused by increased production of bio-fuel raw materials. Forests may be cleared for agricultural land, or forests in natural-state may be transformed to commercial use. The level of land use changes depends for example on possibilities to increase productivity in existing raw materials production areas or possibilities to introduce agricultural areas in reserve.

8.5.1 State of the art for assessing eutrophication in LCIA

Eutrophication is quite a common impact category included in LCAs, although the most popular impact assessment tool, Ecoindicator 99, does not include eutrophication (it combines acidification and terrestrial eutrophication aspects). It is also important to understand that in the most commonly used methodology (Heijungs et al. 1992, see also Guinée et al. 2002) aquatic and terrestrial eutrophication are not distinguished from each other. This site-generic approach also includes emissions of N to air, overestimating the contribution of airborne nitrogen to aquatic eutrophication compared to waterborne nutrients. In addition, emissions of N, P and organic matter (measured as COD) are aggregated on the basis of the so-called Redfield ratio without fate and exposure assessment. In the advanced characterisation methods, only the "effective" amounts of nutrient emissions causing aquatic eutrophication are tried to be taken into account. The contribution of air emissions of nitrogen to aquatic eutrophication is calculated with the help of atmospheric dispersion models. In addition, limiting nutrient aspects are taken into account (biomass growth in fresh water ecosystems is commonly limited by P, whereas in marine water the limiting nutrient is N). This kind of approaches are only available in Europe (Huijbregts & Seppälä 2001; Potting et al. 2002; Seppälä et al. 2004 (Finland-specific approach), and in USA (Norris 2003).

In summary, aquatic eutrophication in LCIA is not very well established for offering reliable results. The actual impacts of eutrophication depend much on local conditions to which water emissions will be released. However, LCA is not a tool for assessing local impacts. The current assessment methodology for aquatic eutrophication is especially a problem for the life-cycle stages of biofuels occurring outside Europe and USA.

8.5.2 Recent results on eutrophication in biofuel LCAs

Similarly to the other environmental impact categories, other than the climate change impacts, eutrophication has often been neglected in biofuel studies. It is important to notice that in the reviews of LCA literature analysed below, eutrophication is considered as a generic eutrophication problem, including both aquatic and terrestrial eutrophication impacts.

Von Blottnitz & Curran (2007) found three studies out of 47 to consider eutrophication. Two of these (a study concerning sugar beet, winter wheat and potato and a study concerning agricultural cellulosic waste) found that the eutrophication potential was higher for biofuels than for conventional fuel. A study concerning waste bagasse ethanol, however, concluded that the eutrophication potential was lower than the option of using conventional fuel and burning the bagasse (Kadam 2002). In a review of Menichetti & Otto (2008), a general trend for biofuels was found to underperform conventional fuels in terms of the eutrophication potential. Total eutrophying impact of biofuels depends on several factors such as the biomass raw material and the total area used for biofuel production. For example, as concluded by Simpson et al. (2008), the rapidly expanding corn based ethanol production in the USA may significantly increase N and P losses to waters. Harvest of corn stover for cellulosic ethanol production would likely further increase erosion and nutrient loads. Therefore the authors suggest that the *cellulosic ethanol* industry based on perennial grass or waste raw materials could provide a more sustainable solution in terms of water quality and also other ecosystem services. However, in a LCA made by Fu et al. (2003), cellulosic ethanol made both from cultivated feedstocks (agricultural and forest) and waste proved to underperform conventional fuels in terms of eutrophication.

Only little information on *palm oil's* potential impact on eutrophication is available, as most of the studies concentrate on palm oil's climate change impacts. Yusoff and Hansen (2007) included eutrophication potential in their LCA, but combined with acidification potential. Schmidt (2007) and Corley and Tinker (2003) estimated an average emission level in Malaysia and Indonesia to be 80 kg N/ha and 1.6 kg P/ha. This hectare based figure is relative high compared to e.g. Finnish turnip rape or Danish rape seed emission levels (Table 17). On the other hand, the yields are much higher in palm oil production. Zah et al. (2007) concluded that palm oil methyl ester shows a higher eutrophication potential than those of conventional diesel, but lower than e.g. those of rapeseed diesel.

When compared with conventional fossil counterparts using the Eco-indicator 99 method, *BTL-FT fuels* showed higher acidification and eutrophication potential (combined in one impact category) than the fossil fuels (Jungbluth et al. 2008). However, the significance of the impact category in total environmental impact was very small.

In Brazil, eutrophication caused by the agricultural production phase does not seem to be a major environmental problem. However, on the other hand, water pollution caused by the discharge of raw sewage and industrial wastes has been a serious problem also in the sugarcane production area of São Paolo, the sugarcane industry being one of the polluters (Goldember et al. 2008; Smeets et al. 2008). Vinasse disposal represents the most important source for potential impact due to the large amounts produced, its high organic loads and its relatively low pH. Vinasse is also rich in nutrients, and to enhance nutrient recycling and to reduce water pollution, it is presently mostly used for ferti-irrigation (Smeets et al. 2008). Sugarcane is a relatively low-intensity plant, and its eutrophication potential in sugar production is about half of the corn's eutrophication potential, but anyway higher than that of sugar beet, in case the displaced products are taken into account (Renouf et al. 2008). According to Zah et al. (2007), the eutrophying potential of sugarcane ethanol is slightly larger than the one of gasoline, but considerably lower than the one of corn or potato ethanol.

8.5.3 Concluding remarks on eutrophication

Biofuels generally underperform the conventional fuels in terms of eutrophication potential. However, due to the current poor methodological practices to assess eutrophication in LCAs it is difficult to obtain reliable results for the comparative studies in which the aim is to assess the eutrophication potentials caused by different product systems located in different parts of the world.

Table 17. Potential sources of eutrophying emissions to waters in the reference biofuel chains. Atmospheric N emissions are discussed in Section 2 Acidification in this appendix.

Raw material	**Emission parameter**	**Production**	**Refining**		
			NexBTL	**FT-diesel**	**2G bioethanol (sugarcane 1G bioethanol)**
Palm oil	N	Average emission level in Malaysia and Indonesia 80 kg N/ha based on the nutrient balance (Schmidt 2007) and 1,6 kg P/ha (Schmidt 2007, Corley and Tinker 2003). Eutrophication is not considered as a serious environmental problem in oil palm cultivation areas.	In palm oil processing, there are no direct wastewater emissions from the refining stage. Palm oil mill effluent (POME) from the crude palm oil processing is applied on the land as a fertilizer after treatment in aerobic and anaerobic ponds. Approximately 57 litres of wastewater per t of rapeseed oil is generated during rapeseed oil processing. It is assumed that waste water is led to wastewater treatment plant (Schmidt 2007). N and P emissions are assumed to be small because the wastewater is treated in a wastewater plant (Nikander 2008). In the NExBTL process (pre-treatment and hydrotreatment), 224 kg of wastewater / t NExBTL is produced and pumped to refinery wastewater plant.	-	-
	P				
Rapeseed oil	N	Average emission level in FI: 14 kg N/ha and 1.6 kg P/ha (Katajajuuri et al. 2007); in CE (Denmark) emission levels of 40 kg N/ha and 0.14 kg P/ha are shown (Schmidt 2007). In FI aquatic eutrophication is considered as a serious environmental problem. In CE terrestrial eutrophication and nitrates in ground waters are more severe problems.			
	P				
Waste oils	N	Waste oils have a positive impact on eutrophication if they replace raw materials that have a negative impact.			
	P				

Reed canary grass	N	Average emission level in FI: 28 kg N/ha and 1.8–2.0 P/ha in organic arable land (Partala & Turtola 2000). In FI aquatic eutrophication is considered as a serious environmental problem.	-	Water is produced in the FT process as a result of chemical reaction between CO and H_2. The produced water is separated from the product and due to the required effective gas cleaning before FT synthesis N and P content in waste water are insignificant.	A relatively high amount of process water is needed (see Section Use of water and von Weymarn 2007). During the process, the nutrients in the raw material are likely to end up in wastewater that needs to be treated.
	P				
Round wood	N	Average emission level caused by forestry in FI: 0.25 kg N/ha and 0.02 P/ha (based on the national emission statistics)			
	P				
Logging residues	N	Nutrient emissions due to forestry allocated 100% to round wood. In the long run, logging residues removing may decrease nutrient content in soil and nutrient load to the waters. On the other hand, residues removing may lead to increased use of mineral fertilizers and nutrient load.			
	P				
Peat	N	Average emission level caused by peat extraction in FI: 6.6 kg N/ha and 0.25 kg P/ha (based on the national emission statistics).			-
	P				-
Straw	N	Nutrient emissions due to cereals farming allocated 100% to grains.			See above
	P				
Sugarcane	N	Average fertilizer use in BR: 60–70 kg		-	According to Smeets et al.

(BR)	P	N/ha and 40–50 kg P/ha (Section 3.4). Aquatic eutrophication is not considered as a major environmental problem in BR. In **AUS**: 16–72 kg NO_3/ha (3–16 kg N/ha) and 2.4–2.7 kg P/ha depending on the farming intensity (Renouf et al. 2008). They used as emission factors for N: 6.6% of N applied (as NO_3-N) and for P: 12.8% of P applied. According to Smeets et al. (2008), mineral fertilizers use in BR is lower compared to conventional crops, but higher than pastures. Fertilization is not identified as a problem.			(2008) uncontrolled wastewater discharges from ethanol production caused severe environmental problems in the 1970s and the 1980s. Presently, most liquid wastes are used for ferti-irrigation.

- = the raw material is not used in this refining process.
FI = Finland
CE = Central Europe
BR = Brazil
AUS = Australia

8.6 Ecotoxicity and human toxicity

Different substances released to the air, water and soil during the life cycle of biofuels have toxicological effects on animals, plants and humans. Some of the substances are also carcinogenic. For the biofuel chain to be sustainable, the risk of cancer or other toxicological effects must not increase when fossil fuels are replaced with biofuels. In this section, some hazardous substances and their relevance in biofuel chains are presented and discussed briefly. In this report, the following substances were considered, due to their significance and data availability reasons (see ENVIMAT 2008): arsenic (As), cadmium (Cd), cobalt (Co), chrome, chrome IV (Cr, CrIV), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb), tin (Sn), antimony (Sb), vanadium (V), zinc (Zn), PAH-compounds (PAH), dioxins and furans (DF). There are also many volatile hydrocarbons like 1,3-butadiene, benzene, formaldehyde and acetaldehyde in exhaust gases of both gasoline and biofuel powered vehicles. These are known to have carcinogenic or mutagenic activity.

Besides metals, PAHs and DFs, and substances in exhaust gases, also pesticides are considered. Data on pesticides application levels were collected in order to get a general view of the potential ecotoxic risks related on pesticides use in biofuel production.

Pesticides use cause harmful emissions to different environmental compartments: fresh and marine waters and sediments, and soil. The environmental impact assessment can not be based only on application levels of active ingredients, but also such issues should be addressed as the percentage of pesticides applied that is transported to above mentioned compartments, and the toxicity of the active ingredients.

There is only little information available on metals and other toxic substances related to biofuel production. Most important factors causing emissions of hazardous substances include the use of chemicals (fertilizers and pesticides) in agriculture and forestry, the use of fossil fuels and the combustion of biofuels. However, the environmental impacts due to the use of pesticides and the emissions of heavy metals, PAHs, dioxins and furans, and other toxic substances are not generally assessed in LCA studies of biofuels. Because of the lack of available information, the potential sources are here discussed only on a general level. Ecotoxicity and human toxicity are discussed also in Appendix A, in the Summary and the analysis of the proposed sustainability criteria, and in Chapters 3.6 and 3.7. The criteria studied in those sections do not directly mention the metals discussed here. Human and Ecotoxicity categories, as covered in different sustainability criteria, mainly cover the toxicity of agrochemicals. Only the Swan labelling system takes into account substances in exhaust fumes that are harmful to health or carcinogenic, and requires monitoring of those (The Nordic Ecolabelling 2008). Recent studies have shown that the use of bioethanol increases the emissions of formaldehyde, acetaldehyde, and other aldehydes (Jacobson 2007).

All of the toxic substances discussed here occur naturally and are released or formed through natural processes such as forest fires and volcanoes. Metals are also released through weathering of rocks. Some metals, such as Zn are Cu are essential for almost all living organisms, while the essentiality of other metals, such as Ni and Cr, has been established for a limited number of species. For other metals, no biological function has been identified. Some of the metals, like arsenic and cadmium, are toxic even in low concentrations, while essential metals are tolerated relatively well.

8.6.1 State of the art for assessing ecotoxicity and human toxicity in LCIA

There have been many characterisation methods available for ecotoxicity and human toxicity in LCIA. It has been a well-known feature that the different methods produce different results. For this reason, the experts working in the field of toxic issues developed the consensus model in the context of the SETAC/UNEP network. This so-called USEtox model (Rosenbaum et al. 2008) can quite well model organic harmful substances in certain fate and exposure conditions applied in the model. However, the methodology has still difficulties in modelling metals. In addition, the USEtox approach is not capable to model damages caused by local environmental conditions.

8.6.2 Potential sources of substances in agricultural and forestry phase

Metals, PAHs, dioxins and furans

In agriculture, metal emissions from biofuel cultivation are possible, since fertilizers and some pesticides contain metals, although the use of metal compounds as pesticides is in most cases prohibited. Probably the only metal containing pesticide that could be used in biofuel cultivation is the arsenic containing methanearsonate (MSMA). It is applied as an herbicide for sugarcane (MacLachlan 2006). However, currently also the use of arsenic containing pesticides is prohibited in many countries.

Fertilizers are usually not sufficiently purified during manufacture for economic reasons, and they usually contain several impurities, among them heavy metals. The accumulation of heavy metals in soils and plants may affect ecosystems and human health. Phosphate fertilizers contain small amounts of at least arsenic, cadmium, chromium, lead, mercury, nickel, and vanadium (Mortvedt 1996). The amount of metals in fertilizers varies a lot and it is in most cases not possible to estimate the significance of this metal emission source. However, relatively significant cadmium emissions are possible if cadmium containing fertilizers or sewage sludge are used in cultivation. Cadmium tends to accumulate in soils and to some extent, also to plants. Cadmium levels vary widely in fertilizers from different locations, the Finnish apatite containing very low cadmium concentrations. As the cadmium concentrations in Finnish fertilizers are usually small, it can be assumed, that cadmium emissions from Finnish turnip rape production are smaller compared to rapeseed cultivated in Central Europe. Harvesting of straw for ethanol production increases the need for additional NPK fertilization, thus increasing the risk for higher releases of cadmium (and other metals).

Wood or peat ash used as a fertilizer in forests can contain several metals like cadmium, lead, arsenic, nickel and chromium (Perkiömäki et al. 2003). Biomass burning is currently often a part of the harvesting procedure in sugarcane fields. Forests for oil palm plantations can be cleared using burning and uncontrolled fires may occur due to the drainage of tropical peat swamp forests. These procedures can be significant in releasing hazardous substances in the environment, since PAHs, DFs and other substances are formed during combustion.

Metals accumulated in soils due to anthropogenic and natural emissions may be released when soil is treated for cultivation. Especially forestry (such as timber harvesting and soil preparation) and peat mining practices may release considerable amounts of mercury from forest and mire soils (Porvari 2003).

Pesticides

The use of pesticides is more common when cultivating biofuel raw materials than when the raw materials are obtained from forests. Furthermore, it is noteworthy that in the case of perennials, such as palm trees and reed canary grass, the use of pesticides varies significantly according to the growing stage (Table 18).

Based on the sales statistics of forest pesticides in 2004–2007 (Evira 2008), urea makes up more than 99.9% of the total amount of active ingredients used in forestry. For example, in 2006 the total sale of active ingredients for forestry totalled 580 986 kg consisting of essential oils (98 kg), glyphosate (0.1 kg), imidacloprid (108 kg), quinoclamine (79 kg) and urea (580 701 kg). Average pesticide use in 2004–2007 in Finnish forestry was 32 g active ingredients per ha of commercial forest annually. Because 100% of the pesticides used in forestry is allocated to roundwood, no pesticides are allocated to logging residues.

In peat production pesticides are not used. Using waste oils as a raw material may decrease the use of pesticides if they replace raw materials from those product systems that include pesticides. For straw no pesticides are allocated. All pesticides used in cereals production are allocated to grains.

Table 18. Use of pesticides (active ingredients; g/ha) in palm trees, rapeseed, reed canary grass and sugarcane production.

Active ingredient	**Palm trees**	**Rapeseed (FI)**	**Reed canary grass**	**Sugarcane**
Trifluralin		960		
Tribenuron-methyl			First year 750 g/ha	
Glyphosate	2300–8200*	600	Before seeding 1200 g/ha	
Herbicides, unspecified				2200[2]
Fungicides, unspecified	0.2–6800*			Not used[3]
Cypermethrin	280–450*			
Alphasyper-methrin		30		
Insecticides, unspecified				120[3]
Pesticides, unspecified				1800–3800[4] Limited quantities compared to conventional crops[5]
Data source	Schmidt 2007	Katajajuuri et al. 2007	Pahkala et al. 2005	[2] Ricci 2007 [3] Arrigoni & Almeida 2007 [4] Renouf et al. 2008 (AUS) [5] Smeets et al. 2008 (BR)

* Depends on the growing stage: nursery, immature plantation or mature plantation.

8.6.3 Emissions of toxic substances from the use of fossil fuels

One of the main sources of metals, dioxins and furans, PAHs and other substances in biofuel production chains is the use of fossil fuels. The energy required for biomass refining and production of auxiliary materials may be provided through conventional fossil sources or through the use of (waste) biomass. Coal contains high concentrations of all the metals studied in this section, but other fossil fuels used for energy production also contain metals. The amount of metals varies a lot, and depends on the origin of the fuel (Vouk & Piver 1983). Power generation (burning of coal, oil, gas, and organic matter) causes also PAH and DF emissions. The use of biomass usually lowers the emissions of toxic substances compared to the use of fossil fuels. However, it is not possible to estimate the relevance of metal emissions of each production chain, due to the lack of data.

Conventional gasoline and diesel are used in the agricultural and forestry machinery and transportation. In general, very few data are available on metals associated with particulate matter emissions from engines and vehicles. Especially for EURO 3 and older technology, the metal emissions are higher for heavy-duty diesel engines than for gasoline engines. Typically, the highest levels of metal emissions are observed for Cr, Fe, Ni, Cu and Zn. These metals come from the engine (wear metals), lube additives, and/or aftertreatment devices. (Aakko-Saksa 2009) The extent of the use of fossil fuelled machinery (and at the same time the emissions of metals) depends on the cultivation, methods of the biofuel plants, and transportation distances. For example establishing a new oil palm plantation requires land preparation in forested areas. Heavy machinery is used in tree felling and area clearing, road construction and planting. The biofuel plants (like palm oil and sugarcane) cultivated outside Europe have relatively higher emissions of hazardous substances because of long transportation distances.

8.6.4 Emissions of toxic substances from the use of biofuels

The emissions of biofuel run vehicles depend on the type of the biofuel. At least in the case of bioethanol, emissions of aldehydes can be higher than in gasoline-powered cars (Jacobson 2007). Aldehyde emissions from various FAME biodiesels are not significantly different from those of diesel fuel (Grabowski et al. 2003). Aldehyde emissions from cars using NExBTL blends may decrease even by 40-50 % compared to fossil diesel fuel (Rantanen et al. 2006). With heavy-duty applications changes in aldehyde emissions are lower or insignificant between NExBTL and diesel fuel (Kuronen et al. 2007).

PAH emissions may be formed during incomplete combustion in engines. Usually the emissions are lower in biofuel run vehicles, at least FFV and NExBTL using vehicles. Particulate associated PAH emissions and mutagenicity of soluble organic material of particulate matter are significantly lower with NExBTL containing fuel when compared to conventional diesel fuel with cars and heavy-duty vehicles (Rantanen et al. 200; Kuronen et al. 2007). Similar benefits are obtained with paraffinic FT diesel.

For E85 fuelled FFV cars, PAH emissions are generally at the same level or lower when compared to conventional gasoline. However, at low ambient temperature (-7°C) increased particulate and semivolatile associated PAH emissions and cancer potency is observed for E85 (Westerholm et al. 2008).

The review made for this report revealed that there are no relevant data on the metal emissions from biofuels. However, copper emissions in exhaust gases might deserve more attention. Some biofuels contain elements, which are present in the exhaust particulates, e.g. sodium, potassium or phosphorus for FAME biodiesel. The same review points out that some biofuels may contain chlorides, which are possible sources of dioxins and furans (Aakko-Saksa 2009).

8.6.5 Concluding remarks on toxic substances

All of the substances studied in this chapter are emitted in at least some parts of the biofuel production chains. The use of fossil fuels is probably the biggest source of metals, PAHs and DFs. The amounts of emissions depend on the fuel used. Production of biofuels raw materials is the most important source of pesticides emissions. Agriculture can also be an important emission source for some metals, such as cadmium. The significance of different substances and the emitted amounts cannot be estimated reliably because of the lack of information. That is why it is not possible to estimate the risk of human or ecological effects either. However, it was assumed, that the effects of metals, PAHs and DFs are probably relatively small compared to toxicity caused by the use of pesticides in raw material production phase in the case of fuels where pesticides are used in the product system. More research is needed to determine the significance of different substances in biofuel chains and to make LCA studies of biofuels more complete and increase knowledge and reduce uncertainties related to the refining of 2nd generation biofuels.

8.7 Land use

Land is a limited resource and growing biofuel production requires additional land area. Biofuels compete for land with food and wood production, and land use change can lead to losses of natural habitats and other ecosystem services, such as natural carbon sinks. Land use change and the loss of existing forests and savannahs can also substantially increase greenhouse gas and other emissions (see e.g. Reijnders & Huijbregts 2008; Searchinger et al. 2008). For example, in a relatively short period of time (~30 years) the carbon sequestered by restoring forests is greater than the emissions avoided by the use of the liquid biofuels (Righelato & Spracklen 2007).

At present, the area of land used for biofuel crop production is estimated to be around 1% of the total area under crops (de Fraiture et al. 2008). Brazil and USA have the largest areas under biofuel raw material production (Brazil's biofuel crop area 2.4 Mha, 5.0% of the total cropped area used for biofuels, USA's biofuel crop area 3.8 Mha, 3.5% of the total cropped area used for biofuels). The demand and the production of biofuels are expected to continue to grow, and with the growing population and standard of living, the competition for land is going to increase. However, the biofuel raw materials differ from each other, and not all of them endanger food and other raw material production. For example algae biomass and growing of the non-edible plant jatropha on low-quality land are seen as potential future biofuel raw materials. Additionally, by the use of abandoned agriculture land for bioenergy, the competition problems could be avoided. A recent study of Campbell et al. (2008), however, shows, that the global potential for bioenergy on abandoned agriculture lands to be less than 8% of the current primary energy demand. Therefore, even taking this meaningful fraction into use, the growing demand on bioenergy will present major challenges on competition for land use.

8.7.1 Occupation and transformation

Land use has different dimensions. First, the operation occupies the land area needed for its processes. For example, the production of biofuel raw materials occupies a certain area of field, forest or plantations. Moreover, the processing of raw materials into biofuels also needs a certain land area, which, however, is much smaller than the raw material production area and is thus not considered here. Secondly, if the production area grows, land needs to be transformed (land use change). The transformation can be direct or indirect. Direct land use change means that land is converted to biofuel crop production or other production is displaced. In indirect land use change, the displaced production further causes land use change by moving to another place. For example in Brazil, it has been claimed that the sugarcane production has expanded on pastures and because of that tropical forests have been converted to pastures. This land use change is indirectly caused by sugarcane.

Land occupation and transformation are not yet systematically included in the LCAs, and the methodology is still under development. Indirect land use change is very difficult to verify, and different opinions exist on how it should be included for example in the biofuel GHG balances. The approach of combining a life cycle assessment study with a macro-economic agro-modelling seems to be a promising way to assess the impacts of both direct and indirect land-use change. Several problems and limitations, however, still exist. We cannot, for example, know what the real displacement effects of some new productions will be in the future.

State of art for assessing land use in LCIA

Due to the LCA limitations on assessing changes in land use, we have chosen to describe the potential changes in land use related to the reference situations qualitatively (Table 19). Information on occupation and transformation of different land use types and their magnitude values are starting points for assessing impacts caused by land use. It is important to notice that some LCIA methods such as the Eco-indicator 99 (Goedkoop & Spriensma 1999) take only transformation into account in the assessment of land use impacts.

Milá i Canals et al. (2006) have determined the principles to assess land use issues in the expert workshop on land use in LCA. These principles are considered as best practices among the LCA community.

Impact aspects related to land use

Land is a limited resource. Increasing biofuel production requires additional land area. Significant expansion on bioenergy production area seems not to be possible without conflicts between food and feed production, production of other biomass raw materials, and other ecosystem services, such as maintenance of carbon storages and biodiversity. Bioenergy production occupies and transforms land directly and also indirectly by making displaced functions to move to other areas. In the LCA methodology, impacts related to land use are still under development. Direct and indirect land-use change can lead to several negative environmental impacts such as losses of carbon storages and high value biodiversity areas. In the LCIA methodology, applied in this work, the impacts of changes in carbon storages are taken into account in the context of climate change, whereas impacts on biodiversities and on soil health and production capacity are considered as sub-impact categories under land-use-related impacts.

Table 19. Occupation and transformation of biofuel raw material production. Occupation describes land area needed for the production of biofuel (ha/MJ). Only direct land use for biomass production is considered, and land area for production facilities or e.g. production of auxiliary energy is not included. Transformation describes change in the land area per a certain timeframe. (Here it is only described qualitatively).

Raw material	**Occupation (ha/GJ)**	**Transformation**
Palm oil	~0.005 (conversion to NExBTL)	In 2006, Malaysia accounted for 43% and Indonesia for 37% of the global oil palm fruit production (FAO 2008). The production area has grown very rapidly especially in Indonesia (more than doubled between the years 2000–2006). Palm oil plantations can expand on different sorts of waste land or secondary forest, or alternatively, they can replace tropical forests. Expansion on waste land is generally seen as a positive development trend. The destruction of tropical forests, often followed by loss of peaty soil, is considered very unsustainable, because it causes biodiversity losses and losses of large carbon sinks.
Turnip rape / Rapeseed	~0.050 / ~0.021 (NExBTL)	Turnip rape/rape seed cultivation for energy purposes may cause significant land use changes because occupation of agricultural land with energy crops may lead to increased clearing of forests for food production.
Tallow and waste cooking oils	n.a.	Smaller environmental pressure in other waste treatment practices (e.g. landfills etc.). Also smaller need to produce primary biofuel raw materials from fields and forests.

Reed canary grass	~0.037 (conversion to ethanol)	There are two alternative methods to cultivate Reed canary grass (RCG): in arable land (a) and in old peat mining areas (b). a) RCG cultivation for energy purposes in arable land may cause significant land use changes because occupation of agricultural land with energy crops may lead to increased clearing of forests for food production. b) If certain acreage of RCG is cultivated e.g. in Finland, RCG cultivation in old peat mining areas decreases the need to occupy arable land for energy purposes compared to the case where all RCG is cultivated in arable land.
Round wood	n.a., very difficult to calculate, because biofuel raw materials most likely originates from thinnings etc., not e.g. from saw logs	Use of round wood as fuel competes with other possible uses of wood (paper, construction material etc.).
Logging residues	n.a., considered as waste and therefore land use not a critical factor	n.a. The effects of using logging residues appear in soil health and production capacity and biodiversity impacts.
Peat	~0,001–0,0003 (FT-diesel) calculated according to conventional peat minig technology,	Peat extraction and use as fuel release a large amount of carbon in form of CO_2 form a long-term stock. Peat extraction has negative biodiversity impacts on species, habitat and landscape levels. Use of peat as biofuel raw material can effect on use of alternative raw materials (logging residues, straw, RCG) as biofuel raw materials or in production of heat and power.
Straw	n.a.	The effects of using straw appear mainly in soil health and production capacity and biodiversity impacts highly dependent on climatic conditions. However, intensive straw collecting from fields for energy purposes may also cause indirect land use effects due to the increased use of alternative litter types in animal shelters (e.g. sawdust, hay)

Sugarcane	~0.002 (ethanol)	Brazil is the world's largest producer of sugarcane (33% of the global production in 2006). The production area in Brazil has enlarged by almost 30% between 2000 and 2006 (FAO 2008). During the previous decades the increase in the sugarcane cultivation has occurred mainly at the expense of agricultural land (mainly pasturelands, not food crop cultivation areas (Goldenberg et al. 2008)). The increase in the area of agricultural land in Brazil is limited, and the increase in the cane production and the possible impacts through land use change on biodiversity and competition with food production has been identified as a major bottleneck for a sustainable sugarcane production (Smeets et al. 2008). (See also Table 20, biodiversity).

n.a. = not applicable

8.7.2 Soil health and production capacity

In addition to the total area of the land used for certain activities it is important to know how the land is used. Soil is a multi-functional medium, and unsustainable use of land leads to reduction in soil fertility and production capacity, which furthermore, can lead to yield losses. Soil health and production capacity is closely related to soil biodiversity. In biofuel chains, soil heath and production capacity relates mainly to the raw material production phase in agriculture and forestry.

Soil production capacity depends on several factors such as soil type and structure, and nutrient content. Production capacity and soil health can be reduced by, for example compaction, erosion, loss of soil organic matter and nutrients, soil sealing, or by soil contamination. Soil sealing and soil contamination are more related to the built and industrial environment, although pesticides applied in agro-forestry can reduce the soil quality. Soil salinisation (sodification, alkalization) can be a problem mainly in irrigated areas where low rainfall, high evapotranspiration rates, or soil textural characteristics impede the washing out of the salts, which subsequently build-up in the soil surface layers (JRC 2008a). The accumulation of salts, particularly sodium salts, is one of the main physiological threats to ecosystems. Salt prevents, limits, or disturbs the normal metabolism, water quality, and nutrient uptake of plants and soil biota.

In agriculture, soil production capacity is reduced for example by soil compaction resulting from the use of heavy machinery, spreading of organic manure, and harvesting. Soil compaction has negative effects on soil biodiversity and structure, and it can also dilute the soil water economy by e.g. water logging (EEA 2006). Soil erosion means that soil is removed by the action of water or wind. In Europe, accelerated soil erosion is a particular problem in the Mediterranean region (EEA 2006). In Finland, erosive rainfall and runoff cause soil particles and attached nutrient to be transported from cultivated land.

In forests, the soil is mainly covered with vegetation reducing the erosion. Heavy machinery is needed relatively seldom compared to agriculture and therefore the soil compaction is a smaller problem. However, soil tillage cause erosion in forest soil and an increasing erosion risk is caused by stump and logging residue removal. The impacts of large-scale long-term energy wood collection are not yet known, but the potential for disturbances in soil nutrient balances have been presented.

Increasing biofuel production and competition of land can expand the biofuel raw material production area or move the displaced production to areas, where risks to soil problems are higher. This means for example that slopes under permanent vegetation are taken under cultivation, reducing the slope stability and increasing the risks of erosion and nutrient transport.

In this study we have verbally described main aspects related to the raw materials examined (Table 20). Quantitative assessment of the problems related to soil health and production capacity was not possible.

State of the art for assessing soil health and production capacity

Even though the problems related to soil health and production capacity is one important environmental problem, the methods for assessing it in LCA are still lacking. In most studies the problems are considered using a qualitative approach, or more often, dismissed.

Concluding remarks on soil health and production capacity

Unsustainable use of land leads to reduction in soil fertility and production capacity, which furthermore, can lead to yield losses. Soil health and production capacity is closely related to soil biodiversity. In biofuel chains, soil heath and production capacity relates mainly to the raw material production phase in agriculture and forestry. Similarly to many other environmental impacts, the methods for assessing soil health and production capacity in LCA are still lacking. Different soil quality problems relate to different soils, climates and plant types. In Finland, the problems relating to this impact category are often referred to in the context of using logging residues and stumps and straw as biofuel raw materials, but long-term research information is not yet available.

Table 20. Impacts of biofuel raw material production on soil health and production capacity. Biodiversity impacts are analyzed separately.

Raw material	***Soil health and production capacity***
Palm oil	Mattsson et al. (2000) compared soil indicators in Malaysian oil palm and Swedish rape seed cultivation. According to them, loss of soil ***organic matter*** is a serious problem during the plantation establishment period. Later, the loss plays a smaller role. ***Erosion*** per hectare in Malaysian oil palm plantations is considerably higher than in Swedish rape seed cultivation. Oil palm plantations showed also an excess of ***nutrients*** applied causing a potential for nutrient leaching. The content of P in the soil was on a steady state, and the content of K possibly accumulating. Soil ***salinisation*** is a risk especially in coastal areas due to salt water intrusion and in arid areas if irrigation is needed. However, typically only nurseries are irrigated. ***Compaction*** is possible, if heavy machinery is used on soft or wet soil. However, oil palms are mainly harvested manually reducing this risk.
Rapeseed oil	**Reference for the comparison:** managed uncultivated arable land**.** Impacts on the ***organic matter*** depend on the intensity of the farming practices. However, soil tilling has a negative impact on soil organic matter compared to managed uncultivated arable land (e.g. Paul & Clark 1996). Soil ***erosion*** caused by water depends also on the intensity of the farming practices. Compared to managed uncultivated arable land cultivation of turnip rape/rape seed and cereals has a higher erosion rate, and the amount of eroded soil depends on things like soil type, slope of the field and the intensity of tilling. According to Ekholm et al. (2005) ploughed arable land results in an averagely 1.5 times higher erosion rate compared to the managed uncultivated arable land in clay and fine sand soils. Turnip rape/rape seed cultivation maintains soil productivity, because successful oilseed and crop farming requires suitable ***soil pH*** level. Without active farming and liming soil pH would slowly resume to its natural level, which is below pH 5 in Finland. Turnip rape/rape seed cultivation maintains soil productivity, because without active farming ***soil nutrient*** – especially plant available P - levels would resume to its natural levels (average concentration of plant available P in agricultural soils in Finland is 11–12 mg/liter of soil (Uusitalo

	et al. 2008). According to Turtola et al. 2005 the soil-P level of permanent, extensively farmed grassland was below 3 mg/liter of soil. ***Salinity*** is not a problem in the Finnish agriculture. ***Compaction*** impacts depend on the intensity, methods and timing of the farming practices. Compared to managed uncultivated arable land turnip rape/rape seed or cereals cultivation increases compaction risk due to the cultivation measures.
Waste oils	Waste oils have a positive impact on soil health and production capacity if they replace raw materials that have a negative soil impact.
Reed canary grass	There are two alternative methods to cultivate Reed canary grass (RCG): in arable land (a) and in old peat mining areas (b). a) and b): Impacts on ***soil organic matter*** depend on the intensity of the farming practices. The less soil is tilled and the more organic matter is left on the surface of the field the higher the organic matter content is (Paul & Clark 1996). Cultivation of RCG is less intensive than cultivation of cereals or oilseeds and close to the intensity of other perennial grasses. ***Wind erosion*** is not a problem in Finland. ***Erosion caused by water*** depends on the intensity of the farming practices and the coverage of plants and plant residues. Erosion risk of the fields with RCG is averagely the same than the fields with perennial grasses. On the one hand the risk is lower because the renewing frequency of RCG is lower compared to that of grasslands. On the other hand erosion risk is higher because RCG is established without protective crop (nurse crop; e.g. oats or barley). Furthermore, during the 1st year the plant coverage is poor and the risk for erosion is high. ***Soil acidification*** a) RCG cultivation in the fields maintains soil productivity because successful RCG farming requires a suitable soil pH level. Without active farming and liming soil pH would slowly resume to its natural level ***Soil nutrient level*** a) RCG cultivation maintains soil productivity, because without active farming soil nutrient – especially plant available P - levels would resume to its natural levels ***Salinity*** is not a problem in the Finnish agriculture. Impacts on soil ***compaction*** depend on the intensity, methods and timing of the farming practices. a) Compared to managed uncultivated arable land RCG farming increases the risk for compaction due to more frequent treatments. b) Compared to old peat mining area with no measures RCG cultivation increases the risk for compaction
Round wood	Logging of round wood has long been a normal practice in Finland, and there are no significant impacts in the soil ***organic matter.*** Harvesting increases ***erosion*** compared to forests in natural state.

	The erosion is the more intensive the more the soil surface is destructed. In round wood some ***nutrients*** are transported from the forest, but this is considerably a considerably smaller amount than the nutrients in soil or logging residues. Harvesting also induces increased leaching of nutrients, but this is also relatively little compared to the soil nutrient stock. The use of machinery can cause ***soil compaction***, but compared to agricultural soil, the problem is significantly smaller due to less frequent treatments. ***Salinity*** is not a problem in boreal forests.
Logging residues	Logging residues protect the soil from the rain, sun and wind. Residue extraction and especially stump removal can cause soil ***erosion*** (EEA 2006). Use of energy wood can change the forest carbon and nutrient cycles due to export of organic matter and nutrients with residues. (EEA 2006; Kuusinen & Ilvesniemi 2008) Export of nutrients (cations) can also ***lower soil pH***, which furthermore can cause solubility of metals (Al, Fe, Mn, Cd) and their leaching to water systems (Kuusinen & Ilvesniemi 2008). On the other hand, export of nutrients in logging residues can reduce leaching to waters (EEA 2006; Kuusinen & Ilvesniemi 2008). Energywood collection may require many drives to the site with different machines. This can lead to physical disturbance of the soil (***compaction***, ***erosion***) and damage trees especially if the soil is wet and not frost. (EEA 2006; Kuusinen & Ilvesniemi 2008). ***Salinity*** is not a problem in boreal forests.
Peat	Peat is, by nature, very different from any other biofuel raw material. Peatland is, in fact, one type of soil, and peat extraction naturally causes losses of soil organic matter and natural production in this type of habitat is destroyed. Peat extraction also causes erosion. On the other hand, after the peat extraction, the production capacity of the area can also grow, and for example reed canary grass can be cultivated.
Straw	Reference: straw left on the field ***Organic matter:*** Crop residues applied to soil are important for soil organic carbon. Soil organic carbon in turn is important for soil structure, limiting erosion, the provision of nutrients, counterbalancing acidification and water holding capacity of soils. Soil organic carbon is an important determinant of soil fertility and within limits crop productivity is positively related to the soil organic matter content (several sources referred by Reijnders 2008). According to Malhi et al. (2006) total organic C and N were generally greater with systems with straw compared to no-straw systems after four years experiment. The same result was obtained by Gabrielle & Gagnaire (2008) Soil organic carbon level has an effect also on ***erosion*** (see above). Furthermore, after oilseed or cereals cultivation, if all straw is

	collected, the soil plant residues coverage after ploughing or cultivating is smaller and risk for erosion by water is bigger than in the case where straw is left on the field. Soil organic carbon level also has an effect on ***soil acidity*** (see above). ***Soil nutrient level***. Soil total organic N content was generally greater in straw compared to no-straw systems after a four years experiment (Malhi et al. 2006). ***Salinity*** is not a problem in the Finnish agriculture. Soil organic carbon level also has an effect on soil structure and, thus, ***compaction*** (see above). Furthermore, straw collecting is an extra phase in the chain of cultivation measures slightly increasing the soil compaction risk by machines compared to the case where straw is not collected.
Sugarcane	Long-term sugarcane monoculture leads to loss of soil's productive capacity and yield losses. Factors contributing to yield loss are the monoculture itself, excessive tillage of the soil at planting and severe soil ***compaction*** resulting from the use of heavy machinery during the harvesting operation. These crop management practices have reduced ***organic C*** and cation exchange capacity, increased bulk density and decreased microbial biomass of sugarcane growing soils (Pankhurst et al. 2003). Sugarcane grown in arid or semiarid areas (India, Australia) often needs to be irrigated leading to a risk of soil ***salinization***. The soil salinity, in turn, is known to contribute to yield losses and reduced sugarcane juice quality, the factor further affecting negatively on the efficiency of sucrose recovery (Lingle & Wiegand 1997). In Brazil, sugarcane is mostly rain-fed (Jungbluth et al. 2007a; de Fraiture et al. 2008). Cane burning, a practice in Brazil, can damage the cell tissue of the cane stem, and thus increase the risk of diseases in the cane, destroy ***organic matter***, damage the ***soil structure*** due to increased drying, and increase the risks of ***soil erosion*** (Goldemberg et al. 2008).

8.8 Impact on biodiversity

Biodiversity refers to all variety of life on Earth. The biodiversity includes a variety and number of plants, animals, and micro-organisms. It also covers the genetic variety and the variety in ecosystems. Diversity in landscapes and geology can also be included in the term biodiversity.

Biodiversity is the key to the biosphere and the Earth to provide different kinds of ecosystem services. A healthy ecosystem is needed also to be able to adapt to climate change. Human interference on biosystems has greatly reduced the biological diversity. The impacts of biofuels life cycles on biodiversity are mainly connected to the raw material production phase. The biofuel refining facilities and the use phase of biofuels (roads, parking lots) reduce space for biological life, but these can be estimated to be less important than the raw material production phase. The impacts of biofuel raw material production on biodiversity are very similar to any other intensive agriculture or forestry activity. Some special characters, however, exist, for example increasing use of logging residues, which can have severe implications on forest saproxylic (deadwood dependent species). Main biodiversity concern of biofuel production probably relates to the land use change: increasing biofuel production needs more production area, which can expand to high-biodiversity areas such as tropical forests or permanent grasslands, and production of biofuel raw materials such as palm oil and sugarcane are seen as major threats to biodiversity (Goldemberg et al. 2008; Fitzherbert et al. 2008).

In Table 21 some biodiversity aspects related to the production phase of the biofuel chains under consideration in this report are described.

8.8.1 State of the art for assessing impacts on biodiversity

In practice, the accepted and commonly used methodology for assessing impacts on biodiversity in LCA is lacking, and therefore this category has been neglected in the LCA studies of biofuels.

8.8.2 Concluding remarks on impacts on biodiversity

Biodiversity losses are probably one of the most important implications of expanding biodiversity production. One of the main concerns is that the biofuel production expands to high biodiversity value areas such as tropical rainforests with permanent and significant losses of habitats and species. In Finland, the main threat is connected to the use of logging residues and stumps, which can have severe implications for forest saproxylic (deadwood dependent species). Peat production is one of the main reasons threatening mire species and habitats in Finland.

Table 21. Possible impacts of biofuel raw material production on biodiversity.

Raw material	**Biodiversity impacts**
Palm oil	Major threat of oil palm on biodiversity is that the plantations expand on high biodiversity areas such as tropical forests causing fragmentation and losses of high conservation value ***ecosystems and habitats***. The ***species*** diversity of birds and mammals is known to be considerably lower in and around the plantations than in the nearby tropical forests, across all taxa, a mean of only 15% of species recorded in primary forest are also found in oil palm plantations (Fizherhert et al. 2008). In Malaysia and Borneo, the number of ant species was found to be significantly lower in plantations than in primary forest. Also invasive ant species were found presenting a threat to the natural ant diversity (Pfeiffer et al. 2008). Invertebrates, although being the vast majority of world species, are however very little studied on the oil palm plantations (Turner et al. 2008).
Rapeseed oil	Direct impacts: fields with turnip rape/rape seed and cereal production are poorer in biodiversity than managed uncultivated arable land. Biodiversity level of managed uncultivated arable land is, however, affected by the seed mixture, establishment method and mowing (Antikainen et al. 2007, Salonen et al. 2008). Indirect impacts: turnip rape/rape seed cultivation for energy purposes may cause significant land use changes because occupation of agricultural land with energy crops may lead to increased clearing of forests for food production, which, in turn, has significant impacts on biodiversity.
Waste oils	***No direct impact*** on biodiversity. The ***indirect*** impacts are mainly positive as less other biofuel raw materials are needed and their biodiversity impacts are avoided.
Reed canary grass	There are two alternative methods to cultivate Reed canary grass (RCG): in arable land (a) and in old peat mining areas (b). Direct impacts: a) Fields with RCG are poorer in biodiversity than the fields with turnip rape/rape seed or cereals due to the fact that RCG forms dense and high vegetation which covers effectively soil surface

	and by that way prevents other vegetation to grow up (Antikainen et al. 2007) b) The impact of RCG cultivation in old peat mining areas on biodiversity is not clear. It depends on the method how the area was managed after peat mining if it is not used for cultivation purposes. On the long run the effect of RCG cultivation in arable land is supposed to be negative. Indirect impacts: a) RCG cultivation for energy purposes may cause significant land use changes because occupation of agricultural land with energy crops may lead to increased clearing of forests for food production, which, in turn, has significant negative impacts on biodiversity. b) If certain acreage of RCG is cultivated e.g. in Finland, RCG cultivation in old peat mining areas decreases the need to occupy arable land for energy purposes compared to the case where all that RCG is cultivated in arable land. Thus, indirect biodiversity impacts of RCG cultivation in old peat mining areas may be positive.
Round wood	Forestry is one of the most important factor that has affected the Finnish ***species and habitat diversity*** (Rassi et al. 2001; Tonteri et al. 2008). Old forests are rare in Finland, one of the main reasons being use of wood and final fellings. Forestry practices have also decreased the diversity in the composition of wood species, reduced the amount of dead and burned wood (Tonteri et al. 2008).
Logging residues	A short summary based on the literature reviews in Antikainen et al. (2007) and Kuusinen & Ilvesniemi (2008) is provided here. More information is available in these reviews and the references therein. The main concern on the use of logging residue probably relates to the habitat loss and fragmentation of ***saproxylic (deadwood dependent) species***. A significant proportion of local populations of these species can also be removed with residues. Logging residues also provide shelter and breeding ground for many ***small animals and birds***. However, there is not much information on the effects of logging residue collection on these. Final fellings have a substantial impact on forest ***plant composition***, and the additional contribution of the collection of the logging residues is minor. New plant species appear the more there are soil disturbances – most when also the stumps are collected. Collection of the logging residues decreases the amount of ***mosses***. There are not enough knowledge of the impacts of energy wood collection on ***endangered plants***, but most of the endangered forest plants live on habitats which are recommended to be left out from felling and energy wood collection areas.

Peat	Peat production is along with draining the main reasons threatening mire ***species*** in Finland, and these are also future threats for these species (Aapala 2001). The threatened mire species are mainly invertebrates, vascular plants and cryptogams (Rassi et al. 2001). Peat production has been one of main factors contributing the loss of mire area (and therefore mire ***habitats***) in Finland, and remains such also in the future (Kaakinen et al. 2008).
Straw	It is supposed that straw removal has a negative effect on soil biodiversity because straw removal decreases soil organic matter and nitrogen contents as well as has a negative impact on soil structure and, thus, has an unfavorable effect on soil biological activity.
Sugarcane	The increase in the sugarcane cultivation took place relatively far away from the most important ***biomes*** (Amazon forest, Atlantic rainforest, Pantanal grasslands), and direct impact on these is not likely to have occurred (Smeets et al. 2008). Expected increase in the cane production for the coming decade will lead to further expansion of cane production area being a threat to an important biome called cerrado (savannah). The indirect impacts are potentially important, but these effects are difficult to quantify and indicate. Loss of biomes causes extinction of species and their habitats, and loss of ecosystem functions. Sugarcane is cultivated in large monocultures, which can have negative impacts to ***species diversity***. Sugarcane burning during harvesting causes death to many animals. Some of them are also sent to zoos (Goldemberg et al. 2008). Long-term monoculture can have negative effects on ***soil biota***; for example, in Australia soil microbial biomass has been verified to decline and the activity of detrimental soil organisms to increase leading to yield decline in long-term sugarcane monocultures (Pankhurst et al. 2005a and 2005b). ***Genetically modified*** cane is being developed, but at this moment not applied due to, inter alia, public and EU resistance (Smeets et al. 2008). However, it is expected that more GM cane will be approved in the future.

8.9 Use of water

One significant current environmental problem relates to the use of water. According to a recent and wide water resources assessment (Molden 2007), annually some 7 130 cubic kilometers of water are consumed by crops to meet global food demand. This is an equivalent of more than 3,000 liters per person per day. Most of the water consumption of crops (78%) comes directly from the rain, while 22% comes from irrigation. Meanwhile, about 1.2 billion people live in river basins characterized by absolute physical water scarcity. Overuse of water also threats ecosystems and soil health and production capacity.

Increasing biofuel production increases pressure on the competition between water for biofuels of for food. In scenarios drawn by the Millennium Ecosystem Assessment (2005), global water withdrawals increase between 20% and 85% between 2000 and 2050. In a bioenergy-intensive scenario, annual global water withdrawal will increase by about 50% to 5 500 km^3, which corresponds roughly to 75% of what is needed for the global food production today (Molden 2007).

Although over-consumption of water faces globally many ecosystems and societies, there are many regions, where water resources are not threatened. The sufficiency of water depends on many factors, such as the climate (rain, evapotranspiration), crop species, agricultural management practices, and other water uses in the region. For example, the water consumption of sugarcane in Australia can vary between 0–12 300 m^3 ha^{-1} (Renouf et al. 2008), and the sugarcane cultivation in India is fully irrigated (de Fraiture et al. 2008). In Brazil, sugarcane is mostly grown under rain-fed conditions, and very little irrigation water is needed for ethanol production (de Fraiture et al. 2008; Goldemberg et al. 2008). The same applies for rapeseed in Europe and the biofuel raw materials in Finland too. Globally on average, the production of one liter of biofuel requires roughly 2 500 l of crop evapotranspiration and 820 l of irrigation water (de Fraiture et al. 2008).

In addition to water consumed in the biomass production phase, water is also needed when refining the biomass into a fuel, but this is a relatively small amount compared to the amounts that are needed in the agri-forestrial production phase. Furthermore, the water utilized in the refining processes may be possible to recycle, reuse and eventually the wastewater is treated.

In this report, the use of water has been included, by estimating the water consumption by irrigation in the biofuel production phase, and the water consumption in the refining phase. The results are presented in Table 22.

8.9.1 State of the art for assessing water use in LCIA

Despite water consumption being a severe problem in many regions, so far it has been neglected in many LCA and energy and GHG balance studies for biofuels (Menichetti & Otto 2008). A complete water balance is missing in most reports. The same can be said for water depletion, water quality, and water pollution indicators. One reason for the non-uniform treatment of the water consumption issue in biofuel LCAs is the fact that a common methodology including site-generic characterisation factors does not allow to take local water conditions into account. The use of water is a regional and a local problem with great variation in different parts of the world. Inclusion of water consumption to the biofuel LCAs will in the future be even more important, because global water resources are expected to undergo a substantial change, due to the climate change. It is possible that the lack of water limits the growth also in Finland in the future, and irrigation will be needed in the fields.

8.9.2 Concluding remarks on the use of water

Water shortage is a significant problem in many areas, and expanding production of biofuels in areas depending on irritation may considerably increase the water problem. Despite water consumption being a severe problem in many regions, so far it and also water depletion, water quality and water pollution indicators have been neglected in many LCA studies for biofuels. One important reason is that a uniform methodology on water resources is lacking from the LCA. In general it can be said that biofuel crops that do not threaten the water resources (e.g. not needing irrigation) should be preferred, but the actual sufficiency of water depends on many factors, such as the climate (rain, evapotranspiration), the crop species, agricultural management practices and other water uses in the region.

Table 22. Water consumption in biofuel raw material production and refining. In the production phase, the external irrigation water is taken into account, but no natural rainfall. In the refining phase, the net water consumption of the process is estimated, but the water consumption of the production of other raw materials and auxiliary materials is not included.

Raw material	**Production (irrigation)**	**Refining (water consumption in process)**		
		NexBTL	**FT-diesel**	**2G bioethanol (sugarcane 1G bioethanol)**
Palm oil	Irrigation not usually needed except for nursery phase.	Processing of t crude palm, rape oil and animal waste oil requires water and/or steam. Additionally, the pre-treatment of raw materials uses 28 kg of process water and 70 kg of cooling water / t NExBTL, and produces 111 kg wastewater. The hydrotreatment phase uses 25 kg process water and 4 kg cooling water / t NExBTL, and produces 113 kg of wastewater. The wastewater is pumped to refinery wastewater plant. In addition, production of hydrogen requires water (8 800 kg water / t H_2) (Nikander 2008)	-	-
Rapeseed oil	Currently, turnip rape/rape seed is not irrigated in Finland (the same in Germany) but due to the predicted impacts of climate change springs become dryer in Finland increasing the irrigation need in the future. (Average irrigation level 2 x 30 mm per year = 600 m^3/ha/yr (Pajula & Triipponen 2003)).			
Waste oils	Waste material, no impact in FI. If waste oil replaces other raw materials that are irrigated, it has a positive impact i.e. need for irrigation is reduced.			

Reed canary grass	Typically, in the field cultivation, RCG is not irrigated in Finland even though RCG often suffers of water shortage after sowing (Pahkala et al. 2005). According to the predicted impacts of climate change springs become dryer in Finland increasing the irrigation need of 1st year RCG.	-	Raw material is dried before feeding into the process and the water is released with fluegas into the atmosphere. Water is produced in the FT process as a result of chemical reaction between CO and H2. The produced water is separated from the product.	Roughly 20 t / t ethanol including the steam not returned back to the power plant. By further integration of steam and water streams, water consumption may reduce significantly (von Weymarn 2007).
Round wood	Not irrigated (FI)			
Logging residues	n.a.			
Peat	Not irrigated (FI)			
Straw	Currently, cereals are not irrigated in Finland, but dryer springs may increase the irrigation need in the future.			

Sugarcane (BR)	Not irrigated (Jungbluth et al. 2007a; Goldemberg 2008; de Fraiture et al. 2008)		-	Consumption of large volumes of water and uncontrolled discharges has previously been a significant problem in Brazil (Smeets et al. 2008). Significant improvements in water consumption efficiency have been achieved by reuses, circuit closing, and process changes, such as the reduction of sugar cane washing, and the consumption has decreased from more than 5 m^3 / t sugarcane to 1.2–1.8 m^3/t sugarcane. Nearly 90% of water is used in four process phases: sugar cane washing; condenser/multijet in evaporation and vacuum; fermentation cooling; and alcohol condenser cooling (Neto 2007).

- = the raw material is not used in this refining process.
FI = Finland
BR = Brazil

8.10 Concluding remarks on environmental impacts

Biofuels have mainly been promoted because they have been considered to reduce greenhouse gas emissions into the atmosphere. However, benefits in greenhouse gas impacts, as regards production and use of biofuels, are subject to significant uncertainties. The most important issues to be considered are the circulation time of bio-carbon compared to the time frame for climate change mitigation, the availability of raw materials and land area, soil implications due to biomass cultivation and harvesting, system impacts from the requirement of auxiliary energy, and substitution credits from the use of co-products and biofuels. More research work to quantify the magnitude of different types of indirect impacts is clearly required in order to reliably assess greenhouse gas impacts of biofuels.

With regard to biofuels the environmental impacts, other than climate change, have been often neglected. Therefore there are a relatively limited amount of published LCA studies about the other environmental impacts. Furthermore, many of these impacts are not well established impact categories in LCA, e.g. soil production capacity, land use, biodiversity and use of water, and many times these categories are analysed on a qualitative level or not at all, and the conclusions are often drawn on a general level. This is also the case in this review.

Basically, the impacts of production of biofuel raw materials do not differ from the production of other biomass raw materials. Therefore existing data on biomass production can be utilised to estimate the biofuels impacts. However, little or no data is available on many aspects of the biofuel refining process. Therefore the impacts of the whole chain are difficult to quantify even in relatively simple impact categories such as acidification.

Biofuels' environmental performance is often compared with the fossil counterparts. Concerning acidifying emissions, biofuels in general seem to cause higher acidification potential than their fossil counterparts, even though significant differences between raw materials and technologies exist. The significance of acidification in the total environmental impact of biofuels does, however, not score very high. Similarly, biofuels life chain impact on tropospheric ozone formation appears to be negative in most cases, and especially if uncontrolled biomass burning is occurring during the life chain (land clearing, biomass burning). In case of particulate matter, the biofuel chains in which biomass burning is part of land clearing or harvesting, PM emissions are significantly higher compared to fossil counterparts. In other chains, the PM emissions are not considerably higher than those of conventional fuels. In the final use of biofuels, PM emissions are typically lower for biofuels than for conventional fuels with older engine technologies. However, with advanced technologies (EURO4 and EURO5) fuel effects on PM emissions appear to be small. Even in this case, the benefit of using biofuels may be seen e.g. as lower emissions of particle-associated polyaromatic hydrocarbons.

Biofuels generally underperform the conventional fuels in terms of eutrophication potential. However, due to the current poor methodological practices to assess eutrophication in LCAs it is difficult to obtain reliable results for the comparative studies in which the aim is to assess the eutrophication potentials caused by different product systems located in different parts of the world.

Assessment of human toxicity and ecotoxicity are under active development in the international LCA community. Relatively little data is available on the emissions of toxic substances in biofuel chains, and more research is needed to determine the significance of different substances in biofuel chains and to make LCA studies of biofuels more complete.

Biofuel production can have significant land use impacts and impacts on soil health and production capacity, biodiversity, and water resources. These problems are mainly related to the biomass cultivation phase. More research and development work is needed to be able to include these categories in LCA and to be able to better compare the performance of different biofuels. In general it can be said that the biofuel crops based on waste materials or growing on waste land should be preferred. However due to the system and different competition impacts, the ranking of different crops is a difficult task.

As very little information is available on potential emissions from the refining phase of new evolving biofuel technologies, it is of utmost importance to fill out this lack before the technologies are finally implemented in full-size and at commercial level.

9. Discussion and conclusions

Sustainability is a multidimensional concept, which can be separated into environmental, economic, and social aspects. Furthermore, these aspects include various dimensions. For example, environmental impacts include e.g. climate change, quality issues related to air, water or soil, ecotoxicity, human toxicity, and biodiversity. Social aspects include e.g. human, labour and property rights, as well as well-being and equity issues. In addition, there are various viewpoints on economic aspects.

The sustainability concept is a very complicated issue, due to its multidimensional characteristics. In addition, the definition of sustainability depends on the context under review and is changing over time. Consequently, it is unclear how sustainability should be assessed, measured, and monitored now and in the future. It is not even clear what the criteria for certain dimensions of sustainability should be. Furthermore, although most of the dimensions can be defined to be *quantitative,* the sustainability cannot be measured or monitored as a whole in quantitative terms.

The assessment of environmental sustainability, which was the main focus of this project, is a challenging task due to several key issues. Firstly, there is no unique or objective methodology to assess environmental impacts of any kind of a system. LCA does not cover all environmental impacts and the ISO Standard 14044 allows for different methodological approaches. For example, land-use effects, biodiversity, soil production capacity, and use of water are cumbersome to deal with. Secondly, in order to enable quantitative assessment, a number of assumptions e.g. *on the reference scenario, the spatial and temporal system boundary, the allocation procedure, and the parameter data set* have to be made. These assumptions may have significant impact on the results and include remarkable uncertainties and sensitivities. The key question arising here is how to deal with the uncertainties and how to interpret the results without drawing any misleading conclusions.

Environmental impacts of biofuels can be roughly separated into direct and indirect impacts, although the boundary between them is more or less unclear. Direct impacts can be assumed to be those that can be managed or influenced within the first-hand links to the biofuel chain, meaning the use of auxiliary energy and other non-energy related goods inputs, production of infrastructure, process emissions from cultivation and harvesting of raw materials and processing of biofuels, and from biofuel combustion. The second-hand impacts can be seen as indirect impacts as they are significantly influenced by market mechanisms. The use of auxiliary inputs (e.g. electricity, fossil fuels, chemicals, machinery etc.) and land area for the production of biofuels likely increase competition between them, causing complicated transition effects. In addition, the substitution effects from replacing products by coproducts of biofuels, or fossil fuels by biofuels can be seen as indirect impacts of producing biofuels.

Both direct and indirect impacts may be difficult to quantify due to lack of knowledge and data. As regards direct impacts the main uncertainties and lack of knowledge are related to the impacts of biomass harvesting on soil carbon and nutrient balances, the feedback mechanism from soil to biomass productivity, nitrous oxide emissions from fertilization and cultivation, process emissions from technologies under development, and emissions of certain substances, in particular heavy metals and toxic compounds. In addition, many case specific characteristics, e.g. regional cultivation circumstances, available energy sources, or transportation distances, may cause significant sensitivity in the results between various cases.

Due to the difficulties in assessing other environmental impacts than those of greenhouse gases and also due to the fact that one of the drivers behind increasing biofuel production is climate change mitigation, the other environmental aspects are often neglected in biofuel LCAs. Therefore there is only a relatively limited amount of published LCA studies about the other environmental impacts. Furthermore, many of these impacts are not well-established impact categories in LCA, e.g. soil production capacity, land use, biodiversity, and use of water and although these categories are often analysed on a qualitative level the conclusions are often made on a general level. More research and development work is needed to be able to include these categories in LCA and to be able to better compare the performance of different biofuels.

Basically, the impacts of production of biofuel raw materials do not differ from the production of other biomass raw materials. Therefore existing data on biomass production can be utilised to estimate the biofuels impacts. However, little or no data is available on many emissions especially on the evolving biofuel refining processes. Therefore the impacts of the whole chain are difficult to quantify even in relatively simple impact categories such as acidification.

Indirect impacts may be very difficult or impossible to recognize as a whole in an objective manner. However, their significance may be remarkable. If biofuel production increases the competition between raw materials or land area, it means that more resources are likely used to satisfy the needs of all competing purposes. This may lead to very harmful impacts such as deforestation and destruction of peat swamps. Such impacts may decrease the overall environmental benefit that would have been achieved, without such impacts, by replacing fossil fuels with biofuels. At the worst, it is possible that the overall impacts are even harmful compared to the reference system. In addition to land use changes, also other indirect impacts are caused, due to the use of auxiliary inputs, e.g. electricity, chemicals etc., and replacement of products by coproducts and biofuels. All indirect impacts are subject to significant uncertainties, which may be very difficult to quantify in practice. In addition, there is typically lack of knowledge where the indirect impacts take place, making regional environmental impact assessment, in particular, very difficult.

In order to ensure that biofuel production and use does not cause significantly harmful environmental, economic or social impacts, various organisations have proposed sustainability criteria for biofuels. However, none of these initiatives can guarantee sustainable production of biofuels. Many of the aspects other than climate change are considered only cursorily and are not based on life cycle thinking, but the handling of greenhouse impact is also defective. Firstly, uncertainties and sensitivities related to assumptions on the reference scenario, the spatial and temporal system boundary, the allocation procedure, and parameters are systematically excluded in the proposed assessment methodologies for greenhouse gas impacts. Secondly, greenhouse impact is not handled in an appropriate way to ensure the most effective use of biomass against climate change. The indicators used for assessment of greenhouse gas impact should measure the potential of biomass in limiting the atmospheric greenhouse gas concentration within a given time period that should be analogical with the fundamental target to mitigate climate change. A typically proposed "*relative emission reduction*" indicator is not an appropriate measurement of biomass effectivity in the mitigation of climate change.

As biomass and available land area are limited resources, from climate change mitigation point of view they should be used as effectively as possible to mitigate global warming. There is scientific evidence that by cascading the use of biomass (first products then energy) and conservation of carbon storage, the effectiveness of biomass in mitigating climate change is likely significantly better than processing it to relatively energy intensive biofuels. Large-scale production of biofuels may make it more difficult to reduce emissions in electricity and/or heat production and through material substitution. Consequently from climate change mitigation point of view, as long as biomass can be used more effectively in mitigation of climate change, it does not provide optimal benefits when converted first to liquid biofuels. This is very likely true for many of the large-scale biofuel applications.

Implementation of any human action is probably always a trade-off between various dimensions of sustainability. For example, the use of biofuels instead of fossil fuels causes negative and positive impacts on sustainability, depending on the dimension. Optimisation of the use of biomass is certainly required in order to be as sustainable as possible. However, it is difficult to compare and value various (environmental) impacts. Although methodologies have been developed to do so they are always more or less subjective. Consequently, compromises need to be made when optimising the benefits from biomass use. Strict binding targets aiming to significantly promote the use of biofuels cannot be justified if they promote environmentally harmful impacts. Such targets may lead to non-optimal solutions on how to use biomass, even (and in particular) from the perspective of climate change mitigation. However, if a certain amount of biofuels are produced, there are more and less sustainable ways to do it with regard to various dimensions of sustainability. This is a fact that is also important to recognise.

In principle, implementation of certain sustainability criteria for biomass use is a reasonable target aiming to ensure that the use of biomass is as sustainable as possible. However due to the complexity of the issue, it is not clear whether there should be only one common criteria for all biomass or more specified criteria for various regions, raw materials, and end-use applications. Furthermore, as objective measurement of sustainability is most likely an impossible task, there is a risk that the use of a general methodology and monitoring guidelines only for monitoring sustainability results in the promotion of systems and actions significantly less sustainable than desired. Consequently, the need for case-specific and more comprehensive analysis with different perspectives and indicators are obvious. Both micro-level bottom-up and macro-level top-down analyses are required to ensure that biomass use is as sustainable as possible with regard to its various dimensions.

Uncertainties related to the sustainability of biofuels should be accepted and considered in both the assessment procedure and in the interpretation of results. Consequently, more attention should be paid on one hand on uncertainty analysis and on the other hand on guidelines on how the uncertain results should be interpreted and utilized in decision-making. There will always be a need for development of methodologies, as new approaches are developed and introduced as a function of increasing understanding and knowledge of the research problems.

Many of the problems, such as land use impacts and impacts on soil health and production capacity, biodiversity and water resources, relating to the biofuel chains originate in the biomass cultivation phase. More research and development work is needed to be able to include these categories in LCA and to be able to better compare the performance of different biofuels. In general it can be said that biofuel crops that are based on waste materials or that grow on waste land should be preferred, but due to the system and different competition impacts, the ranking is a difficult task.

According to macro-economic scenario analysis, the increased use of biofuels has the effect of raising both consumer prices and costs of production. Consequently, it tends to drive down consumption and production in most sectors of the economy, and also makes investment less attractive. While the effects of increased domestic biofuel production are slightly negative at the level of the whole economy, the increased demand for crops and wood obviously increase activity in agriculture and in particular, in forestry.

The definition of system boundaries is perhaps the most critical issue when calculating the environmental impacts of production and use of biofuels. The inclusion of indirect impacts can have an order-of-magnitude impact on the results, if for example the indirect impacts are assumed to lead to destruction of tropical rain forests or peat swamps. Other critical factors include site-specific features, direct soil implications through cultivation or harvesting of raw materials, substitution credits from the use of co-products and biofuels, and lack of data concerning technologies under development. In addition, indicators used to measure greenhouse gas or other environmental impacts may have significant impact on the interpretation of the results.

Further research work is certainly required in various areas and dimensions related to the sustainability of biofuels. The most significant weakness is in understanding how the indirect impacts such as land use change should and could be included in the assessments. Other aspects needing more research include how the sustainability is assessed and measured, and case studies for current and new technologies and raw materials. In addition, reduction of the uncertainties related to assessments is needed. More data and knowledge is also required for socio-economic dimension of sustainability and economic implications of biofuels towards the reference scenario. Finally, important is to increase understanding and knowhow on how the perceived harmful impacts of biofuel chains can be reduced.

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Appendix A: Summary and analysis of the proposed sustainability criteria

(Anne Holma & Riina Antikainen SYKE, greenhouse gas and energy balances by Sampo Soimakallio & Kati Koponen VTT)

General

In this section, different initiatives and certification systems on sustainability criteria for biomass and biofuels are presented and assessed, and a review of the content of these criteria is provided. Critical views on these criteria provided by private companies, scientists, government agencies, NGOs, and other organisations are also presented.

The initiatives selected are the EU Directive Proposal, national level criteria from the Netherlands, United Kingdom (UK) and Germany, criteria prepared by a few NGOs (Roundtable of Sustainable Biofuels (RSB) and Swan labelling) and certification systems for biomass energy crops (RSPO; palm oil, BSI; sugar cane, and RTRS; soy) and forests (FSC and PEFC). Each of these criteria has a slightly different scope and goal, which makes the comparison a challenging task. Some criteria focus only on biofuels[15] and some on biomass, and some on both. Furthermore, some criteria cover the whole life cycle of the product and some only the cultivation phase. The EU Directive Proposal focuses mainly on greenhouse gas reductions and biodiversity aspects. According to the proposal, other criteria cannot be set at a consignment level. However, initiatives of some member states (The Netherlands, Germany and United Kingdom) have a more extensive focus on environmental and social aspects of biomass and biofuel

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[15] Biofuel refers to bioenergy that is used in the transport sector.

production and of their use. All member states must comply with the Directive, and the voluntary certification systems and national criteria must be in compliance with the Directive. All criteria should be used in conjunction with national and international laws and regulations.

A new initiative was launched in the spring of 2008 by the European Committee for Standardization (CEN). The goal is to create a standard on sustainability criteria for biomass. As the work is in its very beginning and no draft versions have yet been produced, the initiative is not included in this analysis. However, as the work is lead by the Dutch, it is presumed that at least the first version of the standard will be very similar to the Netherlands' criteria. Additionally, in September 2008, the International Organisation for Standaridization (ISO) proposed a new work item on Sustainability criteria for biofuel.

Here, the initiatives are first briefly introduced and then their contents are analyzed. The analysis covers mainly environmental aspects, but social and economic aspects are also considered on a general level.

Initiatives on biomass certification

The European Commission (EC) released its climate and energy policy package in January 2008 (EC 2008). The package contains a Proposal for a Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources (RES). It includes environmental sustainability criteria and verification requirements for biofuels and other bioliquids. The aim of the proposal is to set binding targets for renewable energy in general: a 20% share of renewable energy sources in energy consumption, and for transportation biofuels a 10% binding minimum to be achieved by each Member State, as well as binding national targets for year 2020 in line with the overall EU target of 20%. A minimum level of GHG savings compared with fossil fuels from production to actual use is proposed. The suggested GHG saving should be at least 35%, but the exact reduction percentage is still under debate. There are also other sustainability criteria proposed, mainly related to biodiversity and land use practices.

The Proposal is already criticized for several reasons. Land use related issues are one of the most discussed subjects because of rising food prices and cutting of rain forests. Issues such as protection of permanent grasslands, natural and semi-natural forests and other high conservation value areas are also pointed out. Eichout et al. (2008) state that not enough land is available inside EU for cultivation of energy crops. Therefore the target can only be met by imports from outside the EU. The global land use is projected to increase and biofuel cultivation will put an additional pressure on land. Food shortages and loss of biodiversity are a possible consequence of increased cultivation of energy crops (Doornbosch and Steenblik, 2007).

According to the proposal, lifetime greenhouse gas reduction is required to be at minimum 35% compared to those of fossil fuels. However, in reality, the biofuels greenhouse gas reductions will not necessarily reach 35% (Eichout et al., 2008), mainly because of factors such as land use change and deforestation (Fargione et al., 2008). Also heavy use of fertilizers can lead to increasing N_2O emissions. Therefore, besides promoting biofuels, new vehicle technologies, such as electric cars or fuel cell cars running on hydrogen, should also be developed. However, the EU Directive Proposal does not stimulate these alternative routes (Eichout et al., 2008).

The Netherlands' criteria for sustainable biomass production (Cramer et al., 2006) were published in July 2006, followed by a testing framework for sustainable biomass in the next year (Cramer et al. 2007). The criteria concentrate on biomass for electricity and heat production, and on the use as transportation fuel, but they can also be applied to biomass used as raw material for chemicals and food production. The criteria are applicable to biomass from all origins in- and outside the EU, and to harvested crops, as well as to manufactured products (e.g. biodiesel). The criteria include 6 main themes: greenhouse gas emissions, competition with food and other applications, biodiversity, environment, prosperity and social well-being. Within the themes there are nine basic principles for biomass sustainability. The principles include criteria, indicators with minimal requirements, and reporting obligations. In the criteria various standards such as FSC, RSPO, RTRS and others are recognized. Currently, the framework has not yet a legal status. However, some elements will be included in a new policy support mechanism for electricity production from renewable energy sources.

The United Kingdom has implemented a Renewable Transport Fuels Obligation (RTFO) in 2008. The obligation requires companies to sell a minimum of 2.5% renewable transport fuels in the UK in 2008/2009, and the share will increase to 5% in 2010/2011. The scope of the sustainability criteria is limited to biofuels used as traffic fuels and only to the cultivation phase of biofuel crops. Processing and transportation activities are excluded. If the reporting is functioning properly, after the initial phase (2008–2011), it is possible to expand the scope to cover also feedstock processing

The UK criteria are based on an analysis of criteria and indicators defined in existing standards for sustainable agriculture and forestry. The UK and Dutch Governments have developed their criteria in close co-operation and thus have a common approach on many aspects. Wide sustainability reporting is an integral part of the RTFO. For soil conservation, sustainable water use and air pollution, compliance with national laws and good agricultural practices are required. There are three documents available: a framework report describing sustainability reporting *(*Dehue et al. 2007), a methodology report for carbon reporting (E4tech 2007*)* and a technical guidance for carbon and sustainability reporting (Renewable Fuels Agency, 2008).

In **Germany**, the Biofuel Quota Law sets mandatory biofuel blending targets, and also mandatory sustainability requirements for biofuels (Fritsche et al. 2006). The law further empowers the German Government to introduce a specific ordinance to specify in detail the sustainability requirements for biofuels under the Quota Law. The aim of the ordinance (BioNachV) is to ensure minimum requirements for sustainable use of agricultural land and the conservation of natural habitats in biomass production for use as biofuels. It is also required that the biofuels have a certain GHG reduction potential, taking into account the full life-cycle of biofuel production, including emissions from land-use change (Anon. 2007, Union for the Promotion of Oilseeds and Protein Plants & Institute for Energy and the Environment 2008).

The Roundtable on Sustainable Biofuels (RSB) is a multi-stakeholder initiative to develop standards for the sustainability of biofuels launched by the Ecole Polytechnique Federale de Lausanne (EPFL) in 2007. The aim is to achieve a global consensus on the principles and criteria of sustainable biofuel production. The RSB initiative builds on existing national and commodity-based initiatives. The purpose of the RSB principles is to indicate the ideal scenario towards which stakeholders should be striving. The work is done partly in an open wiki-based forum, Bioenergy wiki, where drafted principles have been commented. The aim is to create a tool that consumers, policy-makers, companies, banks, and other actors can use to "ensure that biofuels live up to their promise of sustainability" (www.bioenergywiki.net). The latest version, **"Version zero"**, of the **"Global principles and criteria for sustainable biofuels production"** was issued on 13 August 2008 for comments (RSB, 2008). This version of the draft principles will form the basis of a six-month period of wide-ranging stakeholder comment in preparation for the release of the first official standards in early 2009.

The Swan Labelling of Fuel is an initiative of the Nordic Ecolabel to produce a labeling system for licensing biofuels. The Nordic Ecolabel, commonly known as "The Swan" is an official ecolabel in the Nordic countries. In June 2008 the Nordic Ecolabel announced the requirements that enable companies to apply for a Nordic Ecolabel for fuels (The Nordic Ecolabelling, 2008). The criteria will be revised as the environmental and technical aspects develop within the industry. Fuel products that can apply for this Nordic Ecolabel, are ethanol, biodiesel, biogas and/or a mixture of these fuels. A Swan-labelled fuel is supposed to produce lower emissions and there should not be any risk of increased health or environment impact compared to fossil fuels. At least 1/3 (vol) of a Swan-labelled fuel is based on renewable raw materials. In addition, the origin of the raw materials must be documented.

The Roundtable on Sustainable Palm Oil (RSPO) was created by organizations involved in the entire supply chain for palm oil. There are presently 8 principles and 39 criteria for sustainable palm oil production adopted in 2007 (RSPO, 2007). The principles and criteria will be completely reviewed within five years and may be amended. The criteria cover social, economic, ecological, and general aspects. The first certifications of oil mills, estates and growers are expected in 2008.

The Roundtable on Responsible Soy (RTRS) is a forum of soy production and consumption stakeholders. It seeks to develop and promote criteria for the production of soy on an economically viable, socially equitable and environmentally sustainable basis. A final draft on sustainability principles was published in 2007 (RTRS, 2007).

The Better Sugarcane Initiative (BSI) is a collaboration of stakeholders including sugarcane retailers, investors, traders, producers, and NGOs. The aim is to develop internationally applicable measures and baselines that define sustainable sugar production and processing practices. The initiative includes principles and criteria for environmental, economic, and social issues. The initiative is in a draft phase and it is presented here only on a general level.

Forest Stewardship Council and Programme for the Endorsement of Forest Certification (FSC and PEFC) are the main forest certification organizations. Both concentrate on sustainable forest management by using independent third party assessment of forestry practices against a set of forestry standards. **FSC** is the standard for sustainably produced wood and fibre products and it has been in use since 1994. It encompasses economic, ecological, cultural, and social values of the forest resource (FSC, 2004). FSC certifies wood and fibre products only and is therefore not directly applicable for first generation biofuels. For biomass used for electricity production and for second generation biofuels FSC forms a promising standard. **PEFC** is based on inter-governmental principles that are developed for different forest regions of the world. The standards cover aspects on economic, social and environmental forest functions. Both certification systems are similar, but the FSC has stricter environmental criteria (CEPI, Forest Industries Intelligence Limited, 2006).

Environmental criteria

The initiatives presented above are analysed and compared by establishing categories that can fit all the criteria and certificates on a general level. The categories used are: Greenhouse gas and energy balance, Air quality, Water quality, Use of water, Soil Quality, Ecotoxicity, Human toxicity, Biodiversity, Genetically modified organisms (GMOs), Sustainable land use and competition with other resources, Waste management and recycling, Social impacts and Economic impacts (Table A1). This report concentrates mainly on environmental aspects of biofuel and biomass production. However, social and economic impacts are also addressed (though only on a general level), since these are significant aspects in the sustainability of biofuels and biomass.

Biodiversity is considered in all of the initiatives. Water quality, Soil quality and Ecotoxicity, as well as Social and economic impacts are included in most of the initiatives. Climate change aspects are included in all general biofuel/biomass initiatives, but not in most of those initiatives concentrating on a specific raw material. In the following, the contents of the initiatives are analysed in more detail.

Table A1. Environmental and socio-economic aspects of the sustainability criteria for biomass and biofuels in different initiatives launched.

	EU	**NED**	**UK**	**GER**	**RSB**	**Swan label**	**RSPO**	**BSI**	**RTRS**	**FSC**	**PEFC**
Applicability	BF	BF/ BM/ BE	BF	BM	BF	BF	BM	BM	BM	BM	BM
Environmental aspects											
Climate change	+	+	+	+	+	+	+	-(+)	-	-	-
Energy balance	-	-	-	(+)	(+)	+	-	-	-	-	-
Air quality	-	+	+	+	+	-	+	+	-	-	-
Water quality	(+)	+	+	+	+	-	+	+	+	+	+
Use of water	-	+	+	+	+	-	+	+	+	(+)	(+)
Soil quality	(+)	+	+	+	+	-	+	+	+	+	+
Ecotoxicity	(+)	+	+	+	(+)	-	+	+	+	+	+
Human toxicity	-	-	-	-	-	+	-	+	-	-	-
Biodiversity	+	+	+	+	+	+	+	+	+	+	+
Sustainable land use and competition with other resources	+	+	-	+	+	-	+	-	(+)	+	+
GMOs	-	-	-	-	+	-	+	-	-	+	- (+)*
Waste management and recycling	-	+	(+)	-	-	-	+	-	-	+	-
Social impacts	-	+	+	-	+	+	+	+	+	+	+
Economic impacts	-	+	-	-	+	-	+	+	+	+	+

* PEFC international do not consider GMOs, but some national schemes may have provisions for the use of GMOs.

General overview of the criteria.

\+ and a shaded area indicate that the category is covered by the initiative. Note that the level of detail in methodology, indicators etc. may still vary per certification system.

(+) and a shaded area indicate that the category is mentioned in the initiative, but only on a general level or the initiative covers the issue only partly.

\- indicates that the category is not covered by the initiative.

BM = biomass
BF = biofuel
BE = bioenergy

Climate change and energy balance

Greenhouse gas issues are considered on a most detailed level from various dimensions of sustainability in many of the initiatives reviewed and presented in Table A2. The reason for that is probably the fact that there exist a number of studies dealing with greenhouse gas balances of biofuels, but only a minor of them is assessing the other dimensions of sustainability. In addition, not all dimensions of sustainability, e.g. social aspects, can be measured objectively in quantitative terms. Greenhouse gas balances of biofuels are in many contexts perceived as a well-known or adequately known issue. However, there are also a number of studies pointing out that there are significant uncertainties and lack of knowledge involved in greenhouse gas balances of biofuels.

In this Chapter, analysis of various sustainability initiatives towards key factors to be considered when assessing greenhouse impact is presented. The summary of the analysis with specific explanations is presented in Table A2. From reviewed sustainability initiatives greenhouse gas impacts were not considered in RTRS, FSC and PEFC, but were taken into account at least to some extent in all the others (Table A2). Some of the initials, e.g. the EU RES directive proposal provided a methodology for calculating greenhouse gas balances of biofuels and emission reduction when compared to reference fuels.

As discussed in Chapter 3 the definition of system boundary is one of the most critical issues when assessing greenhouse gas balances of any kind of a system as various approaches and assumptions may lead to significant differences in the results. In order to enable quantitative assessment of greenhouse impact the system boundary should be clearly defined. However, by doing so, the analysis is made more or less subjective as the possible impacts outside the system boundary are not considered. For example, the EU RES directive proposal provides relatively clear guidelines and a methodology on how greenhouse gas impact should be calculated. Competition of raw materials or land use is not considered in that particular methodology. Such indirect impacts may lead to changes in land use outside the considered system boundary and thus cause significant emissions of carbon dioxide e.g. due to deforestation.

If a sustainability initiative provides rules for calculating greenhouse impacts, it should also provide guidelines for allocating emissions for co-products. Table A2 summarises which allocation methods, including allocation based on the energy content or price of a product, as well as a substitution method, were provided by various initiatives. The use of one particular allocation method leads inevitably to subjective results.

Many of the reviewed initiatives include CO_2, CH_4 and N_2O as greenhouse gases to be considered. It can be seen reasonable, as those gases are typically the most relevant ones with regard to biofuel production. However, if some other direct or indirect greenhouse gas plays a significant role in some biofuel chain, it would be necessary to take it into account. In some of the initiatives greenhouse gases to be considered are not defined.

When analysing greenhouse impact of any kind of a system, the emissions and sinks of greenhouse gases should be considered over the whole life-cycle of the particular system. Consequently, in addition to spatial system boundary the timing of inputs and outputs of the system should be taken into account, as discussed here. The consideration of dynamics is the more important, the longer the rotation period of the biomass is and the shorter the time to mitigate climate change is. Dynamics was not considered in any of the reviewed initiatives (Table A2).

Direct land use change e.g. due to cultivation or harvesting of biomass may significantly cause emissions of carbon that otherwise is stored or accumulated in biomass or soil. This kind of emissions should be considered, but are not discussed by some of the initiatives (Table A2). The pay back time of carbon storage losses is set as 20 and 10 years by the EU RES directive proposal and the UK initiative, respectively. In addition, the use of certain carbon rich areas for biofuel production is restricted e.g. by the EU RES directive proposal. Relatively short pay back time for carbon losses is reasonable as the pay back time should be the shorter the more rapid the emissions and the atmospheric concentrations of greenhouse gases need to be reduced. However, as the reference development of carbon storage is not known, the short pay back time may overestimate the negative influence, caused by the biofuel chain considered.

Some of the initiatives including the EU RES directive proposal provide default values that can be used when calculating greenhouse gas impact of biofuel chains. The default values are presented for certain individual parameters and for relative emission reductions of certain biofuels. However, many of the parameters required in assessing greenhouse gas impact of biofuels are subject to significant uncertainties and sensitivities, which may have considerable impact on the results (Soimakallio et al. 2009). Such parameters include e.g. nitrous oxide emissions from soils, soil carbon balances, and emissions from production of electricity consumed in biofuel processes. None of the reviewed initiatives provide uncertainty ranges for default parameters. In addition, the parameter-set provided is not adequately separated and detailed to consider e.g. the impact of regional differences.

Finally, one of the most critical issues is the way in which greenhouse impact of biofuels is measured. It is very typical to compare the emissions from biofuel system to a selected reference system by using the GWP method. The selection of a functional unit towards the greenhouse impacts calculated is crucial. For example, in the EU RES directive proposal the minimum acceptable emission reduction of a biofuel system is defined as 35% compared to a fossil reference system. As the emissions are calculated per energy content of fuels, the possible change in end-use efficiency is not considered. Amore problematic issue related to the particular indicator is the fact that it does not measure the effectiveness of biomass in climate change mitigation. In other words, it is possible to get significant relative emission reductions by wasting a lot of low greenhouse gas emitting biomass. As global biomass resources are limited and the challenge to reduce emissions to mitigate climate change is huge, the biomass should be used as effectively as possible from climate change mitigating point of view. Consequently, significantly more appropriate indicators would be measurements taking into account the greenhouse gas emission reduction achieved per biomass and/or land area consumed (see e.g. Schlamadinger et al. 2005, Pingoud et al. 2006; Soimakallio et al. 2009). These kinds of indicators are sort of hybrids from relative energy and greenhouse gas balance indicators.

Table A2. Summary of sustainability initiatives as regards greenhouse gas impacts.

Greenhouse gas sustainability criteria	**EU RES**	**NED**	**UK**	**GER**	**RSB**	**Swan label**	**RSPO**	**BSI**[1]	**RTRS**[2]	**FSC**[3]	**PEFC**
Spatial system boundary											
– clear definition	(Yes)[4]	Yes[5]	No[6]	No[7]	No[8]	Yes[9]	No[10]	-	-	-	-
competition of land use considered	No	Yes[11]	No	(Yes)[12]	(Yes)[13]	No	(Yes)[14]	-	-	-	-
– competition of raw material use considered	(Yes)[15]	Yes[16]	No[17]	(Yes)	(Yes)	No	No	-	-	-	-
– production of machines, infrastructure, plants considered	No	No[18]	No[19]	No	No	No	No	-	-	-	-
– allocation procedure proposed	E[20]	S/(P)[21]	S/(P,E)[22]	No	(S/E/P)[23]	S/(E,M)[24]	No	-	-	-	-
– relevant Kyoto greenhouse gases considered	Yes	(Yes)[25]	Yes	?	Yes	Yes	No	-	-	-	-
– carbon storage inside system boundary considered	Yes[26]	Yes[27]	Yes[28]	No	(Yes)[29]	(Yes)[30]	No	-	-	-	-
Dynamic system boundary											
– calculation period proposed	20	No[31]	10[32]	No	No[33]	20[34]	No	-	-	-	-
– timing of inputs and outputs considered (radiative forcing)	No	No	No	No	No	No	No	-	-	-	-
– carbon storage inside the system boundary considered	Yes[35]	Yes[36]	Yes[37]	No	Yes[38]	(Yes)[39]	No	-	-	-	-
Parameters											
– default values proposed	Yes	Yes[40]	Yes	No	No[41]	No[42]	No	-	-	-	-
– uncertainty range proposed	No[43]	No[44]	No[45]	No	No	No	No	-	-	-	-
– sensitivity issues considered	No	No	No	No	No	No	No	-	-	-	-
– references clearly presented	No	Yes	Yes	Yes	No	Yes[46]	No	-	-	-	-
– emissions of electricity	Ave	?[47]	?/Marg[48]	-	?	Ave[49]	-	-	-	-	-
Indicators											
– relative emission reduction, (foss. – bio)/foss., [%]	Yes[50] 35%	Yes[51] 30%	Yes[52] ?	No	Yes ?	No[53] (limit)	No	-	-	-	-
– emission reduction per biocarbon consumed	No	No	No	No	No	No	No	-	-	-	-
– emission reduction per land area	No	No[54]	No	No	No	No	No	-	-	-	-
– radiative forcing impact	No	No	No	No	No	No	No	-	-	-	-
– energy balance criteria	No	No	No	(Yes)	(Yes)[55]	Yes[56]	No	-	-	-	-

[1] BSI will consider greenhouse gas emissions but the criterion is still in a draft phase

[2] Some criteria published for responsible soy production, but the environmental criteria are only for minimizing the negative environmental impacts, pollution and waste, for water and soil management and protection of biodiversity. Climate change is not mentioned.

[3] FSC and PEFC are the forest certification criteria which concentrate on sustainable forest management. Climate change is not mentioned.

[4] Methodology is presented but several interpretations are possible.

[5] Calculation tool used but is suitable only for defined biofuel production chains. Calculation formulas are not presented. (GHG calculation methodology, p. 7)

[6] The basis for the calculations presented is not clear. Methodology covers currently only some determined biofuel chains. (Carbon reporting, p. 5)

[7] In future bioenergy standards, GHG emission limits for final bio-based products might be developed to take into account the different conversion routes and by-products. A simplified approach for small-scale, rural systems farming should be developed to avoid excessive costs. (GER, p. 20)

[8] The methodology will be developed, currently just guidance given.

[9] Guidelines for calculating GHG emissions given, however several interpretations are possible. (Swan, Appendix 2)

[10] RSPO has recommended that a working group to consider issues relating to GHG emissions would be established. In this report GHG emissions are not considered. (RSPO, p. 2)

[11] Land prices and other land-use effects will be reported. (Testing framework for sustainable biomass, p. 21)

[12] Land area used for bioenergy production must not be in competition with food production (GER, p. 23)

[33] Biofuel production shall minimize negative impacts on food security giving particular preference to waste and residues as input. Tools will be developed. (Version zero, p. 6)

[14] Plantation development should not put indirect pressure on forests through the use of all available agricultural land in an area. (RSPO, p. 40)

[15] Commission shall monitor the positive and negative effects on food security and the availability of foodstuffs in developing countries. (article 20 / 1 & 5)

[16] There is reporting obligation on the availability of biomass for food, local energy supply, building materials or medicines after 2007and after 2011 indicators, developed by earlier reporting, are used. (reporting obligation only in cases where problems are to be expected like in developing countries) (Criteria for sustainable biomass production, p. 8 & 9,13) See also: (Testing framework for sustainable biomass, p. 21).

[17] No criteria to the competition of biofuel feedstock with food set because no proves existing. However, this question should be monitored. (Sustainability reporting, p. 21)

[18] The emissions of manufacture of machinery are negligible compared to the emissions during machinery lifetime. (GHG calculation methodology, p. 20)

[19] Manufacture and maintenance of machinery classified as minor source of emissions and thus excluded. (Carbon reporting, p. 7)

[20] However, commission is supposed to evaluate how the emission saving estimates of Member States would change if substitution method was used. (article 20 / 4)

[21] Substitution method (system extension) is used to calculate the default GHG values for the main residues and co-products. For some cases other allocation methods, like market-based allocation or energy allocation, can be used. More discussions needed (GHG calculation methodology, p. 23)/ Allocation based on price for emissions of conversion. (Criteria for sustainable biomass production, p. 26)

[22] Substitution method used. However, in cases where double counting of carbon credits is possible, allocation based on market value or energy content is used. (Carbon reporting, p. 17, annex 1)

[23] Guidelines will be developed for how substitution, allocation by energy content and allocation by market values should be used. (Version zero, p. 5)

[24] Substitution method used, in the case of production of by-products. Mass or energy allocation may be used subject to approval by Nordic Ecolabelling. (Swan, Appendix 2)

[25] Not mentioned clearly but seems to be so that Kyoto GHG noticed.

[26] There are some limitations of use of raw materials from lands with high carbon stock like wetlands and continuously forested areas. (article 15 / 4)

[27] Principles presented for conservation of above-ground and underground carbon sinks (peat areas, certain grasslands, mangroves…) when biomass units installed. (Testing framework for sustainable biomass, p. 11)

[28] GHG emissions of significant land-use change i.e. conversing forests or grasslands are counted. However, the reference scenarios for alternative land use are excluded but for previous land use included (Carbon reporting, p. 10, 14). Evidences of land use needed. Reporting of land-use changes (also indirect) required. (Sustainability reporting, p. 9,14)

[29] GHG emissions from indirect land use shall be minimized. (Version zero, p. 5)

[30] Biomass must not be cultivated on land that binds up large quantities of carbon. (Swan, p. 10)

[31] Calculation should be done over the lifetime of the biomass production. Lifetimes will be established in calculation tool under development (GHG calculation methodology, p. 25)

[32] 10 years is the maximum payback time of land use changes (Sustainability reporting, p. 6)

[33] 100 years time horizon GWP values and lifetimes of IPCC shall be used. (Version zero, p. 5)

[34] The total net reduction in emissions of fossil carbon achieved by replacing the equivalent fossil fuel with the fuel over a 20-year period is greater than any non-recurring emission resulting from the change in land use (if the cultivation of biomass has resulted in a change in land use since November 2005). (Swan, p. 10)

[35] In calculation of emissions of biofuel, the annualised greenhouse gas emissions from carbon stock changes due to land use changes are evaluated. There are some default values given for carbon stocks of actual and reference land use. (part C / 7)

[36] Methodology takes into account the direct impact of land-use changes, based on IPCC guidelines for national GHG inventories 2006 (GHG calculation methodology, p. 25)

[37] Carbon intensity is calculated with and without land-use changes because of difficulties to determining some land-use changes (GHG calculation methodology p. 12) Nitrogen emissions calculated with IPCC methodology for N_2O emissions (p. 29)

[38] GHG emissions of direct land-use change shall be estimated by using IPCC Tier 1 methodology and values (Version zero, p. 5)

[39] In the event of changes in land use since 2005 the licenceholder must show by means of calculation that the change in land use has not resulted in a negative CO2 balance. (Swan p. 10) BUT In the GHG calculation emissions associated with changes in the use of land must not be taken into account. (Swan, Appendix 2)

[40] Default values with italic. (GHG calculation methodology, p. 20 →) Risks discussed (GHG calculation methodology, p. 29→) If emission reduction thought to be higher than default value, own calculations according to methodology can be made. (Criteria for sustainable biomass production, p. 12)

[41] Default or measured values will be provided for the major steps of biofuel process. (Version zero,p. 5)

[42] Production-specific data must be used for the production of the renewable fuel. Reference values (from JEC Well to Wheel study) may be used for other parts of the life cycle. (Swan, Appendix 2)

[43] Anyhow, for the default values there are two different values presented; typical value and default value (which can be higher than typical value). (part D & E)

[44] With calculator it is possible to calculate three values: worst case, typical and best practise values. (GHG calculation methodology, p. 29)

[45] Discussion about using conservative or typical default values (Carbon reporting, p. 25)

[46] The reference used is the JEC Study and NEDC 2002 (Swan)

[47] More discussions needed: Should calculations on fossil electricity be based on best available technology (CCGT), 55% gas efficiency, average European production, average national production or estimated marginal production. (GHG calculation methodology, p. 29)

[48] At substitution method electricity generated would replace electricity from grid with marginal carbon intensity. (Carbon reporting, p. 16)

[49] Within EU: emission of electricity is 345 gCO2-eq/kWh, Outside EU electricity mix, or electricity from specific plant not connected to grid… (Swan, Appendix 1)

[50] Emission saving of 35% (article 15 / 2)

[51] Reduction of 30% in 2007–2011, reduction of 50% after 2011, 70% reductions in the long term (Criteria for sustainable biomass production, p. 8, 9, 12, 13). Bioethanol compared with gasoline, biodiesel with diesel (GHG calculation methodology p. 28). For electricity production reduction of 50–70%.

[52] There is discussion if the energy efficiency of the vehicle should be noticed when calculating the emission saving. (Carbon reporting, p. 19)

[53] Limit given as: Emission of GHG must not exceed 50g CO2-eq/MJ_fuel driven (Swan, p. 4)

[54] CO_2 reduction per hectare of agricultural land is mentioned as criterion at the survey for stakeholders. (Criteria for sustainable biomass production, p. 22)

[55] Biofuel projects shall demonstrate a commitment to continuous improvement in energy balance, productivity per hectare, and input use. (Version zero, p. 8)

[56] Energy consumed in the production and transport of a Swan-labelled fuel must not exceed 1,4MJ per MJ fuel produced. (Swan, p. 9)

Air quality

The main causes of air polluting emissions in the plantation phase are the burning of surface vegetation as a part of land clearing or waste disposal, the use of machinery, and the use of agrochemicals. Production and use of biofuels also causes air emissions. The air quality is a matter of concern in most of the criteria except for the EU directive, RTRS, FSC and PEFC. In many initiatives it is defined that the biofuel production should not directly or indirectly lead to air pollution. Still there are no actual or quantitative guidelines on how to avoid air pollution besides a recommendation to obey national and local laws and regulations. The Netherlands, however, calls for best practices to be applied to reduce emissions and air pollution in the production and processing of biomass. This is done by the formulation and application of a strategy aimed at minimum air emissions, with regard to production and processing and waste management. In the UK the company should prove that it is familiar with relevant national and local legislation, and that it complies with these legislations. Also, there should be evidence that no burning occurs as part of land clearing or waste disposal. RSB requires minimizing air pollution from biofuel production and processing along the supply chain. It also requires that open-air burning is avoided.

Air emissions caused by production and use of biofuels are considered in Germany’s criteria, which takes into consideration the depletion of stratospheric ozone and acidification, by stating that the amount of substances causing these impacts should be reduced. Emissions of particulate matter is taken into account only by the Swan labelling system, in which it is said that the concentration of particles (and benzene, formaldehyde, acetaldehyde, ethane, propane, 1-3-butadiene and PAH 2) in exhaust fumes must be measured to estimate cancer risk (see category Health risks).

Water quality

The use of fertilisers, pesticides and agricultural practices in general, as well as further processing of biomass may affect water quality. The water quality category covers issues related to the maintenance of water quality and its prevention from further contamination. All the other initiatives have some reference on water quality except for the Swan labelling, although most of the initiatives discuss the category on a general level only, with no specified concerns, nor any recommendations. The EU Directive Proposal considers only the protection of waters against pollution caused by nitrates from agricultural sources.

The Netherlands and the UK require compliance with national and local laws and regulations with respect to water quality. The Netherlands demand formulation and application of a strategy aimed at sustainable water management. The UK requires application of good agricultural practices to reduce water usage and to maintain and improve water quality, and the documentation of a water management plan. Also the annual documentation of applied good agricultural practices with respect to efficient water usage is required. The RSB states that “Biofuel production shall optimize surface and groundwater resource use, including minimizing contamination or depletion of these resources, and shall not violate existing formal and customary water rights”.

Some criteria recommend measurements and evaluation of the impacts of plantation and production on water resources. The RSB requires a water management plan appropriate to the scale and intensity of production. The UK recommends keeping records of the annual water consumption (litres/ha/y) and the BOD level of water on and nearby the biomass production and processing sites. The BSI points out a need to assess direct and indirect impacts of operations on ecosystems services including water availability and quality. The Forest certification systems require measures to be taken to protect water courses, particularly during harvesting and road construction.

Use of water

Water resources are becoming scarce because of increased use of water in the plantation phase. In countries with water shortages, increasing agricultural production of biofuels will simply add to the strain on stressed water resources (Varghese, 2007). Irrigation demands large amounts of water, depending on both the crop type and the region, as well as on the climate and the mode of cultivation. Also all of the current processes for making biofuels require water in the manufacturing phase. In many regions there is a growing lack of easily available clean water, and this only aggravates an already difficult problem. The production and processing of biomass must not take place at the expense of ground and surface water resources. In most of the initiatives assessed, it is acknowledged that water resources should be used in a sustainable way and that the water resources should not be depleted. Only the EU Directive Proposal and the Swan labelling do not mention the use of water.

The aspects concerning the use of water are discussed above in the context of water pollution and the actions required to ensure sustainable water use are the same as in the water pollution category. The Netherlands and the UK require that production and processing of biomass should not deplete water sources and best practices are required to be applied in the production and processing of biomass. The indicators to ensure this requirement are described in the water quality category.

Soil quality

Maintenance of soil quality and its production capacity is recognized as one of the pillars of sustainable agricultural production. In order to maintain soil production capacity, the following issues should be covered: soil nutrient balance, soil organic matter, soil pH, soil structure and biodiversity, and functions and prevention of salinisation and erosion. This category covers main aspects of soil quality discussed in different criteria, such as the soil fertility and the use of fertilizers, land clearing by burning, and the use of residual side products. The use of pesticides that might affect soil quality is covered in the Ecotoxicity-category. Most of the criteria assessed acknowledge that soil quality must be retained. The EU Directive Proposal refers to protection of soil, only when sewage sludge is used in agriculture. Swan labelling does not have any specific criteria for soil quality.

Each of the criteria covers slightly different aspects of soil quality. The BSI covers the category only on a general level, as the criteria is still under development. The BSI requests continuous improvement of the status of soil resources and the assessment of direct and indirect impacts of operations on ecosystems services, such as of soil quality. The BSI also encourages consulting relevant stakeholders when adverse impacts are apparent. The RSB states that "Biofuel production shall promote practices that seek to improve soil health and minimize degradation". It requires maintaining or enhancing of soil organic matter content and the physical, chemical, and biological health of the soil to its optimal level under local conditions. Also wastes and byproducts from processing units should be managed such that soil health is not damaged.

Soil fertility is mentioned in the criteria of the Netherlands, the UK and the RSPO. The RSPO calls for practices to maintain soil fertility, or where possible to improve it. **Use of fertilizers** should be sustainable. According to the German, the UK's, the Netherlands' and the PEFC initiatives this can be reached by complying with best practices in agriculture and forestry. The RSPO bans the **use of fire** in land clearing operations, when not identified as a best practice. In addition, the Netherlands require that burning should not be used for disposal of agricultural by-products. There are many alternative uses of **residual products/agricultural by-products**. Locally, those can be used as natural fertilizer, mulch, straw for housing, local fuel etc. Residual products and by-products of production are returned to soil to recycle nutrients either by indirectly through livestock feeding and manure production, or through direct application to the soil. The Netherlands' and the UK's initiatives require that the use of residual products/agricultural by-products must not jeopardize the function of local uses of the by-products.

The control of erosion is required by the Netherlands, the UK, Germany, RSPO, RTRS, FSC and PEFC. In addition, the RSPO demands to avoid extensive planting on steep terrains, and/or on marginal and fragile soil. The RTRS calls for best practices in agriculture to attain the objective. The forest certificates stress the need to minimize soil erosion during harvesting and road construction. Erosion can also be prevented, by choosing appropriate tree species.

The forest certificates also require that the soil quality is preserved. The PEFC calls for measures to monitor the health and vitality of forests. The FSC requires that written guidelines must be prepared and implemented to control erosion and to minimise forest damage. In the plantations, measures to minimize soil erosion must be taken to maintain or improve soil structure, fertility, and biological activity. Furthermore, during harvesting, road and trail construction and maintenance, and soil erosion control measures are required. The choice of cultivated species should not result in long-term soil degradation

The UK and the Netherlands require compliance with national laws and regulations relevant to soil degradation and soil management e.g. the use of fertilizers, soil erosion, and environmental impact assessment. Both countries require good agricultural practices to maintain **good soil quality**. To ensure that, both require the formulation and application of a strategy or a management plan. The UK requires also annual documentation and recommends keeping records of annual measurements of soil losses, nutrient balance (N, P and K), soil organic matter and the pH in top soil, and the content of soil salts.

Ecotoxicity

This category concentrates on protecting the environment (mostly water and soil) from negative effects of pesticides and herbicides. Ecotoxicity is in the focus of most of the criteria excluding the Swan labelling and partly the RSB. The RSB refers to the biological health of soil related to pesticide use. However, ecotoxicity as such is not mentioned. The EU Directive Proposal concentrates only on the protection of groundwater against pollution caused by certain dangerous substances. In general, in the criteria that recognise the use of toxic agrochemicals, it is said that agrochemicals should be used in a way that does not endanger health, nor the environment. In addition, the Netherlands and the UK require the compliance of relevant national and local laws and regulations with aspects of ecotoxicity. The Netherlands and the UK provide the formulation and application of a strategy aimed at sustainable water management, with regard to responsible use of agrochemicals.

The Netherlands provide that at least the Stockholm convention[16] (12 most harmful pesticides) is complied in countries with no national legislation. The RSPO and the RSB require that the use of agrochemicals that are categorized as World Health Organisation Type 1A or 1B[17] pesticides is prohibited. The RSPO refers also to the Stockholm and Rotterdam Conventions[18]. Growers should seek alternatives for the most harmful pesticides. The forest certificates focus on minimizing the use of pesticides and herbicides, and want to promote the use of non-chemical methods of pest control. Also the RSPO encourages the use of Integrated Pest Management (IPM) techniques to manage pests, diseases, and weeds. The German criteria points out that it is not possible to set strict requirements of plant protection, as the plantation techniques and protection demands differ from crop to crop.

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[16] The Stockholm Convention on Persistent Organic Pollutants (POPs) targets for reduction and eventual elimination of 12 particularly toxic POPs. More importantly, it sets up a system for tackling additional chemicals identified as unacceptably hazardous. The Convention came into force, thus becoming international law, on 17 May 2004.

[17] The World Health Organization (WHO) Classification of Pesticides by Hazard:1A: extremely hazardous and 1b: highly hazardous.
http://www.who.int/ipcs/publications/pesticides_hazard/en/index.html

[18] The Rotterdam Convention creates legally binding obligations for the implementation of the Prior Informed Consent (PIC) procedure.

Human toxicity

This category covers issues related to health risks, mainly caused by the use of agrochemicals and by substances in exhaust fumes (consumption of biofuels). Health risks from the production or use of biomass or biofuels are not dealt with in detail in most of the criteria. Hazards in working conditions are covered in the category “Social impacts”. The RSPO, the RSB, and the RTRS point out that the use of agrochemicals should be reduced and that they should be used in a way that does not endanger health. Only the Swan labelling system takes into account emissions of substances that are harmful to health or carcinogenic substances. It is said that the risk of cancer must not increase when fossil fuels are replaced. The swan labelling system obligates the applicant to monitor the concentration of particles, benzene, formaldehyde, acetaldehyde, ethane, propene, 1-3-butadiene and PAH 2 (incl. benzopyrene) in exhaust fumes. The cancer risk can be assessed, by calculating with a specified risk factor.

Biodiversity

The reduction in biodiversity has emerged as one of the greatest environmental threats of the 21st century. The United Nations has formulated the core objectives of biodiversity to be the conservation of biological diversity, the sustainable use of the components of this biological diversity, and the fair and equal division of the proceeds of the use of genetic sources (Agenda 21). The biodiversity category in this assessment covers various aspects of biodiversity of species and ecosystems: areas with high biodiversity value or high agrarian, nature and/or cultural values, the conservation of endangered, threatened or rare species and their habitats.

The cultivation of biomass can have both direct or indirect, and negative or positive effects on biodiversity. Furthermore, the biodiversity can be affected by overlapping aspects, especially the climate change and land use change. Biomass and biofuel production is changing land-use patterns in many regions around the world, including some of the most diverse and sensitive regions on the planet. The direct effects can be for example that intact ecosystems and areas with high biodiversity values, such as primary forests and wetlands, are converted into production areas, becoming thus more fragmented. Indirect effects mean secondary impacts of some actions. For example relatively inaccessible areas can become available by e.g. road and other infrastructure constructed for harvesting biomass. This makes it possible for migrants to move in and cultivate the land. Biomass production for biofuel raw material can also cause the indigenous population to be forced to leave their home area and to establish new cultivations elsewhere.

Globally, the protection of biodiversity is one of the cornerstones of sustainable development, and biodiversity is one of the key issues in all of the initiatives. Some criteria (the Netherlands, the UK, Germany, RSB, RSPO, FSC) use the term **High Conservation Value (HCV) areas**[19, 20]. At least the UK recognises that HCV's have not yet been determined for many areas. Therefore the areas considered of importance for the conservation of biodiversity have been specified further by referring to specific areas, as defined by authorities such as the IUCN (IUCN, 1994).

The UK and the Netherlands demand that national laws and regulations that are applicable to biomass production and the production area should not be violated. Both require that biomass production does not lead to the **destruction of or damage areas with HCV.** In new or recent developments there should be no deterioration of biodiversity in protected areas or in other **areas with high conservation value, vulnerability or high agrarian, nature and/or cultural values**. Biodiversity should also be maintained within the biomass production units, such as fields, plantations and forests. To preserve biodiversity at the production sites, both the Netherlands and the UK require that, when new units are established, 10% of the overall surface area must remain in its original state. Biodiversity should be strengthened by applying good agricultural practices on and around the biomass production unit. Ecological corridors should be taken into use to prevent disintegration. The UK requires that the status of rare, threatened or endangered species and high conservation value habitats, that exist in the production site or that could be affected by it, shall be identified and their

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[19] High Conservation Value (HCV) refer to areas that contain globally, regionally or nationally significant concentrations of biodiversity values (e.g. endemism, endangered species, refugia), or that are significant large landscape-level areas where viable populations of most naturally occurring species exist in natural patterns of distribution and abundance or areas that are in or contain rare, threatened or endangered ecosystems, or areas that provide basic ecosystem services (e.g. watershed protection, erosion control).

[20] The terminology related to the high biodiversity value is very diverse. At least the terms high biodiversity value, high conservation value and high diversity value, have been used, referring virtually to a same issue. However, the terminology is not well defined or explained in the initiatives. For simplicity, we use here the term high conservation value (HCV) for all the three terms.

conservation taken into account in management plans and operations. Both the UK's and the Netherlands' initiatives require that the biomass production does not take place in gazetted areas (areas protected by the government or HCV areas).

Germany states that biomass must not be produced in conservation areas or in HCV areas. Protection of endangered natural habitats, especially primeval forests, is in the focus of the German criteria. To conserve the HCV areas, the German initiative refers to the FSC principles and criteria. In addition to conserving forest habitats, also other valuable habitats, like the High Nature Value Farmlands, are taken into cognizance.

The RSB states that "Biofuel production shall avoid negative impacts on biodiversity, ecosystems, and areas of High Conservation Value". This includes identifying and protecting of HCV areas, native ecosystems, ecological corridors and other public and private biological conservation areas, preserving of ecosystem functions and services, protecting or creating of buffer zones and protecting or restoring of ecological corridors.

The RTRS recognizes the importance of biological diversity at all levels and in addition requires management practices that conserve biological diversity and fragile ecosystems in order to minimize and avoid loss of natural habitat. The RSPO requires identification of environmental impacts of plantation and mill management, and plans to mitigate the negative impacts and promotes that positive ones are made, implemented and monitored. The RSPO also requires that the status of rare, threatened or endangered species, and HCV habitats, that exist in the plantation or that could be affected by plantation or mill management, should be identified and their conservation taken into account in management plans and operations.

The EU Directive Proposal states that biofuels shall not be made from raw material obtained from land with recognised high biodiversity value, that is land that had one of the following statuses in or after January 2008, and whether or not the land still has this status:

(a) *forest undisturbed by significant human activity, that is , forest where there has been no known significant human intervention or where the last significant human intervention was sufficiently long ago to have allowed the natural species composition and processes to become re-established*

(b) *areas designated for nature protection purposes, unless evidence is provided that the production of that raw material did not interfere with those purposes*

(c) *highly biodiverse grassland, that is grassland that is species-rich, not fertilised and not degraded.* (The criteria and geographic ranges to determine which grassland shall be covered are established later).

It is also stated that biofuels and other bioliquids shall not be made from raw material obtained from land with high carbon stock that is land that had one of the following statuses in January 2008 and no longer has this status:

(a) *wetlands, that is land that is covered with or saturated by water permanently or for a significant part of the year, including pristine peatland*

(b) *continuously forested areas, that is land spanning over more than 1 hectare with trees higher than 5 meters and a canopy cover of more than 30%, or trees able to reach these thresholds in situ.*

It is agreed by the FSC and the PEFC that biofuel production should not **introduce invasive species**. Both forest certificates prefer using native species for re-establishment of forests. Where exotic species are used, there needs to be measures to ensure that negative impacts on the environment are avoided. Forest certificates aim to protect **ecologically important forest biotopes** and to manage production forests, so as to maintain and enhance bio-diversity. Both require that forest resources are mapped and surveyed, so that rare, sensitive and representative forest ecosystems are identified and protected. Both schemes also require special measures to protect endangered species. According to the PEFC, native species and local provenances that are well adapted to site conditions should be preferred.

Only the Swan labelling requires that all **vegetable raw materials** are traceable and it must be ensured that the raw materials do not originate in areas in which biodiversity or values worthy of protection is under threat.

The reference date for conserving the HCV areas vary in different initiatives. According to the UK and RSPO criteria no conversion of HCV areas should occur after Nov. 30, 2005. In the Netherlands' and Germany's criteria, the reference date is Jan. 1, 2007. In the EU Directive Proposal it is January, 2008.

Even though the sustainability initiatives try to prevent the negative impacts on biodiversity, it is possible that they fail to prevent indirect deterioration of biodiversity. European criteria are probably effective in preventing biodiversity loss only within the European Union. Outside the EU, biodiversity losses cannot be ruled out (Eickhout et al., 2008). To avoid future changes in biodiversity caused by climate change it is important to reduce greenhouse gas emissions. An analysis with a 'biodiversity balance' indicator done by Eickhout et al. (2008) shows that, in most cases, the greenhouse gas reductions from biofuel production are not enough to compensate for biodiversity losses from land use change. The result will be even worse if soil carbon emissions are taken into account.

Sustainable land use and competition with other resources

Sustainable land use and competition with other resources is a large socio-economic as well as an environmental issue. Globally there is a growing need for extra land to produce biofuels. Biomass production may change the land use patterns by deforestation, relocation of food production, and changes in the type vegetation and the share of vegetation and crops. This can result in a more monotonous or, on the contrary, a more diversified land use. Sustainable land use covers not only issues related to competition with food production, but also local applications of biomass and small scale traditional land use, and sustainable use of forest resources. The forest certificates point out also other cultural and aesthetic values and recreational use of forests. Changes in land use might affect biodiversity, GHG emissions, soil and water quality and therefore these aspects should be considered as a whole. The land use aspects have been considered especially in the context of the production of biomass in sub- and tropical areas, mainly in Malaysia, Indonesia and Brazil.

The problem with this criterion is that it may not safeguard from the indirect effects of biomass production, since the criteria refer to a given site, plantation or process unit and do not take into account wider land use of the area or global changes in land use. Additional demand for biomass that is cultivated on good quality farmland increases the competition for land, which may result in higher land and food prices. In that sense, land use has connections also with economic issues. Land use changes may lead to the rise of food and land prices, and to the rise of prices and availability of other biomass products, such as of construction materials and medicines. Cultivation of biomass crops on degraded and marginal lands reduces the pressure on competition with other land use functions.

In the EU Directive Proposal, sustainability criteria to prevent undesired land use changes and loss of valuable biodiversity have been presented. Those criteria are already discussed in the Biodiversity-category. At this stage, in the EU Directive Proposal, the issue of food security is only addressed by the European Commission's reporting obligations. The UK and BSI drafts have no criteria for sustainable land use as such, but most criteria cover land use aspects within the Biodiversity category. The Swan label requires, that land that binds large quantitives of carbon, must not be used for biomass production. In case cultivation occurs on land where the land use has changed since November 2005, the carbon emissions must be repaid using the fuel in question within 20 years. The RSPO refers to land use in its criterion by requiring that a comprehensive environmental impact assessment is undertaken prior to establishing new plantings or operations, or prior to expanding existing ones, and that the results are incorporated into planning, management, and operations. It is also said that plantation development should not put indirect pressure on forests through the use of all available agricultural land in an area. The UK argues that criteria for issues relating to the competition of biofuel feedstock with food cannot be established, as there is no proof of or clear connection between bioenergy production and food insecurity.

The RSB and Germany concentrate on issues concerning **food security**. Germany states that land area used for bioenergy production must not be in competition with food production and the RSB states that biofuel production must not impair food security. Negative impacts on food security must be minimized, by giving particular preference to waste and residues as input (once economically viable), to degraded/marginal/underutilized lands as sources, and to yield improvements that maintain existing food supplies. Biofuel producers implementing new large-scale projects shall assess the status of local food security and shall not replace staple crops if there are indications of local food insecurity.

The Netherlands state also that production of biomass for energy must not endanger the food supply and in addition points out other **local applications of biomass** (such as for medicines or building materials). To ensure these aspects, the Netherlands require information on land use changes in the region and information about changes in prices of land and food in the region. The RTRS recognises the importance of **small-scale and traditional land use systems** and requires measures to integrate and support small-scale producers into the chain of value in accordance with local conditions and practices.

The forest certificates FSC and PEFC focus only on forest land use and they state **that no conversion of forest to farm lands or non-forest land uses** should occur except when conversion entails a very limited portion of the forest, or when conversion does not occur on high conservation value forest areas. The PEFC also encourages in converting **abandoned agricultural and treeless land into forest land,** whenever this can add the economic, ecological, social and/or cultural value. Forest management operations should take into account all socio-economic functions, especially the recreational function and aesthetic values of forests. Adequate public access to forests for the purpose of recreation should be provided, taking into account the respect for ownership rights and the rights of others.

Genetically modified organisms (GMOs)

As a precautionary measure, the WWF recommends that the use of genetically modified organisms as bioenergy crops should be banned, as they could have adverse environmental impacts (Fritsche et al. 2006). The use of genetically modified organisms is not noticed by most of the criteria. Only the FSC prohibits the use of GMOs. PEFC international do not consider GMOs, but some national schemes may have provisions for the use of GMOs (Vallejo & Hauselmann 2001). The Netherlands notice the importance of an indicator aimed at GMOs, but there is no indicator included for this. The RSB states that "the use of genetically modified plants, micro-organisms, and algae for biomass production must improve the productivity and maintain or improve social and environmental performance, as compared to common practices and materials under local conditions. Adequate monitoring and preventive measures must be taken to prevent gene flow" and "genetically modified organisms used in biomass processing must be used in contained systems only". The RSPO claims that there is no genetically modified palm oil available on the market and hence there is no criterion on GM oil palm.

Waste management and recycling

Some of the criteria take into account recycling and waste management. The Netherlands and the UK require compliance with laws and regulations in waste management. The Netherlands also require the application of a strategy aimed at minimum air emissions with regard to waste management. The RSPO requires that waste is reduced, recycled, re-used, and disposed of in an environmentally and socially responsible manner. Also the incineration of waste as a disposal method should be avoided, except in specific situations. The FSC requires that chemicals, containers, liquid and solid non-organic wastes including fuel and oil shall be disposed of in an environmentally appropriate manner at off-site locations.

Socio-economic criteria

Economic impacts

The scope of this criterion is mostly on the development of local prosperity (employment, infrastructure, training, services) and on the efficiency of production. In the explanatory part of the Netherlands criteria, it is said that economic impacts have not been included in any of the existing certification systems, because it is so demanding to test the realisation of the criteria in practice. The Dutch indicators are similar to the Economic Performance Indicators of the Global Reporting Initiative (GRI 2000–2006). All the other initiatives having criteria for economic impacts require development of local economy. The RSB points also out the development of local, rural and indigenous peoples and communities. The RSPO requires an implemented management plan to achieve long-term economic and financial viability. Efficiency of production is recognised by the BSI, which requires maximizing of input, production and processing efficiencies, and continuous improvement of the quality of the product. The EU Directive Proposal, the UK, Germany and Swan labelling system have no criteria for economic impacts.

Social impacts

While the expanding biofuel industry is expected to create new jobs and economic vitality to rural communities, it also creates dilemmas for farmers and rural communities, who need to weight the benefits of income growth and increasing jobs against safety risks, possible violations of land use rights, and plantations workers' rights and welfare. Biomass production may also cause indirect social impacts with potentially rising food prices, which affect especially the developing countries. To be socially sustainable, the production of biomass and biofuels must contribute towards the social well-being of employees and the local population. The aim of this chapter is to briefly describe different aspects concerning social impacts of biomass production. The focus of this category is on the social well-being of employees and the local population.

The EU Directive Proposal and Germany do not mention social impacts. The Netherlands and especially the UK concentrate on various aspects of social impacts of biomass production.

Human and labour rights

Most of the initiatives agree that the production of biomass must at least comply with national and local labour, occupational health and safety regulations, and with all applicable ILO (International Labour Organisation) conventions. Some initiatives (the Netherlands, the RSB) refer also to the Universal Declaration of Human Rights of the United Nations, which covers non-discrimination, freedom of trade union organisations, child labour, forced and compulsory labour, disciplinary practices, safety practices, and the rights of indigenous peoples.

Property rights and the rights of land use

The UK, the Netherlands, the RSB, the RTRS, and the RSPO require that the use of land must not lead to the violation of official property and its use, or of customary law, without the free and prior consent of the sufficiently informed local population. No land should be used without the informed consent of original users/local people. Also, local people must be compensated for any agreed land acquisitions.

Well-being of local population

The Netherlands, the RSB, the RTRS and the forest certificates FSC and PEFC acknowledge that biomass production should affect positively on the social and economic well-being of local people. The forest certificates demand that customary rights of indigenous people are recognised and respected. The biomass production should also improve opportunities for local employment.

Concluding remarks of sustainability criteria

The environmental and socio-economic aspects included in the initiatives vary considerably. Biodiversity is considered in all of the initiatives analysed. Water quality, soil quality and ecotoxicity, as well as social and economic impacts are also included in most of the initiatives. Climate change aspects are included in all general biofuel/biomass initiatives, but not in most of those initiatives concentrating on a specific raw material (RSPO, RTRS, FSC and PEFC). Some of the initiatives, e.g. the EU RES directive proposal provides a methodology for calculating greenhouse gas balances of biofuels and emission reduction, when compared to reference fuels.

Generally speaking, life cycle thinking has only been applied for greenhouse gases, while the approach on other environmental and socio-economic aspects is different from this. For example, regarding the criteria of air pollution it can be stated that the biofuel production should not directly or indirectly lead to air pollution. Still there are no actual e.g. quantitative guidelines on how to avoid air pollution besides a recommendation to obey national and local laws and regulations. The reasons why greenhouse gas issues are considered on a very detailed level in many of the initiatives assessed include probably the facts that one of the main aims of biofuels is generally considered to be a reduction of GHGs when compared to fossil counterparts. In consequence there exist a number of studies dealing with greenhouse gas balances of biofuels, but only minor assess the other dimensions of sustainability. In addition, not all dimensions of sustainability, e.g. social aspects, can be measured objectively in quantitative terms. Greenhouse gas balances of biofuels are in many contexts perceived as a well-known or adequately known issue. However, there are also a number of studies pointing out that there are significant uncertainties and lack of knowledge involved in greenhouse gas balances of biofuels, including the definition of system boundaries and functional unit, use of allocation methods and inclusion of other greenhouse gases than CO_2, $CH_{4,}$ and N_2O. Additionally, the timing of emissions and sinks of greenhouse gases (the dynamics) or the uncertainty range for default parameters are not considered in any of the reviewed initiatives. These aspects in greenhouse impacts are discussed more profoundly in Chapter 4.

To measure sustainability of biofuels and biomass is difficult. There are three sustainability aspects – environmental, economic and social – which each consists of numerous sub-categories. Often the implications of the aspects are contradictory. This makes the setting up of strict sustainability criteria for biomass or biofuels a very challenging task. However, criteria to ensure sustainable production of biomass are needed urgently as many criteria (such as GHG-balance and land use change) cannot be covered within the existing certification systems (see also van Dam et al. 2008).

One of the main problems of the criteria is that indirect effects of biomass production, like competition with food or other use of raw materials, or undesirable effects on biodiversity cannot be monitored or even identified. Furthermore, most of the criteria are not compatible with WTO rules, and therefore their use at least as a mandatory obligation is difficult. The trade of biomass is covered by the WTO rules. Standards for the production of biomass potentially run the risk of arbitrary discrimination and hidden protectionism, and therefore the standards must be in line with principles of the WTO.

Different initiatives analysed here have different starting points, purposes, and terminology. Partly because of this, the final result is also very ambivalent, and it is difficult or even impossible to compare the initiatives and estimate their contribution towards sustainability. Therefore a better international coordination between initiatives is required to improve the coherence and efficiency in the development of biomass certification systems (van Dam et al. 2008). The Dutch and the UK's initiatives are the most comprehensive ones, but at this stage, their validity is open, due to the on-going process with the EU Directive Proposal.

From the consumers' point of view, it is almost impossible to know different initiatives and their real impact on sustainability. This is a problem with all certificates and eco-labels. The consumer has to rely on experts creating the certification systems, which again always are kind of compromises between environmental, social, and different economic aspects.

New approaches towards more sustainable biofuel and biomass production are being taken for example in the standardisation work by the European standardisation organisation (CEN). Its work will mainly be based on the existing sustainability criteria. How effective the final criteria will be in reality in promoting the sustainability remains to be seen. Moreover, enforcement is critical to the functioning of these schemes, and the capability of countries to enforce the requirements is highly variable (GBEP 2008). Even advanced countries may have difficulties. A recent survey commissioned by the UK government found that 4 out of 5 litres supplied at British pumps failed to meet basic industry standards for sustainability. Biofuel manufacturers could not prove that their biofuel feedstock had not been grown by trashing rainforests or by harming the livelihoods of poor farmers. Additionally, the origin of half of the biofuels in UK fuel tanks was unknown (Anon. 2008).

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Appendix B: Properties of raw materials

Table B1. Mineral and nitrogen content in dry matter (DM) of crop samples taken in 1990 (Saijonkari-Pahkala 2001).

Species	Growth stage	Ash %	SiO2 %	Fe mg/kg	Mn mg/kg	Cu mg/kg	N %
Monocotyledons							
RCG	Culms 40 cm	8.76	2.63	56.7	24.0	7.05	1.73
	Panicles emerged	8.51	5.61	83.1	50.2	5.40	0.93
Rye	Seed ripened	5.31	3.61	131.3	18.8	3.26	0.52
Oat	Seed ripened	9.10	3.68	159.0	46.2	4.95	0.96
Barley	Seed ripened	10.03	6.13	48.6	15.3	3.29	0.33
Wheat	Seed ripened	5.41	3.52	97.3	13.0	1.76	0.54
Common reed	Anthesis	7.79	3.30	51.3	13.4	3.58	1.06
	Senescence	4.17	3.82	72.7	13.4	2.78	0.31
Dicotyledons							
Linseed straw	Seed ripened	3.93	<0.10	54.6	87.3	6.09	0.99
Fibre hemp	Seed ripened	3.75	0.19	87.3	11.2	4.05	0.56
Turnip rape	Seed ripened	6.10	0.14	74.5	14.0	3.27	0.96
Rape straw	Seed ripened	6.82	0.36	351.2	25.8	3.66	0.83
Birch, chipped		0.41	<0.10	22.3	114.0	0.90	0.11

Table B2. Mineral and nitrogen content in dry matter (DM) of some forest raw materials and peat (Alakangas 2000).

Species	**Ash %**	**SiO2 % in ash**	**Fe mg/kg**	**Mn mg/kg**	**Cu mg/kg**	**N %**
Conifer						
Stem wood			41	147	2	
Stem wood bark	1.7–2.8		60	507	4	
Branches			101	251	4	
Needles			94	748	6	
Logging residue chips	1.33–6.0					
Pine stem wood chips	0.6					
Pine		4.6				
Spruce		1.0				
Pine bark		1.3–14.5				
Spruce bark		21.7				
Milled peat	5.1–5.9					2.01
Sod peat	3.9–4.9					1.97
Energy peat		40–75			1.4–16.5	

Table B3. Carbon and hydrogen contents of Norway spruce, Scots pine, and birch trees in Finland (Richardson et al. 2002, original data from Nurmi 1997).

	Stemwood	**Inner-bark**	**Outer-bark**	**Foliage**
	Carbon content,%			
Pine and Spruce	52,1	52,1	55,2	51,0
Birch	51,8	51,7	72,5	51,2
	Hydrogen content,%			
Pine and spruce	6,4	5,8	5,6	6,1
Birch	6,2	5,7	9,2	6,0

Table B4. Mineral concentration in the dry mass of small-sized trees from first commercial thinnings in Finland (Hakkila and Kalaja 1983).

Tree component	**Concentration in biomass (%)**				**Concentration in biomass (ppm)**				
	Primary elements				**Trace elements**				
	P	**K**	**Ca**	**Mg**	**Mn**	**Fe**	**Zn**	**S**	**B**
Softwoods									
Stemwood	0,01	0,06	0,12	0,02	147	41	13	116	3
Stembark	0,08	0,29	0,85	0,08	507	60	75	343	12
Branches	0,04	0,18	0,34	0,05	261	101	44	203	7
Foliage	0,16	0,60	0,50	0,09	748	94	75	673	9
Whole-tree	0,03	0,15	0,28	0,05	296	85	30	236	6
Hardwoods									
Stemwood	0,02	0,08	0,08	0,02	34	20	16	90	2
Stembark	0,09	0,37	0,85	0,07	190	191	131	341	17
Branches	0,06	0,21	0,41	0,05	120	47	52	218	7
Foliage	0,21	1,17	1,10	0,19	867	135	269	965	21
Whole-tree	0,05	0,21	0,25	0,04	83	27	39	212	6

Table B5. Effective heating value of oven dry biomass components of young Scots pine, Norway spruce and birch trees in Finland (Richardson 2002; original data from Nurmi 1993, Alakangas 2000).

		Pine	**Spruce**	**Birch**
		Effective heating value, MJ/kg		
Stem mass	Wood	19,3	19,0	18,6
	All bark	19,5	19,7	22,7
	Whole stem	19,3	19,0	19,2
Crown mass	Wood	20,0	19,7	18,7
	All bark	20,7	19,8	22,3
	Foliage	21,0	19,2	19,8
Whole-tree		19,5	19,3	19,3
Stump & roots		19,5	19,1	

Table B6. The energy density of forest biomass chips and chrushed bark in Finland at 40% moisture content of biomass (Richardson 2002 (original data from Nurmi 1993), Alakangas 2000).

Source	**Basic density**	**Energy density**		
	kg/m^3	**MJ/m^3**	**kWh/m^3**	**toe/m^3**
Whole-tree				
Scots pine	395	7100	1970	0,169
Norway Spruce	400	7020	1950	0,167
Birch	475	8270	2300	0,197
Bark				
Scots pine	280	5460	1520	0,130
Norway Spruce	360	7090	1970	0,169
Birch	550	12490	3470	0,297
Crown (excl. foliage)				
Scots pine	405	7780	2160	0,185
Norway Spruce	465	8400	2330	0,200
Birch	500	9040	2510	0,215

Crown with foliage				
Scots pine	405	7660	2130	0,183
Norway Spruce	425	7730	2150	0,184
Stump & roots				
Scots pine	475	8500	2360	0,203
Norway Spruce	435	7570	2100	0,180

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Appendix C: Availability of woody biomass

(Anttila P., Laitila, J., Asikainen A. & Pasanen, K.)

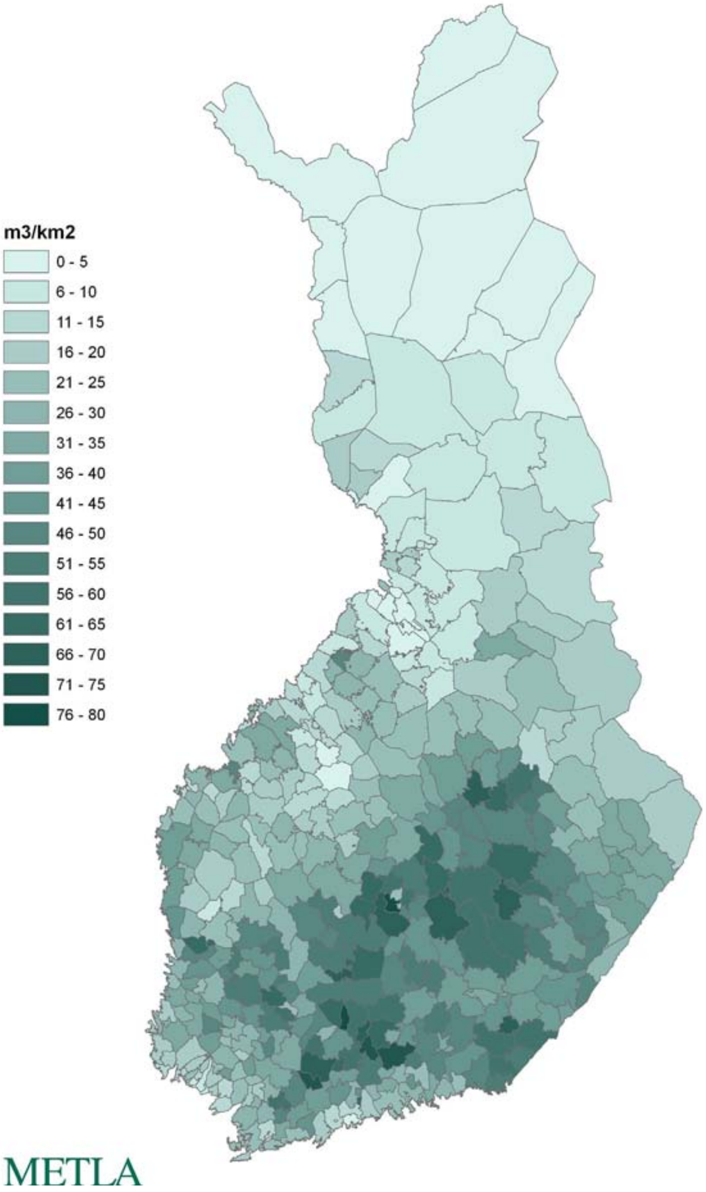

Figure C1. Potential of logging residues from final fellings in Finland (Boundaries: © National Land Survey of Finland, license MYY/179/06-V).

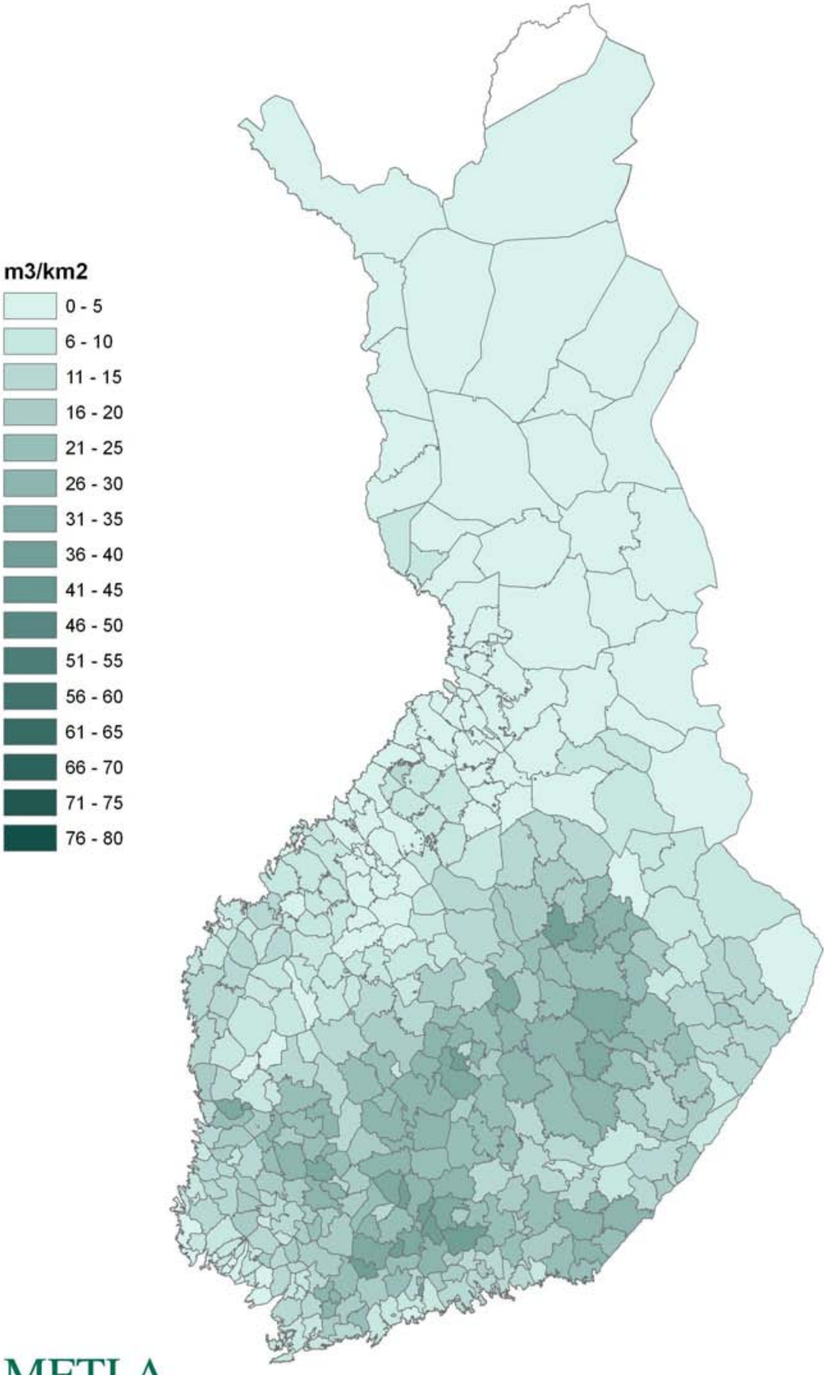

Figure C2. Potential of stump wood in Finland (Boundaries: © National Land Survey of Finland, license MYY/179/06-V).

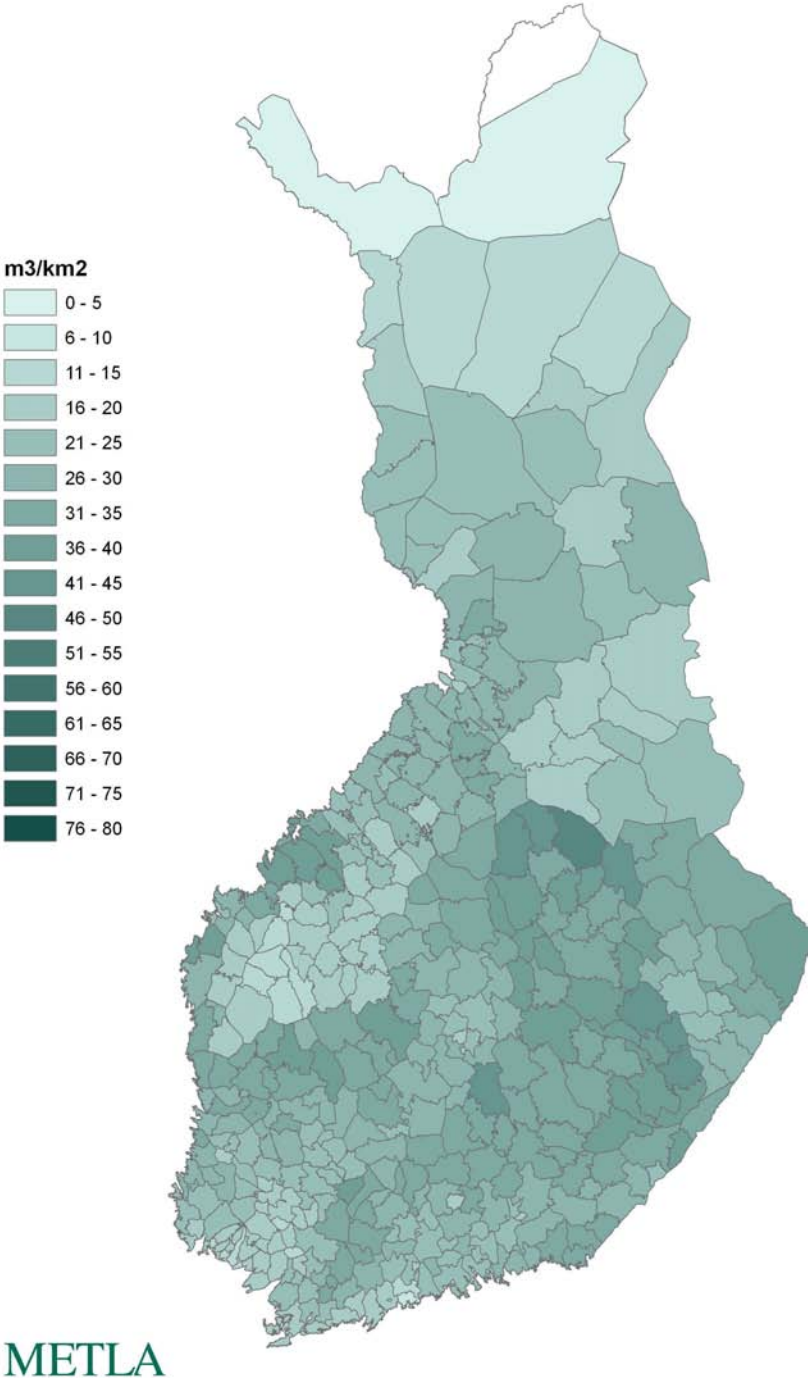

Figure C3. Potential of thinning wood from young forest stands in Finland (Boundaries: © National Land Survey of Finland, license MYY/179/06-V).

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Title

Assessing the sustainability of liquid biofuels from evolving technologies

A Finnish approach

Abstract

The use of biofuels in transportation is increasing and promoted in many areas with the aims of reducing greenhouse gas emissions in the transport sector, securing the energy supply, and improving the self-sufficiency and employment. However, a number of recent studies have concluded that large-scale production of biofuels may cause significant environmental and social problems. Firstly, greenhouse benefits from substituting fossil fuels with biofuels may be questionable due to auxiliary material and energy inputs required, direct land-use impacts and, in particular, due to indirect system impacts e.g. land-use changes leading to deforestation. Secondly, other environmental impacts, such as nutrient losses, toxic emissions, and biodiversity losses, may also be significant and are not well known, in particular those related to technologies still under development. Thirdly, production of biofuels from raw materials that also are, suitable for food production, have been found to increase food prices, thus causing social problems. Consequently, research on and development of biofuels is more and more focusing on raw materials not directly competing with food production. In addition, a number of initiatives on sustainability criteria for biofuels have been announced by various institutions, with the aim of ensuring that the production of biofuels does not cause serious harm to the environment and society.

A sustainability assessment is an extremely complicated and challenging task due to the lack of a unique, objective, and commonly agreed methodology, even though life cycle assessment (LCA) provides a generally accepted methodological background. The definitions of system boundary and reference scenario and other assumptions will have a significant impact on the results. In addition, the sustainability criteria included in different approaches and studies vary, which makes the comparison of the results difficult.

This report presents perspectives on varying challenges and problems that are encountered when assessing the sustainability of biofuels in general. The report aims to identify the most critical factors of different environmental implications that are caused by increased production and use of biofuels. The main uncertainties and sensitivities associated with the assessment task are discussed and suggestions for further research needs are provided. The technological focus is on evolving technologies of highest interest from the Finnish point of view, that are the production of FT diesel from forest residues, production of NExBTL diesel from palm oil and tallow, and bioethanol production based on domestic lignocellulosic raw materials. Critical sustainability aspects of imported Brazilian bioethanol made from sugar cane are also addressed.

The report also provides a brief summary and assessment of sustainability criteria relevant for biofuels that have been proposed by various organisations, institutions, and countries. Finally, the implications of three different biofuel scenarios on the Finnish economy are briefly assessed.

The most critical factors with regard to environmental impacts of production and use of biofuels were noted to be site-specific features, direct soil implications through cultivation or harvesting of raw materials, identification, quantification and allocation of indirect impacts through market mechanisms, substitution credits from the use of co-products and biofuels, and lack of data concerning technologies still under development. In addition, indicators used to measure greenhouse or other environmental impacts may have a significant impact on the results and thus need to be carefully considered in order to avoid the drawing of misleading conclusions.

According to macro-economic scenario analysis, the increased use of biofuels has the effect of raising both consumer prices and costs of production. Consequently, it tends to drive down consumption and production in most sectors of the economy, and also makes investment less attractive. While the effects of increased domestic biofuel production are slightly negative at the level of the whole economy, the increased demand for crops and wood obviously increase activity in agriculture and in particular, in forestry.

Further research work is certainly required in various areas and dimensions related to the sustainability of biofuels. Topics that should be further elaborated include e.g. the assessment procedure of sustainability, case studies of current and new technologies and raw materials, uncertainties related to these, site-specificity and perceived harmful effects. More data and knowledge is also required for socio-economic dimension of sustainability and economic implications of biofuels towards a specific reference scenario. The need for case-specific and more comprehensive analysis with different perspectives and indicators is obvious. Both micro-level bottom-up and macro-level top-down analyses are required to ensure that biomass use is as sustainable as possible with regard to its various dimensions.

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Production of liquid biofuels is promoted in many areas of the world, including the EU, in order to reduce greenhouse gas emissions of the transport sector. At the same time, however, concern of environmental and social problems resulting from the increased use of renewable raw materials and land for biofuel production is growing. Consequently, various institutions have proposed and prepared sustainability criteria for biofuels, but many of them are not easy to respond to. How can i.e. sustainability be defined and how should it be measured? What kind of issues and problems are encountered when aiming to assess the sustainability of biofuels? How to account for site-specific impacts with indirect global substitution effects? These types of questions are tackled in this report by focusing on a few evolving biofuel technologies considered to be relevant for large-scale production in Finland.

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